Christian Splieth (Editor)

Innovations in Preventive Dentistry

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Preface

Preventive dentistry is a cross-sectional success story that has produced a 90% caries decline in children and adolescents, as well as caries reductions in adults in many countries. Periodontology and orthodontics also offer great opportunities for prevention … and prevention in all fields of dentistry has grown from primary prevention through maintaining a healthy state to new concepts of secondary prevention, where initial lesions or imbalances are corrected with minimal intervention. In addition, therapy has shifted from repair to tertiary prevention to regain physiologic and healthy balances that ensure long-lasting therapeutic success.

In order to introduce these new developments and innovations into preventive and clinical dentistry for all ages, a group of internationally recognized specialists presents new diagnostic methods and offers options for putting these into practice both for primary prevention and for non- and minimally invasive treatment. With the introduction of a systematic, evidence-based approach in dentistry, new standards for clinical care are being established in all fields of dentistry, stressing prevention-oriented routines. The understanding of caries and periodontal disease has shifted from a focus on invasive treatment to controlling disease activity, and in orthodontics from mechanics to achieving physiologic function. The various chapters highlight this shift, in addition to a clinical view, the overall concept, interaction with general health, and the common risk-factor approach. The authors offer perspectives for tackling dental and medical problems in the vulnerable populations that exhibit most of the dental and medical disease.

Preventive dentistry has changed for epidemiologic, social, and scientific reasons. Professionals should manage this development actively for the benefit of patients in all fields of dentistry and for all ages.

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Abbreviations

AAPD, American Academy of Pediatric Dentistry
ACFP, amorphous calcium fluoride phosphate
ACP, amorphous calcium phosphate
ACPA, anti-citrullinated protein antibody
AD, Alzheimer disease
ART, atraumatic restorative therapy
BL, bone loss
BMI, body mass index
BOP, bleeding on probing
CAL, clinical attachment level
CHALO, Child Health Action to Lower Oral Health and Obesity
CI, confidence interval
CPP, casein phosphopeptide
CRFA, Common Risk Factor Approach
CRP, C-reactive protein
DIFOTI, digital imaging fiber-optic transillumination
DHSW, Dental Health Support Worker
DM, diabetes mellitus
dmfs, decayed, missing, or filled surfaces
DMFT, decayed, missing, or filled teeth
EADPH, European Association of Dental Public Health
ECC, early childhood caries
EHCP, Essential Health Care Program
EPS, extracellular polymeric substances
FOTI, fiber-optic transillumination
GA, general anesthesia
GBR, guided bone regeneration

GER, guided enamel regeneration
GTR, guided tissue regeneration
GWAS, genome-wide association studies
HA, hydroxyapatite
IADR, International Association for Dental Research
ICDAS, International Caries Detection and Assessment System
IgA, immunoglobulin A
IL, interleukin
MFP, monofluorophosphate
MI, motivational interviewing
MIH, molar incisor hypomineralization
NCD, noncommunicable disease
NHS, National Health Service
NNT, number needed to treat
NOCTP, nonoperative caries treatment program
NRCC, nonrestorative cavity control
NSF, nano silver fluoride
OHI, oral hygiene instruction
OHRQoL, oral health-related quality of life
OR, odds ratio
ORCA, European Organisation for Caries Research
OSAS, obstructive sleep apnea syndrome
PAD, peptidylarginine deiminase
PD, probing depth
PISA, periodontal inflamed surface area
PMPR, professional mechanical plaque removal
PSI, Periodontal Screening Index
QLF, quantitative light-induced fluorescence
RME, rapid maxillary expansion
RR, relative risk
RRR, relative risk reduction

SaC, Specific affected Caries Index
SAPM, self-assembling peptide matrix
SDF, silver diammine fluoride
SDG, Sustainable Development Goal
S-ECC, severe early childhood caries
SES, socioeconomic status
SCT, social cognitive theory
SiC, Significant Caries Index
SMART, silver modified atraumatic restorative technique
SNP, single nucleotide polymorphism
SPT, supportive periodontal therapy
SSB, sugar-sweetened beverages
TMD, temporomandibular disorders
TNF, tumor necrosis factor
VAS, visual analog scale
WASH, water, sanitation, and hygiene
WHO, World Health Organization
WIC, Women, Infants, and Children program

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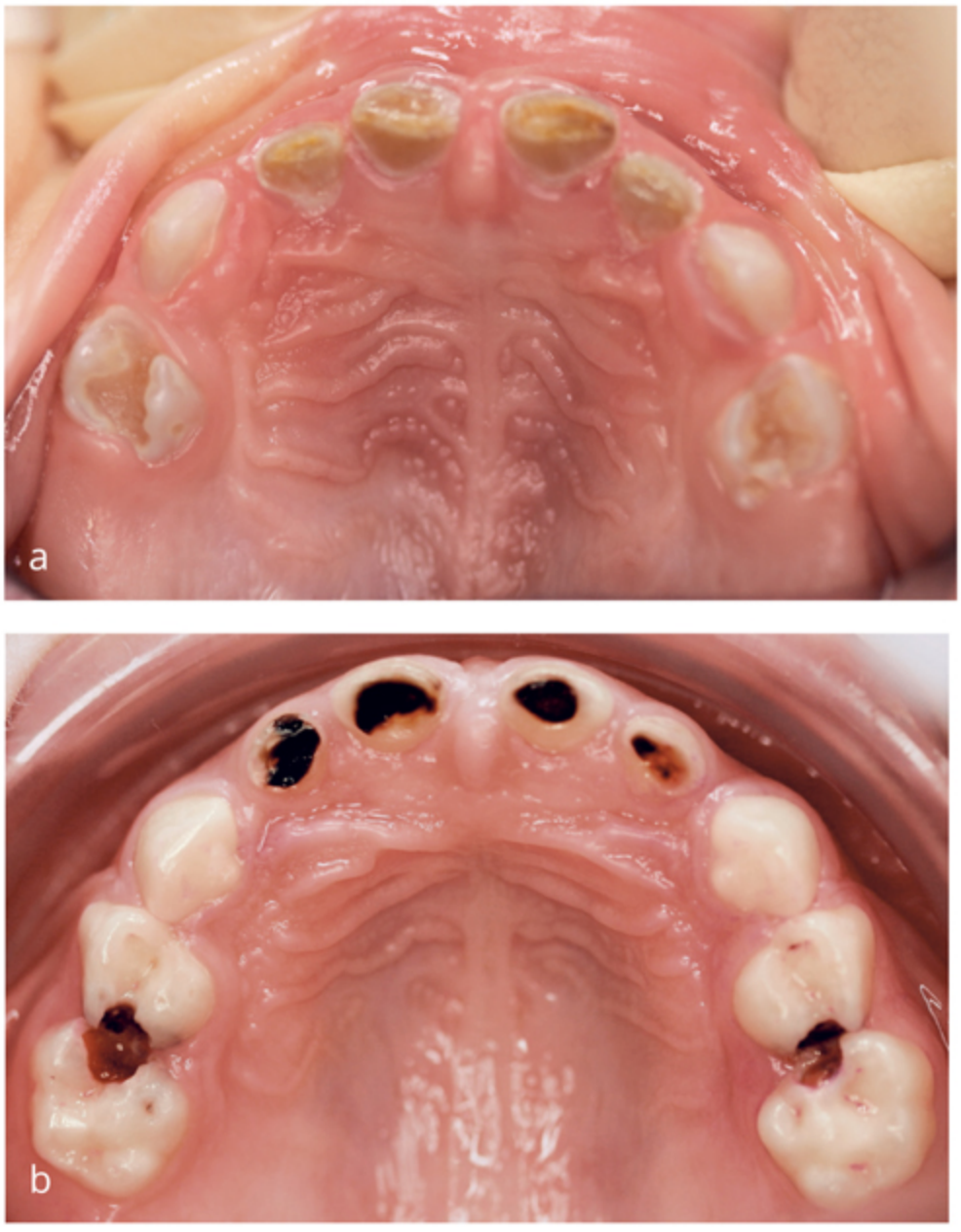
Understanding caries

Christian H. Splieth, Mhd Said Mourad, Mohammad Alkilzy, Julian Schmoeckel, Ruth M. Santamaría

In their new consensus statement on the terminology of dental caries and dental caries management, the European Organisation for Caries Research (ORCA) and the International Association for Dental Research (IADR) define caries as “a biofilm-mediated, diet modulated, multifactorial, noncommunicable, dynamic disease resulting in net mineral loss of dental hard tissues. It is determined by biologic, behavioral, psychosocial and environmental factors. As a consequence of this process, a caries lesion develops.”[1] This very modern definition is based on the concept that caries is an imbalance of demineralization and remineralization that results from a dysbiosis of the oral biofilm, the overconsumption of carbohydrates, and insufficient oral hygiene (Fig 1-1).

Thus, the prevention of caries aims to adjust and ensure a healthy balance of the oral microbiome, dietary intake, oral hygiene, and mineral supply to avoid a net loss in enamel and dentin of healthy teeth. Caries therapy can only be successful in the long run if this is achieved when demineralization has already taken place. Therefore, caries prevention and its

treatment employ the same concept and are nowadays combined as caries control, management, or care.



Figs 1-1a and b Caries is nowadays understood as an imbalance between de- and remineralizing factors resulting in a net loss of minerals **(a)**. Thus, modern caries management modifies oral hygiene, diet, the biofilm, and the mineral equilibrium, keeping sound

tooth surfaces healthy, inactivating existing caries lesions **(b)**, and preventing recurrent demineralization around restorations.

This is also reflected in the ORCA/IADR definition of caries care, management, or control comprising “actions taken to interfere with mineral loss at all stages of the caries disease, including nonoperative and operative interventions/treatment. The terms caries care/management/control may be more appropriate than the term ‘caries prevention’ and because of the continuous de- and remineralization processes, caries control needs to be continued throughout the life course.”[1]

In consequence, the terms of caries prevention and therapy merge, which is not really surprising as restorative care and accompanying efforts to reduce caries activity have been viewed as secondary and tertiary prevention for a long time. Taking this into account, ORCA/IADR state that caries prevention “traditionally meant inhibition of caries initiation, otherwise called primary prevention. Primary, together with secondary and tertiary prevention, comprising nonoperative and operative treatments, are now summarized under caries care, management, or control.”[1]

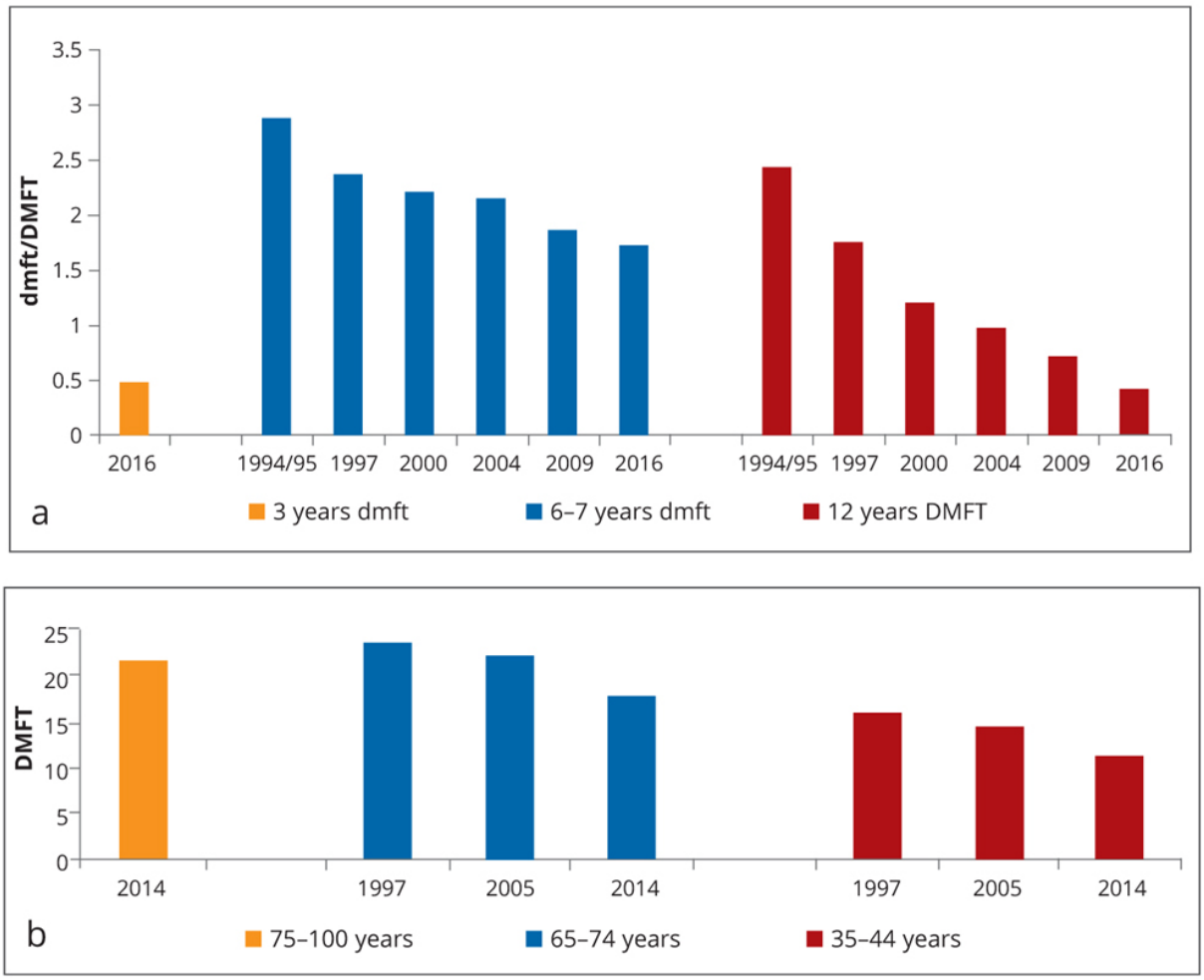
The following chapters regarding caries risk prediction, fluoride use, biofilm and diet control, and promoting oral health are based on this new understanding of caries. As in periodontal disease, the primary goal of all preventive and therapeutic approaches is to achieve a high quality of life by establishing a physiologic, regenerative balance to maintain proper oral health.

Caries epidemiology and its consequences

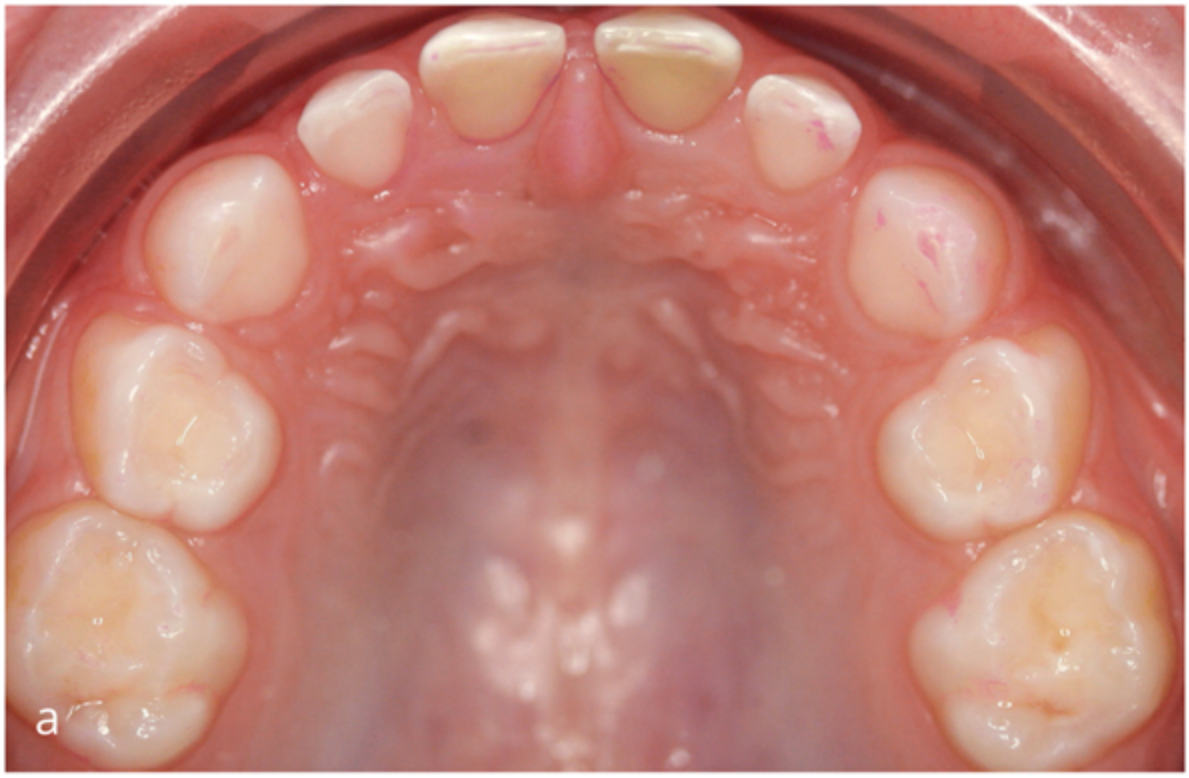
On a global level, a remarkable caries decline could be achieved for the permanent dentition in children and adolescents in many industrialized regions such as the US, Canada, Europe, or Oceania. Although Germany was not the first country to experience this, consecutive and recent national surveys for all ages allow for a

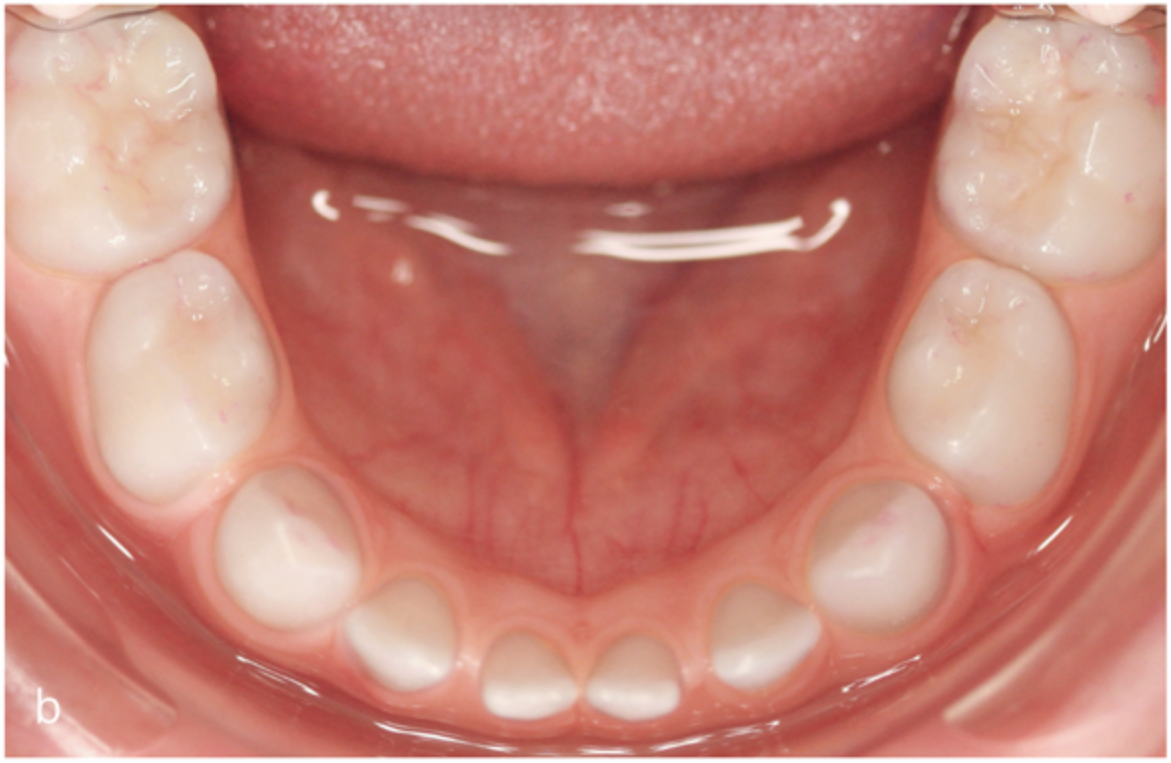
detailed analyses, which reveal trends[2,3] that seem to be similar in many countries (Figs 1-2 and 1-3):

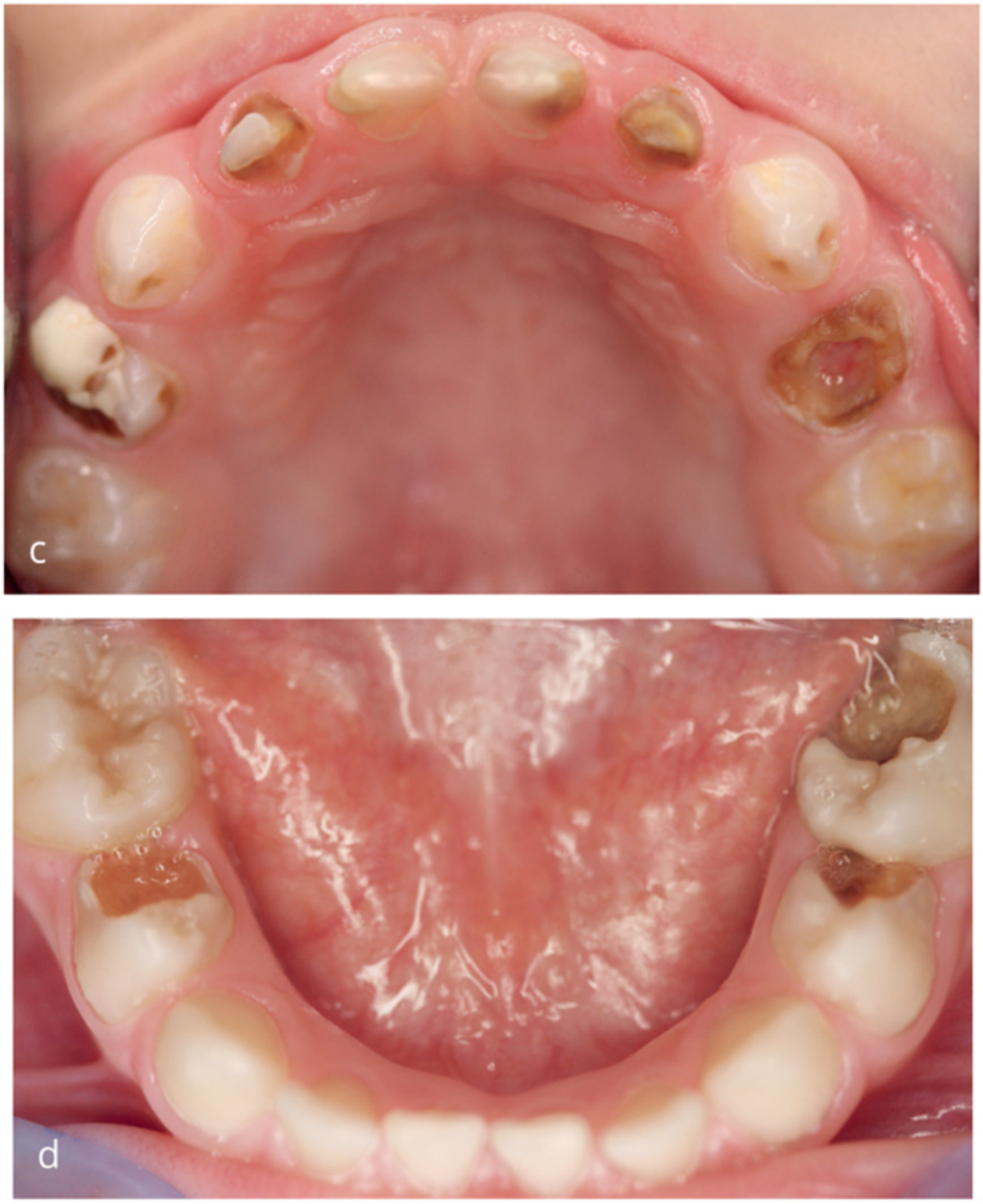
- Caries prevalence has reduced from ten or more affected permanent teeth in adolescents during the 1970s to a mean of less than one decayed, missing, or filled teeth (DMFT) in 12-year-olds nowadays.[4]
- About 90% of the caries burden can be prevented and tooth loss is almost eradicated in the permanent dentition in adolescents.[2,4]
- After the caries decline, 80% of the adolescents are caries-free on a DMFT level and this is not much changed by lowering the threshold to initial caries lesions.[3]
- Thus, the caries distribution is polarized and a so-called high-risk group of about 20% exhibits almost the complete caries burden.[2,4]
- The high-risk group is primarily associated with a low socioeconomic status that leads to less sufficient oral hygiene, fluoride exposure, and often more frequent sugar intake.[2,5]
- In the primary dentition and especially for early childhood caries, the situation is far from satisfactory in many countries.[6] In spite of a less pronounced caries decline in the primary dentition, caries patterns and distribution are equivalent to the situation in adolescents.[7] This is also true for caries in adults.[2] Most likely a further caries decline will also increase the polarization in adults.
- Due to the caries distribution after a major caries decline, primary caries prevention needs a dual strategy of maintaining the high levels of oral health in the majority of the population and trying to find intensified measures to improve the situation in the risk group mostly characterized by a low socioeconomic status.[3]
- There is a realistic perspective that caries levels even in risk groups can be significantly reduced in the future, as the caries decline in this group was proportional to the reductions in the whole population, at least in German adolescents.[4]



Figs 1-2a and b Decayed, missing, and filled teeth (dmft/DMFT) in Germany in **(a)** schoolchildren,[3,7] adolescents,[3,4] and **(b)** adults. In many industrialized countries such as Germany, a remarkable caries decline has been recorded for the permanent dentition in adolescents, as well as in adults, and to a lesser extent for the primary dentition in schoolchildren.







Figs 1-3a to d A large percentage of children are caries-free (80%) **(a and b)**, while a small group of children (20%) **(c and d)** present with high caries rates (80%). The polarization of the caries distribution especially in children leads to two different preventive

approaches: Maintaining the high degree of oral health in the majority group of the population and intensifying measures for the high caries risk group.

In contrast to the general caries decline in many industrialized countries, caries levels in the emerging market economies are still at a high level for most of the population, or even on the rise due to increased wealth and sugar consumption.[8] This imposes a great challenge to these countries; in spite of choosing the restorative approach as was done by many Western countries, strengthening primary prevention would be a better choice.

The current epidemiologic situation of a polarized caries distribution calls for two distinctly different approaches to primary caries prevention: For the majority of the population, individual and professional prevention can reduce 90% of the caries burden and keep it at a tolerable very low level.

The so-called caries risk group that accumulates about 80% of the caries defects and the according treatment needs is characterized by a low socioeconomic status. It seems that outreach programs and tailored health regulations are necessary to achieve further health gains in the groups with often low self-efficacy or (oral) health literacy. A common risk factor approach and cooperation with other professionals are useful for risk grouptargeted prevention to strengthen health and probably also educational competencies in these individuals and their families.

Early childhood caries

Early childhood caries (ECC) appears to be a persistent and neglected topic with rather high levels in many countries (Fig 1-4),

low treatment rates, and, therefore, severe consequences in many small children that clearly affects their well-being and quality of life.[9]

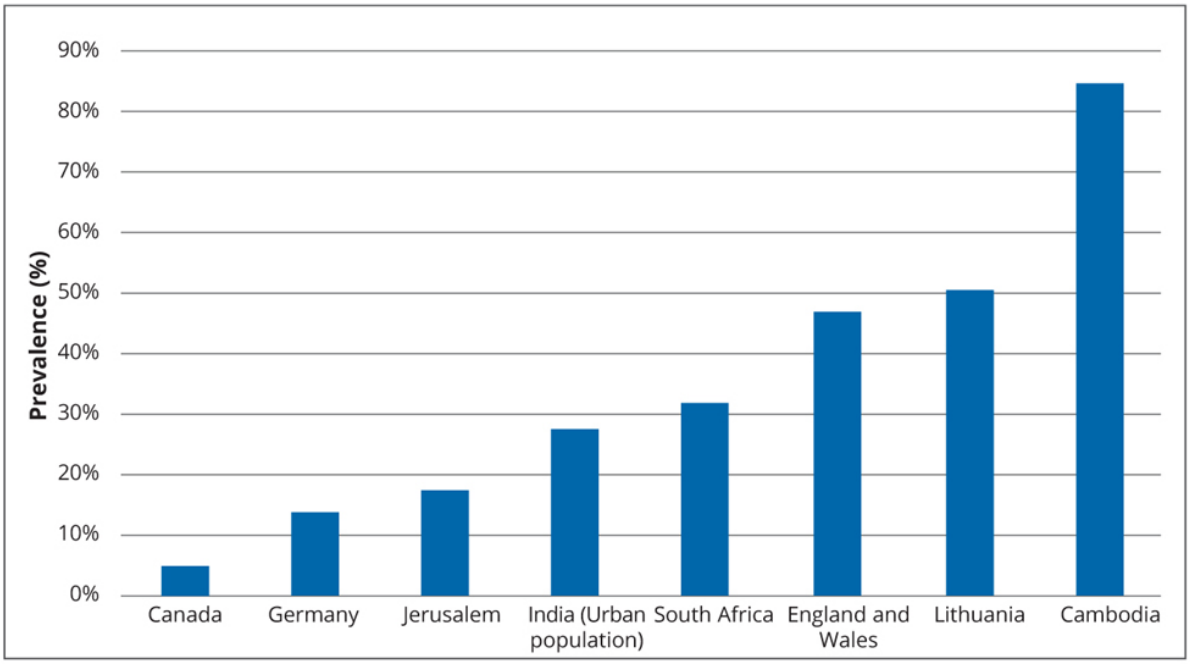


Fig 1-4 Global epidemiology of early childhood caries (ECC). ECC or caries in the primary dentition seem to be a persistent problem, with severe consequences for the affected children. Preventive approaches in almost all countries have to be intensified to mirror the success often achieved in the permanent dentition.[3,10-16]

Only in recent years has research in caries epidemiology focused on early childhood, followed by representative surveys on the prevalence of ECC. Thus, ECC deserves special attention in order to draw conclusions that might deviate from the situation in the permanent dentition.

ORCA and IADR define ECC as “the early onset of caries in young children with often fast progression which can finally result in complete destruction of the primary dentition [Fig 1-1a]. An epidemiologic definition of ECC is the presence of one or more decayed (noncavitated or cavitated lesions), missing (due to caries), or filled surfaces, in any primary tooth of a child under [the] age of

six." They also state that the appearance of ECC deviates from the common caries distribution where pits, fissures, and proximal surface dominate.[1]

"Due to the frequent consumption of carbohydrates, especially sugars, and inadequate to absent oral hygiene in small children, ECC demonstrates an atypical pattern of caries attack, particularly on smooth surfaces of upper anterior teeth."[1] This implies that typical ECC is a type of child neglect, as even minimal and easy preventive oral health measures are omitted for a considerable time. It is amazing that this can be found in so many children in developed and emerging countries.[6] It also calls for clearly intensified primary caries-preventive measures from the first tooth on.

The National German Oral Health Survey in Children and Adolescents revealed 14% of 3-year-olds had caries on a dmft level in Germany,[3] which is at the lower end of an international comparison. The mean value in the affected children (the newly introduced Specific affected Caries Index [SaC][17]) was 3.6 dmft, making pulpal involvement, subsequent toothache, and probably a treatment under general anesthesia (GA) due to the high number of carious teeth as well as the low compliance in these small children likely – or a painful, and potentially traumatic experience when extraction in uncooperative children is performed if GA is not available.[3]

A closer look reveals that in spite of a very low mean caries prevalence of 0.3 dmft in 2-year-olds, a small risk group of children develops "real" ECC from the first tooth onwards (Table 1-1). Here ECC is caused by infant feeding that provides a high sugar content and/or erosive drinks in combination with insufficient or a complete lack of oral hygiene.[18] Regarding the "epidemiologic" definition of ECC, in Germany the prevalence increases to almost 35% at a

defect level until school age.[3,7] The care index of less than 50% is not satisfactory, and clearly lower than in the permanent dentition.[3] The young age of the children and the high burden of the disease in many countries make a primary preventive approach to manage the problem of ECC (see Chapters 5 and 9) more logical than the secondary or tertiary prevention (see Chapters 12 to 14) via, for example, restorations or even extractions.

Table 1-1 Mean caries prevalence data (dmft) for all kindergarten children in Greifswald, Germany, 2019, as well as mean values and care index for the subgroup of children with/without caries, fillings, and/or missing teeth due to caries (dmft = 0 and > 0, n ~ 1,500)[17]

Parameter	Age (years)				
	1 y	2 y	3 y	4 y	5 y
Mean dmft for all children	0.05	0.30	0.50	1.06	1.56
Proportion of children with dmft = 0	99%	95%	87%	76%	65%
Proportion of children with dmft > 0	1%	5%	13%	24%	35%
Mean dmft children with dmft > 0 (SaC)	4.50	5.5	3.88	4.49	4.43
Care index (mft/dmft) in %	0%	8%	17%	44%	69%

SaC, Specific affected Caries Index.

Caries diagnostics

Analogous to the above-mentioned definition of caries as a net loss of minerals, caries diagnostics would assess the change of minerals over time. As caries is a process, this implies that a one-time diagnosis requires a continuous sampling technique or is even per se impossible.

The ORCA/IADR consensus solves this problem by stating that “caries diagnosis is the clinical judgment integrating available information, including the detection and assessment of caries signs (lesions), to determine presence of the disease.”[1] This is especially crucial for secondary or tertiary prevention, with the signs or symptoms of caries already being clearly present in an individual.

"The main purpose of clinical caries diagnosis is to achieve the best health outcome for the patient by selecting the best management option for each lesion type, to inform the patient, and to monitor the clinical course of the disease."[1] This is relevant to all levels of prevention, as many teeth and surfaces within one individual often present different stages of the caries process.

It is important to comprehend that the diagnosis of caries as a process or caries activity differs from the diagnosis of past mineral loss or even cavitation, which was traditionally defined as "caries diagnostics." According to ORCA/IADR, caries activity "is a concept that reflects the mineral balance, in terms of net mineral loss, net mineral gain, or stasis over time."[1] Caries active implies caries initiation or progression; caries inactive implies caries arrest or regression.[19] The diagnosis of caries activity can actually be used as the gold standard for the success of preventive measures because they should reduce the net mineral loss to zero or even remineralize existing lesions. The detection of cavitation due to caries is a comparatively crude diagnostic approach.

Clinical examination

A regular, visual-tactile examination of the mouth and teeth is part of the standard routine in dentistry. However, active initial caries lesions, which are the crucial part of the diagnosis, can only be assessed clinically after removal of the dental plaque and drying of the teeth using sufficient lighting. It is important that no force is applied with a pointed probe during the examination of initial lesions, as this can destroy the intact surface and, therefore, reduce the chance of defect-free remineralization.[20]

The International Caries Detection and Assessment System[21] offers a detailed diagnosis of the various caries stages from 0

(healthy) to 6 (deep caries). In daily practice, however, it is usually sufficient in the diagnosis of caries to distinguish between healthy surfaces, initial lesions, moderate stage lesions, and cavitated lesions, as well as their degree of activity.[21-23]

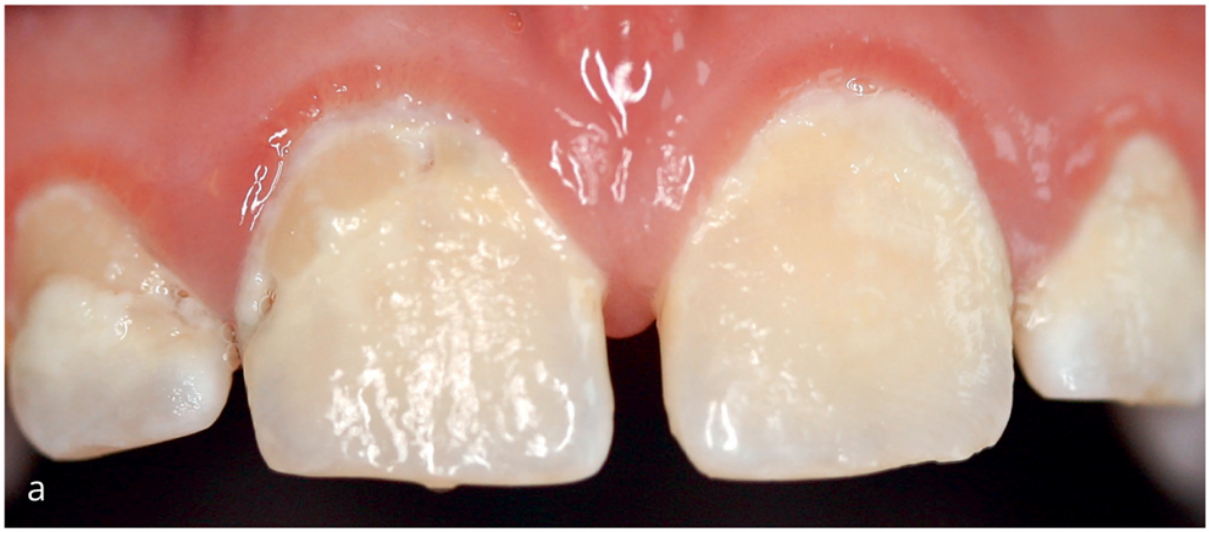
The clinical caries and activity diagnosis allows a fairly precise therapy decision and selection of the right level of care involving primary, secondary, or tertiary prevention. This makes the traditional concept of caries treatment obsolete. A merely restorative approach to caries would fail, as was often the case, due to the persisting net loss of minerals, leading to “secondary” caries, which is actually the nontreated caries activity that had originally led to the first cavitation.

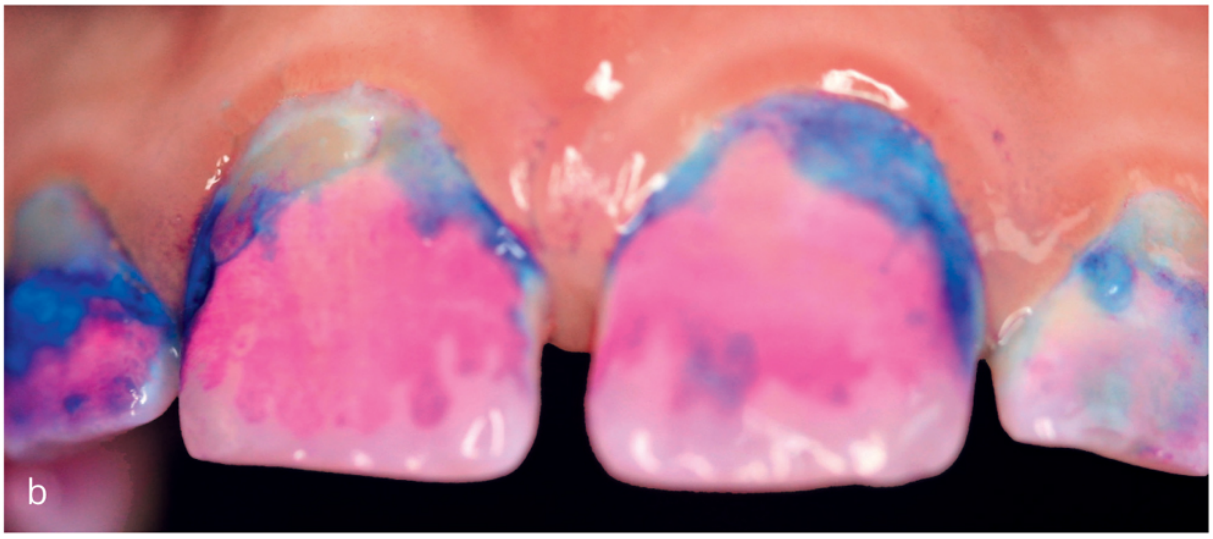
Caries activity

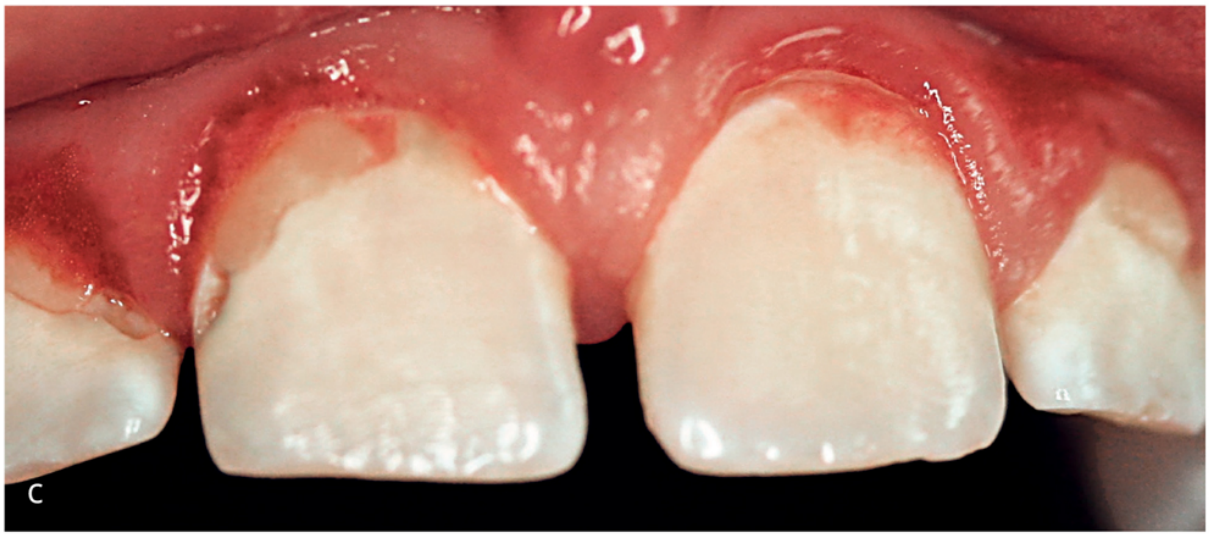
The degree of caries activity is superior to the assessment of the caries risk (see Chapter 17). While risk refers to the conversion of a healthy state to disease, the diagnosis of caries activity actually uses the knowledge of the disease process to record its early signs, whether heavy plaque in stagnation areas, accompanying gingivitis, or initial caries lesion. These should be carefully viewed after cleaning and drying the teeth (Fig 1-5) and differentiated into a probably active or inactive initial lesion.

It is important to note that inactivation is possible at any stage from initial enamel lesion to deep dentinal caries (see Fig 1b),[21,23] and it can be achieved by disturbing the dental biofilm (eg, by brushing teeth) and by influencing the de- and remineralization processes (eg, with fluorides). In spite of being classically primary preventive measures, they are “therapeutic” here and

can be perceived as nonoperative caries treatment or management, which should result in a net gain of minerals.



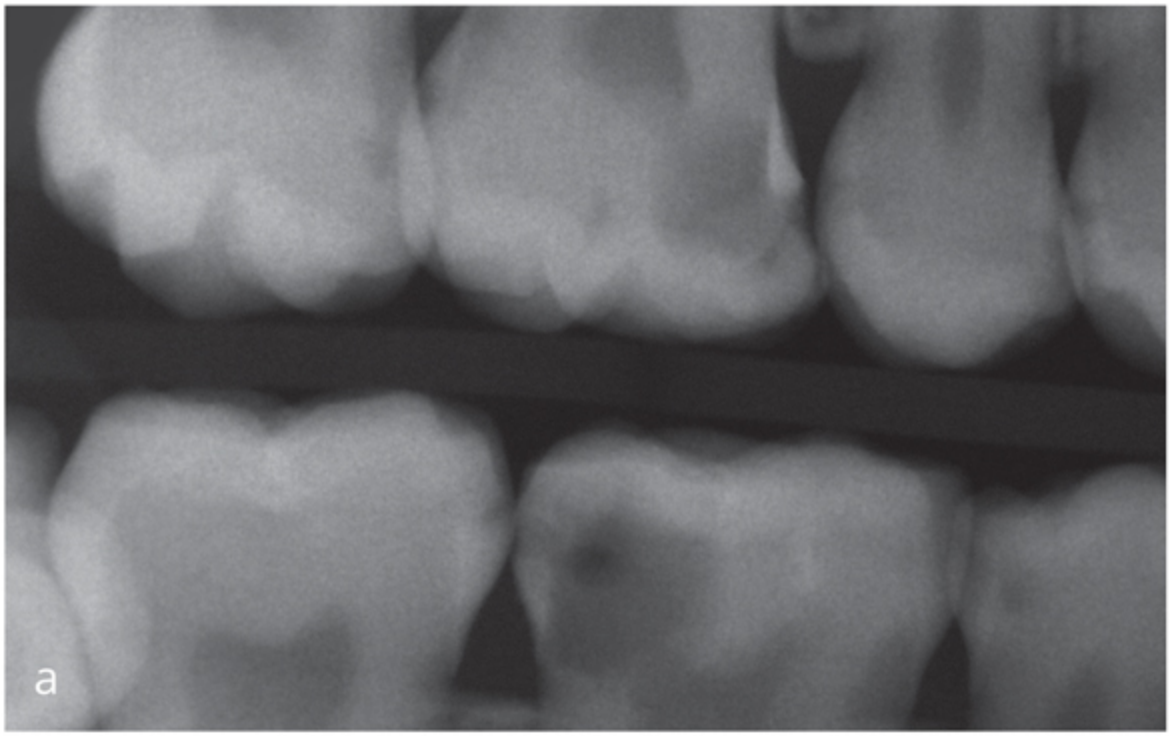


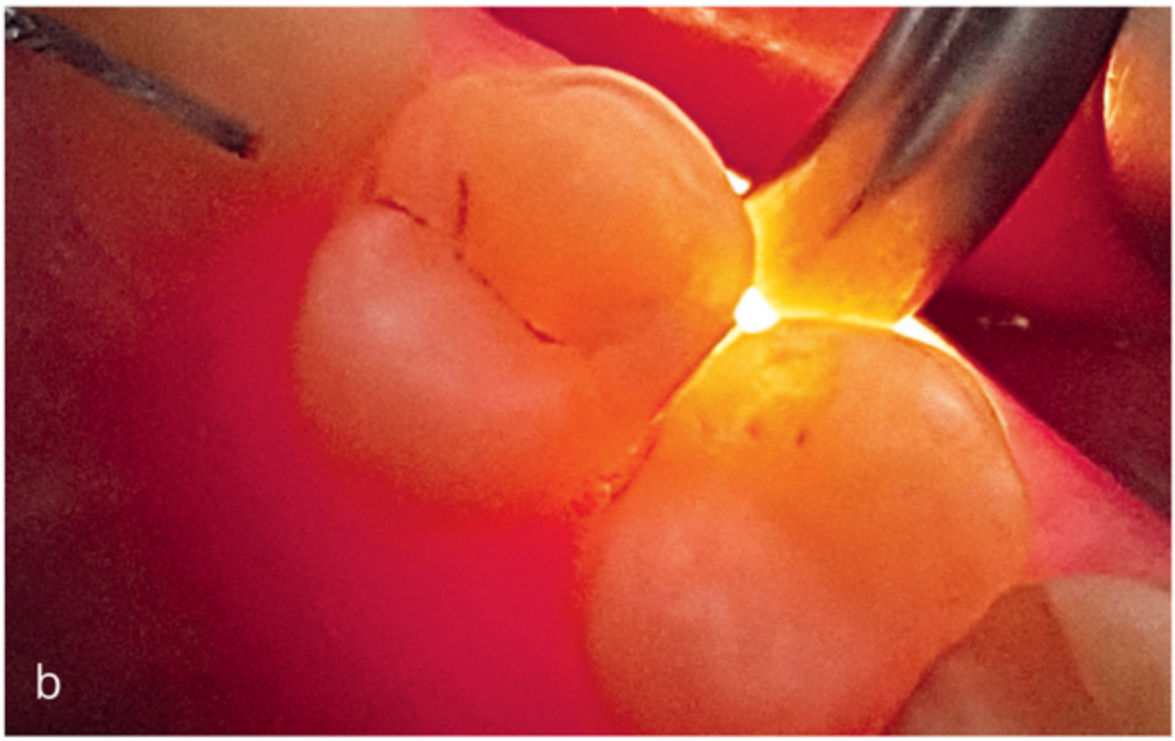


Figs 1-5a to c Maxillary anterior teeth: **(a)** before plaque removal, **(b)** after staining, and **(c)** after brushing. Active caries lesions can only be diagnosed on cleaned tooth surfaces, and gingivitis becomes clearer for the patient as a result of bleeding during cleaning.

Further diagnostics

If proximal caries is present or going to be expected, a radiographic examination should be considered since proximal caries rarely occurs in an isolated spot and pulpal involvement can be assessed (Fig 1-6). Bitewing radiographs are still considered to be the gold standard in proximal caries diagnostics.[24]





Figs 1-6a and b Bitewing radiographs **(a)** allow a staging of proximal lesions and planning of primary preventive measures (flossing and fluorides, see Chapter 7), secondary prevention such as

nonoperative treatment of initial lesions with cleaning and fluorides, proximal sealing or infiltration, and tertiary prevention meaning restorative care. This can be supported by fiber-optic transillumination (FOTI) **(b)**, digital imaging fiber-optic transillumination (DIFOTI), or quantitative light-induced fluorescence (QLF).

Another method to monitor proximal surfaces is fiber-optic transillumination (FOTI), which is particularly suitable for the first examination of "apparently healthy" proximal surfaces,[25] especially if a proximal lesion has already been detected on another tooth. In addition, several new caries diagnostic systems such as digital imaging fiber-optic transillumination (DIFOTI) and quantitative light-induced fluorescence (QLF) have been available on the market for several years with the aim of providing reliable results in caries diagnosis. Still, reviews stress that they can be used as adjunct tools, but they should not substitute x-rays completely, and do not overrule the clinical verification.[26]

Current concepts and treatment approaches in caries management

Primary caries prevention is traditionally considered as the "real" prevention, aiming to maintain the health of sound teeth that are at risk for caries. The concepts of the classical preventive measures are based on a variety of approaches. In several chapters, this book looks at their current evidence base and provides clinical recommendations on how to implement these nowadays, eg for fluorides (see Chapter 3), plaque removal via tooth brushing or flossing (see Chapters 6 and 7), diet control (see Chapter 4), or probiotics (see Chapter 11).

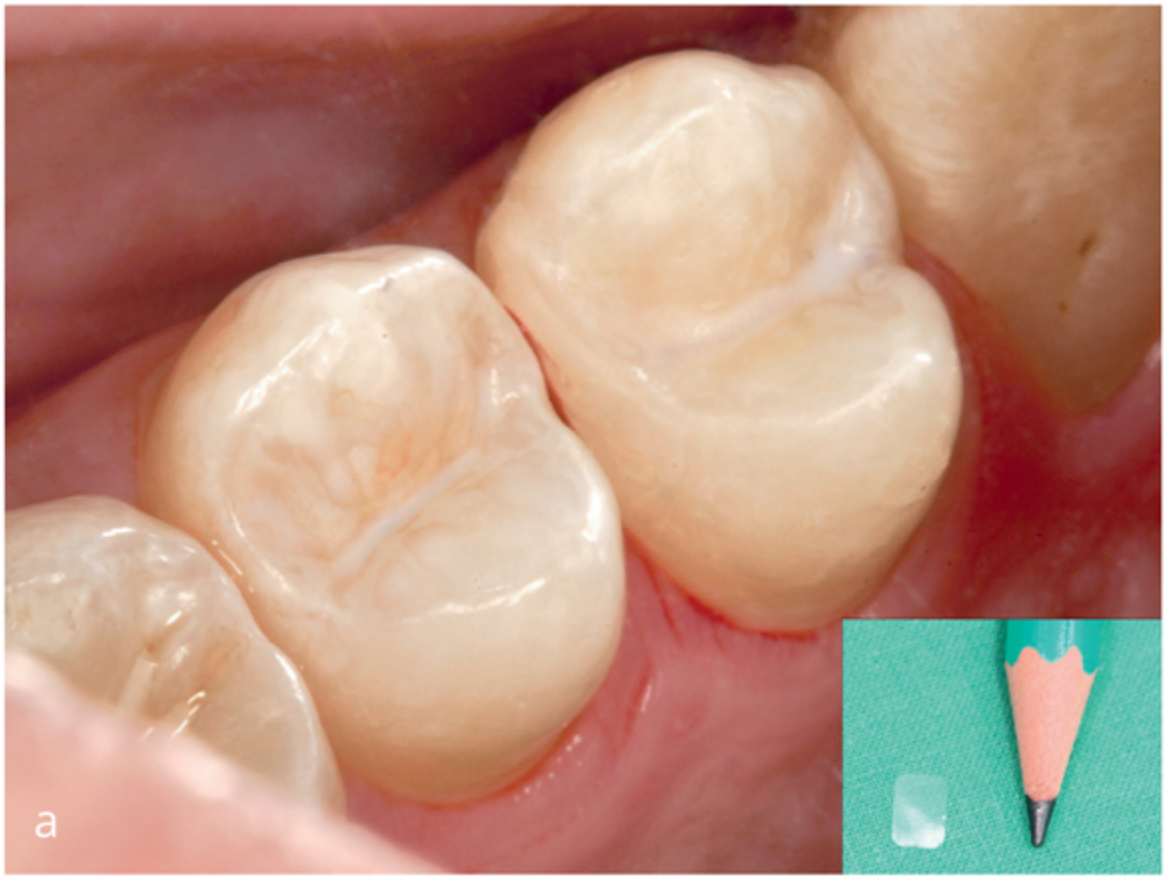
A key issue of primary caries prevention is a change from caries activity to inactivation or, in other words, from predominantly demineralization to remineralization of dental hard tissues, which involves behavior change in the patients or caretaker (see Chapter 9). Especially after the caries decline, oral diseases are concentrated on a minority group, linked to the socioeconomic status.[27] Thus, future gains in oral health must have a focus on this group, possibly employing all levels from individualized, group- and population-based prevention, outreach programs, and a common risk factor approach (see Chapter 5).

Secondary caries prevention aims to arrest or even remineralize initial caries lesions with nonoperative or minimally invasive techniques. These techniques involve nonrestorative caries control, which implements primary caries-preventive measures but employs them for initial or even cavitated caries lesions (see Chapter 14). This can be enhanced with silver fluoride products or other fluorides (see Chapters 3 and 12), antimicrobials, or biomimetic remineralization using self-assembling peptides (Curodont Repair, Credentis),[28] that work like a magnet for attracting minerals (see Chapter 13).

For management of initial caries lesions with intact macroscopic enamel surfaces, plaque control and fluoridation play a central role in arresting the lesions, promoting remineralization, and consequently avoiding further lesion progression to visible cavitation. It is known that tooth brushing with fluoridated toothpaste is the most cost-effective strategy for controlling caries lesions.[29,30]

In addition, individualized preventive strategies that take into consideration patient's caries risk/activity as well as involve parents and other care takers are key factors for successful intervention in caries control. One of the most effective caries prevention strategies is the "Next model."[31,32] These techniques are especially needed in patients with reduced cooperation, such as small children, persons with handicap, chronically ill patients, or elderly patients (see Chapter 16).

As minimally invasive techniques, therapeutic sealants can be used (see Chapter 10), even on proximal surfaces (Fig 1-7a).[33] Another option is caries infiltration (Icon, DMG Dental; Fig 1-7b), where a resin-like material is diffused in the porous initial caries lesion.[34]



Figs 1-7a and b Minimally invasive treatment of approximal initial caries lesions by **(a)** therapeutic sealants and **(b)** caries infiltration with Icon (DMG Dental).

"Tertiary" caries prevention tries to prevent progression of the disease and subsequent complication. Traditionally, complete removal of carious tissue with subsequent restorative treatment was regarded as the standard treatment for carious teeth. In recent years, there has been a paradigm shift in caries understanding: Caries is no longer understood as an infectious disease, but as the result of an ecologic imbalance, which is triggered, for instance, by the frequent consumption of fermentable carbohydrates (see above). In the biofilm, among other things, carbohydrates are metabolized to acids, which cause demineralization of the tooth structure. Not only in the field of primary caries prevention is this of fundamental importance, but also for the treatment of cavitated caries lesions,

dentin demineralization, and (amount of) removal of carious tissues. For instance certain techniques encourage inactivation of caries lesions without carious tissue removal, such as nonrestorative cavity control,[35,36] presented in Chapter 14. Here, also the silver agents[37] (see Chapter 12) or sealing techniques with no carious tissue removal using preformed metal crowns like the Hall Technique[35] are part of the modern caries management spectrum.

Thus, it is possible to control or arrest caries by disturbing the biofilm and influencing the de- and remineralization processes at any time and stage during lesion development.[38,39] For cavitated caries lesions, biologically based techniques such as the selective (to firm, to leathery, to soft dentin) or stepwise carious tissue removal are currently advocated. These techniques are recommended for the management of shallow, moderately deep, and deep lesions in vital teeth in order to prevent pulpal exposure and to preserve the pulp vitality of the carious tooth.[40]

References

1. Machiulskiene V, Campus G, Carvalho JC, et al. Terminology of dental caries and dental caries management: Consensus Report of a Workshop Organized by ORCA and Cariology Research Group of IADR. Caries Res 2020;54:7–14.
2. IDZ. Fünfte Deutsche Mundgesundheitsstudie – DMS V. Köln, 2016.
3. Team DAJ. Epidemiologische Begleituntersuchungen zur Gruppenprophylaxe 2016. 1st ed. Bonn: Deutsche Arb.-Gemeinsch. f. Jugendzahnpflege, 2017.
4. Splieth CH, Santamaria RM, Basner R, Schüler E, Schmoeckel J. 40-year longitudinal caries development in german

adolescents in the light of new caries measures. Caries Res 2019;53:609–616.

5. Schmidt CO, Fahland RA, Franze M, et al. Health-related behaviour, knowledge, attitudes, communication and social status in school children in Eastern Germany. Health Educ Res 2010;25:542–551.
6. Chen KJ, Gao SS, Duangthip D, Lo ECM, Chu CH. Prevalence of early childhood caries among 5-year-old children: a systematic review. J Investig Clin Dent 2019;10:e12376.
7. Santamaria RM, Schmoeckel J, Basner R, Schüler E, Splieth CH. Caries trends in the primary dentition of 6- to 7-year-old schoolchildren in Germany from 1994 to 2016: Results from the German National Oral Health Surveys in Children. Caries Res 2019;53:659–666.
8. Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJL, Marcenes W. Global burden of untreated caries: a systematic review and metaregression. J Dent Res 2015; 94:650–658.
9. Vollú AL, da Costa MdEPR, Maia LC, Fonseca-Gonçalves A. Evaluation of oral health-related quality of life to assess dental treatment in preschool children with early childhood caries: a preliminary study. J Clic Pediatr Dent 2018;42:37–44.
10. DPHEP. National Dental Epidemiology Programme for England: oral health survey of five-year-old children 2015. London: Public Health England, 2016.
11. Turton B, Chher T, Sabbah W, Durward C, Hak S, Lailou A. Epidemiological survey of early childhood caries in Cambodia. BMC Oral Health 2019;19:107.
12. Slabsinskiene E, Milciuviene S, Narbutaite J, et al. Severe early childhood caries and behavioral risk factors among 3-year-old children in Lithuania. Medicina (Kaunas, Lithuania) 2010;46:135–141.
13. Prakash P, Subramaniam P, Durgesh BH, Konde S. Prevalence of early childhood caries and associated risk factors in

preschool children of urban Bangalore, India: a cross-sectional study. Eur J Dent 2012;6:141–152.

14. Livny A, Assali R, Sgan-Cohen HD. Early childhood caries among a Bedouin community residing in the eastern outskirts of Jerusalem. BMC Public Health 2007;7:167.
15. Postma TC, Ayo-Yusuf OA, van Wyk PJ. Socio-demographic correlates of early childhood caries prevalence and severity in a developing country: South Africa. Int Dent J 2008;58:91–97.
16. Colak H, Dülgergil CT, Dalli M, Hamidi MM. Early childhood caries update: a review of causes, diagnoses, and treatments. J Nat Sci Biol Med 2013;4:29–38.
17. Schmoeckel J, Santamaría RM, Basner R, Schüler E, Splieth CH. Introducing a specific term to present caries experience in populations with low caries prevalence: Specific affected Caries index (SaC). Caries Res 2019;53: 527–531.
18. Pine CM, Adair PM, Nicoll AD, et al. International comparisons of health inequalities in childhood dental caries. Community Dent Health 2004;21(1 Suppl):121–130.
19. Fontana M, Gonzalez-Cabezas C. Evidence-based dentistry caries risk assessment and disease management. Dental Clin North Am 2019;63:119–128.
20. Ekstrand K, Qvist V, Thylstrup A. Light microscope study of the effect of probing in occlusal surfaces. Caries Res 1987;21:368–374.
21. ICDAS Foundation. International Caries Classification and Management System (ICCMS). https://www.iccms-web.com/. Accessed 4 September 2019.
22. Nyvad B, Machiulskiene V, Baelum V. Construct and predictive validity of clinical caries diagnostic criteria assessing lesion activity. J Dent Res 2003;82:117–122.
23. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 1999;33:252–260.

24. Bin-Shuwaish M, Dennison JB, Yaman P, Neiva G. Estimation of clinical axial extension of Class II caries lesions with ultraspeed and digital radiographs: an in-vivo study. Oper Dent 2008;33:613–621.
25. Heinrich-Weltzien R, Haak R, Buchalla W, Kühnisch J. Kariesdiagnostik - Eine Herausforderung für den Zahnarzt? DDZ 2008;117:160–168.
26. Winand C, Shetty A, Senior A, et al. Digital imaging capability for caries detection: a meta-analysis. JDR Clin Trans Res 2016;1:112–121.
27. Schwendicke F, Dörfer CE, Schlattmann P, Foster Page L, Thomson WM, Paris S. Socioeconomic inequality and caries: a systematic review and meta-analysis. J Dent Res 2015;94:10–18.
28. Alkilzy M, Santamaria RM, Schmoeckel J, Splieth CH. Treatment of carious lesions using self-assembling peptides. Adv Dent Res 2018;29:42–47.
29. Walsh T, Worthington HV, Glenny A-M, Marinho VC, Jeroncic A. Fluoride toothpastes of different concentrations for preventing dental caries. Cochrane Database Syst Rev 2019;3:CD007868.
30. Twetman S. Prevention of early childhood caries (ECC): review of literature published 1998-2007. Eur Arch Paediatr Dent 2008;9:12–18.
31. Ekstrand KR, Christiansen MEC. Outcomes of a non-operative caries treatment programme for children and adolescents. Caries Res 2005;39:455–467.
32. Ekstrand KR, Christiansen MEC, Qvist V. Influence of different variables on the inter-municipality variation in caries experience in Danish adolescents. Caries Res 2003;37:130–141.
33. Alkilzy M, Berndt C, Meller C, Schidlowski M, Splieth C. Sealing of proximal surfaces with polyurethane tape: a two-year clinical and radiographic feasibility study. J Adhes Dent 2009;11:91–94.
34. Abdullah Z, John J. Minimally invasive treatment of white spot lesions--a systematic review. Oral Health Prev Dent

2016;14:197–205.

35. Santamaría RM, Innes NPT, Machiulskiene V, Schmoeckel J, Alkilzy M, Splieth CH. Alternative caries management options for primary molars: 2.5-year outcomes of a randomised clinical trial. Caries Res 2018;51:605–614.
36. Gruythuysen RJM, van Strijp AJPG, van Palestein Helderman WH, Frankenmolen FW. Niet-restauratieve behandeling van cariës in het melkgebit: doelmatig en kindvriendelijk. Ned Tijdschr Geneeskd 2011;155:A3489.
37. Chibinski AC, Wambier LM, Feltrin J, Loguercio AD, Wambier DS, Reis A. Silver diamine fluoride has efficacy in controlling caries progression in primary teeth: a systematic review and meta-analysis. Caries Res 2017;51:527–541.
38. Fejerskov O, Kidd EAM. Dental Caries: The disease and its clinical management, 2nd ed. Oxford: Blackwell Munksgaard, 2008.
39. Kidd E. The implications of the new paradigm of dental caries. J Dent 2011;39(Suppl 2):S3–S8.
40. Schwendicke F, Frencken JE, Bjørndal L, et al. Managing carious lesions: consensus recommendations on carious tissue removal. Adv Dent Res 2016;28:58–67.

2

Understanding periodontitis

Daniela Hoedke, Henrik Dommisch

Periodontitis is a complex inflammatory human disease. According to the World Health Organization (WHO), periodontitis is considered as a chronic noncommunicable disease (NCD), and it shares social determinants and risk factors with other NCDs such as cardiovascular diseases, diabetes mellitus, cancer, and chronic pulmonary diseases, which account for two-thirds of the worldwide mortality.[1] Thus, prevention of periodontal diseases, such as gingivitis and periodontitis, is highly important for each individuum.

This chapter will give an overview on the current knowledge of the epidemiology, etiopathogenesis, diagnosis, and preventive as well as therapeutic considerations in relation to periodontitis.

Periodontitis is one of the most prevalent oral diseases that can be prevented or treated. Figure 2-1 displays a representative image of a patient with periodontitis. In this specific case, the patient experienced tooth movement, tooth mobility, and generalized bleeding on probing. In addition to the resulting gaps between teeth, plaque deposits and discolored swollen gingival tissue are clearly visible in the interdental regions.

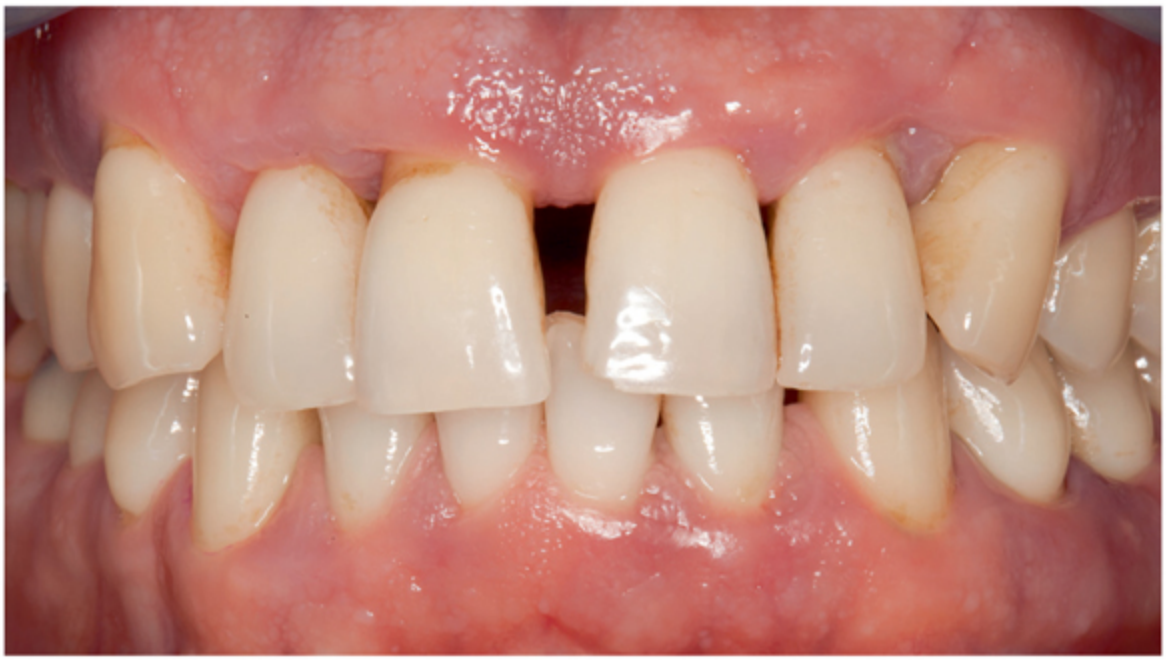


Fig 2-1 Representative image of a patient with periodontitis. This image shows the sequelae of periodontal destruction due to periodontitis: tooth movement, tooth mobility, and generalized gingival inflammation. In addition to the resulting gaps between teeth, plaque deposits and discolored swollen gingival tissue are clearly visible in the interdental regions.

Epidemiology

Gingivitis and periodontitis are considered as two entities of the same biofilm-induced inflammatory disease that affects tissues around teeth.[2] While gingivitis is a reversible inflammation of the gingiva around teeth without attachment loss, periodontitis comprises an additional nonreversible degradation of the periodontal apparatus, including the alveolar bone. In the worldwide population, approximately 12% exhibit severe forms of periodontitis, whereas approximately 50% show mild to moderate forms of periodontal disease. It is important to note that periodontitis represents the sixth most common human disease.[3,4] According to the increasing world population and high numbers of retained teeth, the global burden

due to severe periodontitis increased between 1990 and 2013 by 67%.[5] This led to a higher economic load to the health care systems.[6]

With respect to the distribution of periodontal disease in humans, periodontitis is an age-associated but not age-dependent disease, and the prevalence of periodontitis is strongly elevated between the third and fourth decade of life.[3,7] Low socioeconomic status is associated with higher risk for periodontitis, and men suffer more from periodontitis compared to women.[8,9]

Etiopathogenesis of periodontitis

The periodontium is a unique structure in the human body. While body surfaces, such as skin, mucosal tissues, hair, and nails, are constantly renewed, shed, and grow out, respectively, teeth exhibit a nonshedding surface. In addition, the tooth represents a direct connection between bone and the outside microbial environment, only separated by the junctional epithelium and connective tissue fibers. This allows for the dental plaque biofilm to develop and grow along the tooth surface into the gingival crevice, if not disturbed by routine oral hygiene procedures.

Microbial factors

Although periodontitis is a multifactorial disease, the central role to its pathogenesis refers to the interaction between the dental plaque biofilm, mainly consisting of well-organized bacteria adhering to the dental surface, and the immune inflammatory reaction of the host.[10]

In this context, periodontal health represents a status of homeostasis associated with a symbiotic biofilm and an appropriate immune-inflammatory reaction of the host, including the presence of neutrophils and the expression of antimicrobial peptides.[11,12]

The immune response to the periodontal bacteria is different for each individuum and impairs the composition of the bacterial biofilm

differentiating from a symbiotic into a dysbiotic composition.[13] The change of the relative abundance of pathogenic microorganisms when compared to their abundance in a healthy state leads to alterations within the host-microbial interactions that can further accelerate the inflammatory responses.[13]

The increasing amount of pathogenic periodontal bacteria, including their virulence factors, leads to an elevation of cellular signal transduction, and subsequently, secretion of pro-inflammatory mediators by various periodontal cell types.[14-16] Furthermore, the shift within the microbiota activates the complement system.[17] In the course of periodontal inflammation, more immune competent cells, such as macrophages, polymorphonuclear neutrophil granulocytes, T-cells, and B-cells, are present. The synthesis of additional pro-inflammatory mediators, such as interleukins, cell stimulating and receptor activating factors, and proteinases leads to changes of the connective tissue and bone metabolism, and therewith, to periodontal attachment loss.[18]

Initially, a dysbiosis between an altered biofilm in combination with a dysregulation of the immune reaction of a susceptible host leads to an inflammation of the gingiva (Fig 2-1). Gingivitis is a reversible disease that affects epithelium and connective tissue. The ongoing imbalance between the dysbiotic biofilm and the host-related immune reaction can lead to degradation of connective tissue and alveolar bone.[10,12,19-22]

In the context of the etiopathogenesis of periodontitis, the role of periodontal bacteria has been investigated for decades, and different plaque hypotheses have been developed.[23] Several oral bacterial species, eg *Aggregatibacter actinomycetemcomitans*, *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola*, have been regarded to be pathogenic. Within the periodontal microbiota, a special role is awarded to *P gingivalis*, a Gram-negative, anaerobic periodontal bacterium. *P gingivalis* is considered to be a keystone pathogen in the etiopathogenesis of periodontitis. According to its specifications, *P gingivalis* can influence the course of the periodontal disease by remodeling a health-associated homeostatic biofilm composition into a dysbiotic

biofilm composition, even at very low levels of colonization (< 0.01 % of the bacterial count in an animal model).[13,24]

Within the framework of inflammatory reaction, intercellular connections of periodontal cells disintegrate, and bacteria and their metabolic products can invade into deeper tissue levels, enter the bloodstream, and, eventually, reach the tissues beyond the oral cavity.[25,26] Throughout the body, periodontal bacteria may activate immune cells, which then release pro-inflammatory mediators. In this context, periodontal bacteria are able to modify immune-inflammatory reactions in the whole body. Therefore, it seems to be conceivable that periodontitis may also affect other inflammation-driven diseases, such as diabetes mellitus, cardiovascular diseases, and rheumatoid arthritis (see below).

Smoking

Smoking is considered to be one of the most important modifiable risk factors for periodontitis, with a clearly documented dose-response relationship.[27-29] In this context, smoking affects the composition of the microorganisms within the dental plaque biofilm leading to a higher proportion of pathogenic periodontal bacteria. Moreover, smoking impairs microcirculation and immune response to the bacteria, such as disturbance of the neutrophil function, increased synthesis of pro-inflammatory mediators, and higher levels of activated T-cells.[30,31]

In the context of periodontitis, the progression of periodontal break down is highly increased in smokers when compared to nonsmoking individuals with periodontitis.[32] The importance of the smoking status has now been integrated into the classification system of periodontal diseases.[33]

In respect to the progression of periodontitis, smoking represents one of the two modifying factors affecting the grading of periodontitis.[33] Smoking cessation has positive effects on periodontal conditions, the treatment of periodontitis, and tooth retention.[34-38]

Nutrition

Nutrition and malnutrition, respectively, seem to be of importance in relation to periodontal diseases. It is known that nutrient factors influence inflammatory reactions, and malnutrition may lead to depletion of micronutrients which then increases the susceptibility to periodontitis.[39] For example, there is an association between periodontal inflammatory responses and vitamin C depletion. Historically, the relationship between the intake of vitamin C-rich vegetables or fruits and periodontal disease has been described. In the 18th century, during maritime trading and exploratory seafaring, sailors often suffered from a condition called scurvy. Scurvy represents a vitamin C deficiency disease associated with gingival bleeding and tooth mobility caused by altered collagen formation, impaired connective tissue barrier formation, and fibroblast growth.[40-42] There are a number of different micronutrients associated with periodontal health and disease. For macronutrients, it has been observed that a higher intake of sugar is associated with increased gingival bleeding.[43,44] For more detailed information, the authors refer to the relevant literature.[39]

Obesity

The association between obesity and periodontitis has been described more recently. It was found that central adiposity was associated with an increased risk of developing periodontitis in older adults. However, due to large variability within the available studies, only moderate evidence is currently available.[45,46] In addition, there are some indications that periodontal therapy is more ineffective in obese patients with periodontitis. The effect on the therapeutic

outcome was similar to the effect of smoking in periodontitis patients.[47]

In basic science experiments, it has been demonstrated that the differentiation of osteoblasts was altered in the presence of *P gingivalis* in obese mice.[48] Animal experiments have also shown that age and obesity represent risk factors that may result in reduced alveolar bone crest height even in an otherwise healthy periodontium.[49] Future research is required in order to gain more robust knowledge of how nutrition is related to periodontitis.

Genetic factors

The contribution of genetics to the risk for periodontitis has been estimated as up to 50%. In particular, a strong genetic component is assumed in younger patients with severe periodontitis.[50]

For several years, the identification of single nucleotide polymorphisms (SNPs) in relation to periodontitis was of high scientific interest.[51] SNPs represent the most frequent genetic variation, and an association of this type of variation with disease is, therefore, very likely. Mostly, candidate gene studies have been performed in the past. The evidence, however, for one of the analyzed variations in candidate genes, such as for interleukin-1, is rather weak.[52,53] In relation to periodontitis, it is very likely that genetic susceptibility factors for periodontitis will not be found in the genetic sequence of one distinct candidate gene, but rather in a variety of different genes. The technical progress in combination with the publication of the last human chromosome as part of the human genome project (sequencing of the whole human genome) allowed the simultaneous analysis of high numbers of genetic variations (SNPs), with no distinct a priori hypothesis.[54] Those genome-wide association studies (GWAS) have been performed with large sets of samples from patients with periodontitis.[55-58] To date, a number of different genetic variances in specific genes, such as *ANRIL*, *PLA*, *SIGLEC5*, *DEFBA1A3*, *NPY*, and *GLT6D1* have been described in periodontitis patients, underlying the hypothesis that there are

polygenetic factors that, in a certain but yet unknown combination, alter the susceptibility for periodontitis.[57-61] The individual functional characteristics of the identified variations are the subject of current research projects.[62]

Periodontitis in relation to systemic diseases

Diabetes mellitus

Diabetes mellitus is a metabolic condition with chronic hyperglycemia as the leading symptom. Both diabetes mellitus and periodontitis are chronic, inflammation-driven diseases with mutual influence regarding their impaired immunologic responses.[63,64]

Diabetes mellitus as well as periodontitis are common, chronic, noncommunicable diseases that exhibit a bidirectional relationship (review[65]). The relationship between both diseases was first described by Löe in 1993, and periodontitis found as the sixth complication of diabetes mellitus.[66] It has been shown that patients with diabetes mellitus exhibit more severe and rapidly progressive forms of periodontitis compared to patients without diabetes mellitus.[67-70] It is now widely accepted that diabetes mellitus represents a major risk factor for the development and progression of periodontitis, and thus, diabetes mellitus has now been added as a modifying factor within the grading of periodontitis.[29,33]

Furthermore, during severe periodontitis, the inflammatory process can have detrimental effects on blood sugar control by influencing the insulin resistance, leading to a poorer glycemic control, increasing the rate of incident prediabetes and type 2 diabetes mellitus.[71-74] Here, the periodontal inflammation exhibits a systemic impact along with bacteremia and increased levels of pro-inflammatory mediators detectable in the blood stream, and therewith, blood sugar control and insulin resistance are negatively influenced in patients with periodontitis and diabetes mellitus.[65,70,75-77]

Diabetes mellitus-related complications, such as cardiovascular, cerebrovascular, renal, retinal, and neuropathic complications, are

significantly increased in patients with severe periodontitis and type 2 diabetes mellitus.[78-82]

Cardiovascular diseases

Cardiovascular diseases also belong to the group of chronic noncommunicable diseases, and it has been shown that there is a clear epidemiologic association with periodontitis.[83,84] More precisely, epidemiologic studies have demonstrated that there is a positive association between periodontitis and coronary heart and cerebrovascular disease.[84,85]

Similar to diabetes mellitus, one of the proposed mechanisms of interaction includes the incidence of bacteremia due to daily routine procedures such as tooth brushing or eating.[25] It was found that the magnitude of bacteremia was higher in patients with periodontitis when compared to patients with gingivitis.[26] Analyses of atherothrombotic tissues revealed the presence of periodontal bacteria, and patients with periodontitis showed a greater probability for the detection of periodontal pathogenic bacteria in those tissues.[86,87]

In this context, the influence of periodontitis on the systemic inflammatory status has been recognized as an important mechanism.[75,76] When compared to healthy control individuals, patients with periodontitis exhibited elevated levels for C-reactive protein (CRP), interleukin-(IL)-1 beta, IL-6, IL-8, and tumor necrosis factor alpha (TNF-α).[88-96]

Dyslipidemia is recognized as a risk factor for cardiovascular diseases, and it has been shown that dyslipidemia is present in patients with periodontitis.[97,98] Other parameters, such as increased intima media-thickness or alterations in the flow-mediated dilatation of blood vessels, may indicate pathologic cardiovascular alterations. Periodontitis is associated with an increased intima media-thickness, changes in the flow-mediated dilatation, and hypertension.[99-103]

It is an interesting finding that both periodontitis and cardiovascular diseases seem to share common genetic risk

factors.[58,59,104] This functional and molecular background is the subject of current research projects.[62]

Rheumatoid arthritis

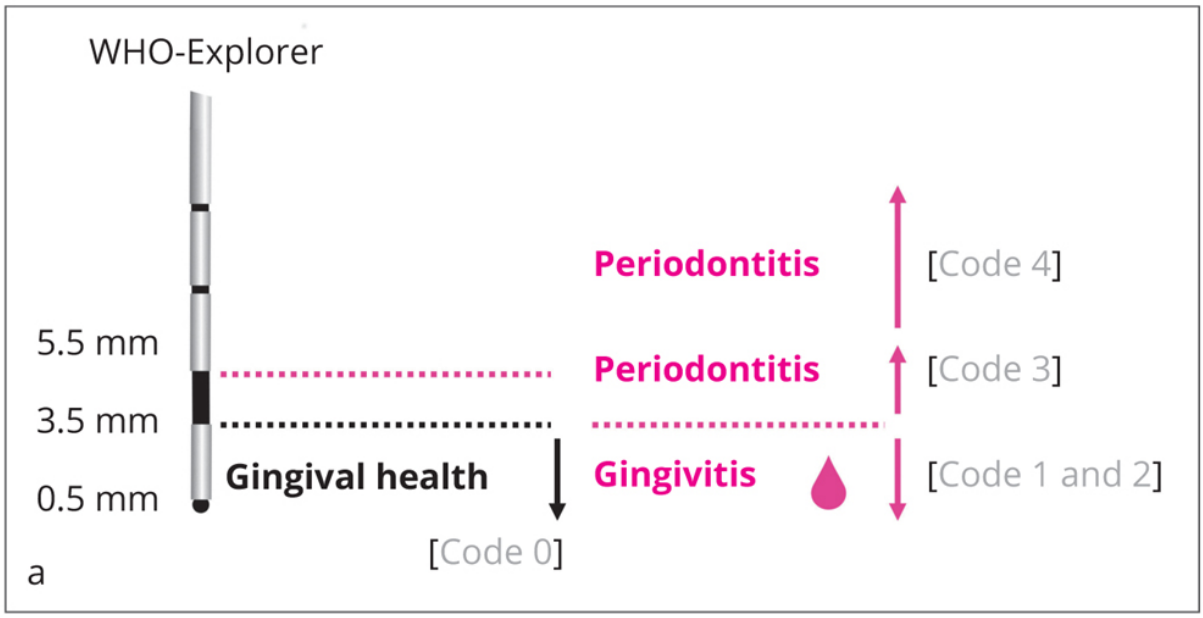
Rheumatoid arthritis is a complex autoimmune disease that is characterized by the infiltration of macrophages and T-cells into the synovial membrane of joints leading to cartilage degradation and bone erosion.[105] The production of auto-antibodies is typical for rheumatoid arthritis, and the auto-antibody against immune globulin G represents the rheumatoid factor.[106,107] Biochemical post-translational processes, such as citrullination and carbamylation, are involved in the mechanisms leading to antibody synthesis.[108,109] Citrullination is a post-translational modification of the amino acid arginine to citrulline promoted by an enzyme called peptidylarginine deiminase (PAD). Based on the current knowledge, the link between rheumatoid arthritis and periodontitis could be via the periodontal pathogen *P gingivalis*, which also expresses a similar enzyme (PPAD).[110] The proteins modified by the PPAD from *P gingivalis* can further promote autoantibody production against citrullinated proteins (anti-citrullinated protein antibodies [ACPAs]), and this may be another stimulus for the development of rheumatoid arthritis.[108,110] Current research investigates the hypothesis of periodontitis to be a risk factor for rheumatoid arthritis.[111,112]

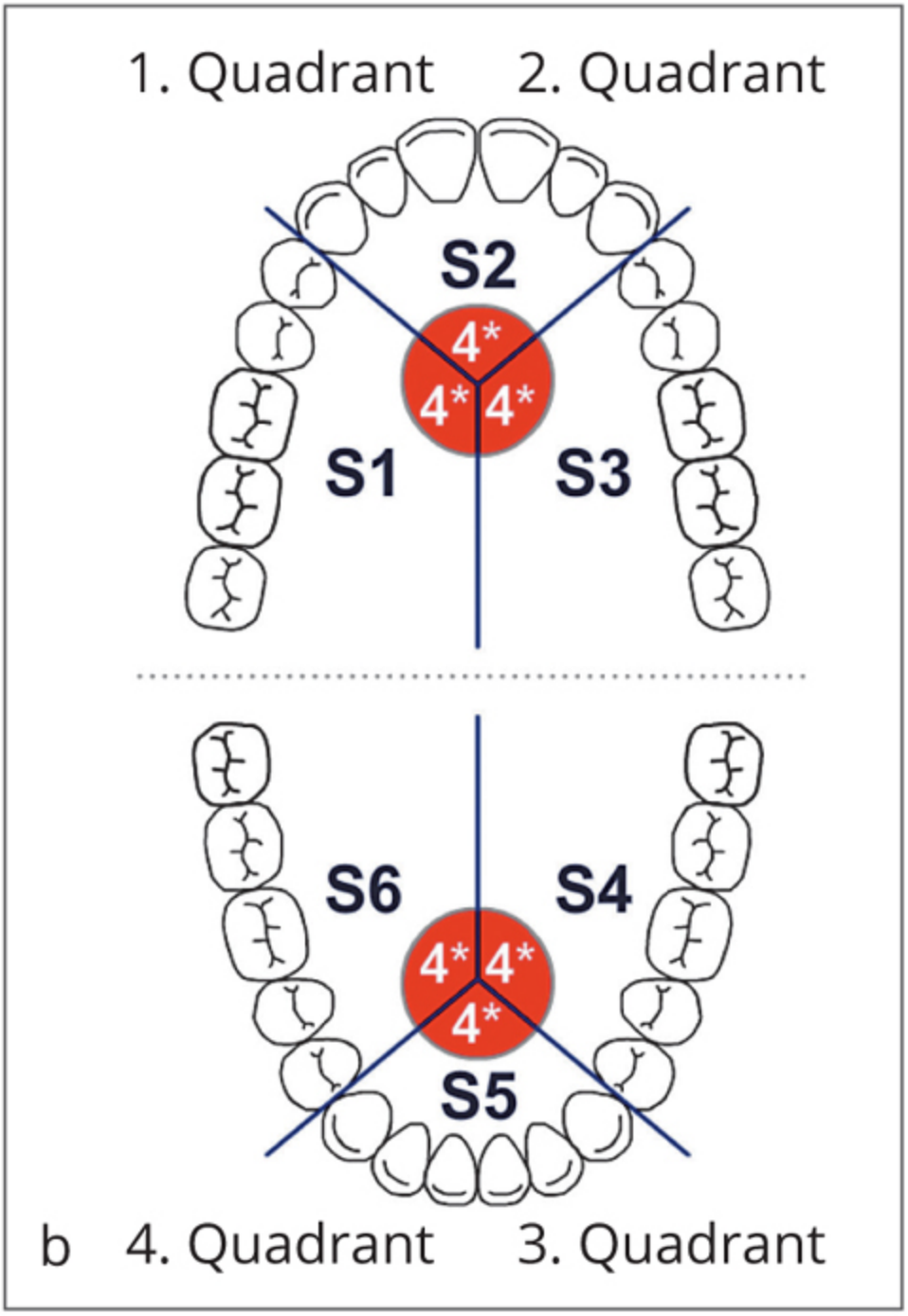
Periodontitis may exhibit a considerable influence on systemic conditions such as diabetes mellitus, cardiovascular disease, and rheumatoid arthritis.

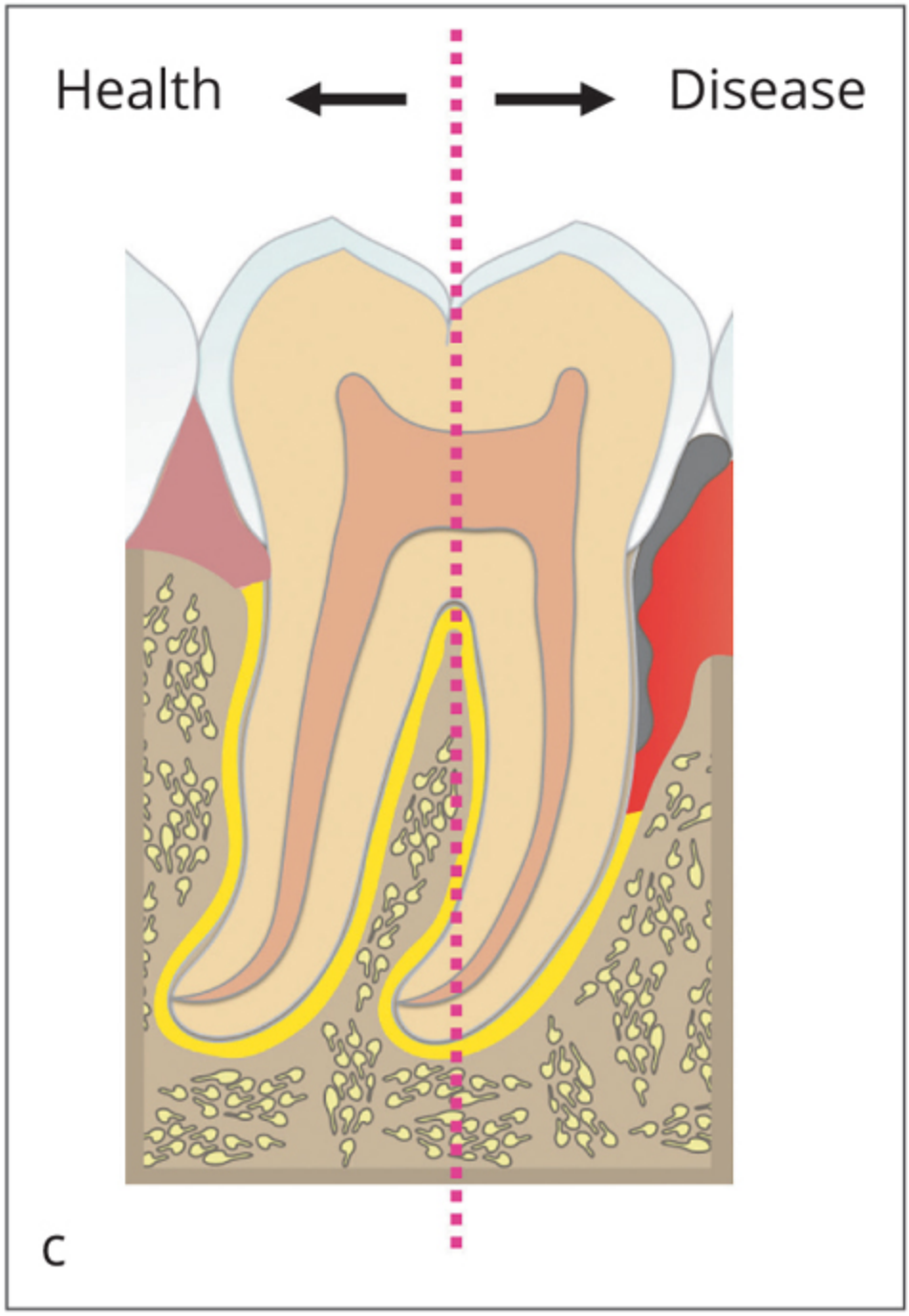
Clinical features and diagnosis

Symptoms, clinical and radiographic features

Periodontitis represents major clinical characteristics including microbial biofilm formation (dental plaque biofilm), inflammation of the gingiva, periodontal attachment loss, and bone loss. The microbial biofilm is visible as dental plaque on tooth surfaces and around the gingival margin, which may calcify and form dental calculus when not routinely removed by daily oral hygiene procedures. In most patients, the amount of plaque formation and calculus is associated with severity of periodontitis. Inflammation of the gingiva around the teeth can be seen by swelling, redness, edema, and bleeding. Pocket formation, bleeding on probing, and gingival recessions combined with periodontal attachment and bone loss are clinical signs of periodontitis. Furthermore, patients with severe periodontitis often suffer from tooth migration, increased tooth mobility, and periodontal abscesses. Clinical periodontal examination comprises the measurements of attachment level, periodontal pocket probing, bleeding on probing, furcation involvement, and tooth mobility. The amount and the type of bone loss (horizontally versus vertically), furcation involvement, and combined periodontal-endodontic lesions are determined by additional radiographic examinations. Figures 2-2 to 2-11 display the periodontal screening index, different types of periodontal explorers, and a complete patient case documentation during active periodontal therapy, and further background information is given in the corresponding legends.

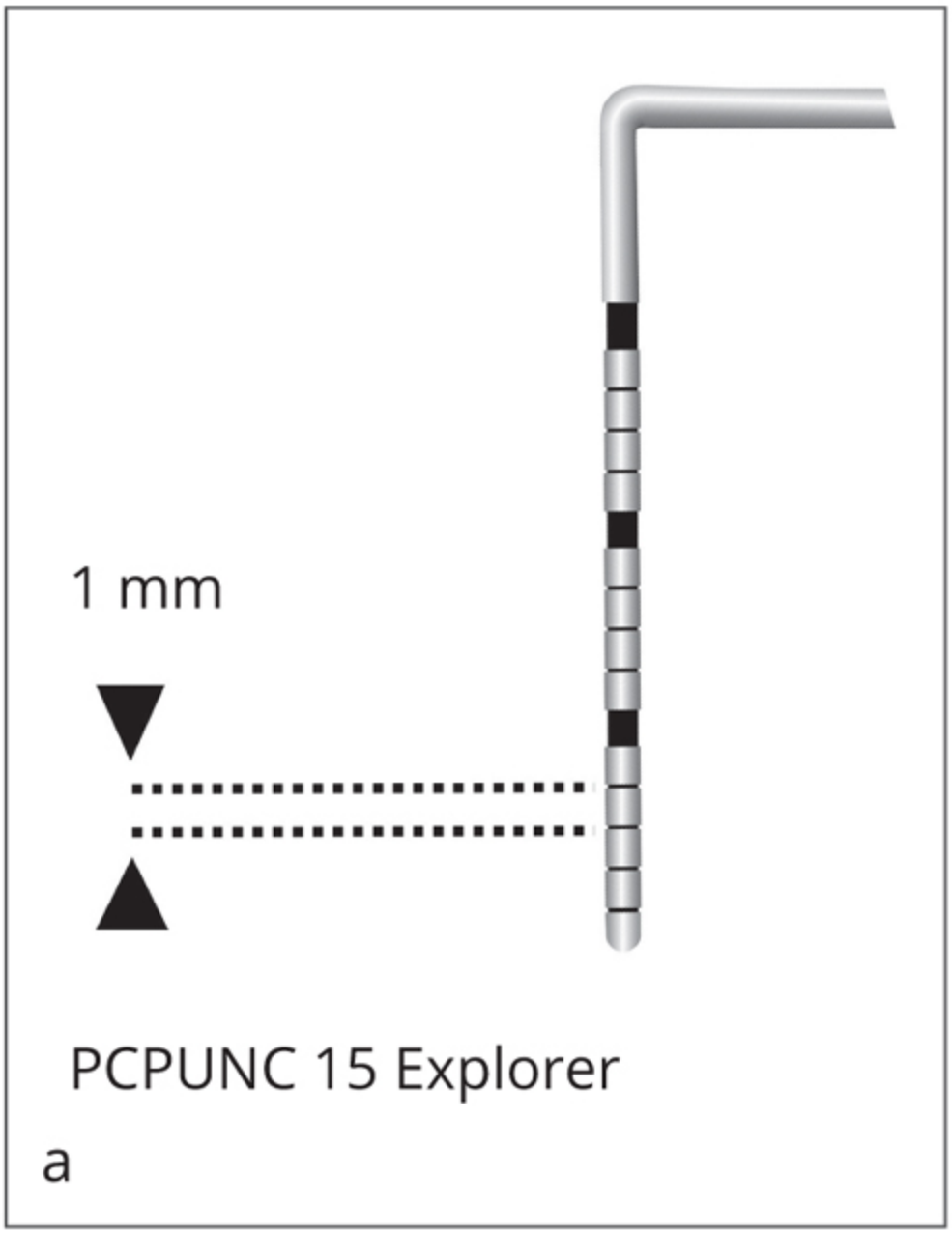






Figs 2-2a to c Periodontal Screening Index (PSI). **(a)** Periodontal conditions are explored by a periodontal probe proposed by the World Health Organization (WHO). This probe is graded in sections of 0.5 mm, 3.5 mm, and 5.5 mm, respectively. Depending on the depth of penetration, different codes refer to the indication of health or disease. Shallow pockets (< 3.5 mm) without bleeding upon

probing are considered healthy (code 0) and with bleeding on probing indicate gingivitis (code 1 and code 2 when calculus and/or overhanging restoration margins are present), whereas pockets > 3.5 mm to 5.5 mm indicate moderate, and ≥ 5.5 mm indicate more severe periodontal destruction (when no pseudopocket is present). **(b)** These codes are charged to each of the six quadrants; * indicates special findings, such as recessions, furcation involvement, tooth mobility, and migration. **(c)** The PSI allows a quick and safe examination of periodontal condition in the dentition. It helps to clearly distinguish between health and more or less severe disease without claiming a distinct periodontal diagnosis.



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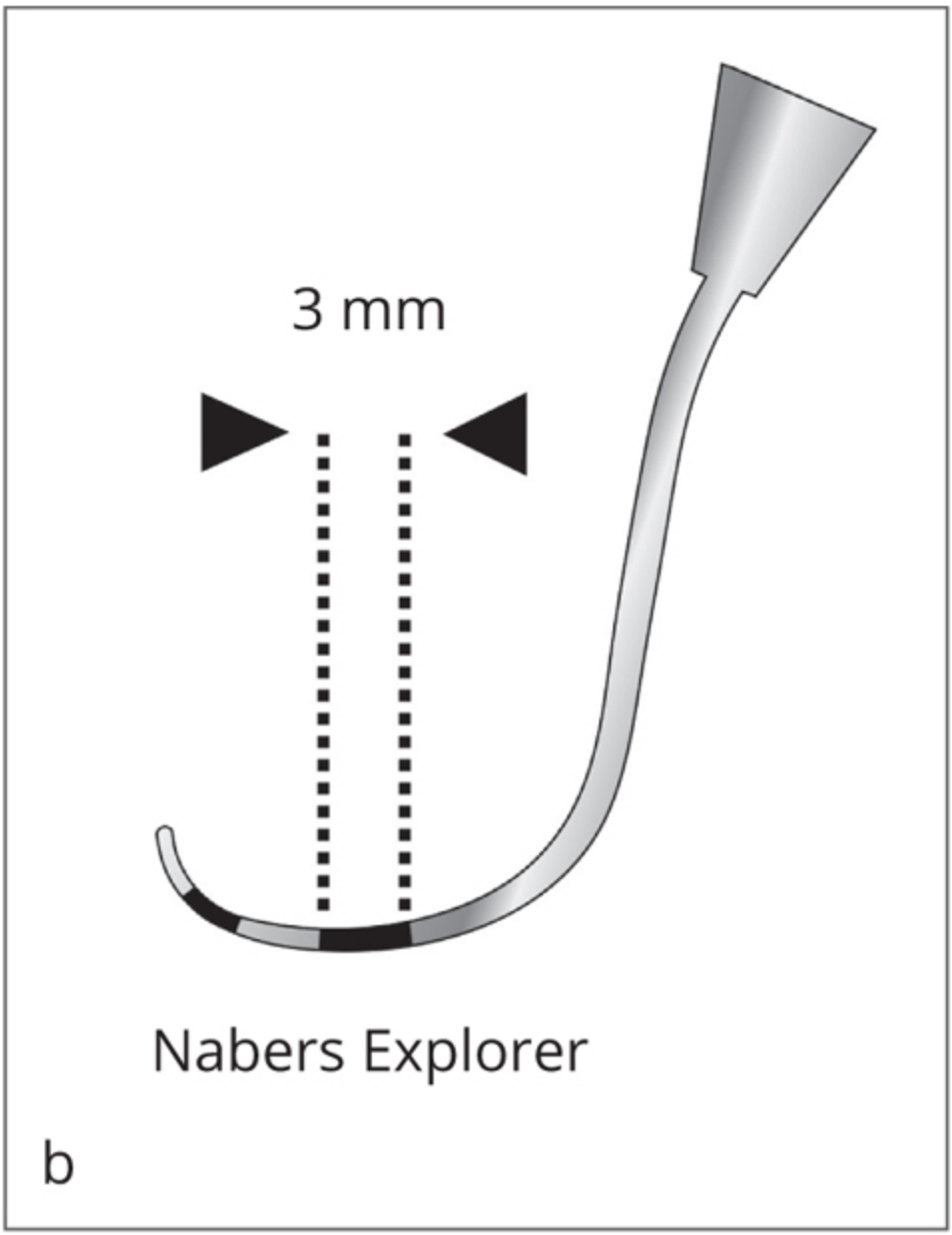
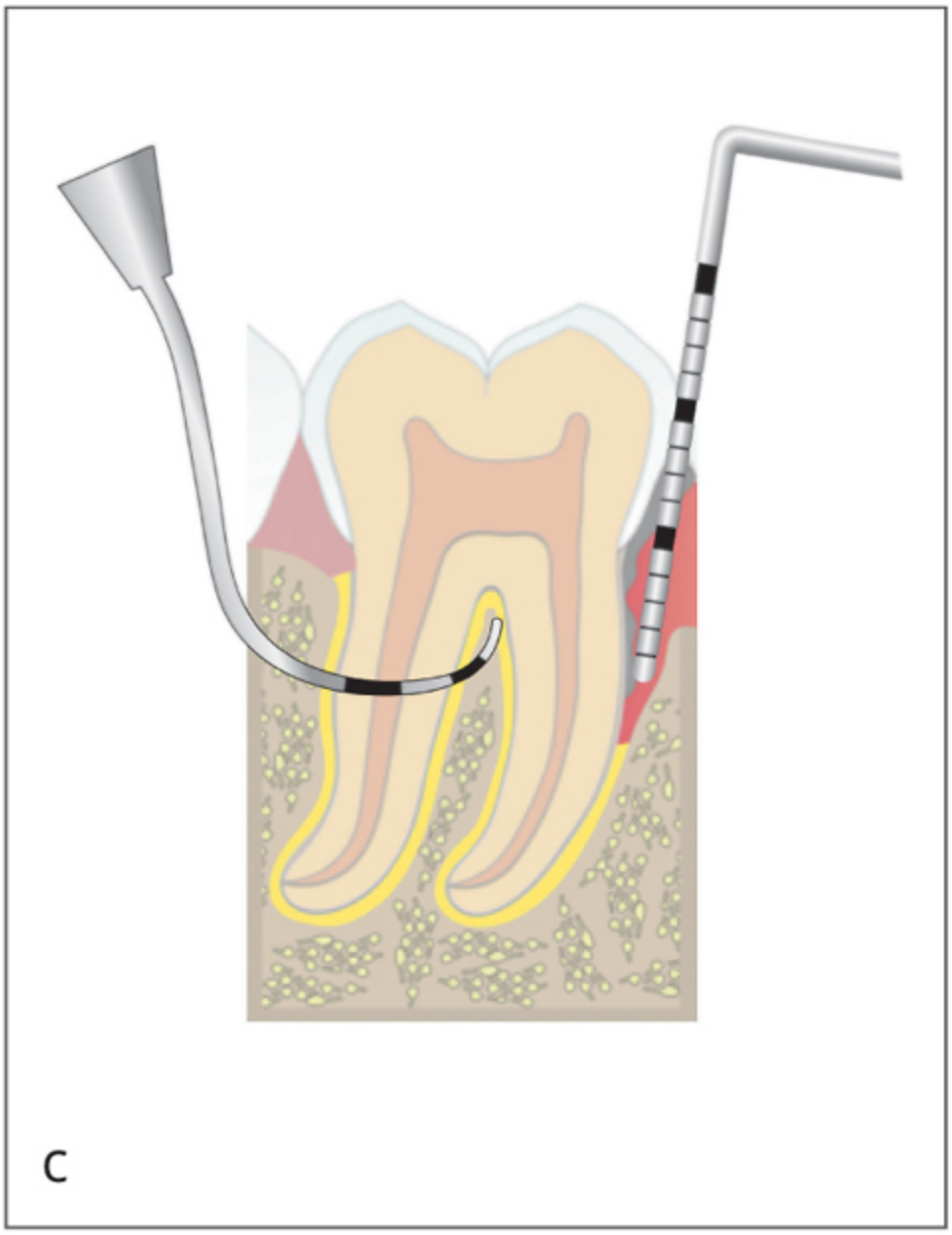
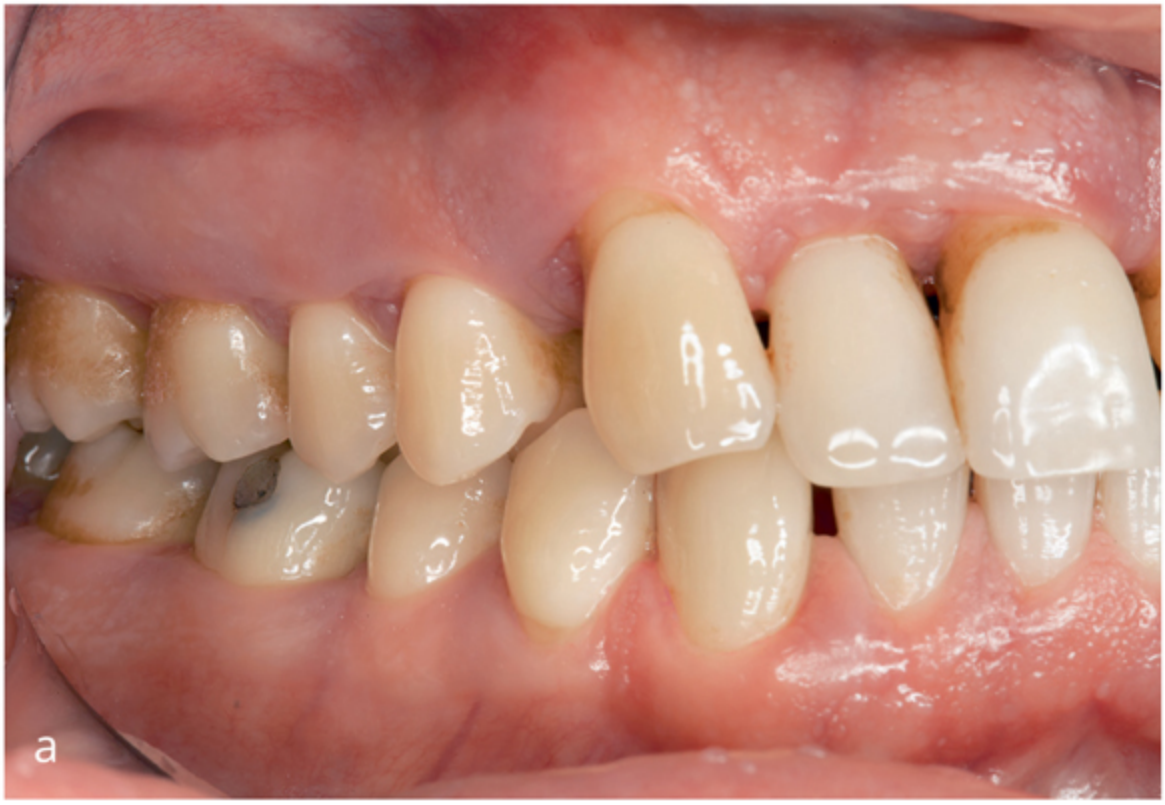
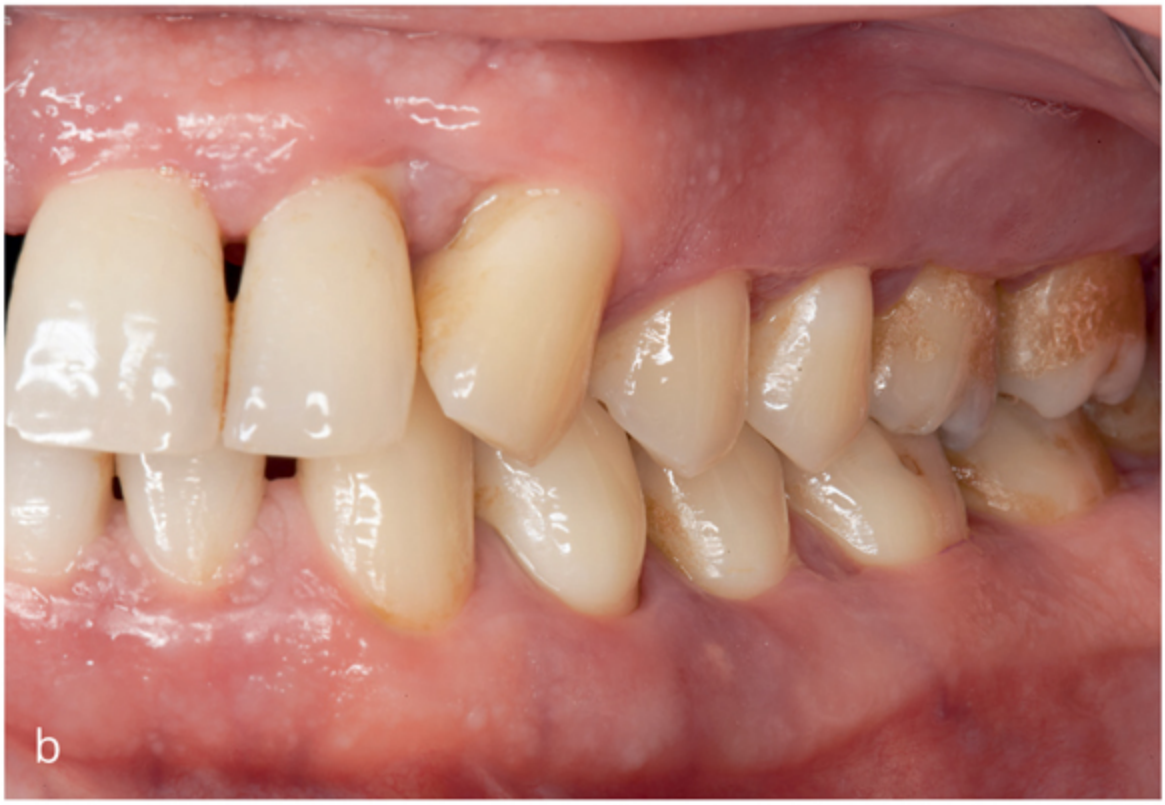
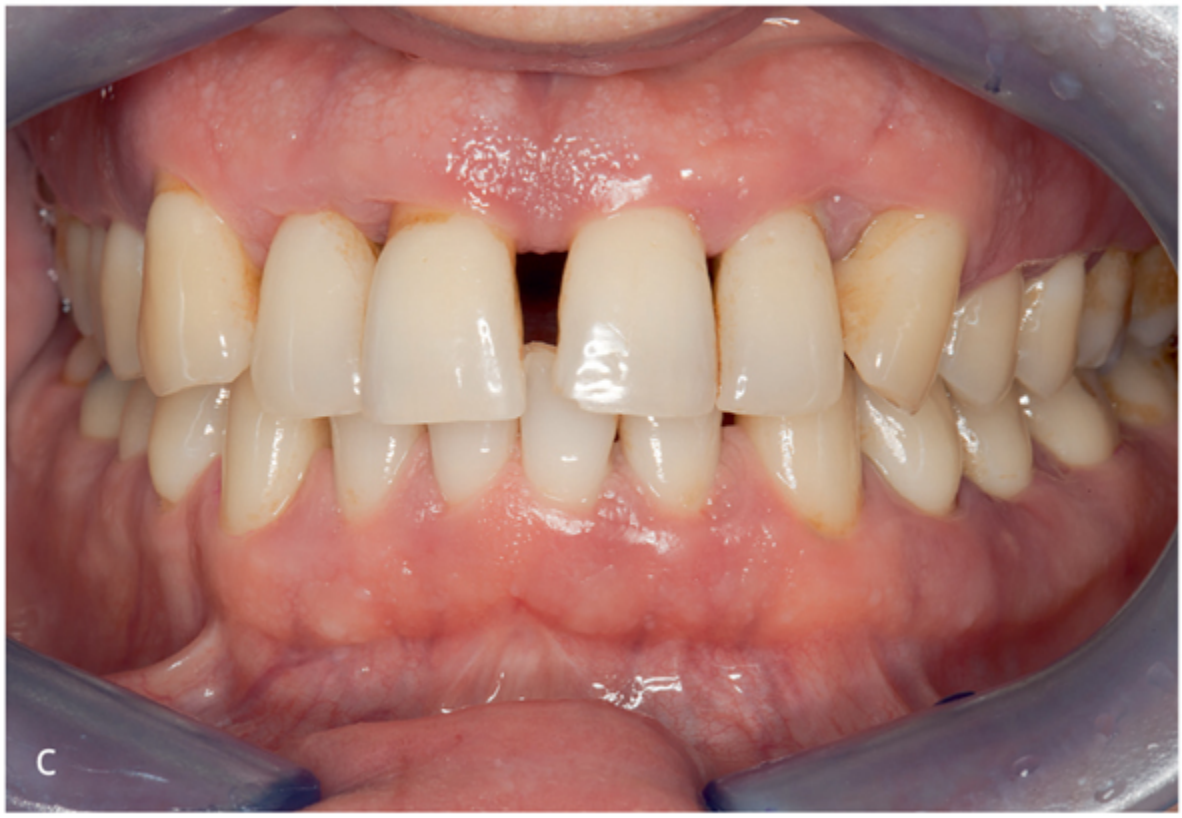


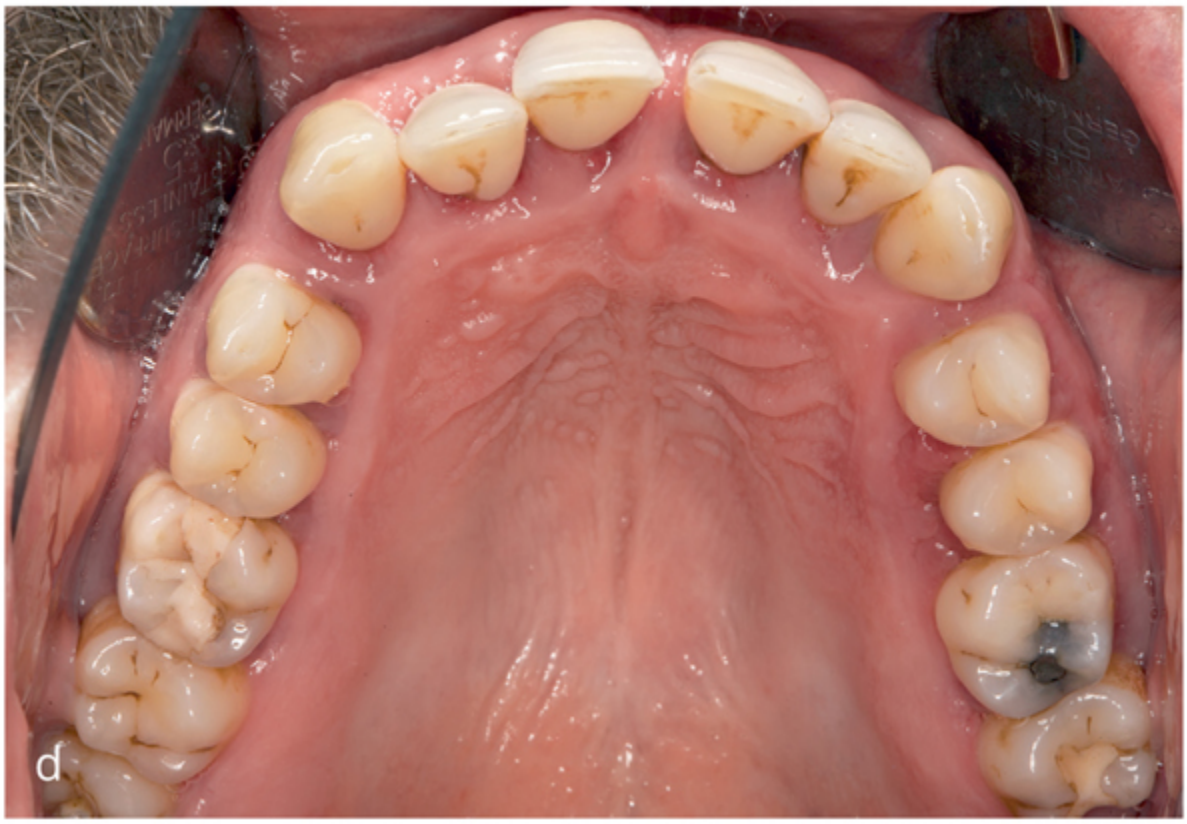


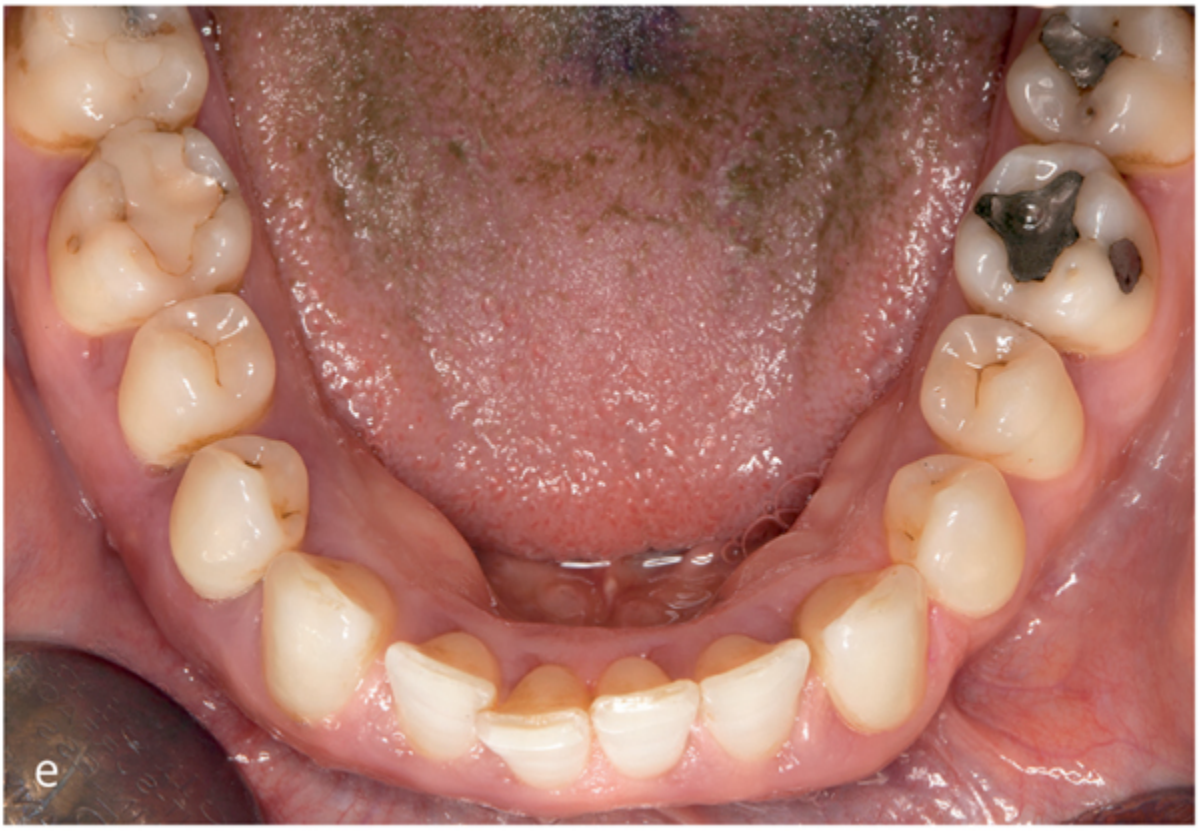
Figs 2-3a to c For a complete periodontal examination, more precisely scaled periodontal probes are required. **(a)** The PCPUNC 15 explorer (pressure calibrated, diameter of 0.5 mm) represents the standard periodontal probe with a graduation of 1 mm steps. **(b)** To explore interradicular attachment loss, a bended periodontal probe (Nabers probe, 3 mm graduation) is recommended for determination of furcation involvement. **(c)** Presentation of the application of periodontal probes around molar teeth.

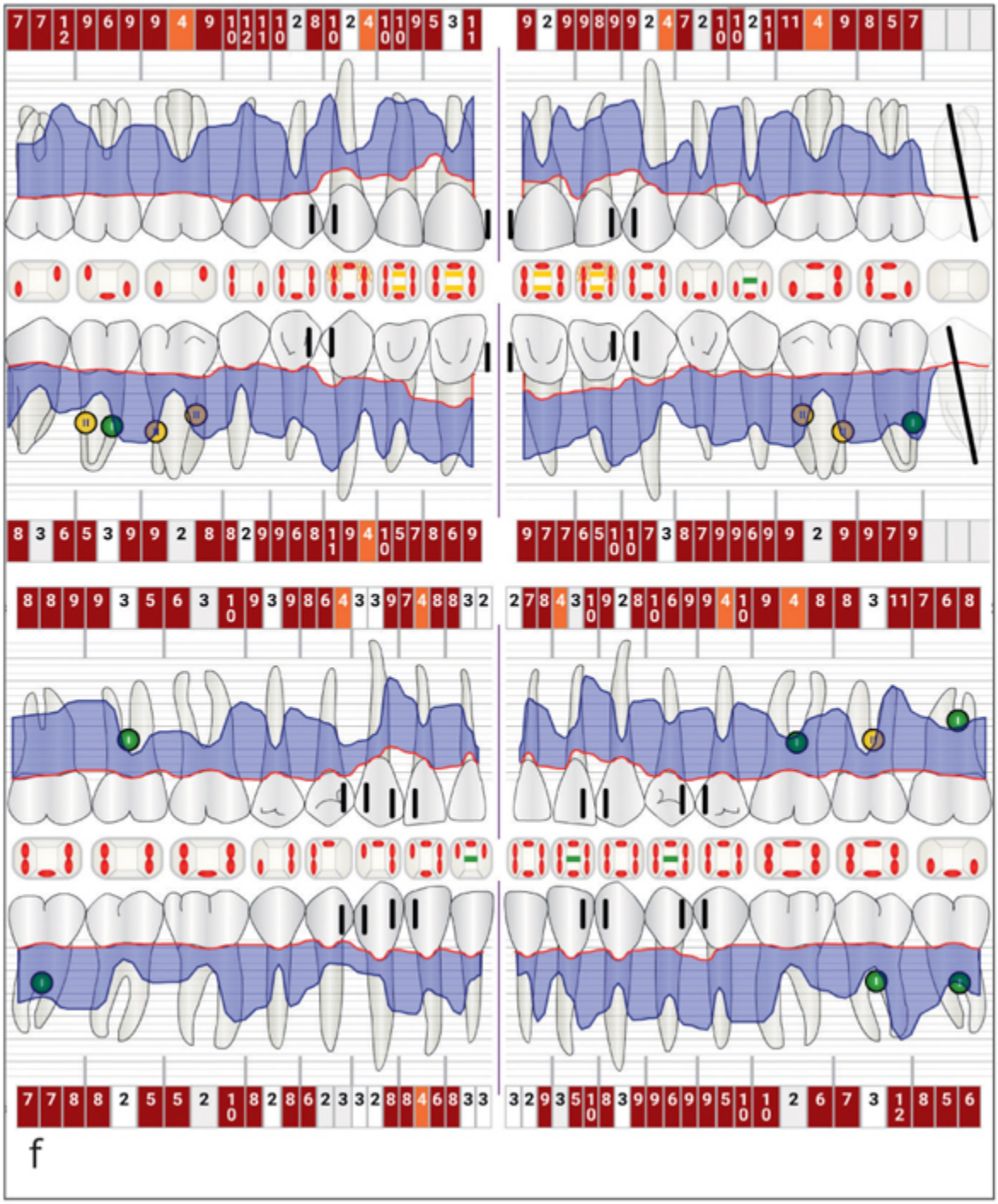






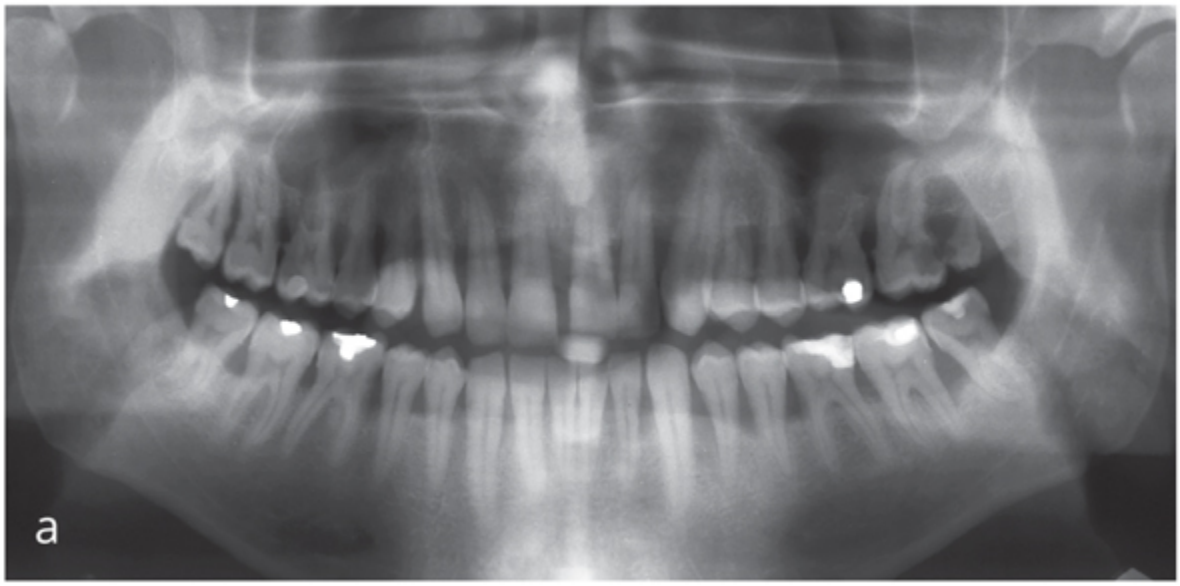


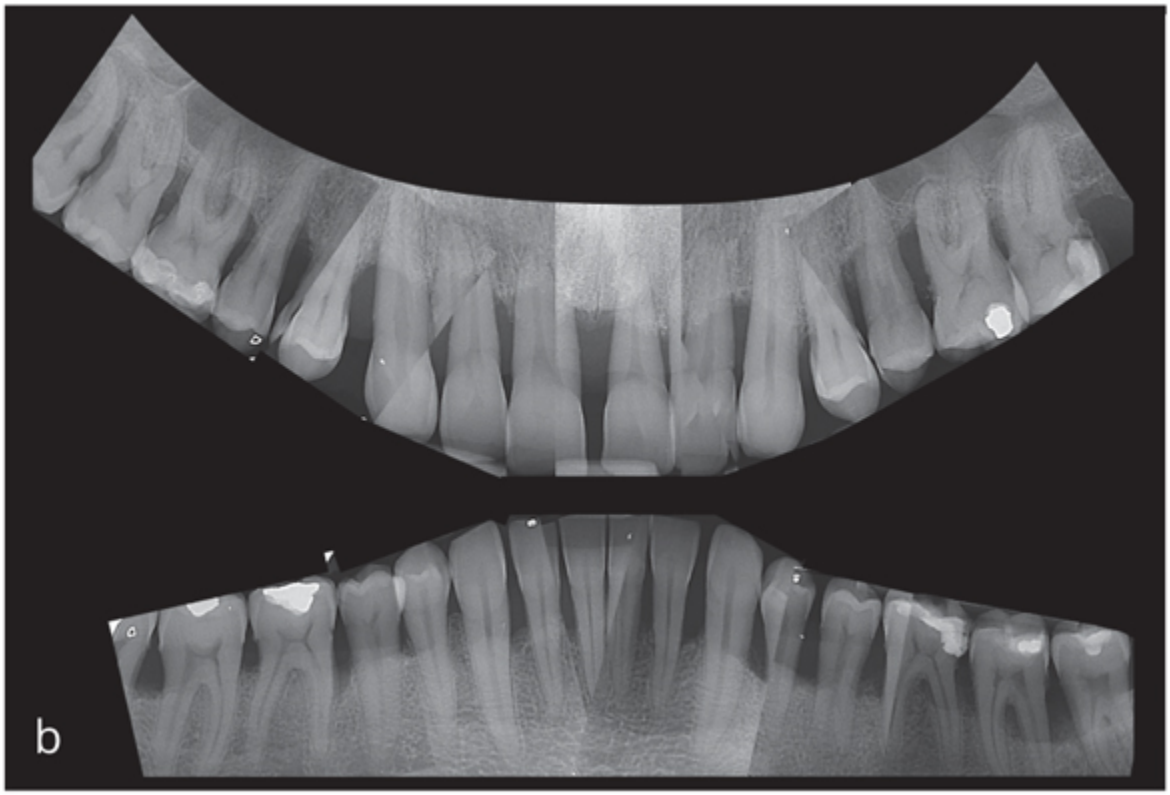




Figs 2-4a to f A 38-year-old (at time of admission) man with an inconspicuous general health and no medication. Diagnosis: periodontitis stage 4, grade C. This case continues in Fig 2-10. Baseline examinations: **(a)** first and fourth quadrants; **(b)** second and third quadrants; **(c)** frontal view; **(d)** maxillary arch; **(e)** mandibular

arch; **(f)** baseline measurements of the clinical attachment level, including tooth migration and loosening, furcation involvement, and bleeding on probing (graphic illustration by Parostatus.de).





Figs 2-5a and b Radiographic examination of the patient introduced in Fig 2-3. **(a)** Panoramic radiograph and **(b)** intraoral radiographs. The radiographs show severe horizontal and vertical (locally) bone loss.

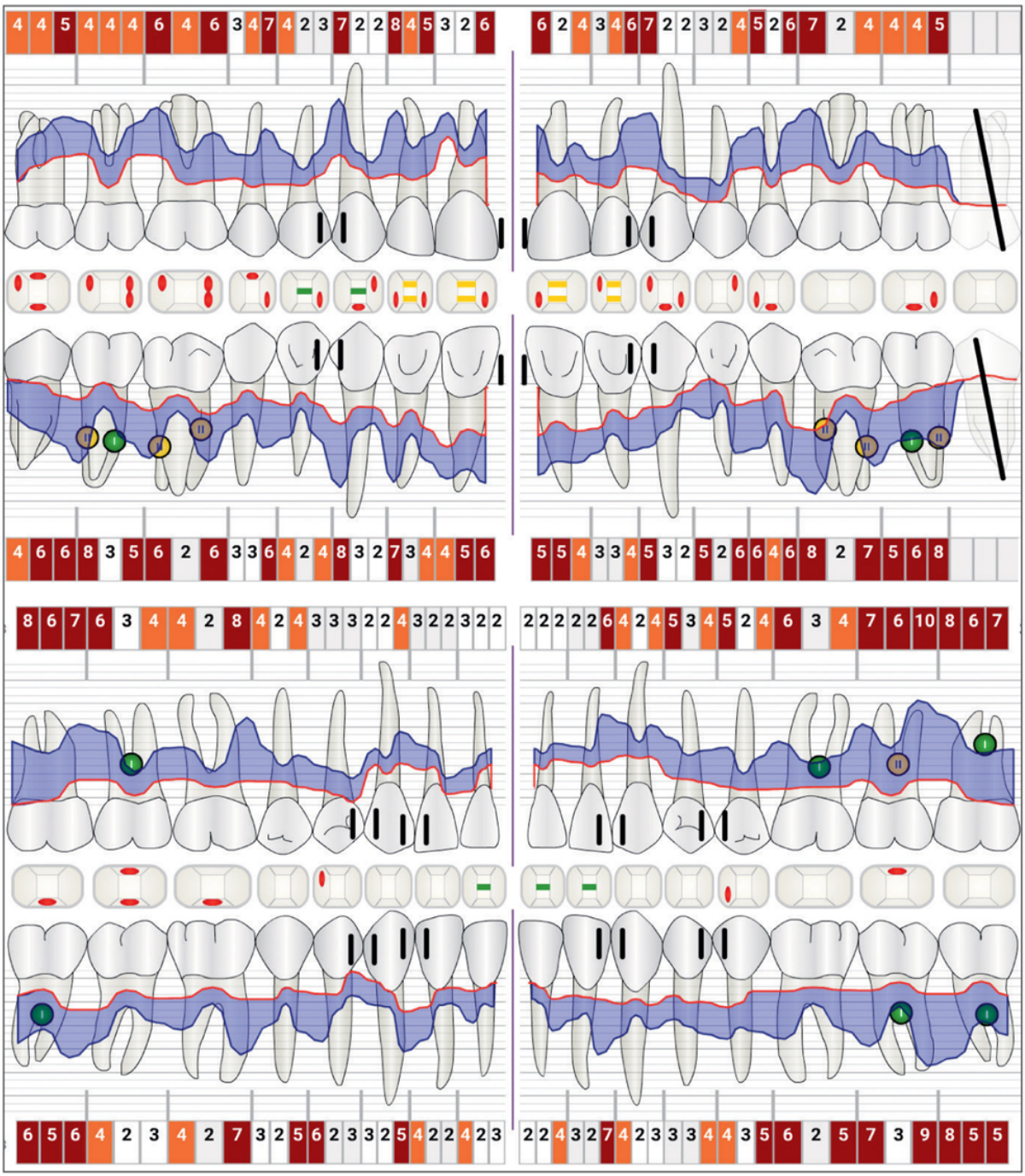
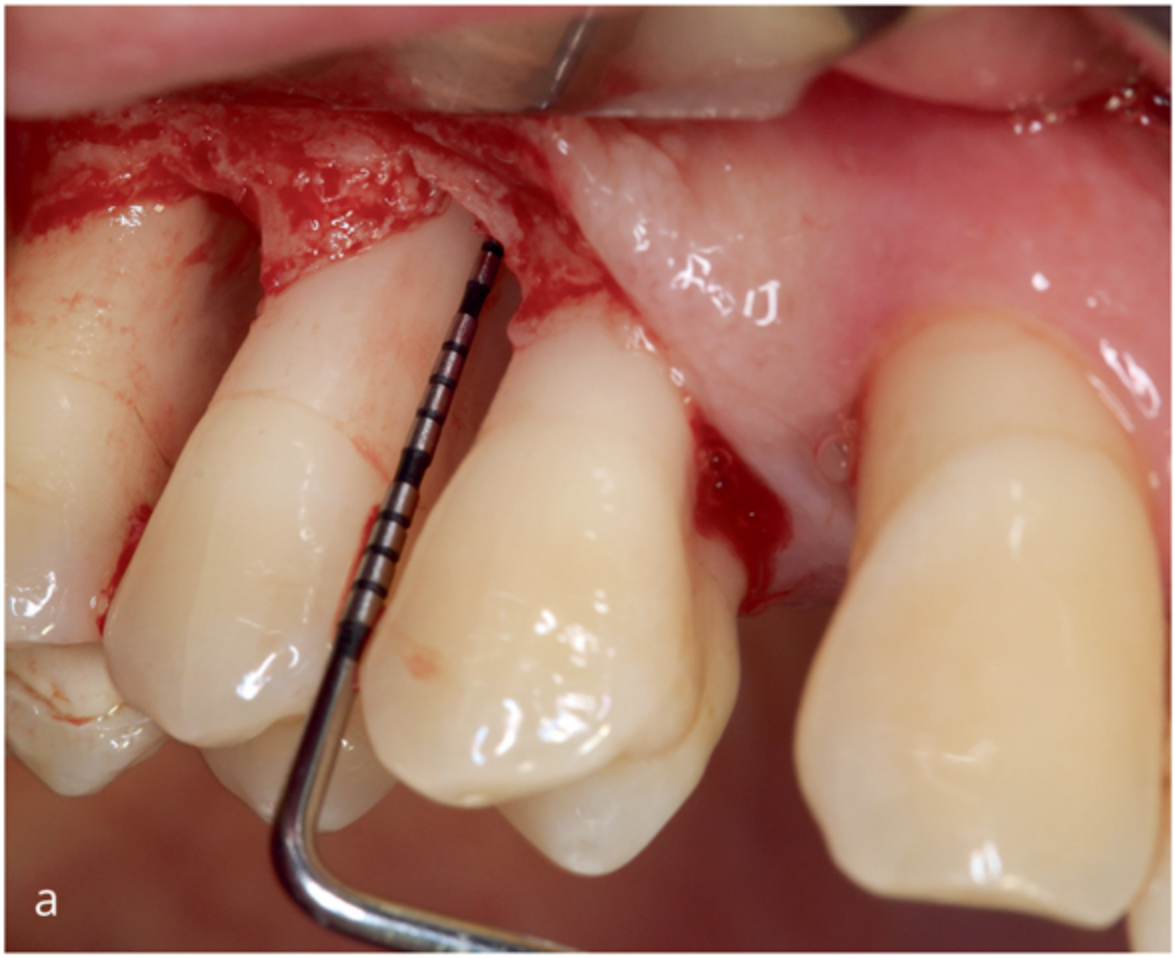
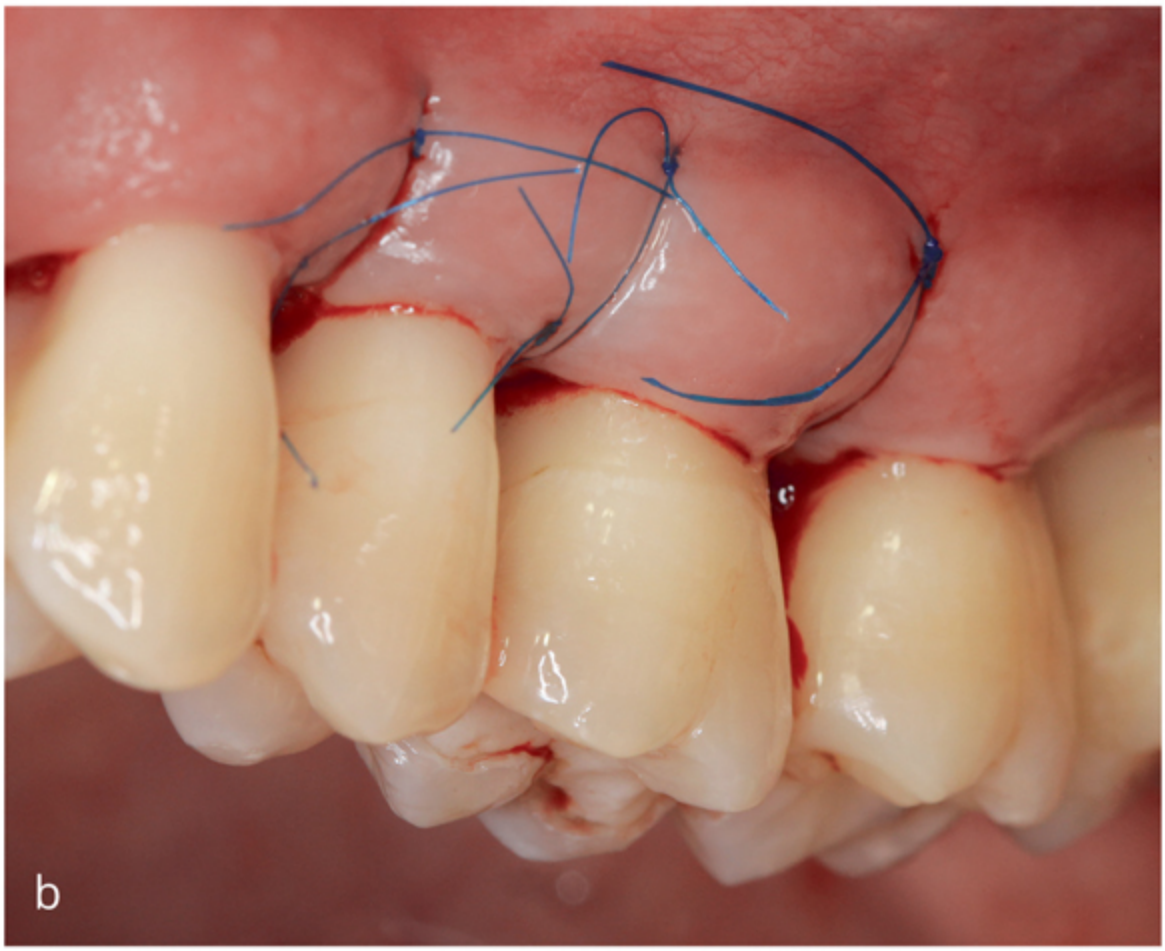
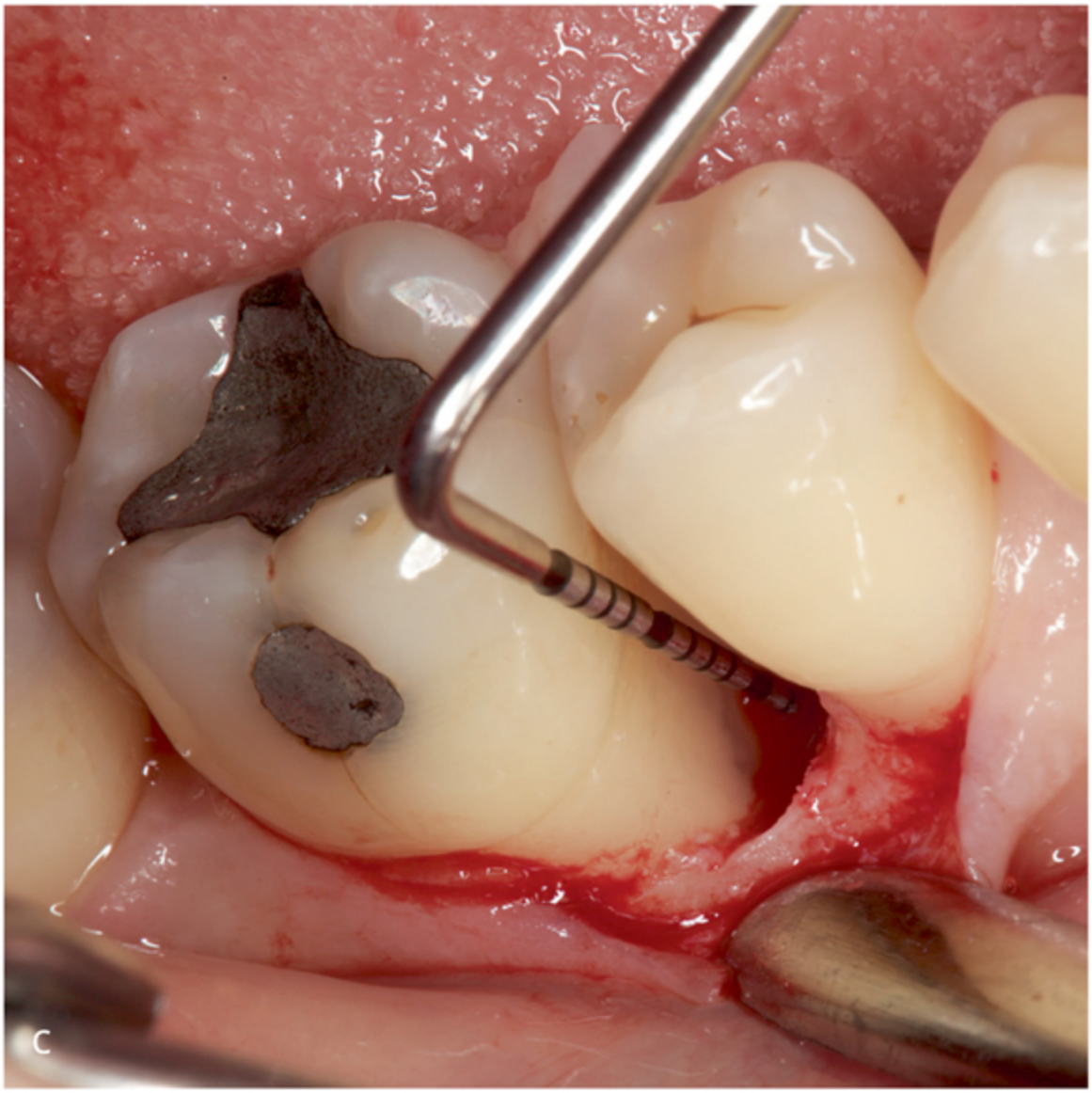
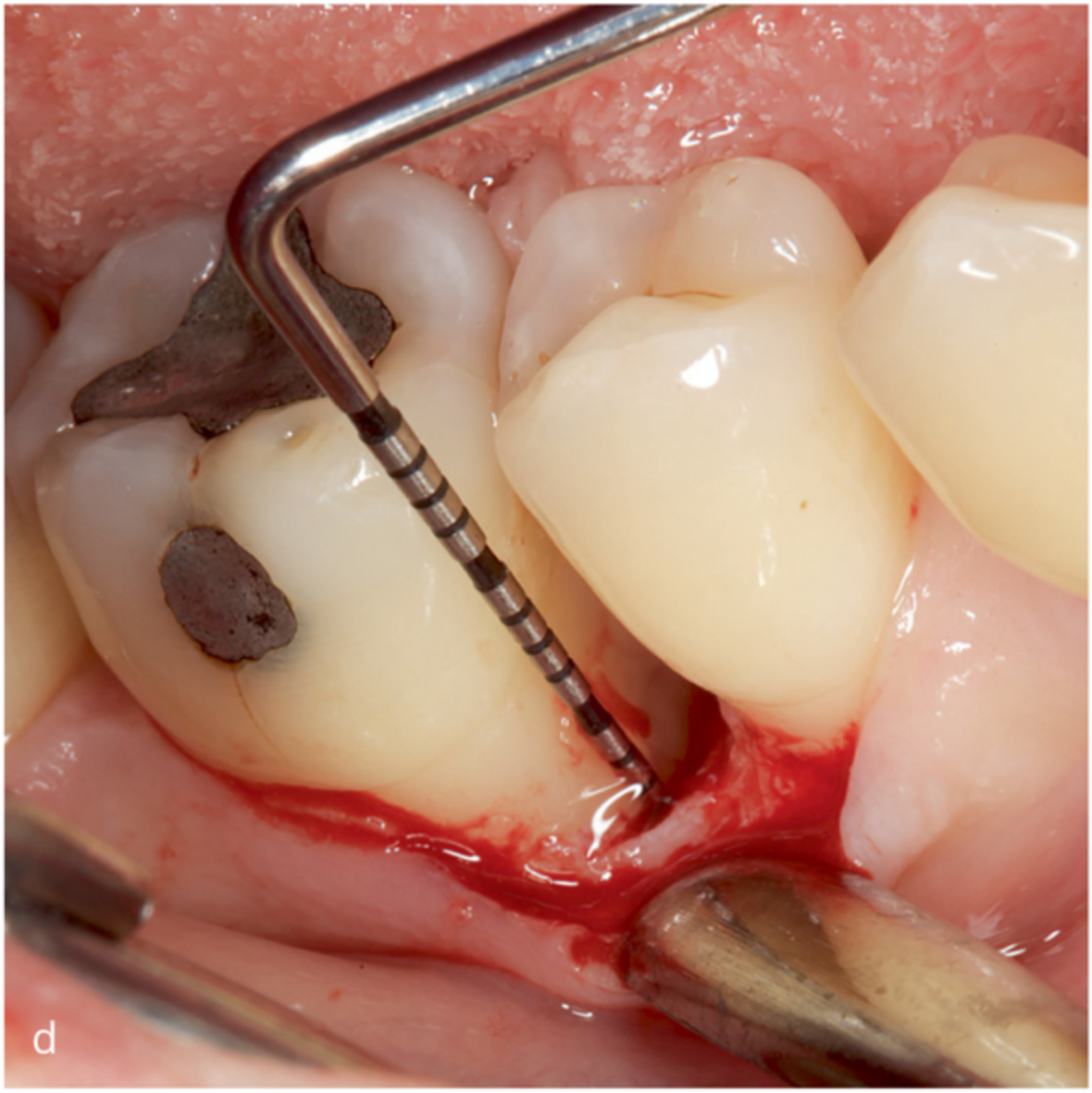


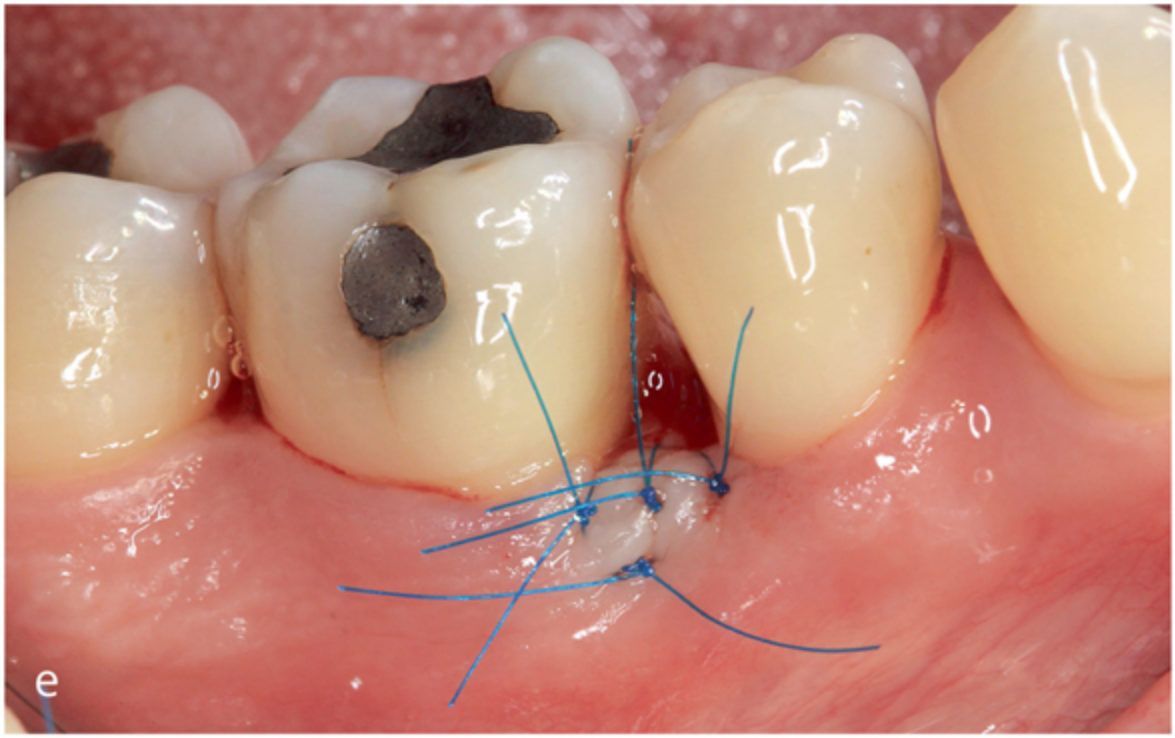
Fig 2-6 Periodontal measurement of the clinical attachment level, including tooth migration and mobility, furcation involvement, and bleeding on probing at the time of reevaluation (3 months after nonsurgical debridement; graphic illustration by Parostatus.de).



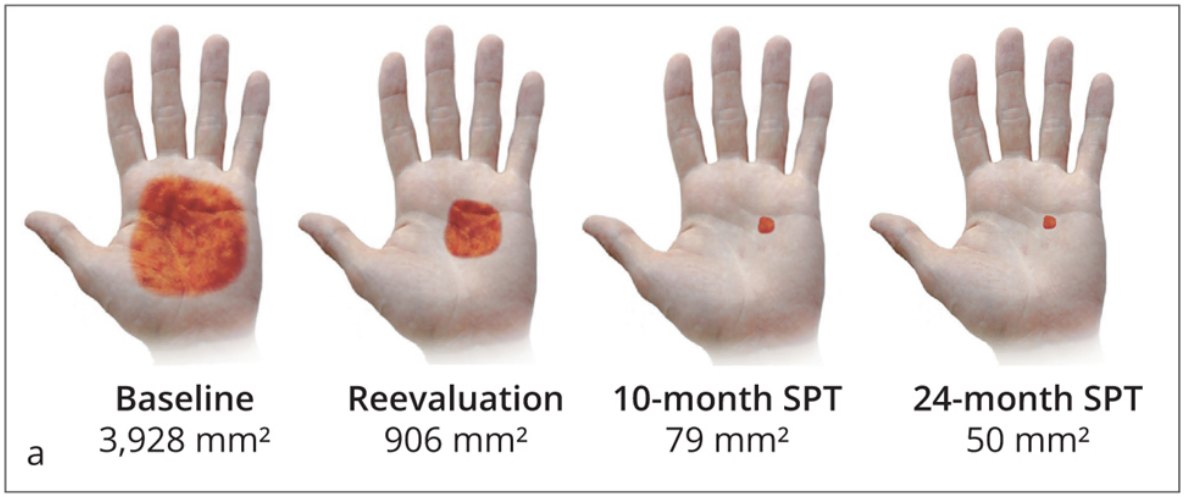


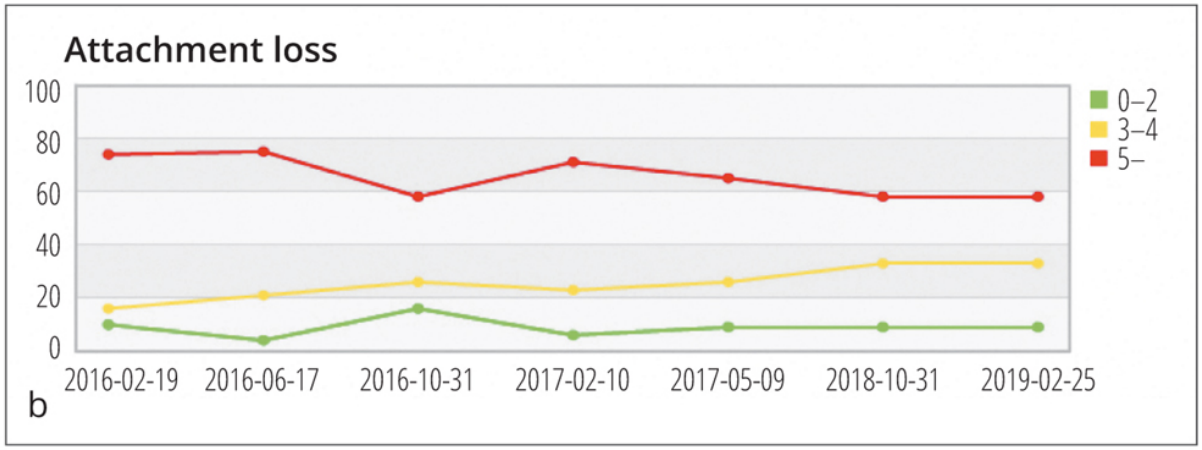


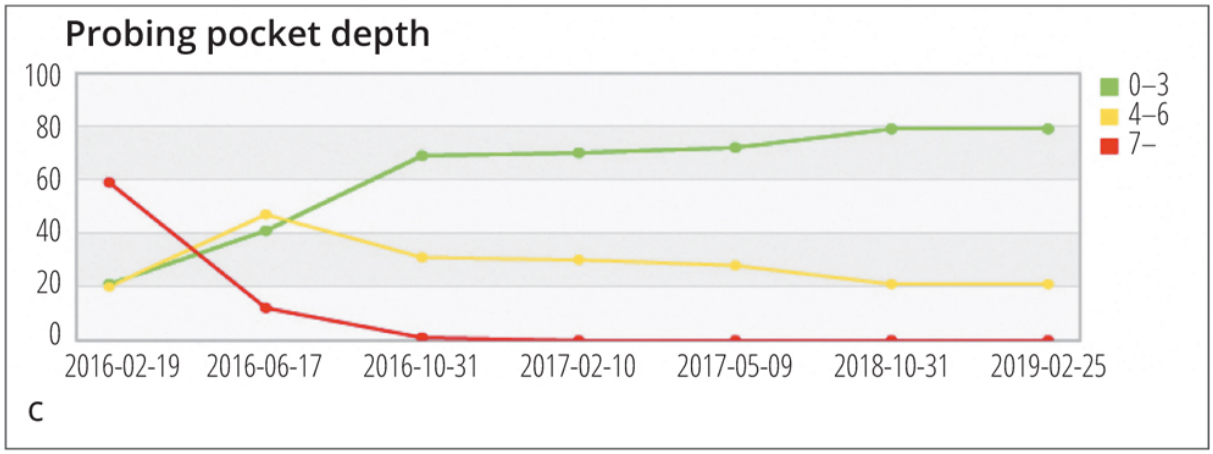


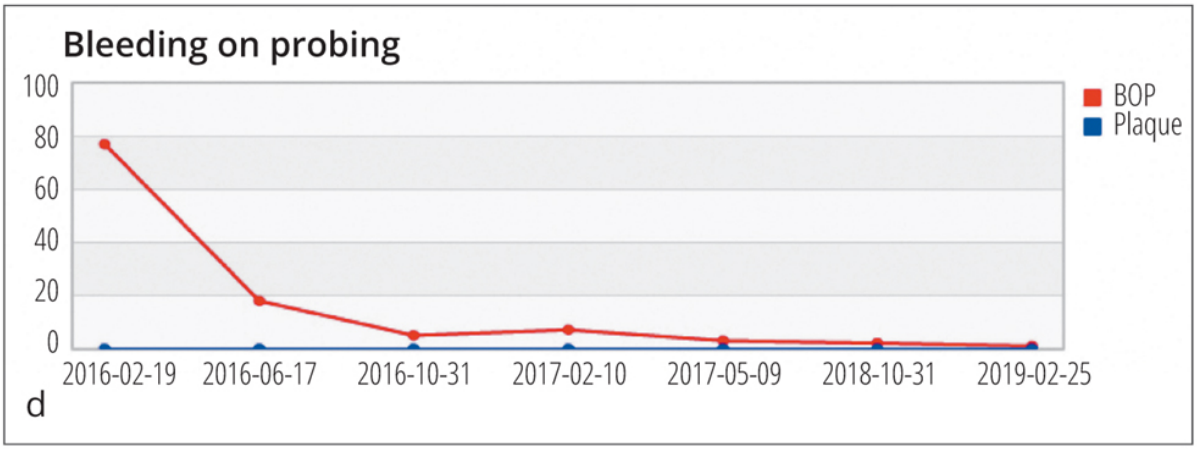


Figs 2-7a to e Representative images of the corrective therapeutic phase. **(a)** Intrabony three-wall defects subjected to regenerative periodontal therapy at maxillary right second premolar and first molar. **(b)** Wound closure upon application of enamel matrix derivatives onto the root surfaces. **(c and d)** Minimally invasive access to the three-wall intrabony defect at the mandibular right first molar. **(e)** Wound closure upon application of enamel matrix derivatives onto the root surface.

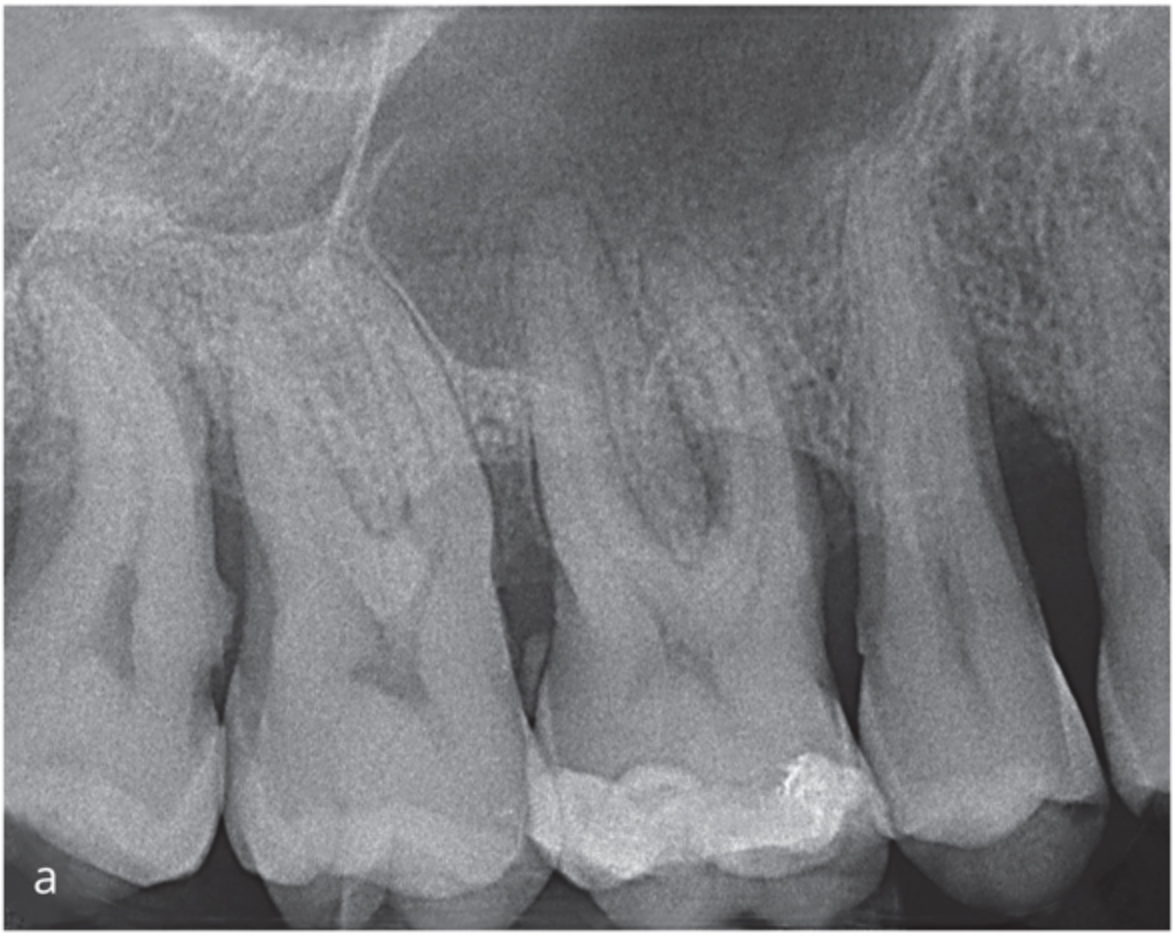


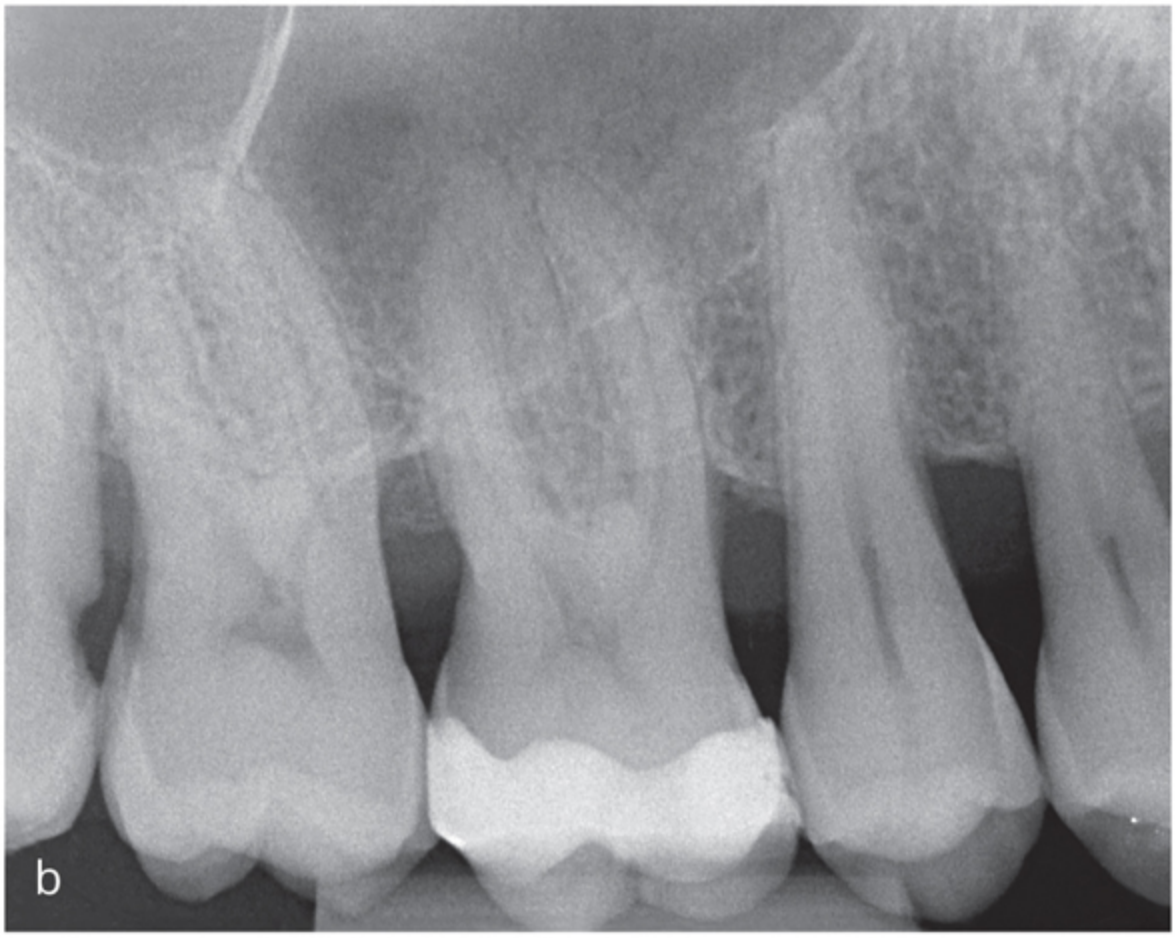


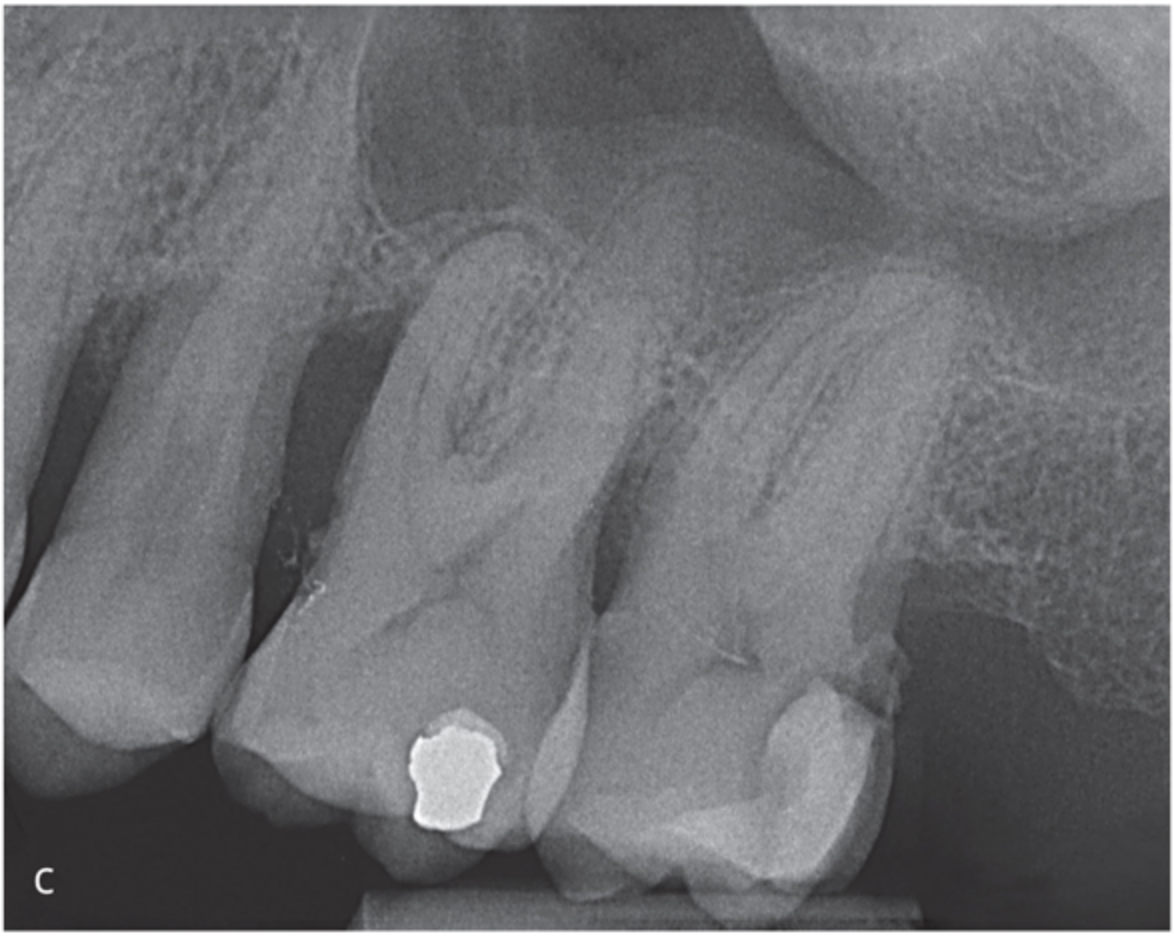


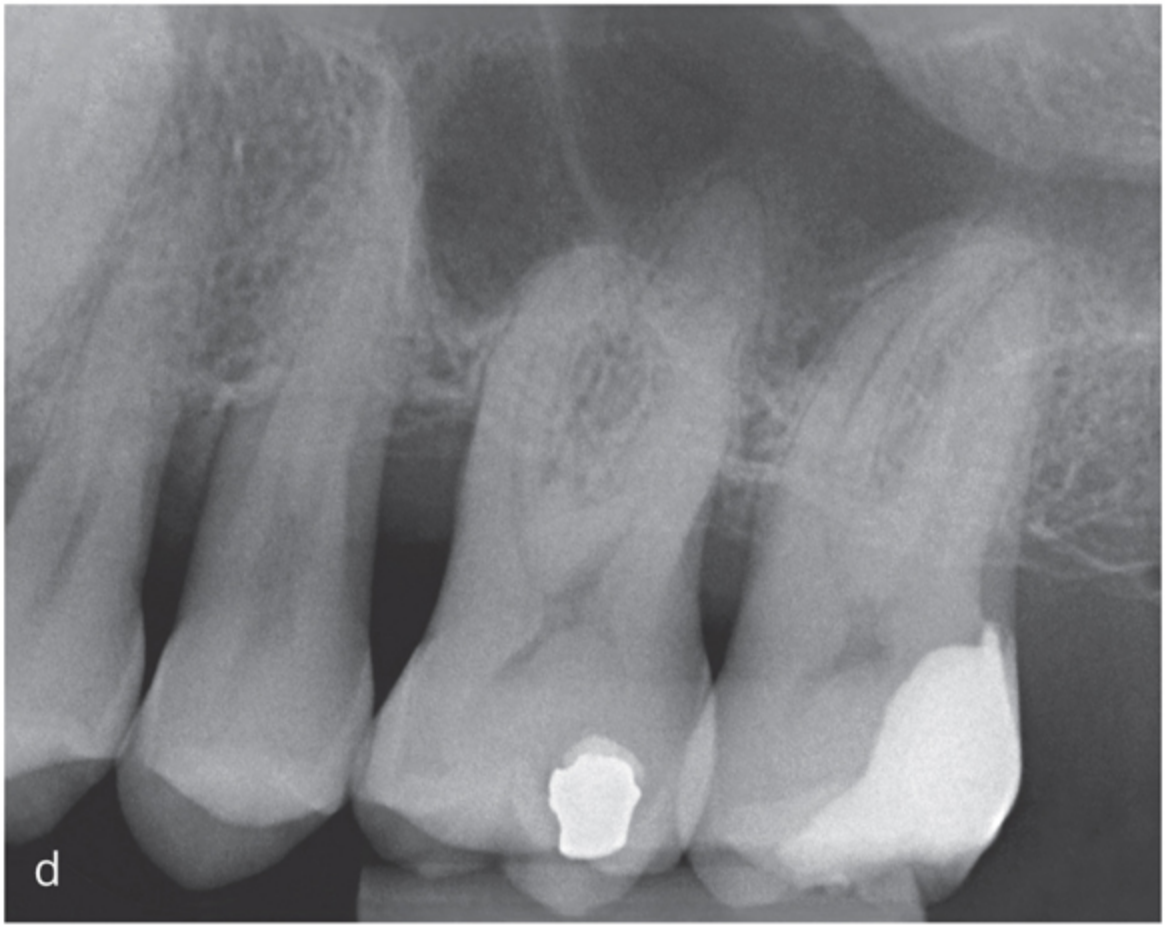


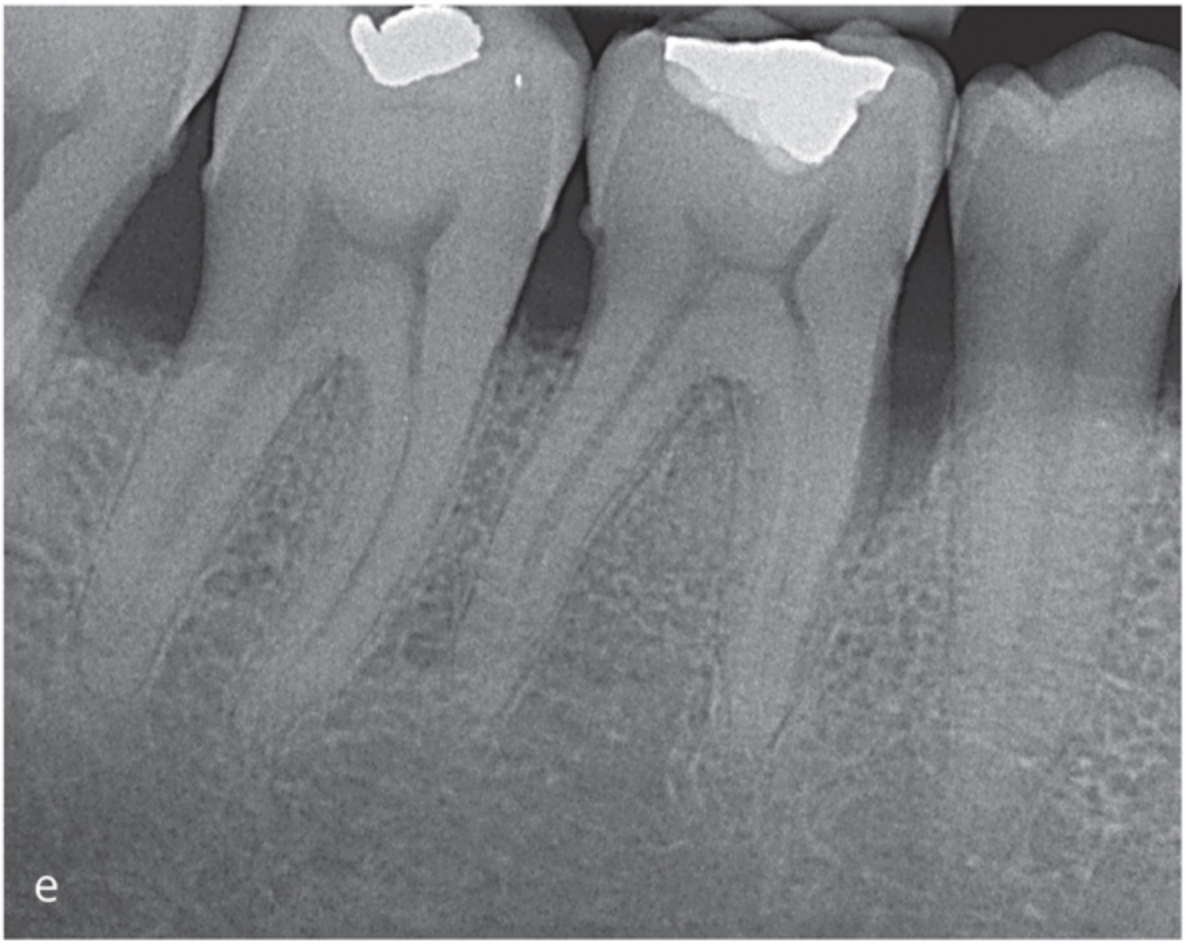
Figs 2-8a to d Periodontal parameters in the course of periodontal therapy. **(a)** Periodontal inflamed surface area (PISA)[113] projected to the palm of a hand; reduction of PISA during therapy up to 24 months after surgical treatment (supportive periodontal therapy [SPT]). **(b)** Attachment loss, **(c)** probing pocket depth, and **(d)** bleeding on probing (BOP) during active periodontal therapy and SPT (graphic illustration by Parostatus.de).

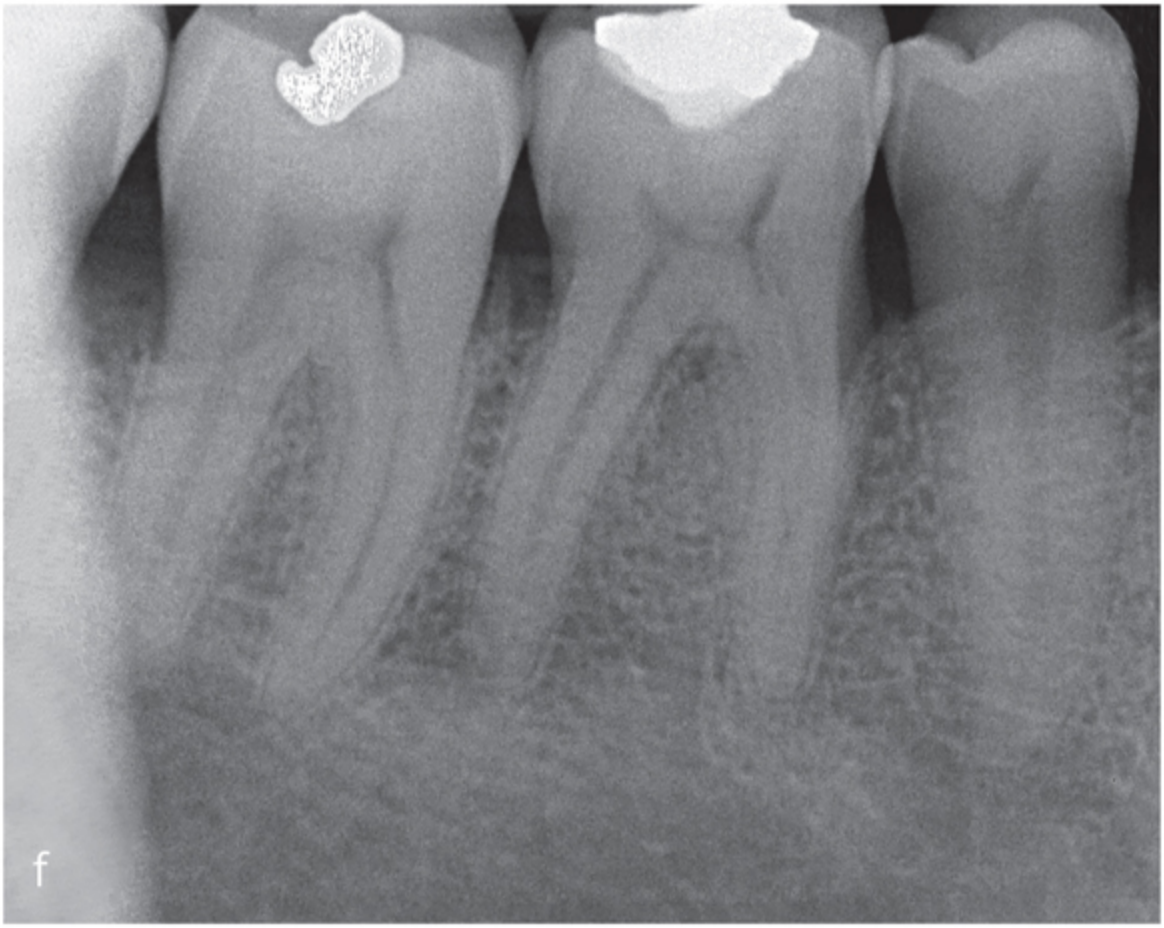




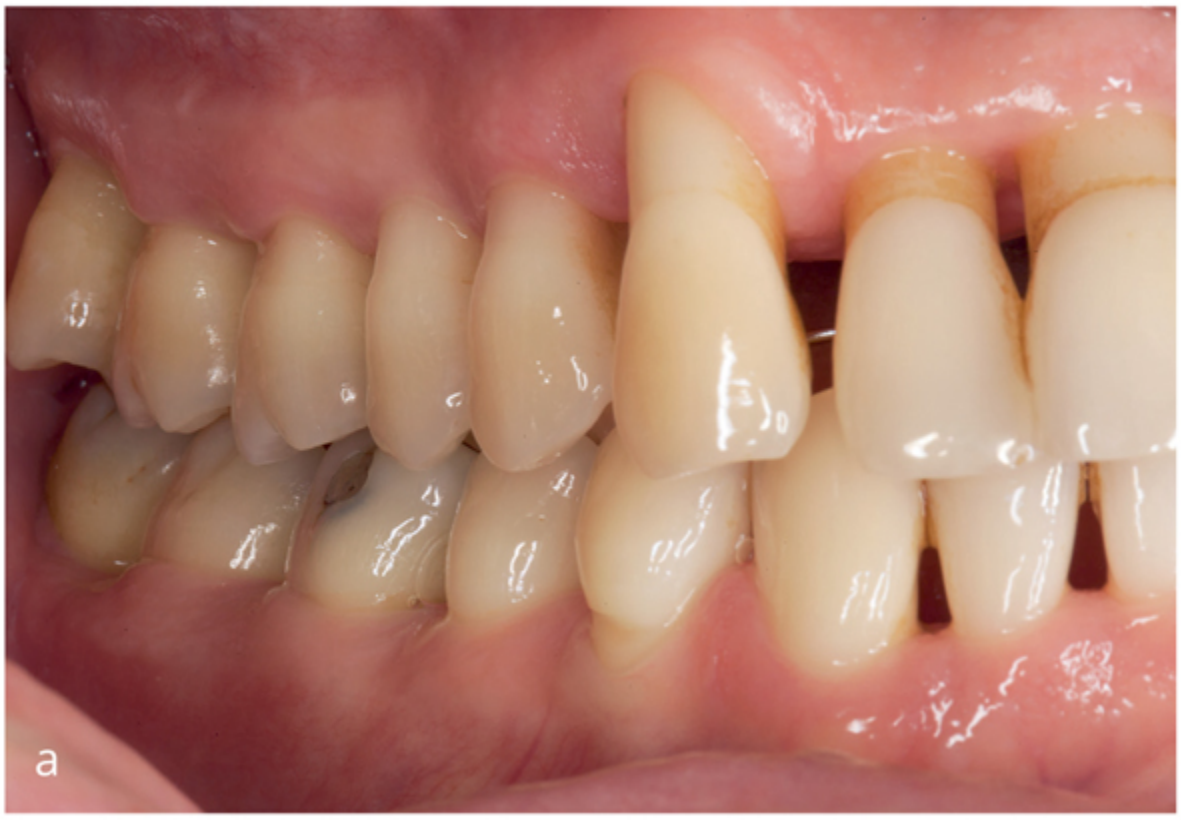


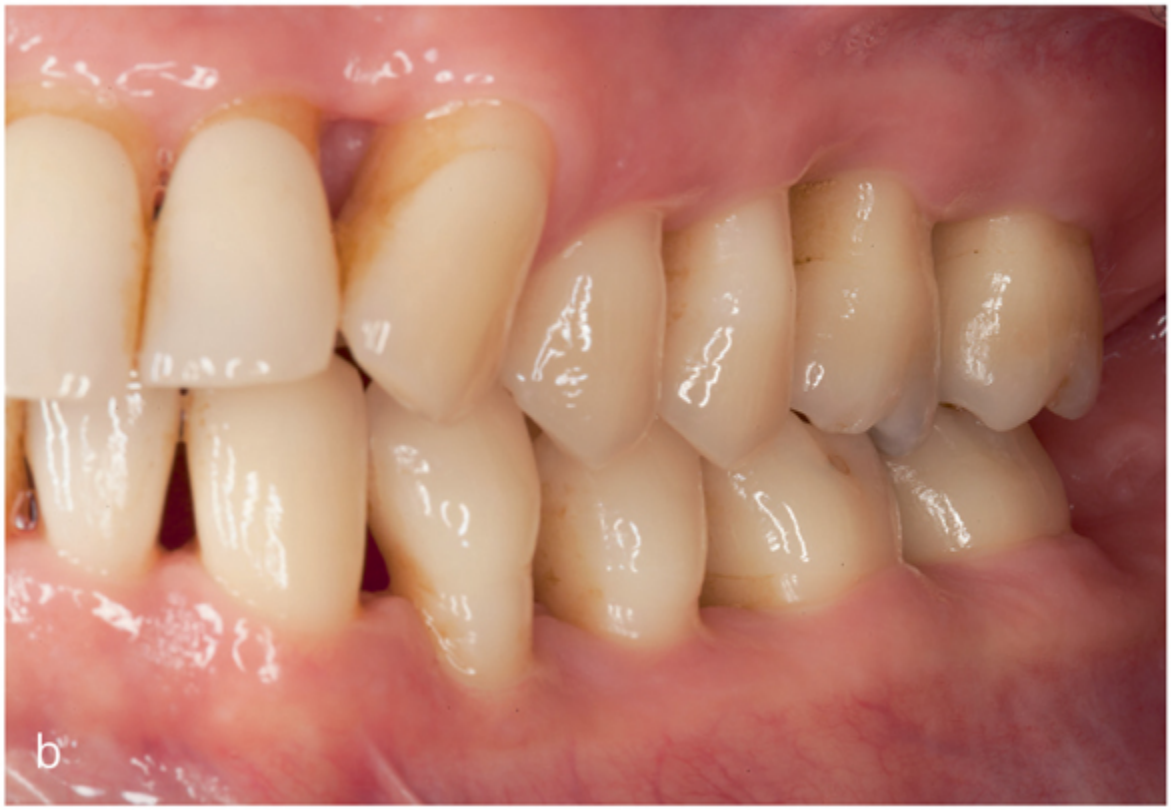


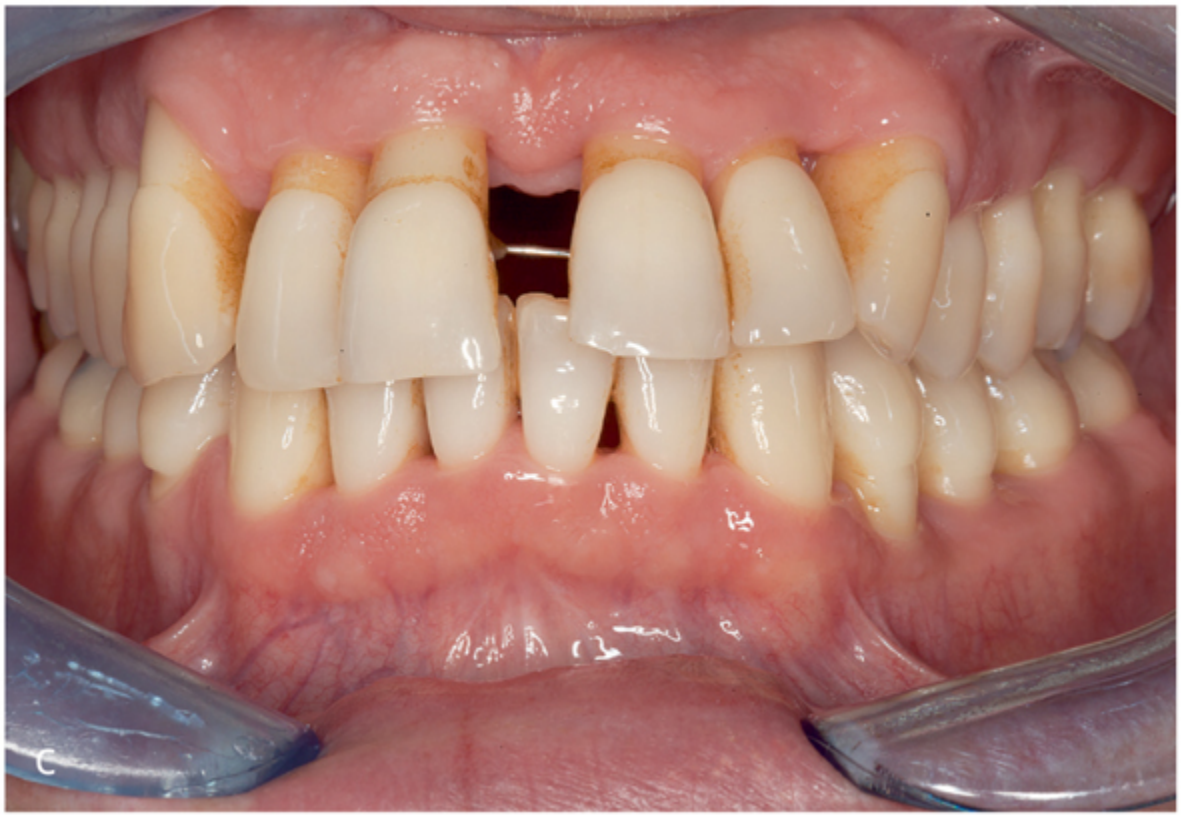


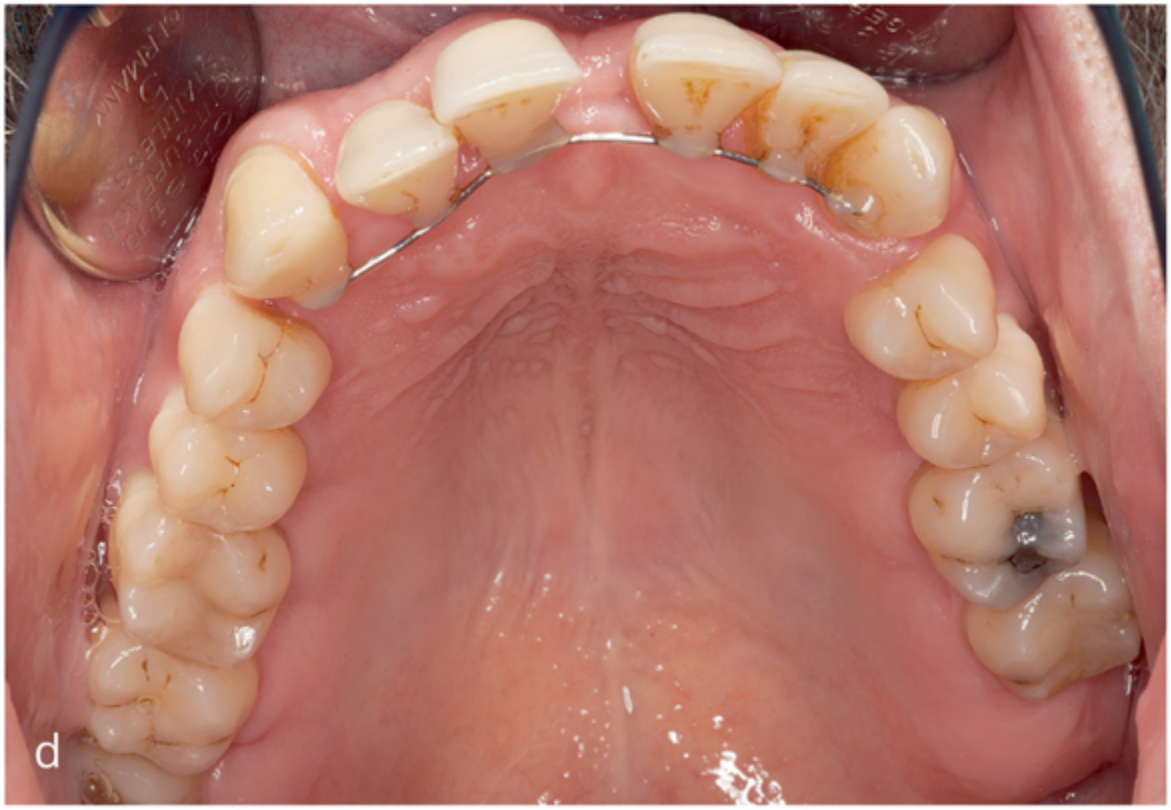


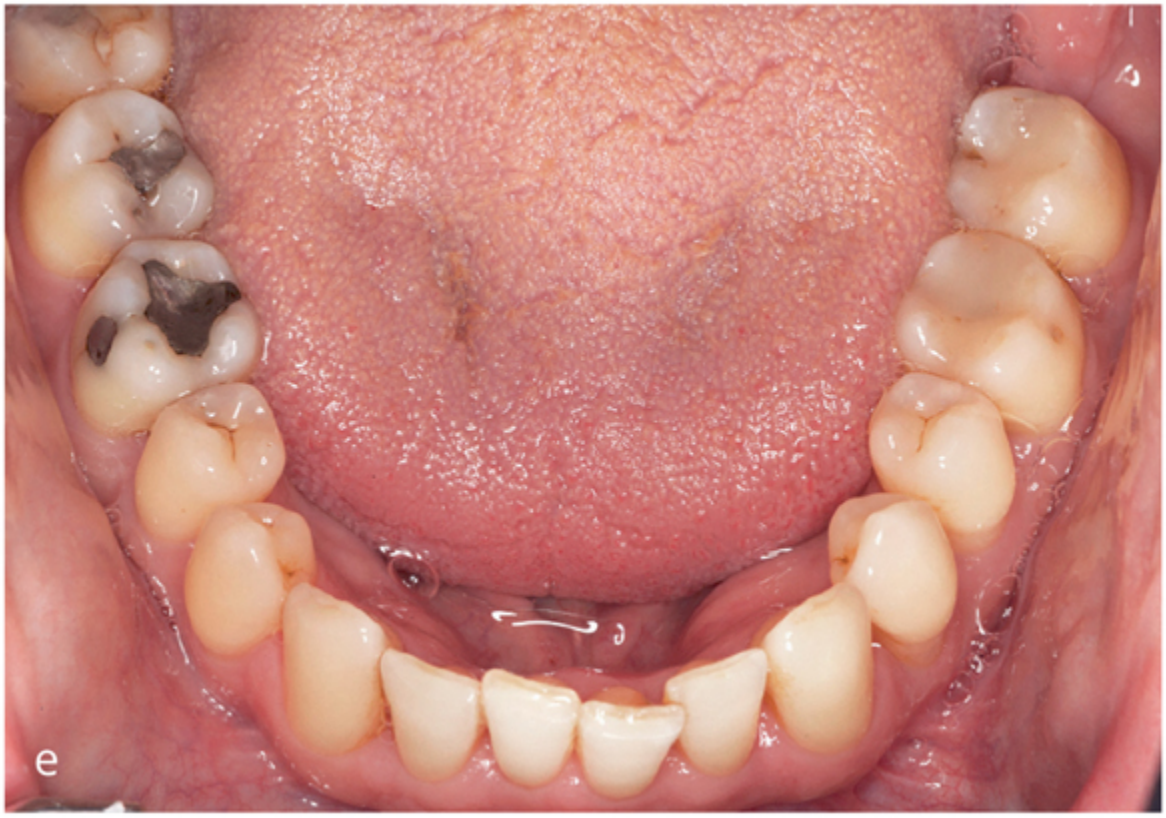
Figs 2-9a to f Radiographic images of the therapeutic outcome 2 years after regenerative surgical therapy. **(a)** Baseline radiograph: maxillary right second premolar to third molar. **(b)** Radiograph 2 years after surgery: maxillary right second premolar to second molar, with radiographic bone fill indicating periodontal regeneration upon application of enamel matrix derivatives. **(c)** Baseline radiograph: maxillary right second premolar to second molar. **(d)** Radiograph 2 years after surgery: maxillary right second premolar to second molar. **(e)** Baseline radiograph: mandibular right second premolar to second molar. **(f)** Radiograph 2 years after surgery: mandibular right second premolar to second molar, with radiographic bone fill indicating periodontal regeneration upon application of enamel matrix derivatives.

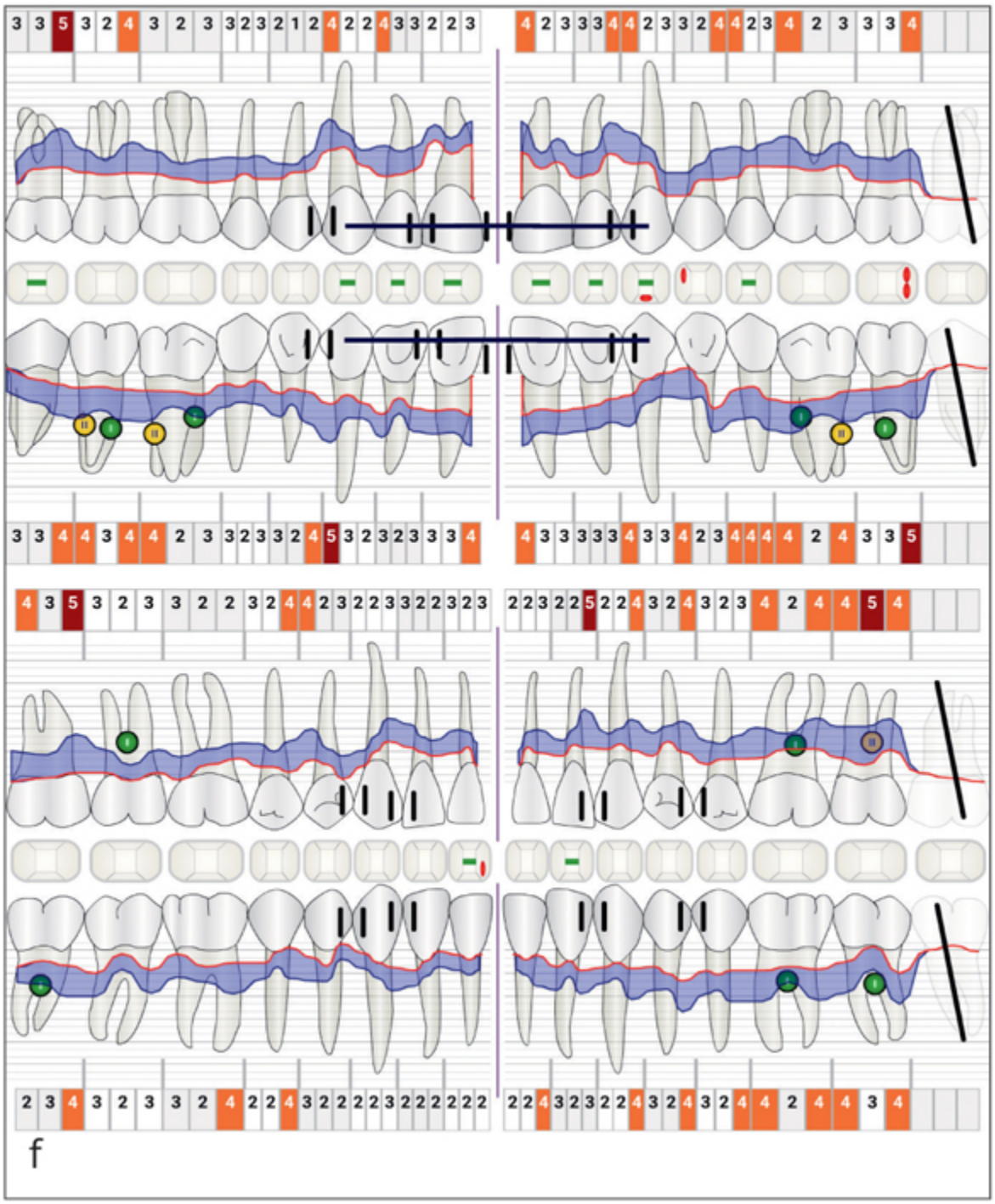












Figs 2-10a to f Case of a male patient (see Fig 2-3): examinations 10 months after surgery. **(a)** First and fourth quadrant. **(b)** Second and third quadrant. **(c)** Frontal view. **(d)** Maxillary arch. **(e)** Mandibular arch. **(f)** Measurements of the clinical attachment level,

including tooth migration and mobility, furcation involvement, and bleeding on probing (graphic illustration by Parostatus.de).

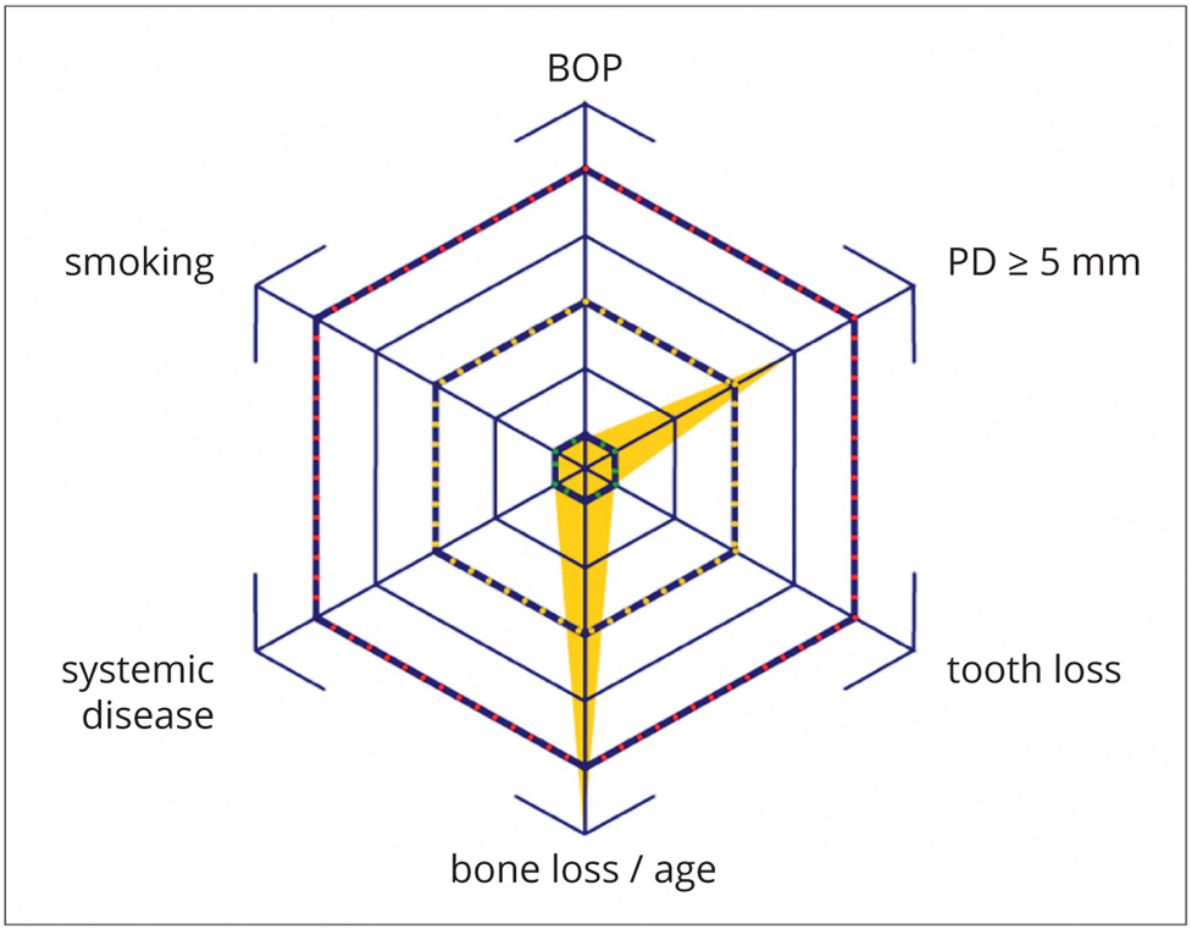


Fig 2-11 Periodontal risk assessment.[114] After active periodontal therapy (nonsurgical and surgical therapy), a moderate individual risk was evaluated. The patient attends the supportive periodontal therapy program four times a year (graphic illustration by Parostatus.de). (BOP, bleeding on probing; PD, probing depth.)

Diagnosis and classification system

Clinical and radiographic examinations are necessary to determine the periodontal diagnosis, and both are prerequisites for any therapeutic consideration. Diagnoses of periodontal diseases are

described in the recently published classification system, which includes staging and grading of periodontitis. This classification system considers the severity and complexity of periodontal destruction by graduating into four stages (I, II, III, and IV) as well as the disease progression graduated into three grades (A, B, and C).[115,116] Furthermore, extended and distributional patterns of periodontitis are also characterized.[116] In the context of staging, periodontitis stage I is considered as initial periodontitis, stage II as moderate periodontitis, stage III as severe periodontitis with potential for tooth loss, and stage IV as advanced periodontitis with extensive tooth loss and potential for loss of dentition. The grading system refers to risk factors or actual evidence of progression of periodontitis and is divided into slow, moderate, or rapid rates of progression. Recognized risk factors, such as smoking or metabolic control of diabetes, affect the progression of periodontitis and may contribute to the conversion to the next higher grade.[117] Besides the description and characterization of the plaque-induced inflammatory disease periodontitis, the classification system also comprises other periodontal diseases and conditions such as gingival diseases (dental plaque-induced and nondental plaque-induced gingivitis), necrotizing periodontal diseases, periodontitis as a manifestation of systemic disease, and recessions (including noncaries cervical lesions, periodontal-endodontic lesions, periodontal abscesses, and peri-implant diseases and conditions).[118-120] More detailed information on periodontitis stages and grades is shown in Tables 2-1 and 2-2, respectively.

Table 2-1 Overview regarding the periodontitis stages according to the Classification of Periodontal and Peri-implant Diseases and Conditions (2018)[115,116]

Category		Periodontitis stage			
		Stage I	Stage II	Stage III	Stage IV
Severity	Interdental CAL (site with greatest loss)	1–2 mm	3–4 mm	≥ 5 mm	≥ 5 mm
	Radiographic bone loss	Coronal third (< 15%)	Coronal third (15% – 33%)	Extending to the middle or apical third of the root	Extending to the middle or apical third of the root
	Tooth loss	No tooth loss due to periodontitis		Tooth loss due to periodontitis ≤ 4 teeth	Tooth loss due to periodontitis ≥ 5 teeth
Complexity	Local	Maximum pocket depth ≤ 4 mm Mostly horizontal bone loss	Maximum pocket depth ≤ 5 mm Mostly horizontal bone loss	In addition to II: PD ≥ 6 mm; Vertical BL ≥ 3 mm; FI: stage II or III; Moderate ridge defects	In addition to III: Complex rehabilitation: • Masticatory dysfunction • Secondary occlusal trauma • Severe ridge defects • Bite collapse, drifting, flaring • < 20 teeth (10 opposing pairs)
Extent/ distribution	Addition to stage as descriptor	For each stage: localized (< 30% of teeth), generalized (> 30% of teeth), or molar/incisor pattern			

BL, bone loss; CAL, clinical attachment level; FI, furcation involvement; PD, probing depth.

Table 2-2 Overview regarding the periodontitis grades according to the Classification of Periodontal and Peri-implant Diseases and Conditions (2018)[115,116]

Criteria			Periodontitis grade		
			Grade A (slow progression)	Grade B (moderate progression)	Grade C (rapid progression)
Primary criteria	Direct evidence for progression	Longitudinal data (radiographs or CAL)	No evidence for bone loss over 5 y	< 2 mm bone loss over 5 y	≥ 2 mm bone loss over 5 y
	Indirect evidence for progression	% Bone loss/age	< 0.25	0.25–1.0	> 1.0
		Case phenotype	Massive biofilm deposits with low levels of destruction	Destruction commensurate with biofilm deposits	Destruction exceeds expectation given biofilm deposits; specific clinical pattern suggestive of periods of rapid progression and/or early onset disease (eg, molar/incisor pattern; lack of expected response to standard therapies)
Grade modifiers	Risk factors	Smoking	Nonsmoker	Smoker < 10 cig/d	Smoker ≥ 10 cig/d
		DM	Normoglycemic/no diagnosis of DM	HbA1c < 7%, patients with DM	HbA1c ≥ 7%, patients with DM

CAL, clinical attachment level; DM, diabetes mellitus; HbA1c, hemoglobin A1c.

Prevention and therapy of periodontal diseases

Periodontal diseases and prevention

Gingivitis and periodontitis are understood as a continuum of a chronic inflammatory disease entity. In the development of periodontitis, the chronic inflammatory process in response to the dental plaque biofilm leads to the development of a dysbiosis within the biofilm along with irreversible periodontal tissue destruction.[10,121]

In the context of periodontal diseases, there are two different preventive strategies: primary and secondary prevention. Primary prevention of gingivitis aims to maintain gingival health, and therewith, protect the gingival tissues from developing clinical signs of inflammation by executing sufficient individual oral hygiene procedures including regular professional mechanical plaque removal.[121] Gingival health is associated with an inflammatory infiltrate as host response consistent with homeostasis in the

presence of a symbiotic biofilm, and the definition describes a condition with no attachment loss, shallow periodontal pockets (≤ 3 mm), less than 10% bleeding on probing, no erythema or edema, no patient symptoms, and no radiographic bone loss in a patient with an intact periodontium.[12,122] This means that gingival health is a condition consistent with a low grade of physiologic inflammatory response, which includes, amongst others, a neutrophil infiltrate and the expression of antimicrobial peptides by not only neutrophils but also periodontal soft tissue cells.[11,123,124] In addition, gingival health may also be present in a patient with a reduced periodontium (in the presence of recessions or in the case of a stable periodontitis patient).[122] In primary prevention of gingivitis, the goal is to maintain this state of gingival health in individuals with an intact or a reduced periodontium.

Prevention of periodontitis may be subclassified as primary and secondary preventive approaches. For the primary prevention of periodontitis, the obviation of periodontitis may be accomplished by preventing the continuation of the inflammatory process, eventually leading to the destruction of periodontal attachment. This means the treatment of gingivitis aiming to avoid the potential conversion from gingivitis to periodontitis in a susceptible patient.[121] Currently, the exact molecular mechanisms of when and how a case of gingivitis converts to a case of periodontitis are not fully understood. Therefore, treatment of patients with gingivitis, including disruption and/or removal of the dental plaque biofilm, is the main aspect in the primary prevention of periodontitis.

Secondary prevention of periodontitis, in contrast, refers to the prevention of disease recurrence.[125] More precisely, the aim of secondary prevention is to avoid the occurrence of gingival inflammation leading to additional periodontal attachment loss in a periodontitis patient who has been successfully treated.[121]

For the prevention of periodontal diseases, it is important to understand that, in addition to the dental plaque biofilm, there

are further risk factors, such as smoking and diabetes mellitus, influencing the susceptibility to gingivitis and periodontitis. To establish a robust preventive strategy, it is mandatory to be aware of the variety of etiologic factors that may affect the periodontal tissues and eventually lead to disease.

Oral hygiene

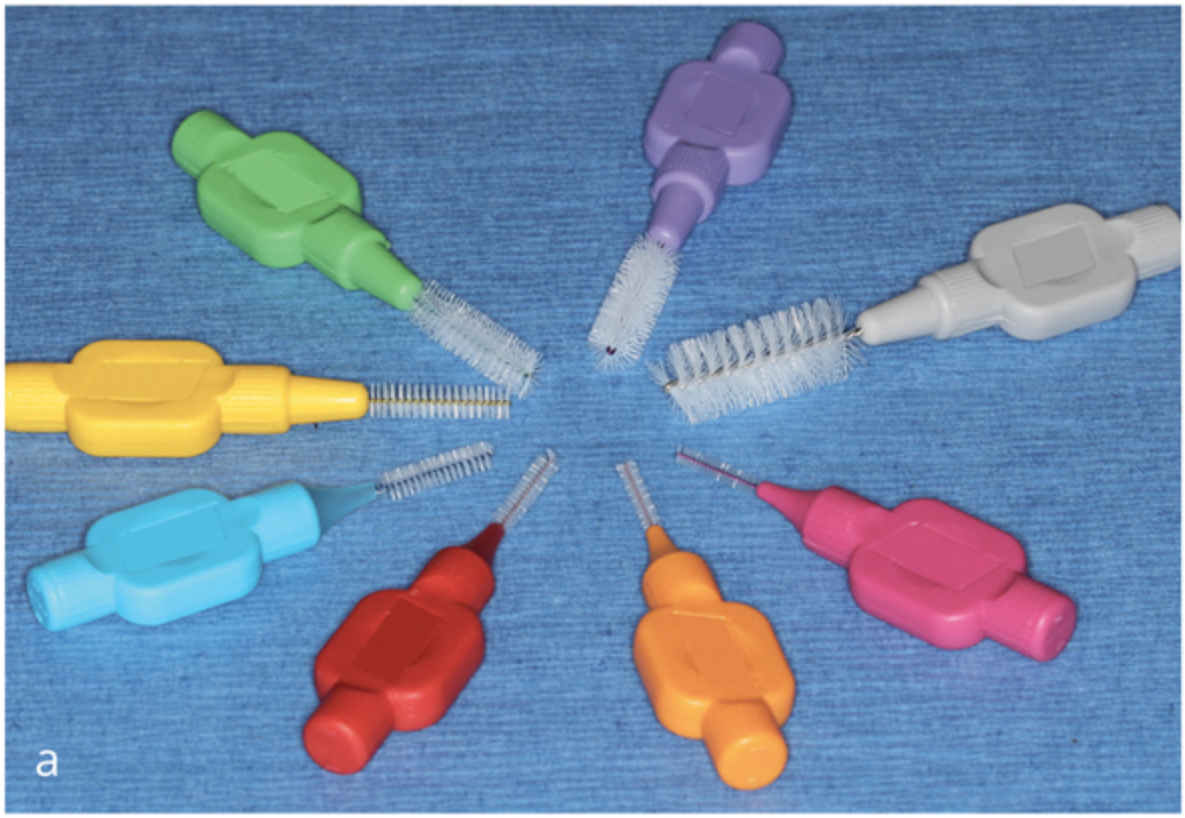
As mentioned earlier, the adherence of a plaque biofilm at and below the gingival margin is the primary etiologic factor for developing gingivitis and periodontitis. Thus, an adequate daily mechanical plaque removal is the most important prevention measure for both diseases. Different aspects have to be taken into account for an individual effective plaque removal; these refer to:

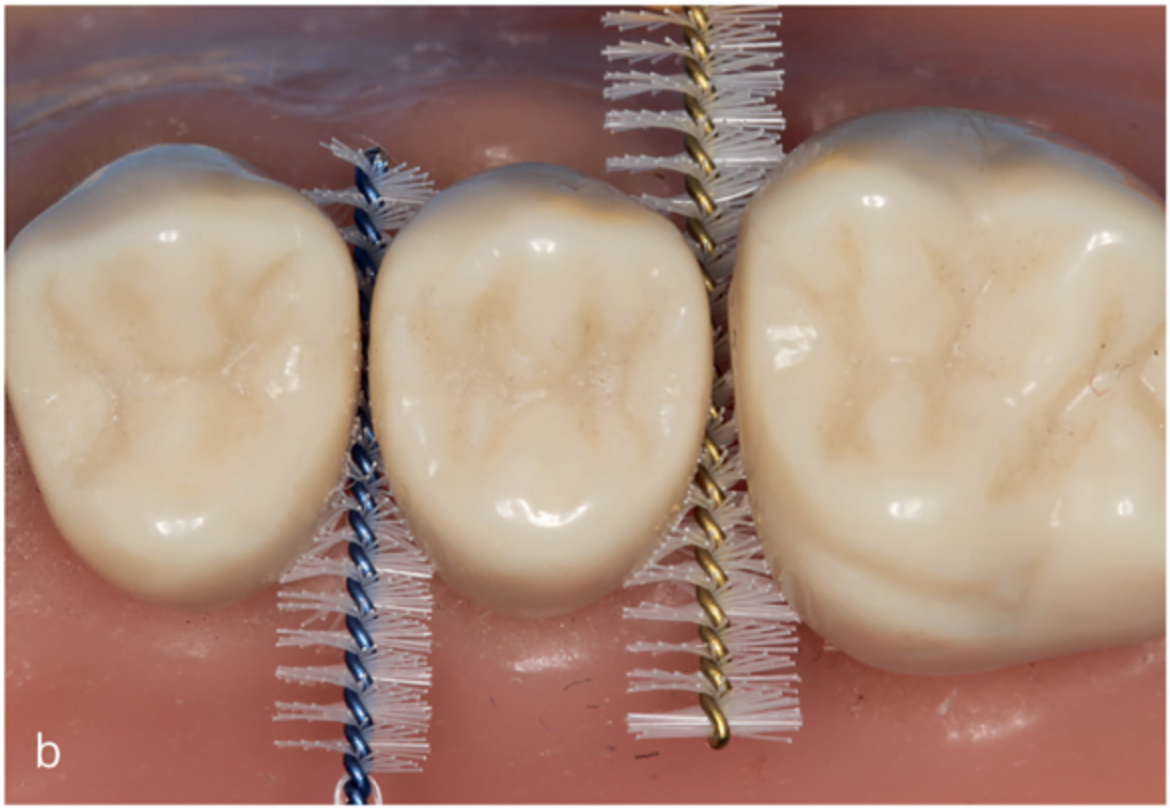
- general tooth cleaning
- interproximal tooth cleaning
- the use of dentifrices and mouth rinses.

Brushing the teeth for at least 2 minutes with a fluoridated dentifrice is a universal recommendation, but it also has to be kept in mind that 2 minutes may not be an adequate time for periodontitis patients.[12] With regard to the effectiveness, power toothbrushes are superior in terms of plaque removal and in gingivitis reduction when compared to manual brushes.[126] Moreover, recent research has shown that in patients with initial or moderate periodontitis, the use of power toothbrushes reduced progression of periodontal pocket depths and led to less attachment loss when compared to manual tooth brushing.[127] In fact, users of power toothbrushes lost approximately 20% less teeth in comparison with manually cleaning individuals within 10 years.[127] Regardless of the type of toothbrush, a detailed instruction for its application is recommended. With this in mind, it is important to implement a systematic way of teeth cleaning to regularly reach every single tooth.

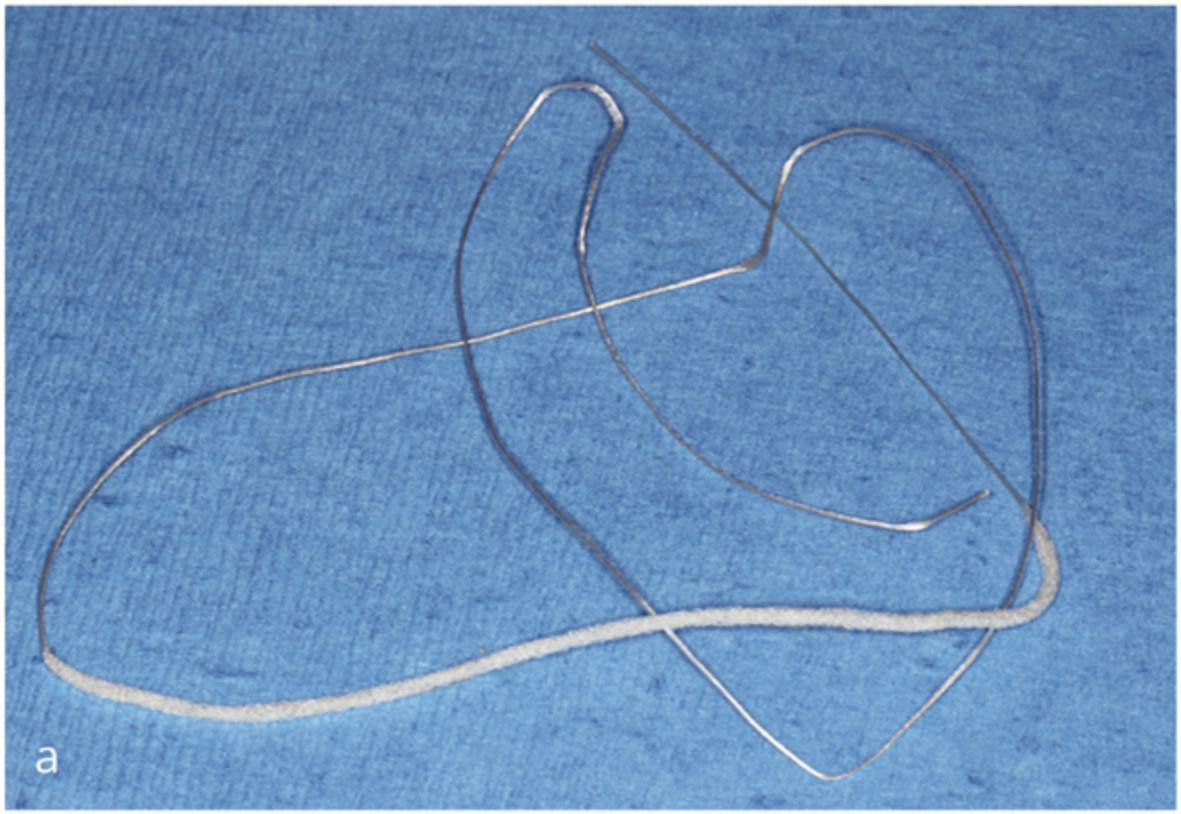
Moreover, with regard to prevention of gingival inflammation it is a very important detail that the toothbrush reaches the gingival margin while cleaning the buccal and oral sites of the teeth. Lastly in the context of general teeth cleaning, if effective tooth cleaning cannot be attained by explanations, individual instructions including practical exercises should be advised.[128]

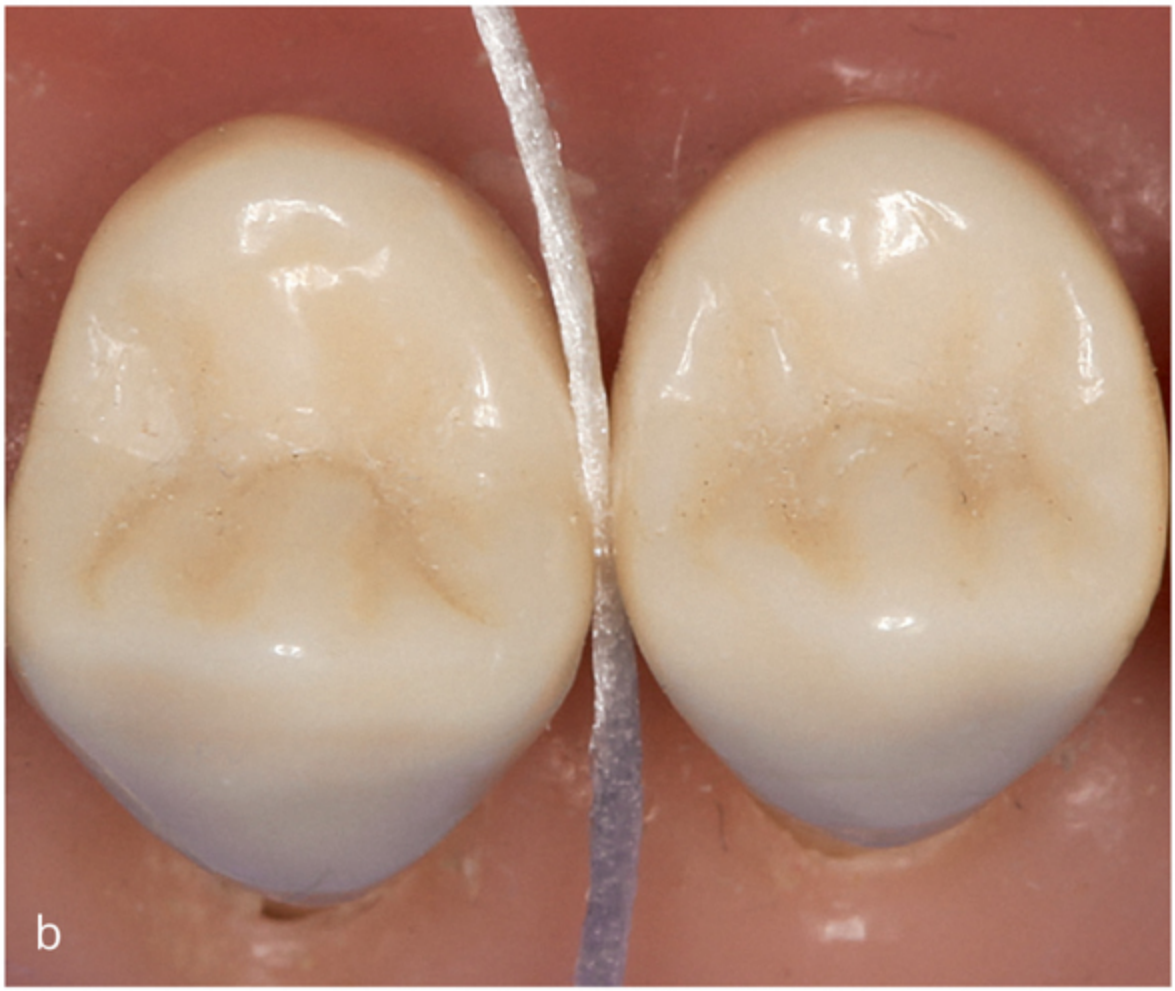
Given the fact that normal sized toothbrushes are not able to reach interproximal areas, additional devices, such as interdental brushes (Fig 2-12) or floss (Fig 2-13), are necessary and effective tools for tooth cleaning and controlling periodontal problems.





Figs 2-12a and b Interdental brushes (available in a number of different sizes and hardness grades).





Figs 2-13a and b (a) Floss and **(b)** SuperFloss (Oral B) for interdental hygiene (available in a number of different configurations).

While interdental brushes help periodontitis patients to reach or maintain gingival health, they can cause traumatic gingival injuries in periodontally healthy individuals due to their size, so other devices, eg floss or wood sticks, may be recommended.[12] For an adequate and effective interproximal cleaning, dental personnel should choose appropriate devices and instruct on correct use in periodontally healthy and diseased individuals.[128] It is worth noting that dentifrices do not have an additional effect in reducing plaque and gingivitis compared to teeth brushing without dentifrice.[129,130] Nonetheless, for

cariogenic considerations fluoridated toothpaste is recommended during general teeth brushing, but not for interdental cleaning.[128]

In addition to mechanical plaque removal, chemical antibacterial mouth rinses may be applicable. The short-term use of antibacterial mouth rinses (eg, chlorhexidine ≥ 0.1%) is recommended for individuals if mechanical plaque removal is not possible, eg after surgical treatment within the oral cavity.[131] Further, mouth rinses with amine fluoride, tin fluoride, essential oils, cetylpyridinium chloride, or chlorhexidine ≤ 0.1 % can be recommended in high-risk groups adjunctive to the mechanical tooth cleaning to prevent gingivitis.[131] These high-risk groups comprise individuals with special need for support and restricted everyday expertise, individuals with physical or mental disabilities who are not able to perform effective biofilm management, individuals under special medications (chemotherapy, radiotherapy), and individuals with areas restricted for mechanical tooth cleaning.

In addition to oral health care products, modification of the oral bacterial flora by probiotic bacteria has been introduced. It has been shown that *Limosilactobacillus reuteri* supports the eubiosis of the bacterial biofilm, which is associated with gingival health.[132] Additional future research is needed to clarify the overall benefit of probiotic bacteria within preventive measures with respect to gingival and periodontal health.

Professional mechanical plaque removal

Professional mechanical plaque removal (PMPR) includes debridement of dental surfaces (crown and root) as well as polishing at supragingival, and to a small extent, subgingival locations by dental professionals. Oral hygiene instruction (OHI) for personally performed mechanical plaque control is often included in this context. Along with the aim of a primary prevention of periodontal diseases, the combination of PMPR and OHI is more effective in reducing plaque and gingival bleeding than no treatment.[133]

Secondary prevention of periodontitis aims to maintain a periodontally healthy state after successful periodontal therapy, and to avoid disease recurrence.[125] The concept of secondary periodontal prevention is part of the systematic periodontal therapy, is termed supportive periodontal therapy (SPT), and includes PMPR.[125] Additionally, the efficacy of oral hygiene procedures is monitored, and re-motivation as well as re-instruction are performed in the same appointment.

Preventive and therapeutic aspects in relation to general health

Smoking habits

It is generally accepted that smoking cessation exhibits positive effects on individual general health. In relation to periodontitis, it has been shown that, in addition to improvements in oral hygiene procedures, smoking cessation positively impacts the management of periodontitis.[134]

Pregnancy

Associations between periodontal diseases and adverse pregnancy outcomes have been discussed for decades. Namely, low birth weight, preterm birth, and preeclampsia were identified to be associated with maternal periodontitis. The strength of the observed association, however, was rather modest, and periodontal therapy during pregnancy has not been shown to reduce adverse pregnancy outcomes.[135] This may be due to the fact that the time point of therapy was too late in the course of periodontitis.[136]

Direct and indirect pathways between oral microorganisms or released immune mediators in response to the oral microbiota and the fetal-maternal unit have been identified.[136] Future research is mandatory in order to identify not only the association between

periodontitis and adverse pregnancy outcomes but also pathogenic pathways that potentially contribute to outcomes for this association.

During pregnancy, it is also important to notice that hormonal changes may affect the gingival health in women without history of periodontitis. Gingival conditions may include increased local gingival bleeding, generalized gingivitis, and granuloma.[137] Those gingival conditions have been shown to resolve spontaneously after delivery. Nonetheless, gingival bleeding or developing granuloma can be alarming to the pregnant women, and therefore, negatively influence the course of their pregnancy. Thus, preventive measures, such as oral hygiene education prior to and during pregnancy, individual oral hygiene instruction, and PMPR, are important to prevent gingivitis and help the mothers to be to experience an uneventful pregnancy. It is interesting to note that a recent study described the reduction of gingival inflammation in response to the intake of a probiotic drug containing *Limosilactobacillus reuteri* in pregnant women.[132] This aspect underlines the importance of a healthy oral homeostasis during pregnancy.

In this context, the identification and treatment of periodontal conditions prior to conception is important to avoid potential pregnancy complications. If treatment of periodontal diseases is necessary in pregnant women, the second pregnancy trimester represents the optimal and safe intervention time-point.[138,139]

Diabetes mellitus

Periodontitis patients show higher blood sugar even with no diagnosis of diabetes mellitus.[140] Therapy of periodontitis contributed to better blood sugar control in patients with diabetes mellitus, and a positive effect on the glycated HbA1c, with an improvement ranging between −0.27% and −0.48%, equivalent to the intake of an additional anti-diabetic drug.[141]

Prevention of gingivitis and periodontitis can, therefore, contribute to improve the blood sugar control in individuals with and without the diagnosis of diabetes mellitus. Furthermore, the systematic

treatment of periodontitis, and a structured supportive periodontal care regimen in relation to the individual periodontal risk, exhibit important preventive characteristics for not only oral health conditions but also long-term blood sugar control in patients with diabetes mellitus.[114,142]

Cardiovascular disease

It has been shown that patients with periodontitis exhibit an increased intima media-thickness and impaired low-mediated dilatation.[143] In addition to generally accepted factors, such as nutrition and physical activity, prevention of gingivitis and periodontitis may also facilitate the vascular function and health.[144,145] In this context, the systematic treatment of periodontitis and a structured individual risk-oriented supportive periodontal care regimen may help to improve cardiovascular measures.[144]

Rheumatoid arthritis

Patients with rheumatoid arthritis and periodontitis may benefit from periodontal therapy not only with respect to their improved periodontal status but also regarding parameters relevant in the treatment of rheumatoid arthritis. For patients with rheumatoid arthritis and periodontitis, it has been shown that biomarkers for rheumatoid arthritis as well as joint symptoms decrease in response to periodontal therapy.[112,146,147]

Therapy of periodontitis

The treatment philosophy mirrors the modern understanding of periodontal disease and the measures for primary prevention with a healthy homeostatic status. Due to the complex nature of periodontitis, a systematic stepwise therapeutic approach is

required. Thus, the therapy of periodontitis comprises four steps (Fig 2-14):

Step 1 of periodontal therapy:

addressing risk factors for periodontitis and removing supragingival dental biofilm

Step 2 of periodontal therapy:

reducing the subgingival biofilm and calculus by subgingival instrumentation

Step 3 of periodontal therapy:

treating areas with persisting deep periodontal pockets after successful completion of step 1 and 2 by surgical procedures

Step 4 of periodontal therapy:

SPT.[148]

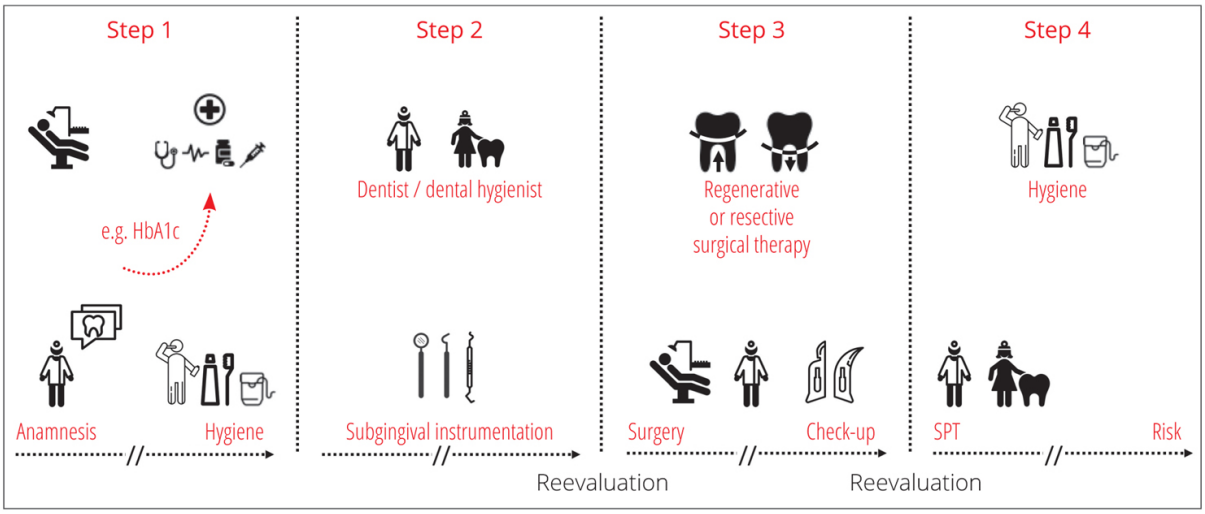


Fig 2-14 Phases of systematic periodontal therapy (SPT, supportive periodontal therapy).

The first step of periodontal treatment aims to address influencing factors of periodontitis, for example reducing blood sugar concentration in diabetes patients with high blood sugar levels or initiating individual strategies for smoking cessation. Furthermore, patients are guided to undertake successful removal of supragingival

dental biofilm by, eg, oral hygiene instructions and professional mechanical plaque removal.

The goal of the second step of periodontal therapy is to reduce subgingival plaque and calculus at each affected tooth as the causative therapy to reduce inflammation of the periodontal tissues. Plaque and calculus are removed mechanically using curettes, sonic, or ultrasonic instruments. For severe forms of periodontitis and/or general health reasons, systemic antibiotic treatment may be indicated subsequent to mechanical debride-ment.[148-152]

In the third step of periodontal therapy, surgical interventions may be performed at teeth with remaining deep probing pocket depths (≥ 6 mm) when steps 1 and 2 of periodontal therapy have been successfully completed and optimal hygiene can be performed.[148] Those interventions may then include procedures of regenerative or resective nature.[148]

Long-term success of periodontal therapy can only be achieved if patients are compliant to maintenance care at their individual risk. The fourth step of periodontal therapy aims at maintaining results from steps 1 to 3. This includes monitoring of risk factors and periodontal status as well as consequent professional mechanical plaque removal, including subgingival instrumentation if appropriate.[148] The individual periodontal risk assessment is mandatory to decide the frequency of SPT sessions.[125,142,153-157] For more detailed information regarding the periodontal therapeutic regimen, the authors refer to the appropriate literature.

- Due to fact that gingivitis and periodontitis are two entities of the same disease, life-long prevention of gingivitis is considered as an important measure to prevent the development of periodontitis.
- Periodontitis is an age-associated but not age-dependent disease, which can also occur in younger adults.
- Treatment of periodontitis requires a consequent regimen consisting of four consecutive steps (steps 1 to 4). Recently, a

guideline for the therapy of periodontitis stages I-III has been implemented.[148]

- Mild to moderate stages of periodontitis (stages I and II) can easily be detected by means of screening indices, and treatment of these stages is less complex compared to more advanced stages of periodontitis (stages III and IV).
- Reduction of the dental plaque biofilm is the key to prevention and treatment of periodontitis.
- Prevention and therapy of periodontitis needs collaboration between the patient and the dental team (dental practitioners, specialists in periodontology, trained dental hygienists).
- Periodontitis is not only a local inflammatory disease but may influence systemic diseases. Further, periodontitis can be modified by diabetes mellitus and other behavioral factors such as smoking.

References

1. Ezzati M, Riboli E. Can noncommunicable diseases be prevented? Lessons from studies of populations and individuals. Science 2012;337(6101):1482–1487.
2. Kinane DF, Attstrom R; European Workshop in Periodontology group B. Advances in the pathogenesis of periodontitis. Group B consensus report of the fifth European Workshop in Periodontology. J Clin Periodontol 2005;32(Suppl 6):130–131.
3. Kassebaum NJ, Bernabé E, Dahiya M, Bhandari B, Murray CJ, Marcenes W. Global burden of severe periodontitis in 1990–2010: a systematic review and meta-regression. J Dent Res 2014;93:1045–1053.
4. Petersen PE, Ogawa H. The global burden of periodontal disease: towards integration with chronic disease prevention and control. Periodontol 2000 2012;60:15–39.

5. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2015 (GBD 2015). Life Expectancy, All-Cause and Cause-Specific Mortality 1980–2015. Seattle: Institute for Health Metrics and Evaluation (IHME), 2016.
6. Listl S, Galloway J, Mossey PA, Marcenes W. Global economic impact of dental diseases. J Dent Res 2015;94:1355–1361.
7. Billings M, Holtfreter B, Papapanou PN, Mitnik GL, Kocher T, Dye BA. Age-dependent distribution of periodontitis in two countries: Findings from NHANES 2009 to 2014 and SHIP-TREND 2008 to 2012. J Periodontol 2018;89(Suppl 1):S140–S158.
8. Boillot A, El Halabi B, Batty GD, Rangé H, Czernichow S, Bouchard P. Education as a predictor of chronic periodontitis: a systematic review with meta-analysis population-based studies. PLoS One 2011;6:e21508.
9. Shiau HJ, Reynolds MA. Sex differences in destructive periodontal disease: exploring the biologic basis. J Periodontol 2010;81:1505–1517.
10. Hajishengallis G. Periodontitis: from microbial immune subversion to systemic inflammation. Nat Rev Immunol 2015;15:30–44.
11. Dommisch H, Jepsen S. Diverse functions of defensins and other antimicrobial peptides in periodontal tissues. Periodontol 2000 2015;69:96–110.
12. Meyle J, Chapple I. Molecular aspects of the pathogenesis of periodontitis. Periodontol 2000 2015;69:7–17.
13. Hajishengallis G, Darveau RP, Curtis MA. The keystone-pathogen hypothesis. Nat Rev Microbiol 2012;10:717–725.
14. Dommisch H, Chung WO, Rohani MG, et al. Protease-activated receptor 2 mediates human beta-defensin 2 and CC chemokine ligand 20 mRNA expression in response to proteases secreted by *Porphyromonas gingivalis*. Infect Immun 2007;75:4326–4333.

15. Dommisch H, Chung WO, Jepsen S, Hacker BM, Dale BA. Phospholipase C, p38/MAPK, and NF-kappaB-mediated induction of MIP-3alpha/CCL20 by *Porphyromonas gingivalis*. Innate Immun 2010;16:226–234.
16. Dommisch H, Reinartz M, Backhaus T, Deschner J, Chung W, Jepsen S. Antimicrobial responses of primary gingival cells to *Porphyromonas gingivalis*. J Clin Periodontol 2012;39:913–922.
17. Hajishengallis G, Lambris JD. Complement and dysbiosis in periodontal disease. Immunobiology 2012;217:1111–1116.
18. Allam JP, Duan Y, Heinemann F, et al. IL-23-producing CD68(+) macrophage-like cells predominate within an IL-17-polarized infiltrate in chronic periodontitis lesions. J Clin Periodontol 2011;38:879–886.
19. Hajishengallis G, Lamont RJ. Beyond the red complex and into more complexity: the polymicrobial synergy and dysbiosis (PSD) model of periodontal disease etiology. Mol Oral Microbiol 2012;27:409–419.
20. Darveau RP. Periodontitis: a polymicrobial disruption of host homeostasis. Nat Rev Microbiol 2010;8:481–490.
21. Kilian M, Chapple IL, Hannig M, et al. The oral microbiome - an update for oral healthcare professionals. Br Dent J 2016;221:657–666.
22. Mira A, Simon-Soro A, Curtis MA. Role of microbial communities in the pathogenesis of periodontal diseases and caries. J Clin Periodontol 2017;44(Suppl 18):S23–S38.
23. Bartold PM, Van Dyke TE. Periodontitis: a host-mediated disruption of microbial homeostasis. Unlearning learned concepts. Periodontol 2000 2013;62:203–217.
24. Hajishengallis G, Liang S, Payne MA, et al. Low-abundance biofilm species orchestrates inflammatory periodontal disease through the commensal microbiota and complement. Cell Host Microbe 2011;10:497–506.
25. Tomas I, Diz P, Tobías A, Scully C, Donos N. Periodontal health status and bacteraemia from daily oral activities: systematic

review/meta-analysis. J Clin Periodontol 2012;39:213–228.

26. Balejo RDP, Cortelli JR, Costa FO, et al. Effects of chlorhexidine preprocedural rinse on bacteremia in periodontal patients: a randomized clinical trial. J Appl Oral Sci 2017;25:586–595.
27. Nociti FH Jr, Casati MZ, Duarte PM. Current perspective of the impact of smoking on the progression and treatment of periodontitis. Periodontol 2000 2015;67:187–210.
28. Palmer RM, Wilson RF, Hasan AS, Scott DA. Mechanisms of action of environmental factors: tobacco smoking. J Clin Periodontol 2005;32(Suppl 6):180–195.
29. Genco RJ, Borgnakke WS. Risk factors for periodontal disease. Periodontol 2000 2013;62:59–94.
30. Heasman L, Stacey F, Preshaw PM, McCracken GI, Hepburn S, Heasman PA. The effect of smoking on periodontal treatment response: a review of clinical evidence. J Clin Periodontol 2006;33:241–253.
31. Loos BG, Roos MT, Schellekens PT, van der Velden U, Miedema F. Lymphocyte numbers and function in relation to periodontitis and smoking. J Periodontol 2004;75:557–564.
32. Eke PI, Wei L, Thornton-Evans GO, et al. Risk indicators for periodontitis in US adults: NHANES 2009 to 2012. J Periodontol 2016;87:1174–1185.
33. Papapanou PN, Sanz M, Buduneli N, et al. Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Clin Periodontol 2018;45(Suppl 20):S162–S170.
34. Chambrone L, Preshaw PM, Rosa EF, et al. Effects of smoking cessation on the outcomes of non-surgical periodontal therapy: a systematic review and individual patient data meta-analysis. J Clin Periodontol 2013;40:607–615.
35. Costa FO, Cota LO, Lages EJ, et al. Associations of duration of smoking cessation and cumulative smoking exposure with

periodontitis. J Oral Sci 2013;55:245–253.

36. Fiorini, T, Musskopf ML, Oppermann RV, Susin C. Is there a positive effect of smoking cessation on periodontal health? A systematic review. J Periodontol 2014;85:83–91.
37. Rosa EF, Corraini P, Inoue G, et al. Effect of smoking cessation on non-surgical periodontal therapy: results after 24 months. J Clin Periodontol 2014;41:1145–1153.
38. Dietrich T, Walter C, Oluwagbemigun K, et al. Smoking, smoking cessation, and risk of tooth loss: The EPIC-Potsdam Study. J Dent Res 2015;94:1369–1375.
39. Dommisch H, Kuzmanova D, Jönsson D, Grant M, Chapple I. Effect of micronutrient malnutrition on periodontal disease and periodontal therapy. Periodontol 2000 2018;78:129–153.
40. Glickman I. Acute vitamin C deficiency and the periodontal tissues; the effect of acute vitamin C deficiency upon the response of the periodontal tissues of the guinea pig to artificially induced inflammation. J Dent Res 1948;27:201–210.
41. Glickman I. Acute vitamin C deficiency and periodontal disease; the periodontal tissues of the guinea pig in acute vitamin C deficiency. J Dent Res 1948;27:9–23.
42. Sutton G. Putrid gums and ‘dead men’s cloaths’: James Lind aboard the Salisbury. J R Soc Med 2003;96:605–608.
43. Hujoel P. Dietary carbohydrates and dental-systemic diseases. J Dent Res 2009;88:490–502.
44. Woelber JP, Bremer K, Vach K, et al. An oral health optimized diet can reduce gingival and periodontal inflammation in humans: a randomized controlled pilot study. BMC Oral Health 2016;17:28.
45. Munoz-Torres FJ, Jiménez MC, Rivas-Tumanyan S, Joshipura KJ. Associations between measures of central adiposity and periodontitis among older adults. Community Dent Oral Epidemiol 2014;42:170–177.
46. Suvan JE, Finer N, D’Aiuto F. Periodontal complications with obesity. Periodontol 2000 2018;78:98–128.

47. Suvan J, Petrie A, Moles DR, et al. Body mass index as a predictive factor of periodontal therapy outcomes. J Dent Res 2014;93:49–54.
48. Dittmann C, Doueiri S, Kluge R, Dommisch H, Gaber T, Pischon N. *Porphyromonas gingivalis* suppresses differentiation and increases apoptosis of osteoblasts from New Zealand obese mice. J Periodontol 2015;86:1095–1102.
49. Damanaki A, Memmert S, Nokhbehsaim M, et al. Impact of obesity and aging on crestal alveolar bone height in mice. Ann Anat 2018;218:227–235.
50. Loos BG, Papantonopoulos G, Jepsen S, Laine ML. What is the contribution of genetics to periodontal risk? Dent Clin North Am 2015;59:761–780.
51. Loos BG, John RP, Laine ML. Identification of genetic risk factors for periodontitis and possible mechanisms of action. J Clin Periodontol 2005;32(Suppl 6):159–179.
52. Schaefer AS, Jepsen S, Loos BG. Periodontal genetics: a decade of genetic association studies mandates better study designs. J Clin Periodontol 2011;38:103–107.
53. Schaefer AS. Genetics of periodontitis: Discovery, biology, and clinical impact. Periodontol 2000 2018;78:162–173.
54. Gregory SG, Barlow KF, McLay KE, et al. The DNA sequence and biological annotation of human chromosome 1. Nature 2006;441(7091):315–321.
55. Munz M, Willenborg C, Richter GM, et al. A genome-wide association study identifies nucleotide variants at SIGLEC5 and DEFA1A3 as risk loci for periodontitis. Hum Mol Genet 2018;27:941–942.
56. Vaithilingam RD, Safii SH, Baharuddin NA, et al. Moving into a new era of periodontal genetic studies: relevance of large case-control samples using severe phenotypes for genome-wide association studies. J Periodontal Res 2014;49:683–695.
57. Schaefer AS, Richter GM, Nothnagel M, et al. A genome-wide association study identifies GLT6D1 as a susceptibility locus for

periodontitis. Hum Mol Genet 2010;19:553–562.

58. Schaefer AS, Richter GM, Groessner-Schreiber B, et al. Identification of a shared genetic susceptibility locus for coronary heart disease and periodontitis. PLoS Genet 2009;5:e1000378.
59. Schaefer AS, Bochenek G, Jochens A, et al. Genetic evidence for PLASMINOGEN as a shared genetic risk factor of coronary artery disease and periodontitis. Circ Cardiovasc Genet 2015;8:159–167.
60. Munz M, Willenborg C, Richter GM, et al. A genome-wide association study identifies nucleotide variants at SIGLEC5 and DEFA1A3 as risk loci for periodontitis. Hum Mol Genet 2017;26:2577–2588.
61. Freitag-Wolf S, Dommisch H, Graetz C, et al. Genome-wide exploration identifies sex-specific genetic effects of alleles upstream NPY to increase the risk of severe periodontitis in men. J Clin Periodontol 2014;41:1115–1121.
62. Hubberten M, Bochenek G, Chen H, et al. Linear isoforms of the long noncoding RNA CDKN2B-AS1 regulate the c-myc-enhancer binding factor RBMS1. Eur J Hum Genet 2019;27:80–89.
63. Calle MC, Fernandez ML. Inflammation and type 2 diabetes. Diabetes Metab 2012;38:183–191.
64. Knight ET, Liu J, Seymour GJ, Faggion CM Jr, Cullinan MP. Risk factors that may modify the innate and adaptive immune responses in periodontal diseases. Periodontol 2000 2016;71:22–51.
65. Graziani F, Gennai S, Solini A, Petrini M. A systematic review and meta-analysis of epidemiologic observational evidence on the effect of periodontitis on diabetes: An update of the EFP-AAP review. J Clin Periodontol 2018;45:167–187.
66. Loe H. Periodontal disease. The sixth complication of diabetes mellitus. Diabetes Care 1993;16:329–334.

67. Salvi GE, Carollo-Bittel B, Lang NP. Effects of diabetes mellitus on periodontal and peri-implant conditions: update on associations and risks. J Clin Periodontol 2008;35(8 Suppl):398–409.
68. Khader YS, Dauod AS, El-Qaderi SS, Alkafajei A, Batayha WQ. Periodontal status of diabetics compared with nondiabetics: a meta-analysis. J Diabetes Complications 2006;20:59–68.
69. Emrich LJ, Shlossman M, Genco RJ. Periodontal disease in non-insulin-dependent diabetes mellitus. J Periodontol 1991;62:123–131.
70. Polak D, Shapira L. An update on the evidence for pathogenic mechanisms that may link periodontitis and diabetes. J Clin Periodontol 2018;45:150–166.
71. Taylor GW. Bidirectional interrelationships between diabetes and periodontal diseases: an epidemiologic perspective. Ann Periodontol 2001;6:99–112.
72. Chang JF, Yeh JC, Chiu YL, Liou JC, Hsiung JR, Tung TH. Periodontal pocket depth, hyperglycemia, and progression of chronic kidney disease: a population-based longitudinal study. Am J Med 2017;130:61–69.e1.
73. Gokhale NH, Acharya AB, Patil VS, Trivedi DJ, Setty S, Thakur SL. Resistin levels in gingival crevicular fluid of patients with chronic periodontitis and type 2 diabetes mellitus. J Periodontol 2014;85:610–617.
74. Longo PL, Artese HP, Rabelo MS, et al. Serum levels of inflammatory markers in type 2 diabetes patients with chronic periodontitis. J Appl Oral Sci 2014;22:103–108.
75. Schenkein HA, Loos BG. Inflammatory mechanisms linking periodontal diseases to cardiovascular diseases. J Periodontol 2013;84(4 Suppl):S51–S69.
76. Reyes L, Herrera D, Kozarov E, Roldán S, Progulske-Fox A. Periodontal bacterial invasion and infection: contribution to atherosclerotic pathology. J Clin Periodontol 2013;40(Suppl 14):S30–S50.

77. Kocher T, König J, Borgnakke WS, Pink C, Meisel P. Periodontal complications of hyperglycemia/diabetes mellitus: Epidemiologic complexity and clinical challenge. Periodontol 2000 2018;78:59–97.
78. Abrao L, Chagas JK, Schmid H. Periodontal disease and risk for neuropathic foot ulceration in type 2 diabetes. Diabetes Res Clin Pract 2010;90:34–39.
79. Noma H, Sakamoto I, Mochizuki H, et al. Relationship between periodontal disease and diabetic retinopathy. Diabetes Care 2004;27:615.
80. Saremi A, Nelson RG, Tulloch-Reid M, et al. Periodontal disease and mortality in type 2 diabetes. Diabetes Care 2005;28:27–32.
81. Southerland JH, Moss K, Taylor GW, et al. Periodontitis and diabetes associations with measures of atherosclerosis and CHD. Atherosclerosis 2012;222:196–201.
82. Thorstensson H, Kuylenstierna J, Hugoson A. Medical status and complications in relation to periodontal disease experience in insulin-dependent diabetics. J Clin Periodontol 1996;23(3 Pt 1):194–202.
83. Tonett MS, Van Dyke TE; working group 1 of the joint EFP/AAP workshop. Periodontitis and atherosclerotic cardiovascular disease: consensus report of the Joint EFP/AAP Workshop on Periodontitis and Systemic Diseases. J Periodontol 2013;84(4 Suppl):S24–S29.
84. Dietrich T, Sharma P, Walter C, Weston P, Beck J. The epidemiological evidence behind the association between periodontitis and incident atherosclerotic cardiovascular disease. J Clin Periodontol 2013;40(Suppl 14):S70–S84.
85. Blaizot A, Vergnes JN, Nuwwareh S, Amar J, Sixou M. Periodontal diseases and cardiovascular events: meta-analysis of observational studies. Int Dent J 2009;59:197–209.
86. Armingohar Z, Jørgensen JJ, Kristoffersen AK, Abesha-Belay E, Olsen I. Bacteria and bacterial DNA in atherosclerotic plaque

and aneurysmal wall biopsies from patients with and without periodontitis. J Oral Microbiol 2014;6: 10.3402/jom.v6.23408.

87. Mahendra J, Mahendra L, Felix J, Romanos G. Prevelance of periodontopathogenic bacteria in subgingival biofilm and atherosclerotic plaques of patients undergoing coronary revascularization surgery. J Indian Soc Periodontol 2013;17:719–724.
88. Koppolu P, Durvasula S, Palaparthy R, et al. Estimate of CRP and TNF-alpha level before and after periodontal therapy in cardiovascular disease patients. Pan Afr Med J 2013;15:92.
89. Lopez NJ, Quintero A, Casanova PA, Ibieta CI, Baelum V, López R. Effects of periodontal therapy on systemic markers of inflammation in patients with metabolic syndrome: a controlled clinical trial. J Periodontol 2012;83:267–278.
90. Patil VA, Desai MH. Effect of periodontal therapy on serum C-reactive protein levels in patients with gingivitis and chronic periodontitis: a clinicobiochemical study. J Contemp Dent Pract 2013;14:233–237.
91. Ling MR, Chapple IL, Matthews JB. Neutrophil superoxide release and plasma C-reactive protein levels pre- and post-periodontal therapy. J Clin Periodontol 2016;43:652–658.
92. Noack B, Genco RJ, Trevisan M, Grossi S, Zambon JJ, De Nardin E. Periodontal infections contribute to elevated systemic C-reactive protein level. J Periodontol 2001;72:1221–1227.
93. Loos BG. Systemic markers of inflammation in periodontitis. J Periodontol 2005;76(11 Suppl):2106–2115.
94. Loos BG, Craandijk J, Hoek FJ, Wertheim-van Dillen PM, van der Velden U. Elevation of systemic markers related to cardiovascular diseases in the peripheral blood of periodontitis patients. J Periodontol 2000;71:1528–1534.
95. Ebersole JL. Humoral immune responses in gingival crevice fluid: local and systemic implications. Periodontol 2000 2003;31:135–166.

96. Ebersole JL, Cappelli D, Mathys EC, et al. Periodontitis in humans and non-human primates: oral-systemic linkage inducing acute phase proteins. Ann Periodontol 2002;7:102–111.
97. Allen EM, Matthews JB, O'Halloran DJ, Griffiths HR, Chapple IL. Oxidative and inflammatory status in Type 2 diabetes patients with periodontitis. J Clin Periodontol 2011;38:894–901.
98. Teeuw WJ, Slot DE, Susanto H, et al. Treatment of periodontitis improves the atherosclerotic profile: a systematic review and meta-analysis. J Clin Periodontol 2014;41:70–79.
99. Leivadaros E, van der Velden U, Bizzarro S, et al. A pilot study into measurements of markers of atherosclerosis in periodontitis. J Periodontol 2005;76:121–128.
100. Ahn YB, Shin MS, Han DH, et al. Periodontitis is associated with the risk of subclinical atherosclerosis and peripheral arterial disease in Korean adults. Atherosclerosis 2016;251:311–318.
101. Orlandi M, Suvan J, Petrie A, et al. Association between periodontal disease and its treatment, flow-mediated dilatation and carotid intima-media thickness: a systematic review and meta-analysis. Atherosclerosis 2014;236:39–46.
102. Amar S, Gokce N, Morgan S, Loukideli M, Van Dyke TE, Vita JA. Periodontal disease is associated with brachial artery endothelial dysfunction and systemic inflammation. Arterioscler Thromb Vasc Biol 2003;23:1245–1249.
103. Martin-Cabezas R, Seelam N, Petit C, et al. Association between periodontitis and arterial hypertension: a systematic review and meta-analysis. Am Heart J 2016;180:98–112.
104. Bochenek G, Häsler R, El Mokhtari NE, et al. The large non-coding RNA ANRIL, which is associated with atherosclerosis, periodontitis and several forms of cancer, regulates ADIPOR1, VAMP3 and C11ORF10. Hum Mol Genet 2013;22:4516–4527.
105. Firestein GS. Evolving concepts of rheumatoid arthritis. Nature 2003;423(6937):356–361.

106. Wegner N, Lundberg K, Kinloch A, et al. Autoimmunity to specific citrullinated proteins gives the first clues to the etiology of rheumatoid arthritis. Immunol Rev 2010;233:34–54.
107. Bright R, Proudman SM, Rosenstein ED, Bartold PM. Is there a link between carbamylation and citrullination in periodontal disease and rheumatoid arthritis? Med Hypotheses 2015;84:570–576.
108. Holers VM. Autoimmunity to citrullinated proteins and the initiation of rheumatoid arthritis. Curr Opin Immunol 2013;25:728–735.
109. Demoruelle MK, Deane KD, Holers VM. When and where does inflammation begin in rheumatoid arthritis? Curr Opin Rheumatol 2014;26:64–71.
110. Rosenstein ED, Greenwald RA, Kushner LJ, Weissmann G. Hypothesis: the humoral immune response to oral bacteria provides a stimulus for the development of rheumatoid arthritis. Inflammation 2004;28:311–318.
111. Leech MT, Bartold PM. The association between rheumatoid arthritis and periodontitis. Best Pract Res Clin Rheumatol 2015;29:189–201.
112. Loutan L, Alpizar-Rodriguez D, Courvoisier DS, Finckh A, Mombelli A, Giannopoulou C. Periodontal status correlates with anti-citrullinated protein antibodies in first-degree relatives of individuals with rheumatoid arthritis. J Clin Periodontol 2019;46:690–698.
113. Nesse W, Abbas F, van der Ploeg I, Spijkervet FK, Dijkstra PU, Vissink A. Periodontal inflamed surface area: quantifying inflammatory burden. J Clin Periodontol 2008;35:668–673.
114. Lang NP, Tonetti MS. Periodontal risk assessment (PRA) for patients in supportive periodontal therapy (SPT). Oral Health Prev Dent 2003;1:7–16.
115. Dietrich T, Ower P, Tank M, et al. Periodontal diagnosis in the context of the 2017 classification system of periodontal

diseases and conditions: implementation in clinical practice. Br Dent J 2019;226:16–22.

116. Papapanou PN, Sanz M, Buduneli N, et al. Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Periodontol 2018;89(Suppl 1):S173–S182.
117. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. J Clin Periodontol 2018;45(Suppl 20):S149–S161.
118. Caton JG, Armitage G, Berglundh T, et al. A new classification scheme for periodontal and peri-implant diseases and conditions - Introduction and key changes from the 1999 classification. J Periodontol 2018;89(Suppl 1):S1–S8.
119. Jepsen S, Caton JG, Albandar JM, et al. Periodontal manifestations of systemic diseases and developmental and acquired conditions: Consensus report of workgroup 3 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Clin Periodontol 2018;45(Suppl 20):S219–S229.
120. Berglundh T, Armitage G, Araujo MG, et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Clin Periodontol 2018;45(Suppl 20):S286–S291.
121. Tonetti MS, Eickholz P, Loos BG, et al. Principles in prevention of periodontal diseases: Consensus report of group 1 of the 11th European Workshop on Periodontology on effective prevention of periodontal and peri-implant diseases. J Clin Periodontol 2015;42(Suppl 16):S5–S11.
122. Chapple ILC, Mealey BL, Van Dyke TE, et al. Periodontal health and gingival diseases and conditions on an intact and a reduced periodontium: Consensus report of workgroup 1 of the 2017 World Workshop on the Classification of Periodontal and

Peri-Implant Diseases and Conditions. J Clin Periodontol 2018;45(Suppl 20):S68–S77.

123. Chung WO, Dommisch H, Yin L, Dale BA. Expression of defensins in gingiva and their role in periodontal health and disease. Curr Pharm Des 2007;13:3073–3083.
124. Dommisch H, Skora P, Hirschfeld J, Olk G, Hildebrandt L, Jepsen S. The guardians of the periodontium-sequential and differential expression of antimicrobial peptides during gingival inflammation. Results from in vivo and in vitro studies. J Clin Periodontol 2019;46:276–285.
125. Sanz M, Bäumer A, Buduneli N, et al. Effect of professional mechanical plaque removal on secondary prevention of periodontitis and the complications of gingival and periodontal preventive measures: consensus report of group 4 of the 11th European Workshop on Periodontology on effective prevention of periodontal and peri-implant diseases. J Clin Periodontol 2015;42(Suppl 16):S214–S220.
126. Yaacob M, Worthington HV, Deacon SA, et al. Powered versus manual toothbrushing for oral health. Cochrane Database Syst Rev 2014:CD002281.
127. Pitchika V, Pink C, Völzke H, Welk A, Kocher T, Holtfreter B, et al. Long-term impact of powered toothbrush on oral health: 11-year cohort study. J Clin Periodontol 2019;46:713–722.
128. Graetz C, El-Sayed KF, Sälzer S, et al. Häusliches mechanisches Biofilmmanagement in der Prävention und Therapie der Gingivitis; S3-Leitlinie. November 2018. https://www.awmf.org/uploads/tx_szleitlinien/083-022l_S3_Haeusliches-mechanisches-Biofilmmanagement-Praevention-Therapie-Gingivitis_2018-11.pdf. Accessed 9 May 2019.
129. Valkenburg C, Slot DE, Bakker EW, Van der Weijden FA. Does dentifrice use help to remove plaque? A systematic review. J Clin Periodontol 2016;43:1050–1058.

130. Figuero E, Herrera D, Tobías A, et al. Efficacy of adjunctive anti-plaque chemical agents in managing gingivitis: A systematic review and network meta-analyses. J Clin Periodontol 2019;46:723–739.
131. Auschill T, Sälzer S, Arweiler N. Häusliches chemisches Biofilmmanagement in der Prävention und Therapie der Gingivitis. S3-Leitlinie. November 2018. https://www.awmf.org/uploads/tx_szleitlinien/083-016l_S3_Haeusliches-chemisches-Biofilmmanagement-Praevention-Therapie-Gingivitis_2018-11.pdf. Accessed 9 May 2019.
132. Schlagenhauf U, Jakob L, Eigenthaler M, Segerer S, Jockel-Schneider Y, Rehn M. Regular consumption of *Lactobacillus reuteri*-containing lozenges reduces pregnancy gingivitis: an RCT. J Clin Periodontol 2016;43:948–954.
133. Needleman I, Nibali L, Di Iorio A. Professional mechanical plaque removal for prevention of periodontal diseases in adults: systematic review update. J Clin Periodontol 2015;42(Suppl 16):S12–S35.
134. Ramseier CA, Suvan JE. Behaviour change counselling for tobacco use cessation and promotion of healthy lifestyles: a systematic review. J Clin Periodontol 2015;42(Suppl 16):S47–S58.
135. Sanz M, Kornman K; working group 3 of the joint EFP/AAP workshop. Periodontitis and adverse pregnancy outcomes: consensus report of the Joint EFP/AAP Workshop on Periodontitis and Systemic Diseases. J Periodontol 2013;84(4 Suppl):S164–S169.
136. Madianos PN, Bobetsis YA, Offenbacher S. Adverse pregnancy outcomes (APOs) and periodontal disease: pathogenic mechanisms. J Periodontol 2013;84(4 Suppl):S170–S180.
137. Silva de Araujo Figueiredo C, Gonçalves Carvalho Rosalem C, Costa Cantanhede AL, Abreu Fonseca Thomaz ÉB, Fontoura Nogueira da Cruz MC. Systemic alterations and their oral

manifestations in pregnant women. J Obstet Gynaecol Res 2017;43:16–22.

138. American Academy of Pediatric Dentistry. Council on Clinical Affairs, Committee on the Adolescent. Guideline on oral health care for the pregnant adolescent. Pediatr Dent 2012;34:153–159.
139. Vitale SG, Privitera S, Gulino FA, et al. Dental management in pregnancy: recent trends. Clin Exp Obstet Gynecol 2016;43:638–642.
140. Borgnakke WS, Ylöstalo PV, Taylor GW, Genco RJ. Effect of periodontal disease on diabetes: systematic review of epidemiologic observational evidence. J Clin Periodontol 2013;40(Suppl 14):S135–S152.
141. Sanz M, Ceriello A, Buysschaert M, et al. Scientific evidence on the links between periodontal diseases and diabetes: Consensus report and guidelines of the joint workshop on periodontal diseases and diabetes by the International Diabetes Federation and the European Federation of Periodontology. J Clin Periodontol 2018;45:138–149.
142. Ramseier CA, Nydegger M, Walter C, et al. Time between recall visits and residual probing depths predict long-term stability in patients enrolled in supportive periodontal therapy. J Clin Periodontol 2019;46:218–230.
143. Yu H, Qi LT, Liu LS, et al. Association of carotid intima-media thickness and atherosclerotic plaque with periodontal status. J Dent Res 2014;93:744–751.
144. Jockel-Schneider Y, Bechtold M, Haubitz I, et al. Impact of anti-infective periodontal therapy on parameters of vascular health. J Clin Periodontol 2018;45:354–363.
145. Tonetti MS, D'Aiuto F, Nibali L, et al. Treatment of periodontitis and endothelial function. N Engl J Med 2007;356:911–920.
146. Kaur S, Bright R, Proudman SM, Bartold PM, et al. Does periodontal treatment influence clinical and biochemical

measures for rheumatoid arthritis? A systematic review and meta-analysis. Semin Arthritis Rheum 2014;44:113–122.

147. Silvestre FJ, Silvestre-Rangil J, Bagán L, Bagán JV. Effect of nonsurgical periodontal treatment in patients with periodontitis and rheumatoid arthritis: a systematic review. Med Oral Patol Oral Cir Bucal 2016;21:e349–e354.
148. Sanz M, Herrera D, Kebschull M, et al. On behalf of the EFP Workshop Participants and Methodological Consultants. Treatment of stage I–III periodontitis: The EFP S3 level clinical practice guideline. J Clin Periodontol 2020;47:4–60.
149. Herrera D, Alonso B, León R, Roldán S, Sanz M. Antimicrobial therapy in periodontitis: the use of systemic antimicrobials against the subgingival biofilm. J Clin Periodontol 2008;35(8 Suppl):45–66.
150. Pretzl B, Sälzer S, Ehmke B, et al. Administration of systemic antibiotics during non-surgical periodontal therapy: a consensus report. Clin Oral Investig 2019;23:3073–3085.
151. Cionca N, Giannopoulou C, Ugolotti G, Mombelli A. Amoxicillin and metronidazole as an adjunct to full-mouth scaling and root planing of chronic periodontitis. J Periodontol 2009;80:364–371.
152. Harks I, Koch R, Eickholz P, et al. Is progression of periodontitis relevantly influenced by systemic antibiotics? A clinical randomized trial. J Clin Periodontol 2015;42:832–842.
153. Eickholz P, Kaltschmitt J, Berbig J, Reitmeir P, Pretzl B. Tooth loss after active periodontal therapy. 1: patient-related factors for risk, prognosis, and quality of outcome. J Clin Periodontol 2008;35:165–174.
154. Pretzl B, El Sayed S, Weber D, Eickholz P, Bäumer A. Tooth loss in periodontally compromised patients: Results 20 years after active periodontal therapy. J Clin Periodontol 2018;45:1356–1364.
155. Trombelli L, Franceschetti G, Farina R. Effect of professional mechanical plaque removal performed on a long-term, routine

basis in the secondary prevention of periodontitis: a systematic review. J Clin Periodontol 2015;42(Suppl 16):S221–S236.

156. Hirschfeld L, Wasserman B. A long-term survey of tooth loss in 600 treated periodontal patients. J Periodontol 1978;49:225–237.

157. Lang NP, Tonetti MS. Periodontal diagnosis in treated periodontitis. Why, when and how to use clinical parameters. J Clin Periodontol 1996;23(3 Pt 2):240–250.

3

Fluoride: How much is needed?

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Few areas in health have seen such a dramatic change in the epidemiology of a disease as dentistry after the discovery of fluoride as an anticaries agent. The prevalence and severity of dental caries declined tremendously in many areas of the world after the introduction of fluoride in different manners: added to water or table salt for general consumption, formulated in oral health products for individual (toothpastes, rinses) or professional use (fluoride varnishes, fluoride gels). Despite this major public health accomplishment, untreated dental caries remains as the major burden of all oral conditions.[1]

Around a century ago, fluoride was identified as an anticaries agent by observations of mottled teeth in populations exposed to water with naturally high fluoride concentration.[2,3] It was discovered that these populations experienced almost no caries lesions, but suffered from a side effect of chronic, systemic fluoride exposure at high levels: dental fluorosis. Therefore, since the beginning of the history of fluoride as an anticaries agent, balancing the anticaries

benefit with the risk of developing dental fluorosis has always been of primary importance.

After some decades of dental caries prevalence decline, the disease is still highly prevalent, and current anti-caries strategies, which are mostly based on fluoride, seem to have reached an efficacy plateau.[4] Meanwhile, there is a perceived increase in the prevalence of dental fluorosis, and some dental professionals have prompted discussions on the benefits and risks of fluoride, questioning the necessity of using fluoride to control caries.

This chapter aims to answer the question of how much fluoride is needed. With the main focus on individual and professional fluoride use, the best evidence currently available for the safe use of fluoride for caries control is presented and discussed.

Fluoride: the mode of action and why it is needed

In order to define the role of fluoride in caries control, it is necessary to describe the caries process itself. Dental caries is regarded as a multifactorial disease, with many factors affecting the appearance and severity of the disease. Two main conditions must be present for the disease to develop: biofilm accumulation on the tooth surface and its regular exposure to fermentable carbohydrates. Bacteria in the biofilm will metabolize the carbohydrates, generating organic acids that can dissolve enamel and dentin.[5] Oral biofilms (or dental plaque) continuously form on teeth, starting immediately after effective tooth brushing or professional tooth cleaning. Additionally, sugars are omnipresent in the modern diet. With both necessary factors in place, caries lesions can develop in anyone's mouth.

Fluoride is a unique agent for caries control, with significant impact on the balance of mineral loss/gain between tooth structure and the surrounding environment, favoring mineral gain even at very low concentrations (as low as 0.02 parts per million) in the oral cavity.[6]

Today's understanding of fluoride as a modifier of the caries process,[7] in contrast to earlier times when fluoride was thought to exert its action solely by being incorporated into the teeth, emphasizes that fluoride is needed in the oral fluids such as saliva or dental biofilm fluid to control the progression of caries. In the biofilm, fluoride will reduce the mineral loss during a cariogenic challenge (reduction of demineralization) or, after the challenge, induce regain of minerals that were previously lost, enhancing remineralization. When present in saliva, it can enhance remineralization of cleaned teeth. Therefore, all methods of fluoride used to control caries aim to increase fluoride concentrations in the oral fluids and maintain increased levels for as long as possible. This can be accomplished by different mechanisms, such as by drinking fluoridated water or eating food prepared with it, which will increase the fluoride concentration in the oral fluids during the ingestion[8] and later, at a lower extent, return fluoride to the mouth via saliva secretion; by brushing with fluoride toothpaste; or by forming fluoride reservoirs on the surface of teeth by using professionally applied high concentration fluoride products (Table 3-1). All of these methods will slow down caries development by increasing the concentration of free fluoride in the oral fluids, thus affecting the balance of mineral loss, favoring mineral precipitation and reducing the mineral loss caused by the exposure of dental biofilm to sugars. Unless one has a very strict biofilm control, which is close to utopic in some tooth surfaces, and a very strict control of intake of fermentable carbohydrates, in particular sugars found in beverages and many between-meal snacks, he/she will need fluoride to help overcome the cariogenic challenges to which teeth are exposed on a daily basis.

Table 3-1 Overview of different methods of fluoride use and their mode of action

Method	Category	Fluoride concentration	Mode of action
Water fluoridation	Community approach	0.5–1.0 ppm (mg/L)	Increases fluoride concentration in the oral fluids during the consumption of water or food prepared with it, and throughout the day by saliva secretion of the absorbed fluoride
Salt fluoridation	Community approach	200–250 ppm (mg/kg)	Increases fluoride concentration in the oral fluids during the consumption of food prepared with it, and throughout the day by saliva secretion of the absorbed fluoride
Fluoride toothpaste	Individual use	1,000–1,500 ppm F (standard concentration)*	Increases fluoride concentration in the oral fluids considerably in the first hours after brushing. Long-term daily use results in a small but significant increase of the background fluoride concentration in the oral fluids
Fluoride mouthrinse	Individual use	Typically 226 ppm F (daily use); 900 ppm F (weekly use)	Increases the fluoride concentration in the oral fluids for some hours after rinsing
Fluoride gel, foam, solution, varnish	Professional use	Typically 9,000–12,300 ppm F (gel, foam, solution); 22,600 ppm F (varnish)	Reacts with the tooth structure forming soluble fluoride reservoirs, to be released over time (weeks–months)

*Lower (typically 500–550 ppm F) or higher (typically 5,000 ppm F, prescription level) are also available; please refer to evidence-based recommendations in the following section.

The current understanding of the fluoride mode of action stresses the topical effect, and this has made the individual prescription of fluoride supplements questionable.[6,7] The local enrichment of the oral fluids with fluoride is easily obtained by the use of fluoride toothpaste, even in areas where water fluoridation is not available. Water fluoridation continues to be considered important in many countries as a public health approach to fluoride use.[9]

Importantly, although fluoride is very effective in retaining minerals within the tooth structure during a cariogenic challenge, it is not enough to totally avoid mineral loss. The development of caries lesions over time, and their progression, will be a balance between the frequency of exposure of dental biofilm to sugar, and availability of fluoride to overcome part of the mineral loss (Fig 3-1).

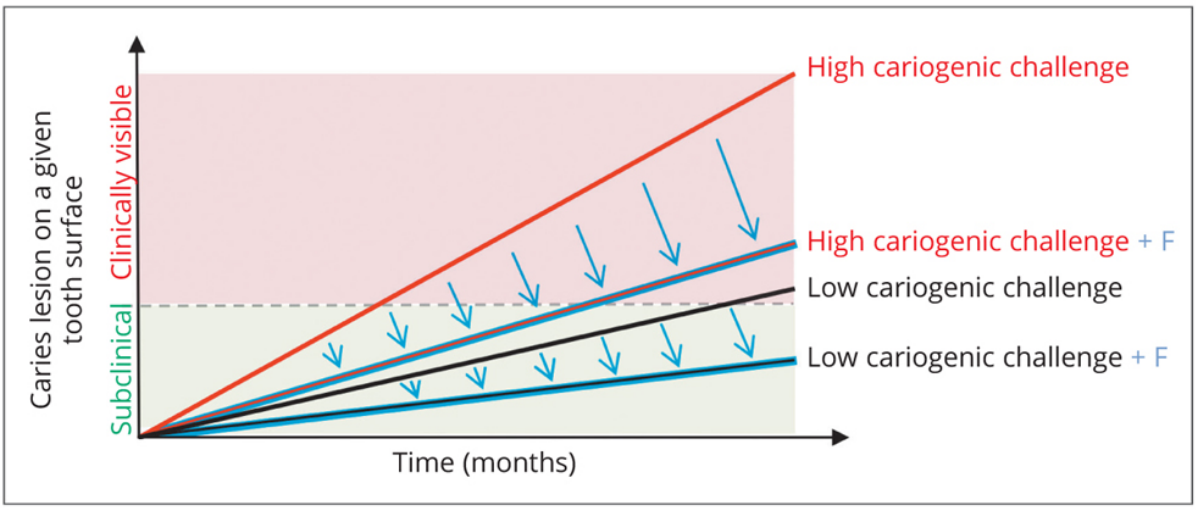
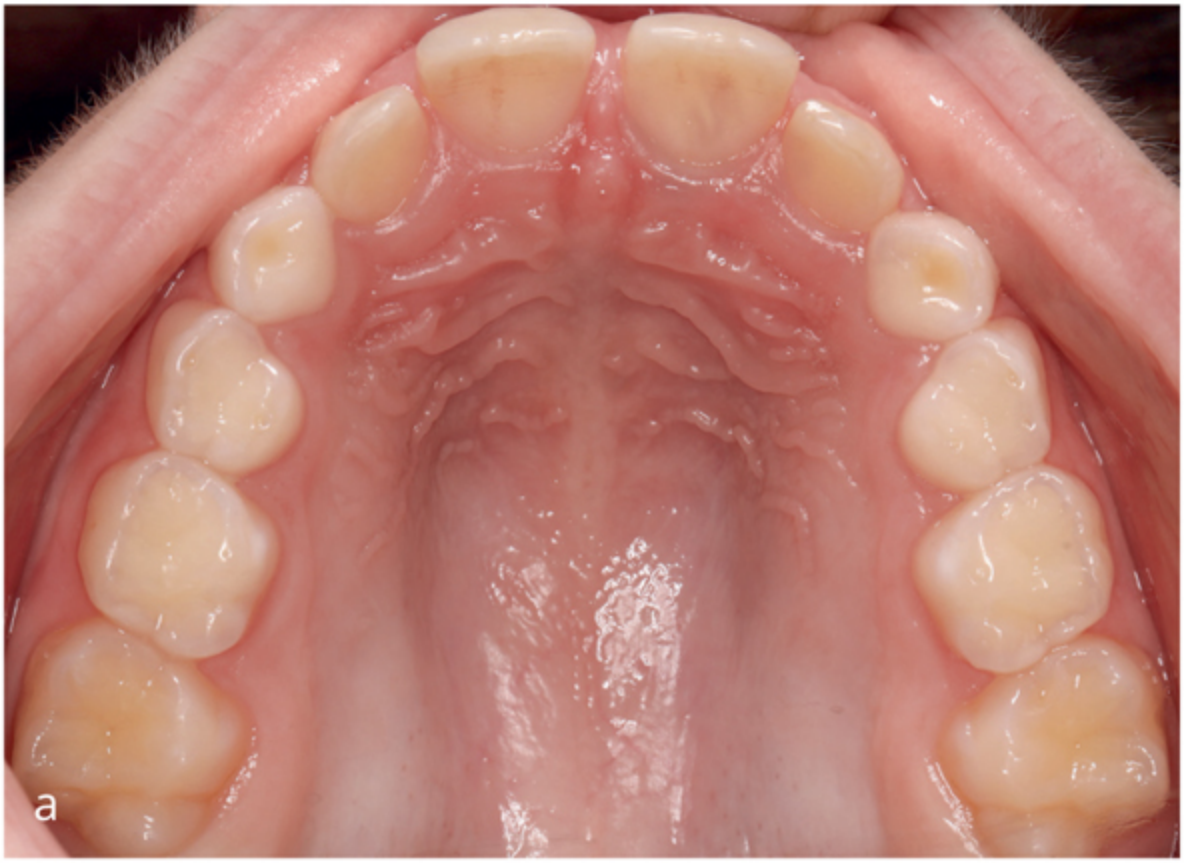
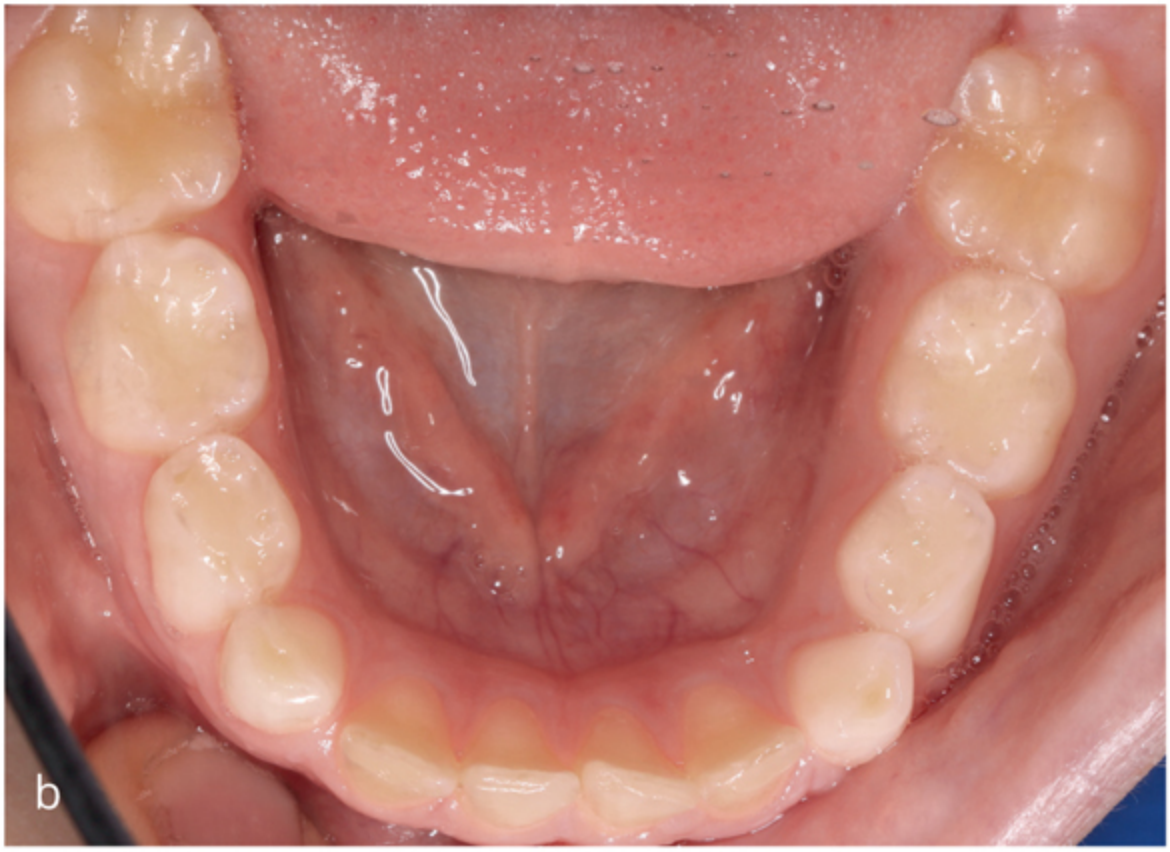


Fig 3-1 The relationship between caries lesion development over time, under a low or high cariogenic challenge, in the presence or absence of fluoride. Fluoride is able to reduce mineral loss, but the clinical result (no new lesions or progression of lesions versus new lesions appearing and progressing) will depend on the level of the cariogenic challenge (biofilm + sugar interaction).

If the cariogenic challenge is not high, for instance if the biofilm is disorganized frequently by tooth brushing and/or the daily frequency of sugar exposure is not excessive, brushing with a fluoride toothpaste will be enough to maintain an individual free of clinically visible caries lesions (Fig 3-2). On the other hand, if the cariogenic challenge is high due to poor biofilm control and high frequency of daily sugar exposure, fluoride may not be enough to avoid the appearance of new lesions, or the progression of existing ones.





Figs 3-2a and b A 10-year-old boy who has been clinically caries free after using fluoride toothpaste (1,100 to 1,450 ppm F, twice/day), since the first tooth erupted, and moderate sugar consumption, including restraint on the frequency of sugary between-meal snacks (images courtesy of Line Staun Larsen).

In these individual cases, the dental practitioner could employ professional methods of fluoride delivery in order to increase the amount of available fluoride in the mouth. However, the clinical outcome will be the result of the interaction between the cariogenic challenge and the exposure to fluoride; even a combination of different methods of fluoride delivery may not be enough if the cariogenic challenge is high and not controlled (Fig 3-1).

Fluoride toothpaste: how much fluoride is enough?

Fluoride toothpaste is considered the most rational way of using fluoride, because it involves the removal of biofilm and the exposure of the oral cavity to fluoride. Not surprisingly, experts agree that fluoride toothpaste has significantly contributed to the worldwide decrease in dental caries that has been observed in the past decades.[10,11]

Although there is substantial evidence on the effectiveness of fluoride toothpaste for caries control,[12,13] the recommendations are not straightforward. Evidence-based, clinical recommendations on which toothpaste formulation to use during the different stages of an individual's life may be influenced by a number of factors; for example, the availability and affordability of the different fluoride toothpastes on the market, the professional assessment of the patient's caries activity, and, in the case of children, fluorosis risk, the certainty of the evidence on the benefits and risks of toothpastes with different fluoride concentrations, and the preferences and values of the patient.

In this complex scenario, when discussing how much fluoride in toothpaste is enough, two main questions need to be answered:

- What is the lowest concentration that shows (a clinically relevant) anticaries effect? Using the lowest effective concentration is especially important when recommendations for young children are made, aiming to reduce their exposure to fluoride and thereby lowering the risk of developing dental fluorosis.
- Is more better? In patients that are no longer at risk of developing fluorosis, should higher concentration toothpastes be used?

In the next section, these two points are discussed, based on the best evidence currently available.

Dental fluorosis

Fluorosis is the only scientifically proven side-effect of chronic exposure to fluoride. Dental fluorosis occurs during amelogenesis when teeth are exposed to elevated fluoride doses for a prolonged period of time. The level of fluorosis is dependent on the dose and duration of the exposure, and permanent teeth take years to complete their mineralization. Considering the probably most important esthetic teeth, the maxillary permanent central incisors, the overall duration of fluoride exposure is thought to be more important than short specific risk periods for the development of dental fluorosis.[14] Accordingly, children with a history of long exposure (> 2 years during the first 4 years of life) have been shown to be 5.8 times more likely to develop dental fluorosis than children with < 2 years of exposure during the same period of life. Therefore, only methods used daily, like water fluoridation, fluoride tablets, and the overdosing of fluoride toothpaste, have been associated with fluorosis development.[15]

It should be emphasized that the level of fluorosis currently observed in populations exposed to fluoridated water and toothpaste is mainly restricted to the very mild or mild levels (Fig 3-3).[16,17] At these levels, the clinical appearance is seldom regarded as disfiguring by the patients themselves and people around them. Even so, the balance of benefits versus risks of fluoride toothpaste use by children in the first years of their lives, when they are not yet capable of spitting out the toothpaste slurry and may ingest most of it, has been debated, especially in areas with water fluoridation. Therefore, in the last few years researchers have been summarizing the evidence on the benefits and risks of fluoride toothpaste use by young children, as discussed in the next section.

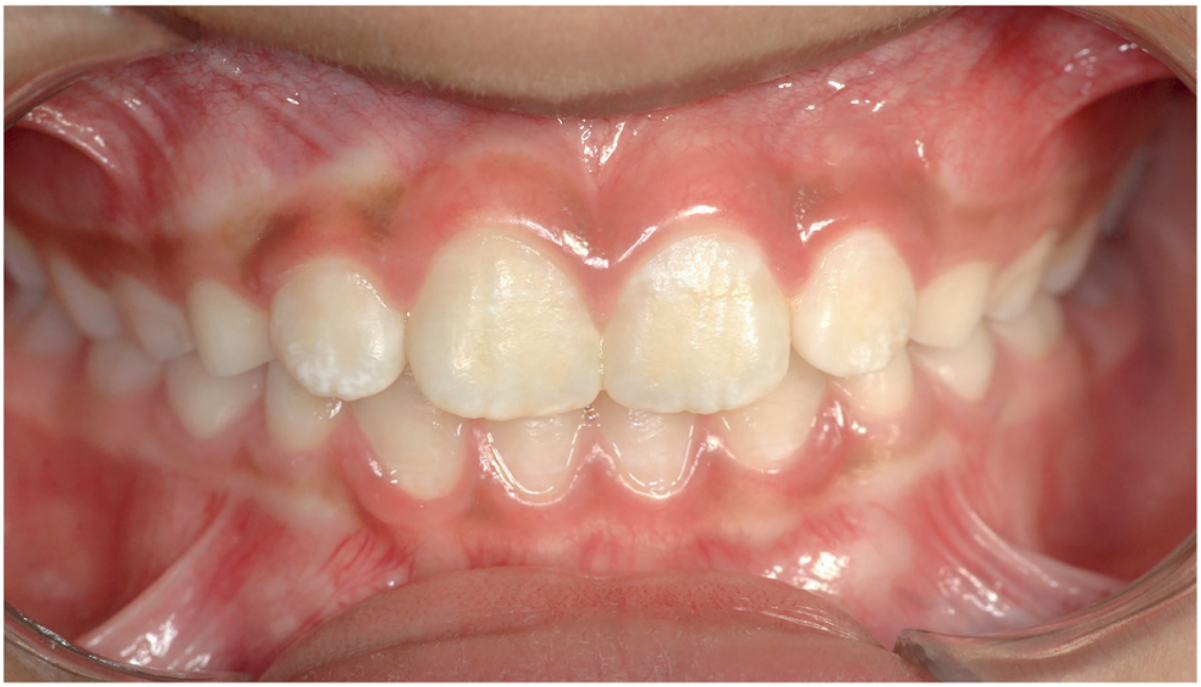


Fig 3-3 Mild fluorosis typical of regions where water fluoridation has been implemented and fluoride toothpaste use is widespread. Given the superficial nature of mild fluorosis, the whitish aspect observed in the incisal areas tend to fade away as the patient ages, as a result of enamel wear.

Evidence-based recommendations for fluoride toothpaste use throughout life

The evidence behind the use of fluoride toothpaste for caries prevention, and the risks associated with its use, have been summarized in a number of systematic reviews and meta-analyses in recent years.[12,13,18-21] Although in some instances the evidence from clinical trials is not abundant, these reviews have served as an important resource to guide professionals on the best available evidence. Table 3-2 describes the most common effect measures used in clinical trials and how they are usually presented in these reviews.

Table 3-2 Common effect measures used in clinical trials on fluoride toothpaste*

Term	Interpretation
Prevented fraction (PF)	Difference in mean caries increment between treatment and control groups, expressed as the percentage of mean caries increment in the control group. This is the relative difference in caries increment. It is also called the percentage reduction in caries increment.
Absolute risk (AR) or risk difference (RD)	Proportion of subjects developing new caries lesions in the untreated group or the group treated with a placebo (caries incidence in the control group) minus the proportion of subjects developing new caries lesions in the group treated with fluoride (caries incidence in the test group). The absolute risk reduction (ARR) is usually presented as counts (eg, 1 out of 100).
Number needed to treat (NNT)	Number of people who need to receive the experimental rather than the comparator intervention for one additional person to either have or avoid an event in a given time frame (eg, one subject with new caries lesion[s]/one new carious tooth or surface). The NNT is derived from the risk difference.
Relative risk (RR)	Proportion of subjects developing new caries lesions in the untreated group or the group treated with a placebo (caries incidence in the control group) divided by the proportion of subjects developing new caries lesions in

Term	Interpretation
	the group treated with fluoride (caries incidence in the test group). The relative reduction in caries incidence is usually presented as a percentage reduction: RRR = 100% × (1 – RR).

*In meta-analysis the results of individual trials with similar study designs are pooled. Thus, the combined effects are presented, for example, as pooled RR and pooled PF with their respective confidence intervals (CI). NNTs cannot be pooled but pooled RRs may be converted to NNTs.

The first comprehensive review with meta-analyses on the effect of fluoride toothpaste for caries prevention in children and adolescents was published in 2003.[12] This review found a mean 24% (prevented fraction; decayed, missing, or filled surfaces [DMFS]) decrease in caries severity in the permanent dentition of children who brushed with fluoride toothpaste in comparison to children who brushed with nonfluoride toothpaste for a period of 3 years. When considering a lifetime exposure to fluoride toothpaste, this would represent a remarkable anticaries effect. Also, an increased anticaries effect was observed in populations with higher caries levels, higher frequency of tooth brushing, and supervised tooth brushing. However, these last findings should be interpreted with caution because they were obtained through subgroup analyses and meta-regression, which are subject to the limitations of any observational investigation.

The only data on adverse effects available in the primary studies that were included in this review[12] were tooth staining in children brushing with stannous fluoride toothpaste; the pooled risk difference between placebo and fluoride toothpaste was significant. This

problem seems to be solved in the current toothpaste formulations based on stannous fluoride.[22]

In 2010, a systematic review with the objective of assessing whether the anticaries effect of fluoride toothpastes in children and adolescents differs according to their fluoride concentration was published.[23] The updated 2019 version[13] also assessed the benefits of fluoride toothpastes in adults. The results of these reviews confirmed the expressive caries preventive effect of fluoride toothpastes with 1,000 ppm F and above for both children and adults, and showed a dose-response effect for DMFS in children and adolescents. However, moderate-certainty evidence was not capable of showing a difference in caries increment when comparing 1,700 to 2,800 ppm F toothpaste to 1,450 to 1,500 ppm F.

Low-fluoride toothpastes (< 600 ppm F) have been developed as an alternative to standard fluoride toothpastes (1,000 to 1500 ppm F) in order to deliver fluoride during tooth brushing to the oral environment while reducing the risk of fluorosis. They are targeted at children 6 years of age and younger who are more likely to swallow toothpaste while brushing teeth, therefore at risk of developing dental fluorosis.

Regarding the balance of benefits versus risks of the use of low fluoride toothpastes observed in clinical trials, a systematic review published in 2010[20] investigated the role of individual and professional use of fluoride as a cause of dental fluorosis. The use of fluoride toothpaste with 1,000 ppm F or more was found to be associated with an increased risk of any fluorosis. The authors of this review recommended the fluoride level of toothpaste for young children to be lower than 1,000 ppm if the risk of fluorosis was of concern. However, another systematic review published in 2013[19] was designed to answer specifically the question of whether low-fluoride toothpastes (< 600 ppm F) in comparison to standard fluoride toothpastes (1,000 to 1,500 ppm F) would prevent dental caries in children younger than 8 years and, at the same time, would protect them against esthetically objectionable fluorosis in permanent teeth. Low-fluoride toothpastes were shown to increase by 13% the risk of developing new dentin caries in the primary

dentition (relative risk [RR] = 1.13; 95% confidence interval [CI] 1.07 to 1.20; three studies). Among 1,968 children analyzed in two studies, there were only 34 cases (11 in the low-fluoride group and 23 in the standard-fluoride group) of esthetically objectionable fluorosis in the maxillary permanent incisors, and the risk of developing fluorosis between the "< 600 ppm F" and "> 1,000 ppm F" groups was not significantly different. Another systematic review[21] addressed the caries protective effect of 1,055 to 1,450 ppm F toothpastes versus 250 to 550 ppm F toothpastes in preschoolers at high risk of developing dental caries. In the head-to-head comparisons, the differences in pooled mean decayed, missing, and filled teeth (dmft) and dmfs between the two groups favored the higher concentration toothpastes, but only the dmft difference reached statistical significance. With respect to the indirect comparisons, the pooled estimates of dmfs and dmft increments with toothpastes with 500 ppm F or more in comparison to nonfluoride toothpastes produced statistically significant lower mean caries, whereas the pooled estimates regarding toothpastes with less than 500 ppm F failed to produce statistically significant differences. The same review found that there was a tendency for fluorosis to decrease with the use of toothpaste containing lower fluoride concentrations, but the pooled effect was not significant.

The body of evidence on low-fluoride toothpastes (< 600 ppm) appears to indicate that they confer no significant protection against dental caries in primary teeth and fluorosis in permanent teeth. Thus, in order to gain maximum anticaries benefit with minimum fluorosis risk, most professional and research associations in dentistry advise caretakers of young children to brush their children's teeth twice a day with small amounts of standard fluoride toothpaste (≥ 1,000 ppm, Fig 3-4).

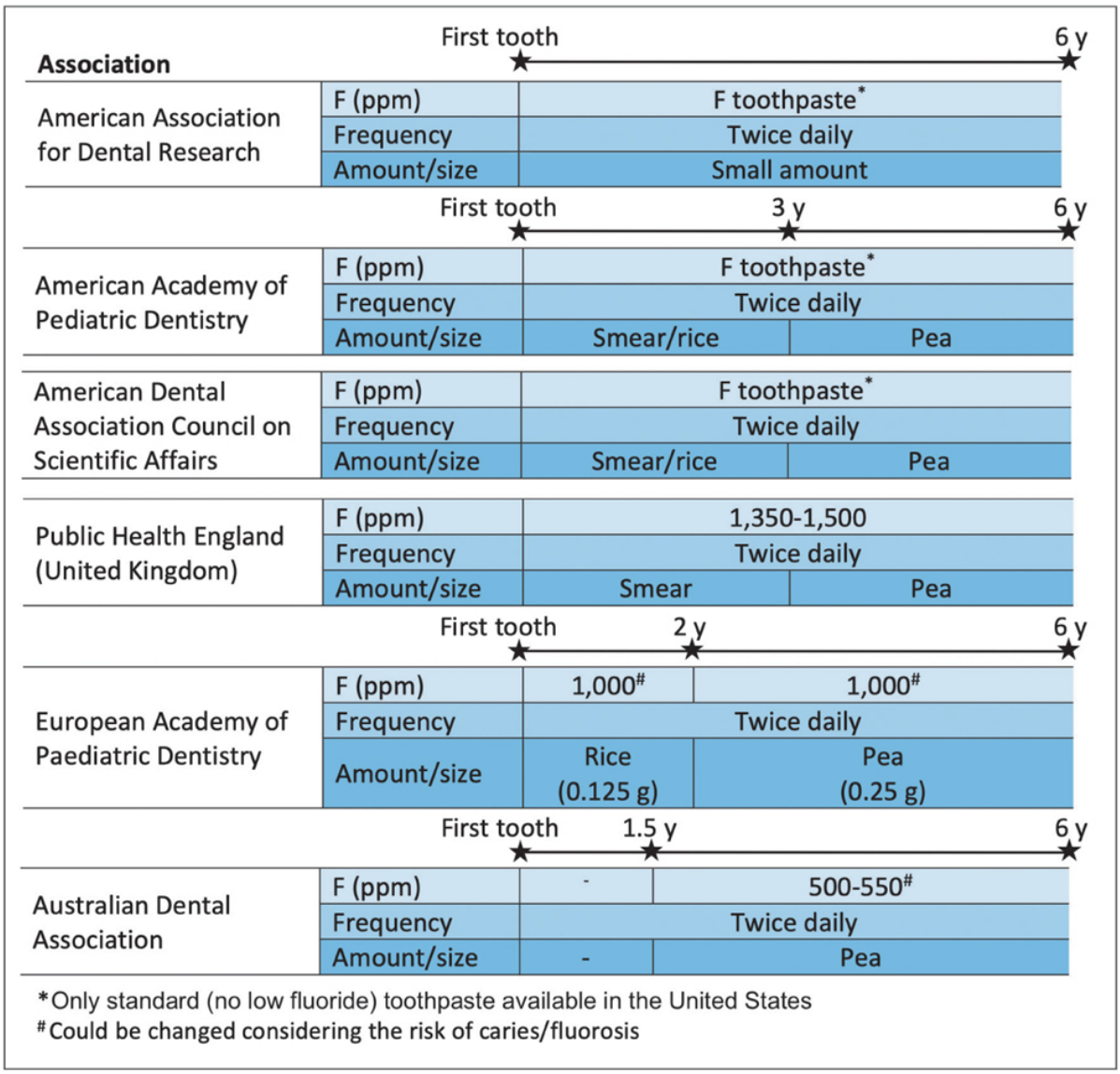


Fig 3-4 General recommendations regarding the use of toothpastes by pre-school children given by six different dental associations.[24-29]

Nevertheless, as can be seen in Fig 3-4, this subject is far from being standardized, as many different protocols have been recommended according to the child's age.

It should also be noted that recommendations on the fluoride concentration in toothpaste aiming to reduce the risk of dental fluorosis need to take into account the specific formulations available on the market locally. For example, in some countries, a number, if

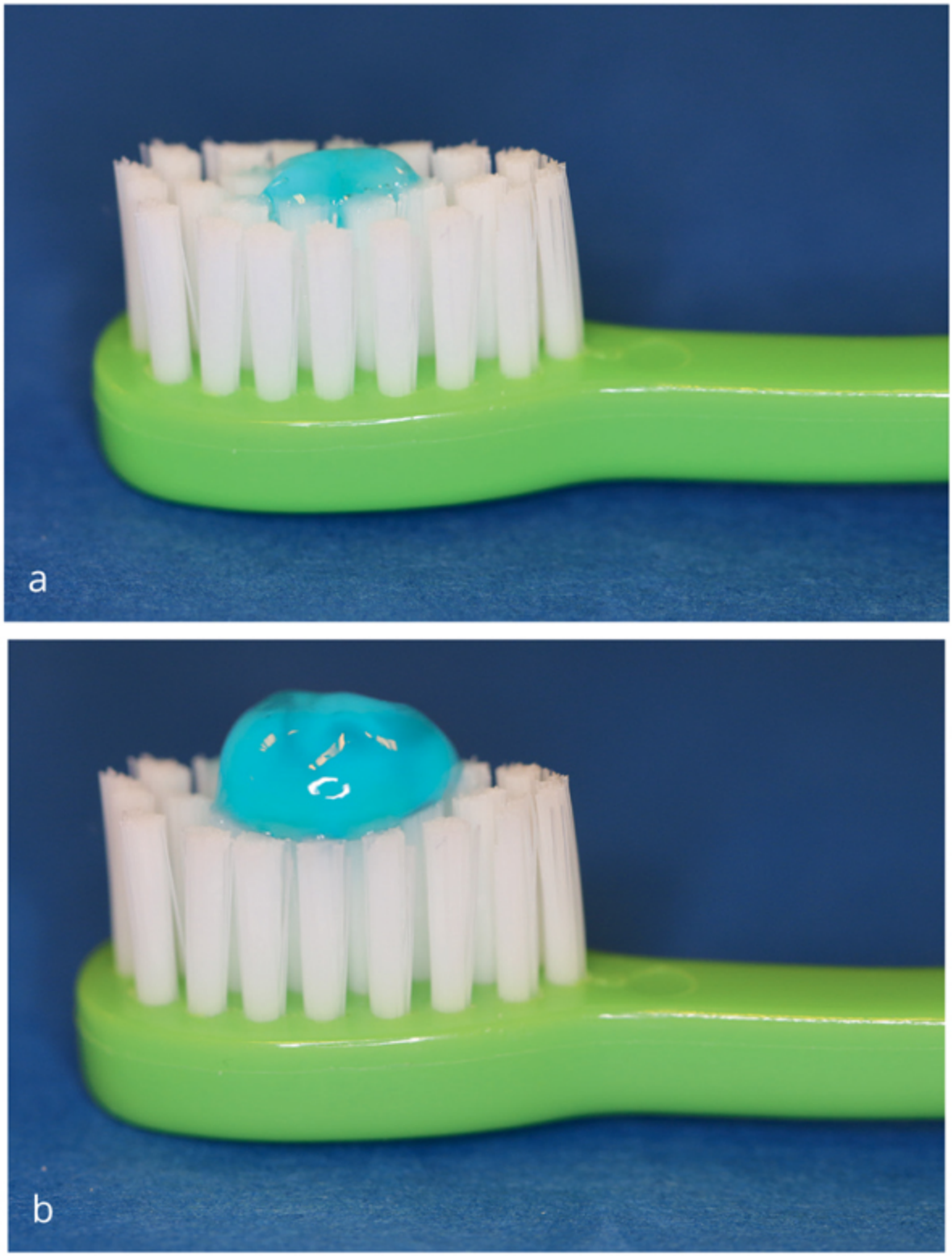
not most of the 1,450 to 1,500 ppm F toothpastes have a monofluorophosphate (MFP)/calcium-based formulation,[30-33] in which only around 1,000 to 1,200 ppm F is bioavailable for absorption.[34] These toothpastes are therefore not thought to be different in fluorosis risk compared to toothpastes comprising 1,000 to 1,100 ppm F having an ionic fluoride source (such as sodium fluoride, stannous fluoride)/silica formulation.[32] Therefore, for some countries it does not make sense to have different recommendations for 1,100 or 1,450 ppm F toothpastes, because they end up having the same amount of active, bioavailable fluoride.

So when it comes to asking "how much," the best recommendation for children at risk for fluorosis development is to focus on the amount of toothpaste used ("how much toothpaste?") instead of the fluoride concentration in the toothpaste ("how much fluoride in the toothpaste?"). Table 3-3 describes the amount of fluoride applied on the toothbrush considering the use of "a small versus big amount" of toothpaste with "low versus standard" fluoride concentration. The recommendations of small amounts to be used by children are shown in Fig 3-5.

Table 3-3 Amount of fluoride applied to the toothbrush when using different amounts and concentrations of fluoride in toothpastes[35] (and implications for children at risk of developing fluorosis)

Amount applied on toothbrush	Fluoride concentration in the toothpaste	
	500 ppm F (500 µg/g)	1,100 ppm F (1,100 µg/g)
"Smear" (0.125 g)	0.062 mg F (the least amount, but effectiveness is compromised due to the use of low F toothpaste)	0.14 mg F (best case scenario, using the best evidence available on the effectiveness, with the least fluoride exposure)

Amount applied on toothbrush	Fluoride concentration in the toothpaste	
	500 ppm F (500 µg/g)	1,100 ppm F (1,100 µg/g)
“Half head” (0.5 g)	0.25 mg F (using a low F toothpaste with no recommendation on amount will lead to more exposure than the standard toothpaste used in small amounts)	0.55 mg F (recommendations on amount of toothpaste to be used by young children are always needed)



Figs 3-5a and b Toothpaste use by children should be controlled in order to reduce the risk of dental fluorosis. Often a grain of rice is

recommended for children younger than 3 years **(a)**, and a pea-size dosing for children aged 3 to 6 **(b)**.

High fluoride concentration toothpastes (> 1,500 ppm F) are in the other spectrum of the fluoride toothpaste recommendation. In most countries, high-fluoride toothpastes are not found over-the-counter, meaning that they need a prescription from a dental practitioner to be purchased. Depending on the country, toothpastes with around 2,500 ppm F and/or 5,000 ppm F are available for prescription. Although the increase in the risk of fluorosis in children brushing with these toothpastes has not been investigated in clinical trials, it would not be wise to use them in children younger than 6 years of age. Moreover, the risk of acute intoxication from 5,000 ppm fluoride toothpastes should not be overlooked and these products should be kept out of reach of children.

It seems that the prescription of high fluoride concentration toothpastes has increased in recent years,[36] with recommendations being made that the cost-effectiveness of these products should be properly assessed (they are typically several times more expensive). A clinical trial is underway in the United Kingdom to determine the cost-effectiveness of usage of high-fluoride toothpastes in older adults with high risk for caries.[37]

High-fluoride toothpastes have been mainly tested in elderly people with root caries.[38-40] A systematic review published in 2019[41] pooled the results of two of these trials and concluded that the risk of root caries progression was 49% lower in elderly people brushing with 5,000 ppm F toothpaste for 6 to 8 months in comparison to those brushing with 1,100/1,450 ppm F toothpaste. Another recent clinical study also observed a significant effect for the 5,000 ppm F toothpaste when compared to a 1,450 ppm F formulation, with a relative risk reduction (RRR) of 90% for new root caries lesions after 2 years.[42]

If the evidence behind the use of high-fluoride toothpastes for root caries control in older adults, although scarce, seems to indicate they are effective, there is even less evidence for the use of these

toothpastes to control caries in younger people and orthodontic patients, and these studies have not yet been systematically summarized (Fig 3-6). The few studies on enamel caries are highly heterogenous.[43] Overall, the current recommendation on high-fluoride toothpastes seem to be based mainly on the biologic plausibility of a higher effect as the fluoride concentration in the toothpaste increases.[43,44] This is to be confirmed in the future by more clinical trials and meta-analyses of their data. Currently, the recommendations found in evidence-based guidelines seem to indicate these toothpastes are effective for caries control in children above 6 years of age and older adults to control root caries, with benefits outweighing the risks, but based on low levels of certainty.[45]

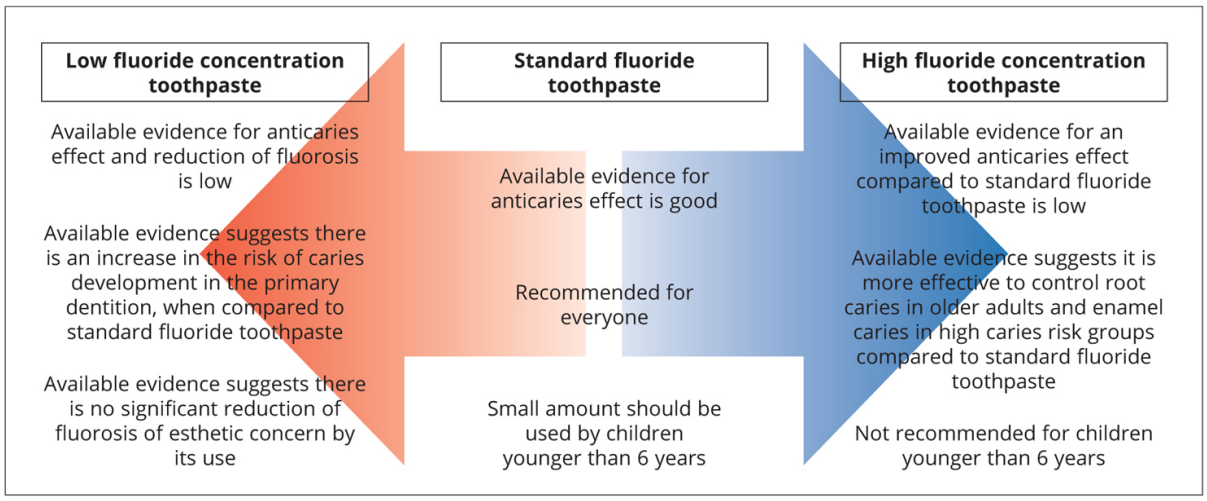


Fig 3-6 Schematic drawing on the options around the use of standard fluoride toothpaste, either using higher or lower fluoride concentration formulations.

Professional fluoride use: mechanism and evidence

Fluoride gels and varnishes are among the arsenal of fluoride approaches to be used by dental practitioners and health professionals to help patients control the progression of caries. Used

at the community or individual levels, these products are the fluoride tool that clinicians have to help balance the mineral loss in their challenged patients. This chapter asks how much flouride is needed, so a discussion follows on the mode of action of professional products, as well as the evidence to support them, especially in combination with the widespread use of fluoride toothpaste seen today.

Professional fluoride products: how do they work?

The believed mode of action of professional fluoride products is the reaction of fluoride in high concentrations with calcium from the tooth structure forming soluble calcium fluoride-like deposits on tooth surfaces and in caries lesions.[46] These deposits are considered reservoirs of fluoride, to be released over time, covering weeks to months,[47] whereby the fluoride concentrations in the dental biofilm formed over them are elevated.[48] Due to the prolonged release of fluoride, the treatment only has to be performed two to four times yearly.

It is interesting to note that although all of these products should work by the mechanism highlighted above, they have very different compositions and react differently (Table 3-4). Although fluoride gels, or even an aqueous solution with a high fluoride concentration, as originally proposed for professional fluoride application,[49] react fast because all fluoride in these products is already ionized,[50] with the varnishes typically the major part of the fluoride salt (often sodium fluoride) is undissolved and distributed in the varnish base. In order to become reactive, the fluoride in the salt therefore has to be released by the oral fluids. This release is thought to occur slowly over time; the kinetics of reactivity of the varnish formulation most tested in clinical trials (Duraphat, Colgate) show that the peak of formation of fluoride reservoirs occurs 12 to 24 hours after the application (Table 3-4).[51,52]

Table 3-4 Composition and reactivity of different professional fluoride formulations

Product	Fluoride concentration	Reaction details
Fluoride gel or foam, acidified formulation (APF)	Typically 12,300 ppm F (1.23% F)	Reacts fast (1 min) with the tooth structure due to the acidic nature and the high amount of free fluoride
Fluoride gel or foam, neutral formulation	Typically 9,040 ppm F (2% NaF)	Reacts fast (1 min) with the tooth structure due to the high amount of free fluoride, but the concentration of reaction products is lower than with the acidified gel due to the higher pH. The clinical significance of its reduced reactivity when compared with the acidified gel, however, is unknown
Fluoride varnish	Typically 22,600 ppm F* (5% NaF)	Reacts slowly with the tooth structure, due to the relatively low amount of free fluoride usually present in the formulation; saliva needs to penetrate into the varnish matrix, dissolve the NaF powder, and release fluoride ions for the reaction with the tooth surface

*Total fluoride concentration; solubility of NaF in water is maximum 4%; solubility in the hydrophobic matrix of the varnish is significantly

lower.

Therefore, fluoride varnishes require longer retention time in order to produce a significant amount of reaction with the tooth structure, forming fluoride reservoirs. However, they are considered safer than fluoride gels because they adhere to the tooth surface, and are ingested over time, not producing peak fluoride concentrations in the blood which could be a concern in terms of acute fluoride toxicity.[53]

Nevertheless, gels can be safely used, with patients in a sitting position and with suction to avoid ingestion during application. The application should be followed by removal of the excess and rinsing with water, and these do not seem to affect its reactivity or anticaries effect.[54] Fluoride foams combine the fast reaction of the gel formulation, with significantly lower weight of material applied. Plain 2% sodium fluoride solution has also been used for professional fluoride application,[55,56] reducing the amount of potentially ingested fluoride.

Current evidence on professional fluoride use

A series of seven Cochrane reviews was published between 2003 and 2004, compiling hundreds of reports of clinical trials investigating fluoride for the control of dental caries in children and adolescents, as summarized by Marinho in 2009.[57] Between 2013 and 2016, three of these reviews were updated[58-60]; they addressed the effectiveness of fluoride varnishes, gels, and mouthrinses. Conclusions did not change; all modalities of treatment were found to provide a substantial anticaries benefit (Table 3-5). Nevertheless, these results should be interpreted with caution, as most of the studies included in these reviews, especially on the fluoride gel and mouthrinses, were conducted almost 30 years ago. One of the aforementioned

Cochrane reviews[61] compared the effects of combined and single fluoride use on caries increment in the permanent dentition. There was evidence from nine trials that the simultaneous use of a professional fluoride treatment together with daily fluoride toothpaste usage results on average in an additional 10% (95% CI 2% to 17%) reduction in DMFS.

Table 3-5 Pooled prevented fractions calculated from differences in the DMFS (permanent dentition) or dmfs (primary dentition) increment in the fluoride groups and no-treatment or placebo groups found in the updated versions of the Cochrane reviews addressing professional fluoride application for the control of dental caries in children and adolescents[57]

Type of professional treatment	Pooled prevented fraction, estimated at tooth surface level (95% CI)	Certainty of evidence
Varnish	Permanent dentition (13 studies): 43% (30% to 57%)	Moderate
	Primary dentition (10 studies): 37% (24% to 51%)	Moderate
Gel	Permanent dentition (25 studies): 28% (19% to 36%)	Moderate
	Primary dentition (3 studies): 20% (1% to 38%)	Low
Mouthrinse*	Permanent dentition (35 studies): 27% (23% to 30%)	Moderate

*Although mouthrinses are not considered professional fluoride products, they are included here in order to summarize the evidence

around fluoride approaches that can be used in addition to fluoride toothpaste.

It should be noted that, given the major differences in varnish formulations (eg, matrix used, mechanism by which the insoluble sodium fluoride is dissolved to react with the tooth structure), results of the systematic reviews cannot be extrapolated to all formulations available on the market as most of them have not been tested in clinical trials.

Also, as the number of clinical trials increases, new systematic reviews can be conducted, revisiting the known evidence. For instance, in a recently published systematic review aiming to assess the effectiveness of fluoride varnish in reducing dentin caries in preschoolers, varnishes showed a modest and uncertain effect. The RRR was 12% and the number needed to treat (NNT) in a population where 50% of children develop new dentin caries was estimated to be 17.[62] Therefore, future decisions about using professional fluoride, especially as preventive approaches in communities, needs to be assessed. In terms of effect, using effectiveness data from the 2013 Cochrane review regarding fluoride varnishes, a study conducted in Germany found that in low-risk groups, fluoride varnish applied twice a year between 6 and 18 years of age at dental clinics was nearly twice as costly and minimally more effective (293 Euro, 8.1 DMFT) than no varnish (163 Euro, 8.5 DMFT).[63]

Using as much fluoride as needed

This chapter describes the mechanisms and available evidence to guide a scientific-based decision on fluoride use throughout the lifespan. The use of fluoride has been crucial to the decline in dental caries observed in the world in recent decades.

Fluoride toothpaste should be considered the main method of fluoride use, recommended to all individuals, because it is associated with tooth brushing assisting with the removal of one of the necessary factors for caries development: the dental biofilm. Personal oral hygiene per se with a nonfluoride toothpaste, despite careful biofilm removal, has no significant effect on decreasing DMFS.[64]

Fluoride from the toothpaste, however, will help control mineral loss where the biofilm removal is not perfect (ie, where caries lesions are prone to develop). Most of the evidence available supports the use of conventional formulations (1,000 to 1,500 ppm F), which can be used by everyone, irrespective of age. Still, when using fluoride toothpaste, if the cariogenic challenge (ie, biofilm + sugar exposure) is not controlled, lesions may continue to develop.

In order to help high caries risk patients to control caries, an increase in the exposure to fluoride has been suggested. This can be achieved by the increase in fluoride concentration in the toothpaste, which may be helpful for patients with low salivary flow or exposed roots,[44] or by adding additional methods of fluoride use, such as fluoride mouthrinses for individual use, or professionally applied, high fluoride concentration products. The association of these methods to fluoride toothpaste has been shown to achieve a modest increase in the anticaries effect of fluoride toothpaste used alone.[61,65] However, when the use of fluoride toothpaste is not regular, or for more challenging situations such as the control of root caries,[66] or the prevention of white spot lesions in orthodontic patients,[67] there is evidence to support the anticaries effect of these supplemental methods of fluoride use.[58-60]

With the reduction in caries incidence, mainly caused by widespread fluoride use, the effectiveness of the combination of methods and the cost-effectiveness of preventive programs

based on fluoride will have to be continuously assessed. This should be done considering especially the most vulnerable populations, which currently concentrate most of the disease burden, ensuring adequate fluoride use in these groups.

References

1. Kassebaum NJ, Smith AGC, Bernabe E, et al. Global, regional, and national prevalence, incidence, and disability-adjusted life years for oral conditions for 195 countries, 1990–2015: a systematic analysis for the global burden of diseases, injuries, and risk factors. J Dent Res 2017;96:380–387.
2. Ainsworth NJ. Mottled teeth. Br Dent J 1933;55:233–250.
3. Black GV, McKay FS. Mottled teeth. An endemic development imperfection of the teeth heretofore unknown in the literature of dentistry. Dental Cosmos 1916;58:129–156.
4. Haugejorden O, Birkeland JM. Evidence for reversal of the caries decline among Norwegian children. Int J Paediatr Dent 2002;12:306–315.
5. Fejerskov O, Nyvad B, Kidd E. Dental caries: what is it? In: Fejerskov O, Nyvad B, Kidd E (eds). Dental Caries: The disease and its clinical management. 3rd ed. Oxford: Wiley Blackwell, 2015:7–10.
6. Featherstone JD. Prevention and reversal of dental caries: role of low level fluoride. Community Dent Oral Epidemiol 1999;27:31–40.
7. Fejerskov O, Thylstrup A, Larsen MJ. Rational use of fluoride in caries prevention. A concept based on possible cariostatic mechanisms. Acta Odontol Scand 1981;39:241–249.
8. Lima CV, Tenuta LMA, Cury JA. Fluoride increase in saliva and dental biofilm due to a meal prepared with fluoridated water or salt: a crossover clinical study. Caries Res 2019;53:41–48.

9. Kumar JV. Is water fluoridation still necessary? Adv Dent Res 2008;20:8–12.
10. Lagerweij MD, van Loveren C. Declining caries trends: are we satisfied? Curr Oral Health Rep 2015;2:212–217.
11. Sheiham A. Changing trends in dental caries. Int J Epidemiol 1984;13:142–147.
12. Marinho VC, Higgins JP, Sheiham A, Logan S. Fluoride toothpastes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2003:CD002278.
13. Walsh T, Worthington HV, Glenny AM, Marinho VC, Jeroncic A. Fluoride toothpastes of different concentrations for preventing dental caries. Cochrane Database Syst Rev 2019:CD007868.
14. Bårdsen A. “Risk periods” associated with the development of dental fluorosis in maxillary permanent central incisors: a meta-analysis. Acta Odontol Scand 1999;57:247–256.
15. Mascarenhas AK. Risk factors for dental fluorosis: a review of the recent literature. Pediatr Dent 2000;22:269–277.
16. Beltrán-Aguilar ED, Barker L, Dye BA. Prevalence and severity of dental fluorosis in the United States, 1999–2004. NCHS data brief, no 53. Hyattsville: National Center for Health Statistics, 2010.
17. Brazil, Ministry of Health. SB Brasil 2010: national survey on oral health: main results (in Portuguese). Brasilia: Ministério da Saúde, 2011.
18. Santos AP, Nadanovsky P, de Oliveira BH. A systematic review and meta-analysis of the effects of fluoride toothpastes on the prevention of dental caries in the primary dentition of preschool children. Community Dent Oral Epidemiol 2013;41:1–12.
19. Santos APP, Oliveira BH, Nadanovsky P. Effects of low and standard fluoride toothpastes on caries and fluorosis: systematic review and meta-analysis. Caries Res 2013;47:382–390.
20. Wong MCM, Glenny AM, Tsang BWK, Lo ECM, Worthington HV, Marinho VCC. Topical fluoride as a cause of dental

fluorosis in children. Cochrane Database Syst Rev 2010:CD007693.

21. Wright JT, Hanson N, Ristic H, Whall CW, Estrich CG, Zentz RR. Fluoride toothpaste efficacy and safety in children younger than 6 years: a systematic review. J Am Dent Assoc 2014;145:182–189.
22. Li Y, Suprono M, Mateo LR, et al. Solving the problem with stannous fluoride: extrinsic stain. J Am Dent Assoc 2019;150:S38–S46.
23. Walsh T, Worthington HV, Glenny AM, Appelbe P, Marinho VC, Shi X. Fluoride toothpastes of different concentrations for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2010:CD007868.
24. American Academy of Pediatric Dentistry. Guideline on Fluoride Therapy. Pediatric Dent 2016;36:181–184.
25. American Association for Dental Research. Policy statements: Topical Fluorides. https://www.iadr.org/AADR/About-Us/Policy-Statements/Science-Policy/Topical-Fluorides. Last revised 2015. Accessed 20 April 2021.
26. American Dental Association Council on Scientific Affairs. Fluoride toothpaste use for young children. J Am Dent Assoc 2014;145:190–191.
27. Australian Dental Association. Policy Statement 2.2.1 – Community Oral Health Promotion: Fluoride Use (Including ADA Guidelines for the Use of Fluoride). Last revised November 2018. St Leonards: Australian Dental Association, 2018.
28. European Academy of Paediatric Dentistry. Guidelines on the use of fluoride for caries prevention in children: An updated EAPD policy document. Eur Arch Paediatr Dent 2019;20:507–516.
29. Public Health England. Health matters: child dental health. Guidance Published 14 June 2017. https://www.gov.uk/government/publications/health-matters-

child-dental-health/health-matters-child-dental-health. Accessed 20 April 2021.

30. Carrera CA, Giacaman RA, Muñoz-Sandoval C, Cury JA. Total and soluble fluoride content in commercial dentifrices in Chile. Acta Odontol Scand 2012;70:583–588.
31. Fernández CE, Carrera CA, Muñoz-Sandoval C, Cury JA, Giacaman RA. Stability of chemically available fluoride in Chilean toothpastes. Int J Paediatr Dent 2017;27:496–505.
32. Oliveira MJ, Martins CC, Paiva SM, Tenuta LM, Cury JA. Estimated fluoride doses from toothpastes should be based on total soluble fluoride. Int J Environ Res Public Health 2013;10:5726–5736.
33. Ricomini Filho AP, Tenuta LM, Fernandes FS, Calvo AF, Kusano SC, Cury JA. Fluoride concentration in the top-selling Brazilian toothpastes purchased at different regions. Braz Dent J 2012;23:45–48.
34. Falcão A, Tenuta LM, Cury JA. Fluoride gastrointestinal absorption from Na_2FPO_3/$CaCO_3$- and NaF/SiO_2-based toothpastes. Caries Res 2013;47:226–233.
35. Ellwood RP, Cury JA. How much toothpaste should a child under the age of 6 years use? Eur Arch Paediatr Dent 2009;10:168–174.
36. Duane BG, Richards D, Young L, Archibald B. Trends and costs of high concentration fluoride toothpaste prescribing in Scotland. Br Dent J 2014;216:589–591.
37. Tickle M, Ricketts DJN, Duncan A, et al. Protocol for a Randomised controlled trial to Evaluate the effectiveness and cost benefit of prescribing high dose FLuoride toothpaste in preventing and treating dEntal Caries in high-risk older adulTs (reflect trial). BMC Oral Health 2019;19:88.
38. Baysan A, Lynch E, Ellwood R, Davies R, Petersson L, Borsboom P. Reversal of primary root caries using dentifrices containing 5,000 and 1,100 ppm fluoride. Caries Res 2001;35:41–46.

39. Ekstrand KR, Poulsen JE, Hede B, Twetman S, Qvist V, Ellwood RP. A randomized clinical trial of the anti-caries efficacy of 5,000 compared to 1,450 ppm fluoridated toothpaste on root caries lesions in elderly disabled nursing home residents. Caries Res 2013;47:391–398.
40. Srinivasan M, Schimmel M, Riesen M, et al. High-fluoride toothpaste: a multicenter randomized controlled trial in adults. Community Dent Oral Epidemiol 2014;42:333–340.
41. Meyer-Lueckel H, Machiulskiene V, Giacaman RA. How to intervene in the root caries process? Systematic review and meta-analyses. Caries Res 2019;53:599–608.
42. León S, González K, Hugo FN, Gambetta-Tessini K, Giacaman RA. High fluoride dentifrice for preventing and arresting root caries in community-dwelling older adults: A randomized controlled clinical trial. J Dent 2019;86:110–117.
43. Pretty IA. High fluoride concentration toothpastes for children and adolescents. Caries Res 2016;50(Suppl 1):9–14.
44. Ekstrand KR. High fluoride dentifrices for elderly and vulnerable adults: does it work and if so, then why? Caries Res 2016;50(Suppl 1):15–21.
45. Weyant RJ, Tracy SL, Anselmo TT, et al. Topical fluoride for caries prevention: executive summary of the updated clinical recommendations and supporting systematic review. J Am Dent Assoc 2013;144:1279–1291.
46. Larsen MJ, Lambrou D, Fejerskov O, Tachos B. A study on accumulation and release and loosely bound fluoride on enamel. Caries Res 1981;15:213–217.
47. Dijkman TG, Arends J. The role of ‘CaF2-like’ material in topical fluoridation of enamel in situ. Acta Odontol Scand 1988;46:391–397.
48. Tenuta LM, Cerezetti RV, Del Bel Cury AA, Tabchoury CP, Cury JA. Fluoride release from CaF_2 and enamel demineralization. J Dent Res 2008;87:1032–1036.

49. Knutson JW. An evaluation of the effectiveness as a caries control measure of the topical application of solutions of fluorides. J Dent Res 1948;27:340–357.
50. Bruun C, Givskov H. Formation of CaF_2 on sound enamel and in caries-like enamel lesions after different forms of fluoride applications in vitro. Caries Res 1991;25:96–100.
51. Fernández CE, Tenuta LM, Zárate P, Cury JA. Insoluble NaF in Duraphat® may prolong fluoride reactivity of varnish retained on dental surfaces. Braz Dent J 2014;25:160–164.
52. Tenuta LM, Dall Agnol MA, Maia CB, Marín LM, Cury JA. In vivo prolonged retention of fluoride varnish increases reactivity with enamel. Caries Res 2016;50:260(Abstract 179).
53. Ekstrand J, Koch G, Petersson LG. Plasma fluoride concentration and urinary fluoride excretion in children following application of the fluoride-containing varnish Duraphat. Caries Res 1980;14:185–189.
54. Delbem AC, Carvalho LP, Morihisa RK, Cury JA. Effect of rinsing with water immediately after APF gel application on enamel demineralization in situ. Caries Res 2005;39:258–260.
55. Bergman G. The caries inhibiting action of sodium fluoride; experimental studies. Acta Odontol Scand Suppl 1953;11:5–112.
56. Richards A, Staun Larsen L, Nørregaard MM, et al. Clinical guideline on use of fluoride (in Danish). Aarhus University: Department of Dentistry and Oral Health, 2017.
57. Marinho VC. Cochrane reviews of randomized trials of fluoride therapies for preventing dental caries. Eur Arch Paediatr Dent 2009;10:183–191.
58. Marinho VC, Chong LY, Worthington HV, Walsh T. Fluoride mouthrinses for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2016;7:CD002284.
59. Marinho VC, Worthington HV, Walsh T, Chong LY. Fluoride gels for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2015:CD002280.

60. Marinho VC, Worthington HV, Walsh T, Clarkson JE. Fluoride varnishes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2013:CD002279.
61. Marinho VC, Higgins JP, Sheiham A, Logan S. Combinations of topical fluoride (toothpastes, mouthrinses, gels, varnishes) versus single topical fluoride for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2004:CD002781.
62. de Sousa FSO, Dos Santos APP, Nadanovsky P, Hujoel P, Cunha-Cruz J, de Oliveira BH. Fluoride varnish and dental caries in preschoolers: a systematic review and meta-analysis. Caries Res 2019;53:502–513.
63. Schwendicke F, Splieth CH, Thomson WM, Reda S, Stolpe M, Foster Page L. Cost-effectiveness of caries-preventive fluoride varnish applications in clinic settings among patients of low, moderate and high risk. Community Dent Oral Epidemiol 2018;46:8–16.
64. Hujoel PP, Hujoel MLA, Kotsakis GA. Personal oral hygiene and dental caries: a systematic review of randomised controlled trials. Gerodontology 2018;35:282–289.
65. Paes Leme AF, Dalcico R, Tabchoury CP, Del Bel Cury AA, Rosalen PL, Cury JA. In situ effect of frequent sucrose exposure on enamel demineralization and on plaque composition after APF application and F dentifrice use. J Dent Res 2004;83:71–75.
66. Vale GC, Tabchoury CP, Del Bel Cury AA, Tenuta LM, ten Cate JM, Cury JA. APF and dentifrice effect on root dentin demineralization and biofilm. J Dent Res 2011;90:77–81.
67. Benson PE, Parkin N, Dyer F, Millett DT, Germain P. Fluorides for preventing early tooth decay (demineralised lesions) during fixed brace treatment. Cochrane Database Syst Rev 2019:CD003809.

4

Nutrition and caries: Sugar is the enemy, but what solutions are offered by preventive dentistry?

Cor van Loveren

After focusing on the reduction of intake of mainly saturated fatty acids for several decades, contemporary dietary advice also includes the reduction of added and free sugars for the prevention of obesity, diabetes, and related cardiovascular diseases. The most recent World Health Organization (WHO) guideline[1] advocates to reduce free sugar consumption to below 10% of the energy intake (10 E%) or even below 5 E% of the diet. Free sugars are defined as all monosaccharides and disaccharides added to foods by the manufacturer, cook, or consumer, and sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates (Fig 4-1).[1] Sugars in whole fruits and vegetables are excluded from this list probably due to the health benefits of the structure and bite, and other beneficial constituents. These benefits may be limited if the fruit or vegetables are crushed or squeezed. It is beyond debate that the consumption of sugar-containing foods imposes a risk on the

integrity of our teeth. The WHO guideline to use less sugar may thus be an opportunity, and support dentistry, in collaboration with other health and nutrition authorities, in its goal to get the message across to the public of using less sugar in lower frequencies. As these are national collaborations, a prerequisite is that the national health and nutrition authorities are clear on their goals, and for the present in many countries the WHO guidelines are not (yet) adopted or translated exactly into the national recommendations. The Dutch dietary guidelines for the sensible use of sugars simply advise not to use products to which sugars are added, or products with free sugars as a result of processing. Furthermore, it is advised to drink as little as possible sugar-sweetened beverages (SSB) and to use whole grain products instead of refined grains.[2,3] For combined general health and dental health strategies, the oral health benefits of these strategies should be guaranteed.

Fig 4-1 The amount of sugar in 100 g of each product is shown. Sugar is clearly associated with the etiology of caries, but the question is whether diet counselling and sugar reduction offers a realistic and evidence-based approach in caries prevention – besides the necessary control for obesity and other general health problems.

The actual oral health risk of a certain food is modulated by many factors, and these are divided into food-related factors and consumer-related factors. Food-related factors involve the release of the sugars, the stickiness of the product (although this may be less important at tooth sites where food is impacted), and, to a lesser extent, the type and concentration of the sugar. Consumer-related factors are the frequency of the consumption, the drinking and chewing habits, the chewing and swallowing efficiency, salivary flow and composition, the presence of cariogenic dental plaque, and the use of fluorides. It is a common observation that with a comparable number or amount of sugar-containing products, some people are able to manage the risk and will not develop caries, while others will develop significant amounts of dental caries. Advice aimed at some of the modulating factors may have a great impact on oral health without necessarily creating a reduction in the total sugar intake; for instance, suggestions to combine eating and drinking moments, avoid nightly consumption, or clean the mouth after consumption. On the other hand, this advice does not obstruct additional advice to limit the energy intake from free sugars to (below) 10 E%.

The two ways (as well as all combinations of these) to achieve a reduction of sugar consumption are a reduction of the amount of sugar in products, a strategy deployed by some retailers and manufacturers, or a reduction of the number or portions of consumptions of sugar-containing products, which hopefully may result in a reduction of the frequency of consumption. The latter strategy may be a topic of health education programs but may also be targeted by selective taxation measures to make unhealthy foods more expensive and healthy foods cheaper. To answer the question

of how these strategies would impact oral health, the following six issues are of importance:

- the shape of the dose-response association between sugar intake and caries
- the influence of fluoridated toothpaste usage on the association of sugar intake and caries
- the relative contribution of frequency and amount of sugar intake to caries levels[4]
- whether, in relation to oral health, there is a safe amount of sugar in products
- the effectiveness of selective taxation
- the effectiveness of dietary advice in the dental office.

Any strategy has to be accepted by those that add the sugars to products (retailers and manufacturers) and by consumers of the products in a way that ensures a real reduction of sugar intake is accomplished.

Shape of the dose-response association between sugar intake and caries

In the late 1970s, before fluoride was widely used and when the quality of oral hygiene was generally poor, Sreebny[5] compared caries prevalence among 12-year-old and 6-year-old children in 47 and 23 nations respectively, with the availability of sugar per capita. Regression analysis with these data revealed an increase of 1 decayed, missing, or filled tooth (DMFT) at the age of 12 for every 25 g of sugar availability per day, and an increase of 1 decayed, missing, or filled surface (dmfs) in the 6-year-olds for every 50 g of sugar available per day.[5] Sreebny[5] suggested that 18.25 kg (approximately 10 E%) per person per year may represent an upper limit of safe, or at least “acceptable” sugar consumption for oral health. Based on the data of Sreebny[5] and the effect of the wartime

diets,[6] Sheiham[7,8] suggested that the relationship between sugar intake and caries levels is sigmoid. Sheiham[7,8] claimed that below approximately 15 kg/person/year most of the population will not develop dental caries. Between 15 and 35 kg there is a steep increase in the rate of caries. Beyond 35 kg the dose-response curve flattens. In many western societies the sugar availability is around or above 40 kg/person/year.

A sigmoid relationship between sugar intake and caries would explain why the relatively small differences in sugar consumption between persons in these high-sugar societies are not necessarily reflected in differences in caries experience. No other studies, however, have confirmed the sigmoid curve. Most studies found no, a linear, or a log-linear relationship between sugar availability or consumption and caries.

Influence of fluoridated toothpaste

In more recent studies in countries where fluoride supplements were widely used, the relationship between sugar availability and caries was less clearly observed. Woodward and Walker[9] studied the relationship in 61 developing countries and 29 industrialized countries. In the developing countries, approximately 26% of the variation in the caries data was explained by sugar availability. In the industrialized countries, less than 1% was explained, while the slope of the linear regression line was estimated to be −0.013, not significantly different from zero. These data suggest that, where fluoride is available, variation in the availability of sugar may be of lesser importance as a determinant of caries prevalence and severity. Ruxton et al[10] used data from Sreebny[5] and Woodward and Walker[9] to inventory sugar availability and dental caries in more than 60 countries in the 1970s and 1980s to assess the relation between caries rates and the sugar supply. In 18 countries, both DMFT and

the sugar supply declined, whereas in 25 countries DMFT declined and sugar supply increased. In another 18 countries, the incidence of caries and the sugar supply increased. The authors concluded that the relationship between sugar reduction and caries on a nationwide basis was unreliable. Downer et al[11] reported that dental caries experience (DMFT) of 12-year-old children in 29 countries of Europe yielded a strong negative correlation with sugar disappearance ($r = -0.561$, $P < .01$). The authors suggested the possible explanation that the extensive use of (mainly fluoride-containing) toothpaste neutralizes the potential damage from high sugar consumption.[11] A recent global evaluation confirmed that amongst high income countries there is a negative correlation between sugar disappearance (kg/capita/year) and dental caries level, while in low income countries this correlation is a positive one.[12] In the ensuing discussion Masood et al[12] explained their findings also by the accessibility of fluoride.

Burt and Pai[13] reported that, of the 69 studies on diet and caries published between January 1980 and July 2000, only two showed a strong diet-caries relation. Of the other studies, 16 showed a moderate relation and 18 showed a weak relation. They emphasized that the findings of their review differed from sugar-caries studies published in the decades before fluoride use. They concluded that sugar consumption is still likely to be a more powerful indicator for risk of caries infection in persons that don’t have regular exposure to fluoride.

Out of 10 epidemiologic studies published between 1995 and 2006, five found no association, one a positive association, and four a complex association meaning statistically significant association in certain subgroups between the use of sugars and caries.[14] The subgroups in which the association was demonstrated were the groups who brushed their teeth once a day or less. An example of a study with a complex outcome was the cross-sectional National Diet and Nutrition Survey of children aged 1.5 to 4.5 years.[15] Caries was associated with sugar confectionary (amount and frequency) but only in children of nonmanual-labor households whose teeth were brushed less than twice a day.

The importance of fluoride use on the relationship between sugar intake and caries is also confirmed by the fact that in spite of the dramatic decline in dental caries prevalence that occurred in the 1970s to 1990s in most Western industrialized countries, sugar consumption remained virtually unchanged.[16,17]

The low correlation between sugar consumption (disappearance, calculated according to production and sales) and caries prevalence when fluoride is used, indicates that proper use of fluoridated toothpaste has a major preventive effect on caries prevalence, although this protection is not easily achieved by everyone or at every site in the mouth. The low correlation is no license to disregard reduction of sugar intake as a caries preventive measure, but during dietary counselling, the paramount importance of fluoride should always be stressed.

Frequency or amount of sugar

Rugg-Gunn et al[18] showed that the bivariate correlations with caries were higher when the sugar variables were calculated for snacks alone than for all intakes. Burt et al[19] showed the energy from total sugars and meal sugars was not significantly different between low caries children and high caries children, but the energy from snacks, snack carbohydrate, and snack sugars were different. Both studies may confirm the conclusions of the Vipeholm study that in-between meal snacking is a great risk for caries development, while as much as 300 g additional sugar during the mean meals is not.[20]

Bernabé et al[4] showed in Finnish adults that DMFT increased over a period of 4 to 11 years by 0.15 and 0.1 units for every additional occasion of sugar consumption and every additional 10 g of sugars consumed, respectively. In the mutually adjusted model, only the amount of sugar remained significantly associated with DMFT levels although the coefficient was reduced to 0.09. When the population

was divided in those who used fluoride daily vs those who used it less frequently, the coefficient for amount was 0.08 and for frequency 0.12 for the frequent fluoride users, and 0.26 and 0.43 at infrequent fluoride use.

Dusseldorp et al[21] dichotomized the number of eating moments as more than 7 a day vs less than 7 a day, which is the nationally recommended maximum frequency of food and drinks consumption per day in the Netherlands. With this dichotomization the number of foods and drinks consumed per day had impact on caries prevalence in the primary teeth of 9-year-olds (odds ratio [OR] 2.78, 95% confidence interval [CI] 1.21 to 6.40), but not on the caries experience in the permanent teeth of 9-year-olds (OR 0.97, 95% CI 0.65 to 1.44) or prevalence and experience in the permanent dentition of 15- or 21-year-olds. The authors concluded that the used number of eating moments is an appropriate cut-off point for recommendation.

A study conducted in nursery homes showed that 3-year-old low socioeconomic schoolchildren with the highest frequency of sugar consumption (4 ± 5 times per day) at the nursery were 4.7 times more likely to have a high caries increment over 1 year, compared to those with the lowest frequency (1 ± 2.9 times per day) (OR 4.7, 95% CI 2.7 ± 8.2, $P < .001$). Daily frequency of sugar intake at the nursery showed a dose-response trend with the risk of having high caries increment.[22] Feldens et al[23] studied the relationship between feeding practices in the first year of the life and the occurrence of severe early childhood caries (S-ECC) at 4 years of age. A total of 340 children were examined. The multivariable model showed a higher adjusted risk of S-ECC for the following dietary practices at 12 months: daily breastfeeding frequency at 12 months 0 to 2, 3 to 6, or ≥ 7 times showed relative risk (RR) values of 1.00, 2.04 (95% CI 1.22 to 3.39), and 1.97 (95% CI 1.45 to 2.68, $P < .001$), respectively; number of daily meals and snacks at 12 months < 7, 7 to 8, > 8 showed RR values of 1.00, 0.99 (95% CI 0.70 to 1.39), and 1.42 (95% CI 1.02 to 1.97, $P = .025$); bottle use for fruit juices/soft drinks at 12 months “no/yes” demonstrated a RR of 1.41 (95% CI 1.08 to 1.86) for the users ($P = .025$); high-density sugar foods at 12 months

(> 50% of simple carbohydrates in unit of food) “no/yes” gave a RR of 1.43 (95% CI 1.08 to 1.89, *P* = .003); bottle use for liquids other than milk showed a RR of 1.41 (95% CI 1.08 to 1.86).

The studies of Rodrigues and Sheiham[22] and Feldens et al[23] strongly indicated that the increased frequency of sugary foods imposed caries risk in the low socioeconomic populations studied. Thus, all these data still support the scientific basis for dental health professionals to focus their dietary advice on reducing the frequency of intake of sugars.

Also, the type of products, SSB, and fruit drinks, sweets, and candy, and sugared dairy products contributing to the intake of sugar[24] lend themselves to skiping, combining, or reducing the moments of intake.

Reduction of sugar content in products

The present author observed that retailers and manufacturers are willing to produce products with reduced amount of sugar and to label them as “no sugar” (0 kcal), “low sugar” (0 to 10 kcal/250 mL), “middle sugar” (10 to 75 kcal/250 mL), and “high sugar” (> 75 kcal/250 mL), for example the retailer Ahold Delhaize.[25] An interesting question is the relative cariogenicity of these four categories assuming that “no sugar” is safe and “high sugar” is highly cariogenic. A compass to answer this question might be the results of intraoral pH measurements as done by Imfeld.[26] He asked patients to rinse the mouth with various concentrations of sugar and measured pH in the plaque grown on a pH-electrode placed in the mouth (Fig 4-2). This study showed that starting from a concentration of 1.25% (12.5 kcal/250 mL) sugar, the pH value did drop to cariogenic values. Therefore, SSB in the category “middle sugar” need to be classified as cariogenic. For the category “low sugar,” the judgment is conditional. In the study of Imfeld,[26] there

was only one rinse with a 10 mL solution for 2 minutes. This rinse could be classified as noncariogenic. Drinking a glass (250 mL) or a can (330 mL), the first gulp/rinse is followed by a number of subsequent gulps or rinses. This probably loads the sugar concentration in dental plaque and stimulates the pH drop. Under these conditions drinking the product should be classified as cariogenic.

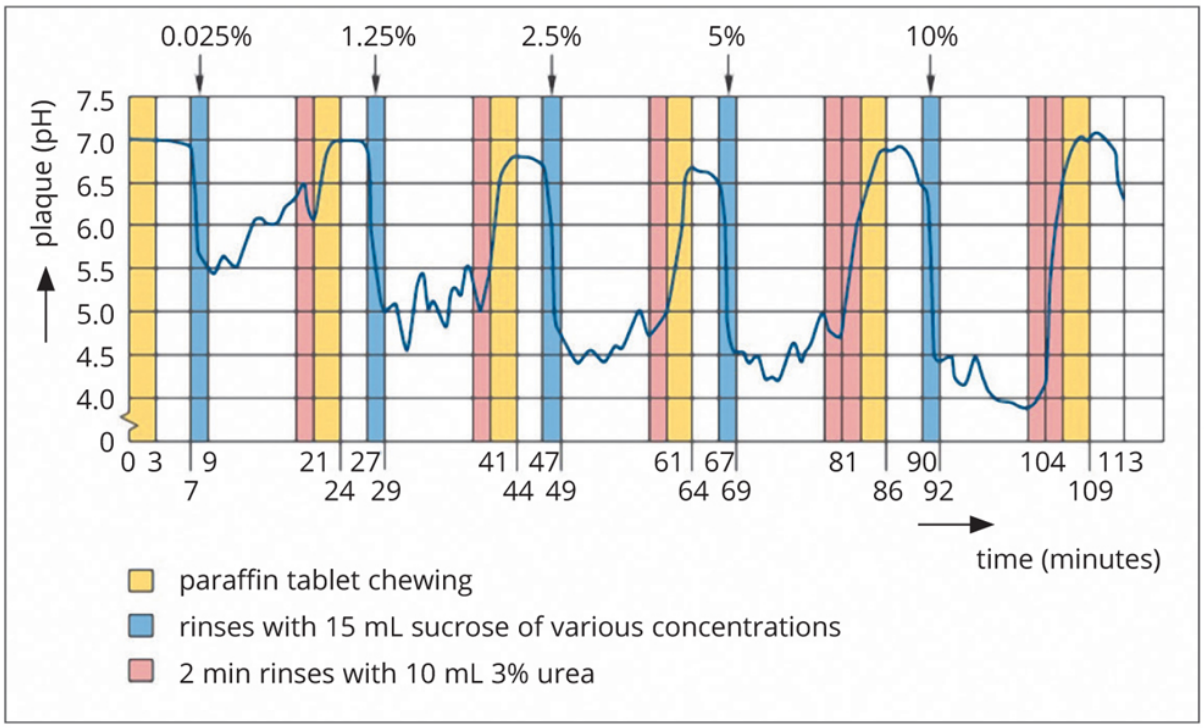


Fig 4-2 pH values in 4-day-old dental plaque after rinses with various concentrations of sucrose (0.025% to 10%).

The general health benefits of reducing the amount of sugar in products may not necessarily be accompanied by oral health benefits, when the frequency of consumption is not changed. Dental health professionals need to provide individuals and their parents/carers with clear consistent dietary information that does not conflict with advice from other health professionals. Conversely, other health professionals may pay attention to the

sugar caries relationship and opt for the reduction of the frequency of sugar intake in order to reduce the amount.

Examples of two other relevant studies related to the question of relative cariogenicity of foods are the studies of Linke and Birchmeier[27] and of Ribeiro et al.[28] Linke and Birchmeier[27] measured lactic acid production in saliva while rinsing with solutions containing 5%, 10%, 15%, 20%, and 30% sucrose (w/v). Lactic acid in saliva was significantly increased with increasing sucrose concentrations up to 15% sucrose, then leveled out at higher concentrations.

Ribeiro et al[28] designed a randomized controlled trial where enamel attached to prosthetic devices was exposed to sugar (10%), starch (2%), or a combination of sugar and starch. The solutions were dripped onto the enamel eight times per day. The greatest demineralization was found with the starch/sucrose combination > sucrose > starch = water.[28] This study suggests that starch can be an important co-determinant of cariogenicity. This finding has been confirmed by several other studies.[29,30]

Selective taxation for unhealthy and healthy products

Most studies focused on health taxes that are applied at the point of sale, and are intended to try to motivate consumers to change their consumption decisions. It may also be, however, that specific raw materials (ingredients) are taxed to incentivize manufacturers to change their products, using healthier recipes. Wright et al[31] identified three studies in a systematic review targeted at manufacturers or retailers. One such study[32] modeled an approach to taxation that targeted the process of adding sugars to products and compared this with a consumption tax on sugared products. The authors concluded that both approaches are potentially effective, but that taxing added sugars is likely to have a smaller impact on

consumers' real expenditures than taxing final products. Another study, which assessed the impacts of a set of complex unhealthy food taxes in Hungary, found that substantial changes were made to the manufacturing of certain products.[33] In Scotland, a public health supplement on large retailers selling tobacco and alcohol to discourage retailers from selling and to insulate consumers from the burden of the tax failed, as the level of the tax was too low to stimulate changes in retail practice.

The taxation strategies to reduce sugar intake mainly focused on the SSB. Fletcher et al[34] found that current state SSB taxes in the United States had no significant effect on children's weight. In contrast, Fletcher et al[34] found that children consumed more calories from SSB in states that had implemented an SSB tax than in states that had not, although this was not statistically significant. The researchers posited that, in this case, the consumers were likely not reacting to the small and possibly hidden taxes on SSB. In a separate article, Fletcher et al[35] again found existing SSB taxes did not significantly reduce weight in young people, which was attributed to youths substituting other high-calorie drinks such as whole milk. Using cross-sectional data on American adolescents, Powell et al[36] found no statistically significant associations between body mass index (BMI) and state-level SSB taxes in grocery stores and vending machines. Sturm et al[37] also examined existing SSB taxes in the US and their impact on young people's obesity. Using longitudinal data from an early childhood study, the authors found no significant relationship between current taxes (usually no higher than 4% in grocery stores) and children's SSB consumption or obesity. In contrast to modeling studies that often model taxes at higher rates and more often find positive health impacts, the above evaluation studies provide valuable insight into the effectiveness of existing taxes implemented at lower rates.

Modeling studies were more likely to find a positive effect perhaps because these studies often model the impact of higher

tax rates than the above-mentioned evaluation studies.[38] A tax rate of 20%+ is regarded as the turning point above which the taxation becomes effective.[31]

A systematic review of Cabrera Escobar et al[39] confirmed the observation of Fletcher et al[35] that SSB were replaced by alternative beverages such as fruit juice and whole milk. Surprisingly, they also showed that there was a reduced demand for diet drinks.

To estimate whether oral health would benefit from taxation of SSB the following issues are still unclear:

- Does taxation of SSB really lead to a reduction of consumption?
- What are the oral health implications of the substitution drinks?

Personal advice

The regular and not illness-induced visits to the dental office seem to be an excellent opportunity to discuss the patient's own responsibility for his or her health and, for instance, to reduce sugar intake. To be successful in this, steps of behavioral change strategies have to be followed. In this it has to be realized that sugar (SSB, sweets, candy, etc) is not only used for its taste but also because it significantly contributes to the energy intake. For instance, in the Netherlands, the average daily energy intake from free sugars is 14% for the whole population but varies from 20% for children and adolescents to 11% for those over the age of 50.[24] Added sugars constitute approximately 80% to 90% of this energy intake from free sugars. Significant contributors given as examples in boys from 7 to 18 years, are nonalcoholic beverages (SSB and fruit drinks) 34%, sweets and candy 35%, and dairy products with the exception of milk 12.4%.[24] For successful reduction of the intake of sugars, the individual must be provided with acceptable alternatives to compensate for the potential shortage of energy and to maintain a feeling of satiety during the day. A good breakfast may contribute to

this as it has also been demonstrated that caries prevalence is related to having breakfast regularly.[21] When advising on energy replacement, the advice should ensure that sugars are not replaced with energy from fat or foods high in salt such as fries and salty corn snacks. Ideally, any energy deficit from free sugars reduction should be replaced with starch-rich staple carbohydrate foods such as bread, cereals, rice, pasta, preferably wholegrain varieties, and fresh fruits and vegetables.[40]

These challenges in changing a patient's dietary routine do not belong to the standard armamentarium of the oral health professional, which would make referral to a dietician the appropriate and sensible option.

In conclusion:

- The most recent WHO guideline advocates to reduce free sugar consumption below 10% of the energy intake (10 E%) or even below 5 E% of the diet.
- In many countries the WHO guidelines are not (yet) adopted or translated directly to national advice.
- To have a significant effect on oral health, strategies of reducing sugar intake should involve a reduction of the frequency of intake. Goals set in frequency may be more tangible for patients to follow than, for instance, to drink as few sugary drinks as possible.
- Dental health professionals need to provide individuals and or their parents/carers with clear consistent dietary information that does not conflict with advice from other health professionals.[40]
- Challenges in changing patients' dietary routines do not belong to the standard armamentarium of the oral health professional. Therefore, all dental health professionals should receive adequate education in nutrition and there is a need to define

the core content of the dental curriculum with respect to nutrition.[40]

- The low or absent correlation between sugar consumption (disappearance, calculated according to production and sales) and caries prevalence when fluoride is used, indicates that proper use of fluoridated toothpaste has a major preventive effect.
- The low or absent correlation is no license to disregard reduction of sugar intake as a caries preventive measure. During dietary counselling the paramount importance of fluoride should always be stressed.
- Effectiveness of taxation of SSB is not clear, and neither is the effect of substitution drinks.

References

1. World Health Organization. Sugars intake in adults and children. Geneva: World Health Organization, 2015.
2. Health Council of the Netherlands. Richtlijnen goede voeding 2015. Den Haag: Gezondheidsraad, 2015.
3. Voedingscentrum. Richtlijnen Schijf van Vijf. 2018. https://www.voedingscentrum.nl/nl/gezond-eten-met-de-schijf-van-vijf.aspx. Assessed 24 June 2019.
4. Bernabé E, Vehkalahti MM, Sheiham A, Lundqvist A, Suominen AL. The shape of the dose-response relationship between sugars and caries in adults. J Dent Res 2016; 95:167–172.
5. Sreebny LM. Sugar availability, sugar consumption and dental caries. Community Dent Oral Epidemiol 1982;10:1–7.
6. Takeuchi M. Epidemiological study on dental caries in Japanese children before, during and after World War II. Int Dent J 1961;11:443–457.
7. Sheiham A. Sugars and dental decay. Lancet 1983; 1:282–284.

8. Sheiham A. Why free sugars consumption should be below 15 kg per person per year in industrialised countries: the dental evidence. Br Dent J 1991;171:63–65.
9. Woodward M, Walker AR. Sugar consumption and dental caries: evidence from 90 countries. Br Dent J 1994; 176:297–302.
10. Ruxton CH, Garceau FJ, Cottrell RC. Guidelines for sugar consumption in Europe: is a quantitative approach justified? Eur J Clin Nutr 1999;53:503–513.
11. Downer MC, Drugan CS, Blinkhorn AS. Correlates of dental caries in 12-year-old children in Europe: a cross-sectional analysis. Community Dent Health 2008;25:70–78.
12. Masood M, Masood Y, Newton T. Impact of national income and inequality on sugar and caries relationship. Caries Res 2012;46:581–588.
13. Burt BA, Pai S. Is sugar consumption still a major determinant of dental caries? A systematic review. J Dent Educ 2001;65:1017–1024.
14. Ruxton CH, Gardner EJ, McNulty HM. Is sugar consumption detrimental to health? A review of the evidence 1995–2006. Crit Rev Food Sci Nutr 2010;50:1–19.
15. Gibson S, Williams S. Dental caries in pre-school children: associations with social class, toothbrushing habit and consumption of sugars and sugar-containing foods. Further analysis of data from the National Diet and Nutrition Survey of children aged 1.5–4.5 years. Caries Res 1999; 33:101–113.
16. Einarsdottir KG, Bratthall D. Restoring oral health. On the rise and fall of dental caries in Iceland. Eur J Oral Sci 1996;104:459–469.
17. Nyvad B. Sukker og caries. In: Mølgaard C, Lyhne Andersen N, Barkholt V, et al (eds). Sukkers sundhedsmaesiige betydning (in Danish). Copenhagen: Danish Board of Nutrition, 2003;59–67.

18. Rugg-Gunn AJ, Hackett AF, Appleton DR, Jenkins GN, Eastoe JE. Relationship between dietary habits and caries increment assessed over two years in 405 English adolescent schoolchildren. Arch Oral Biol 1984;29:983–992.
19. Burt BA, Eklund SA, Morgan KJ, et al. The effect of sugars intake and frequency of ingestion on dental caries in a three-year longitudinal study. J Dent Res 1988;67: 1422–1429.
20. Gustaffson BE, Quensel CE, Lankel S, et al. The Vipeholm dental caries study; the effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. Acta Odontol Scand 1954;11: 232–264.
21. Dusseldorp E, Kamphuis M, Schuller A. Impact of lifestyle factors on caries experience in three different age groups: 9, 15, and 21-year-olds. Community Dent Oral Epidemiol 2015;43:9–16.
22. Rodrigues CS, Sheiham A. The relationships between dietary guidelines, sugar intake and caries in primary teeth in low income Brazilian 3-year-olds: a longitudinal study. Int J Paediatr Dent 2000;10:47–55.
23. Feldens CA, Rodrigues PH, de Anastácio G, Vítolo MR, Chaffee BW. Feeding frequency in infancy and dental caries in childhood: a prospective cohort study. Int Dent J 2018;68:113–121.
24. Sluik D. Van Lee L, Engelen AI, Feskens EJM. Total, free, and added sugar consumption and adherence to guidelines: The Dutch National Food Consumption Survey 2007–2010. Nutrients 2016;8:70–84.
25. Albert Heijn. https://www.ah.nl/suikerwijzer/frisdrank. Accessed 24 June 2019.
26. Imfeld T. Identification of low caries risk dietary components. Monogr Oral Sci 1977;11:1–198.
27. Linke HA, Birchmeier RI. Effect of increasing sucrose concentrations on oral lactic acid production. Ann Nutr Metab 2000;44:121–124.

28. Ribeiro CC, Tabchoury CP, Del Bel Cury AA, Tenuta LM, Rosalen PL, Cury JA. Effect of starch on the cariogenic potential of sucrose. Br J Nutr 2005;94:44–50.
29. Al-Khatib GR, Duggal MS, Toumba KJ. An evaluation of the acidogenic potential of maltodextrins in vivo. J Dent 2001;29:409–414.
30. Al-Khatib GR, Toumba KJ, Duggal MS, Pollard MA, Curzon MEJ. An in vivo evaluation of the demineralising potential of maltodextrins using an intra oral cariogenicity testing method. Caries Res 1997;30:316.
31. Wright A, Smith KE, Hellowell M. Policy lessons from health taxes: a systematic review of empirical studies. BMC Public Health 2017;17:583.
32. Miao Z, Beghin J, Jensen H. Taxing sweets: sweetener input tax or final consumption tax? Contemp Econ Policy 2012; 30:344–361.
33. Zhen C, Wohlgenant MK, Karns S, Kaufman P. Habit formation and demand for sugar-sweetened beverages. Am J Agric Econ 2011;93:175–193.
34. Fletcher JM, Frisvold D, Tefft N. Taxing soft drinks and restricting access to vending machines to curb child obesity. Health Aff Proj Hope 2010;29:1059–1066.
35. Fletcher JM, Frisvold DE, Tefft N. The effects of soft drink taxes on child and adolescent consumption and weight outcomes. J Public Econ 2010;94:967–974.
36. Powell LM, Chriqui JF, MA TK, Wada R, Chaloupka FJ. Assessing the potential effectiveness of food and beverage taxes and subsidies for improving public health: a systematic review of prices, demand and body weight outcomes. Obes Rev 2013;14:110–128.
37. Sturm R, Powell LM, Chriqui JF, Chaloupka FJ. Soda taxes, soft drink consumption, and children's body mass index. Health Aff Proj Hope 2010;29:1052–1058.

38. Schwendicke F, Thomson WM, Broadbent JM, Stolpe M. Effects of taxing sugar-sweetened beverages on caries and treatment costs. J Dent Res 2016;95:1327–1332.
39. Cabrera Escobar MA, Veerman JL, Tollman SM, Bertram MY, Hofman KJ. Evidence that a tax on sugar sweetened beverages reduces the obesity rate: a meta-analysis. BMC Public Health 2013;13:1072.
40. Moynihan P, Makino Y, Petersen PE, Ogawa H. Implications of WHO Guideline on sugars for dental health professionals. Community Dent Oral Epidemiol 2018;46:1–7.

5

Healthy life, healthy mouth? Interdisciplinary and common risk factor interventions

Denise Duijster, J. H. (Erik) Vermaire

Over the last decades, major progress has been made in reporting the public health significance of dental caries. The burden of dental caries has been well-described in terms of its prevalence, impact on well-being, and societal costs.[1] Dental caries is one of the most common childhood diseases, affecting more than 486 million young children worldwide.[2] In addition, social inequalities in childhood dental caries have become a major concern. Data from across the globe consistently demonstrate that children from lower socioeconomic status (SES), deprived regions, and minority ethnic groups are having disproportionately higher levels of dental disease than their more privileged peers.[3] As a consequence, disadvantaged children more often experience negative impacts on quality of life, well-being, and social functioning. For example, children with higher caries levels are almost three times more likely to miss days from school as a result of dental pain and have poorer school performance, than those with low levels of caries (Fig 5-1).[4]

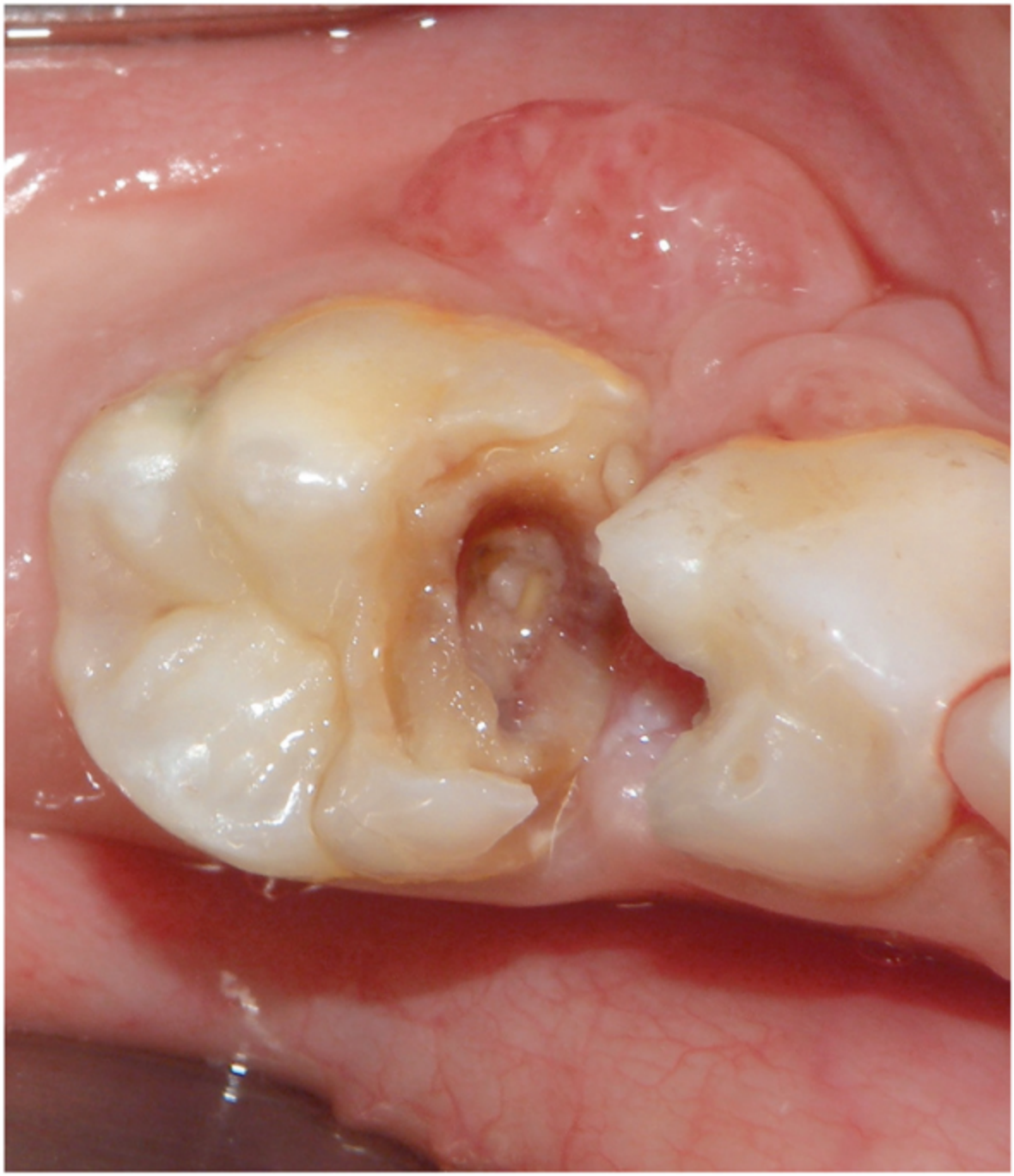


Fig 5-1 Childhood dental caries often presents with a high degree of destruction and clearly reduced quality of life. (Image courtesy of P. van Meurs, Noordwest Ziekenhuisgroep, Alkmaar, the Netherlands.)

It is increasingly recognized that restorative dental treatment and chairside prevention alone will not be sufficient to tackle inequalities in childhood dental caries. Action is also required at community and population levels to address the broader determinants underlying these inequalities. Ideally, action should be focused on closer integration of dental and general health, since dental caries shares many risk factors with other chronic diseases.

This chapter describes the rationale for integrated interventions to prevent dental caries in childhood. Furthermore, without claiming to be comprehensive, a number of caries-preventive interventions are described that are based on the Common Risk Factor Approach (CRFA) or use partnership across different sectors and disciplines.

Determinants of childhood dental caries

To prevent dental caries and reduce inequalities thereof, the underlying determinants should be understood to identify potential opportunities for intervention. Traditionally, researchers have mainly focused on understanding the biologic and behavioral risk factors of dental caries. Behaviors such as poor oral hygiene, lack of fluoride use, and a cariogenic diet, are key risk factors of dental caries and they are more prevalent among children with low SES.[5] Yet these factors only explain a small part of the inequality in dental caries.[6,7] In recent decades, empirical attention has shifted towards investigating the broader social context in which children's health behaviors are shaped and biology is affected, known as the "social determinants." Social determinants refer to the conditions in which people are born, grow, live, and age.[8]

In 2007, Fisher-Owens et al[9] presented a comprehensive conceptual model of factors influencing childhood dental caries, identified from the literature. The model acknowledges the multilevel

nature of influences on children's oral health, and includes a wide range of determinants such as proximal psychosocial factors (eg, parental attitudes, stress, family functioning, and social support) and more distal factors (eg, living environment, culture, social capital, and the [dental] health care system). These determinants are suggested to operate at child-, family-, and community level. The model has been increasingly used as a theoretical basis for the development of community and population-based dental health promoting interventions at upstream, midstream, and downstream levels (Fig 5-2).

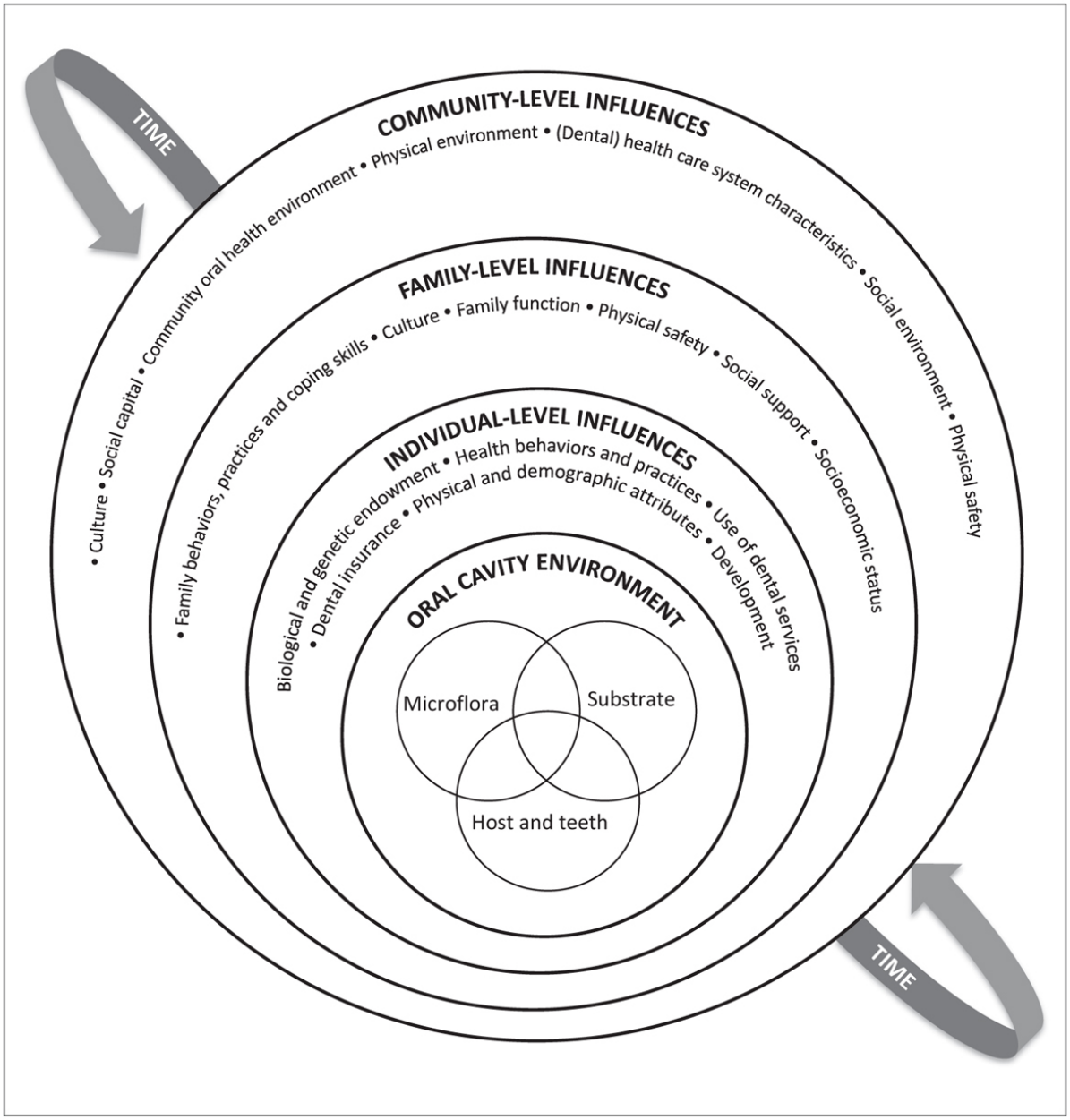


Fig 5-2 Fisher-Owens' model of influences on children's oral health (modified from Fisher-Owens et al[9]).

The rationale for the Common Risk Factor Approach and interdisciplinary action

In 2000, Watt and Sheiham[10] introduced the CRFA as a rational basis for promoting oral health. The CRFA encourages an integrated approach to chronic disease prevention, by addressing risk factors common to many chronic diseases in the context of the wider social environment. The conceptual basis for the CRFA stems from the evidence that many noncommunicable diseases (NCDs), including a range of oral diseases, share the same social determinants and a small set of behavioral risk factors, namely sugar, tobacco, alcohol, and diet. Hence, working in partnership across relevant sectors and professions is essential to improve both oral and general health outcomes and would lead to more efficient use of resources, effort, and expertise. The CRFA has now been widely accepted and endorsed by (dental) policy makers and researchers. This is reflected, for example, in the World Health Organization (WHO) global action plan, which now recognizes oral health as an integral element to reduce the global burden of NCDs (Fig 5-3).[11]

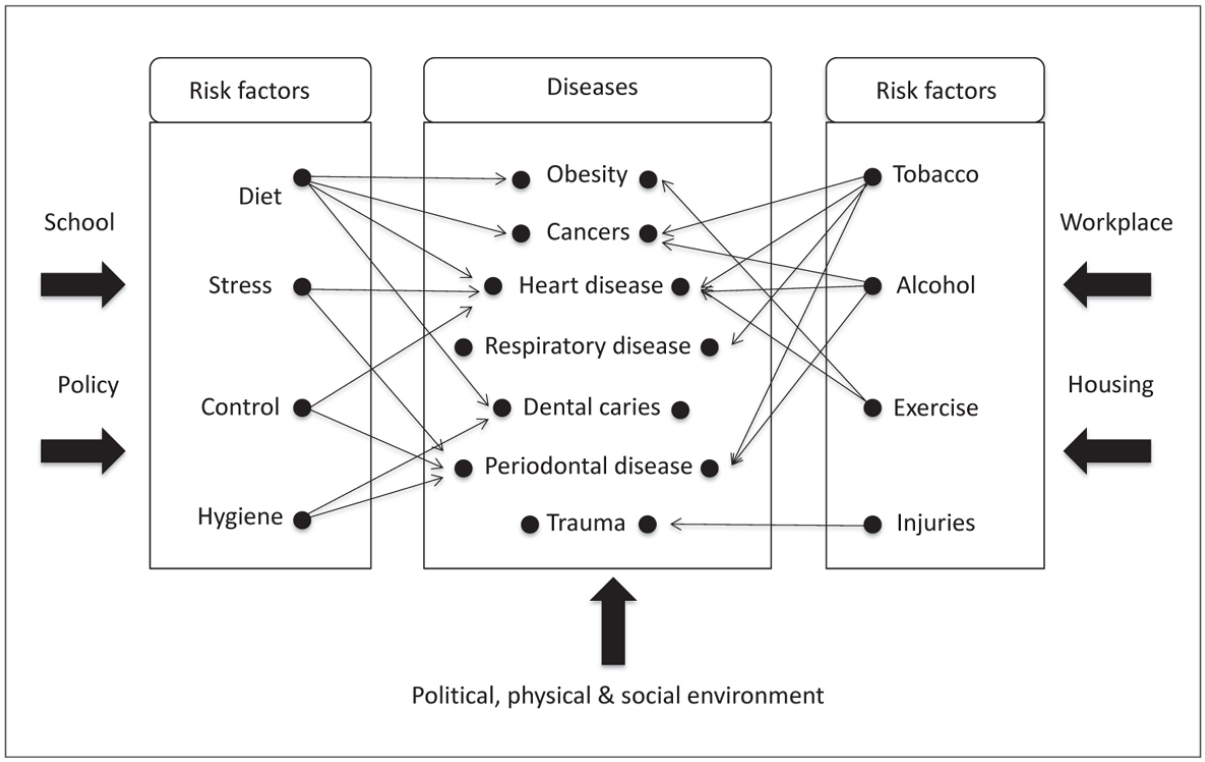


Fig 5-3 The common risk factor approach (modified from Sheiham and Watt[12]).

Interventions using interdisciplinary partnerships for the prevention of dental caries

The sections below describe a number of caries-preventive interventions using partnerships across different disciplines and across various settings.

Healthy teeth: all aboard! GigaGaaf in the Netherlands

In the 1980s, a new system of nonoperative caries treatment program (NOCTP) was introduced in the municipality of Nexø on the Danish island Bornholm.[13] In this program, oral health professionals used risk criteria to assess an individualized recall interval and need for (preventive) treatment with an emphasis on the mechanical plaque control of plaque-stagnation areas (eg, erupting molar teeth). In the year 2000, 18-year-olds living in Nexø had a remarkably low number of mean decayed, missing, and filled tooth surfaces (dmfs) (1.25 ± 2.01) and a high percentage (56%) did not have any caries experience.[14] Dmfs scores were significantly lower in the Nexø group in comparison to four Danish low caries municipalities.[13] These differences could not be explained by other caries-related background variables. The program was implemented in several other countries with varying, but mostly positive results in studies by Kuzmina and Ekstrand[14] (Russia), Arrow[15] (Australia), Vermaire et al[16,17] (the Netherlands), and Ekstrand and Qvist[18] (Greenland).

The NOCTP program formed the basis of a currently conducted randomized controlled trial in the Netherlands on the effectiveness and cost-effectiveness of a mixed individual and community-based approach to improve oral health in 0- to 5-year-old children and to

reduce socioeconomic inequalities in oral health (Healthy Teeth; all aboard! / GigaGaaf intervention).[19] In this program, all children in the intervention group visiting a well-baby clinic are referred to a participating dental health clinic at approximately 6 to 9 months of age (from the eruption of the first tooth). Well-baby clinics are visited by 95% of the Dutch child population and offer 13 consultations for parents and their child between birth and 4 years of age. When referred to the dental health clinic, parents receive advice and oral health instruction to keep their child's oral health in perfect condition and they receive a second appointment before the second birthday. From that point onwards, children follow the NOCTP program where both the need for caries-preventive measures and recall interval are individually assessed using the NOCTP-adapted risk criteria. These criteria include parental motivation, understanding, tooth eruption phase, and caries activity (Fig 5-4). To enhance parental motivation, motivational interviewing (MI) is used as a communication strategy in this intervention (see Motivational Interviewing textbox overleaf). Preliminary results on behavior change show that children referred to dental clinics by the use of well-baby clinics, had a 16 times higher odds of children having their first preventive dental visit.[20] Final results on the (cost-) effectiveness, including clinical results are expected in 2022.

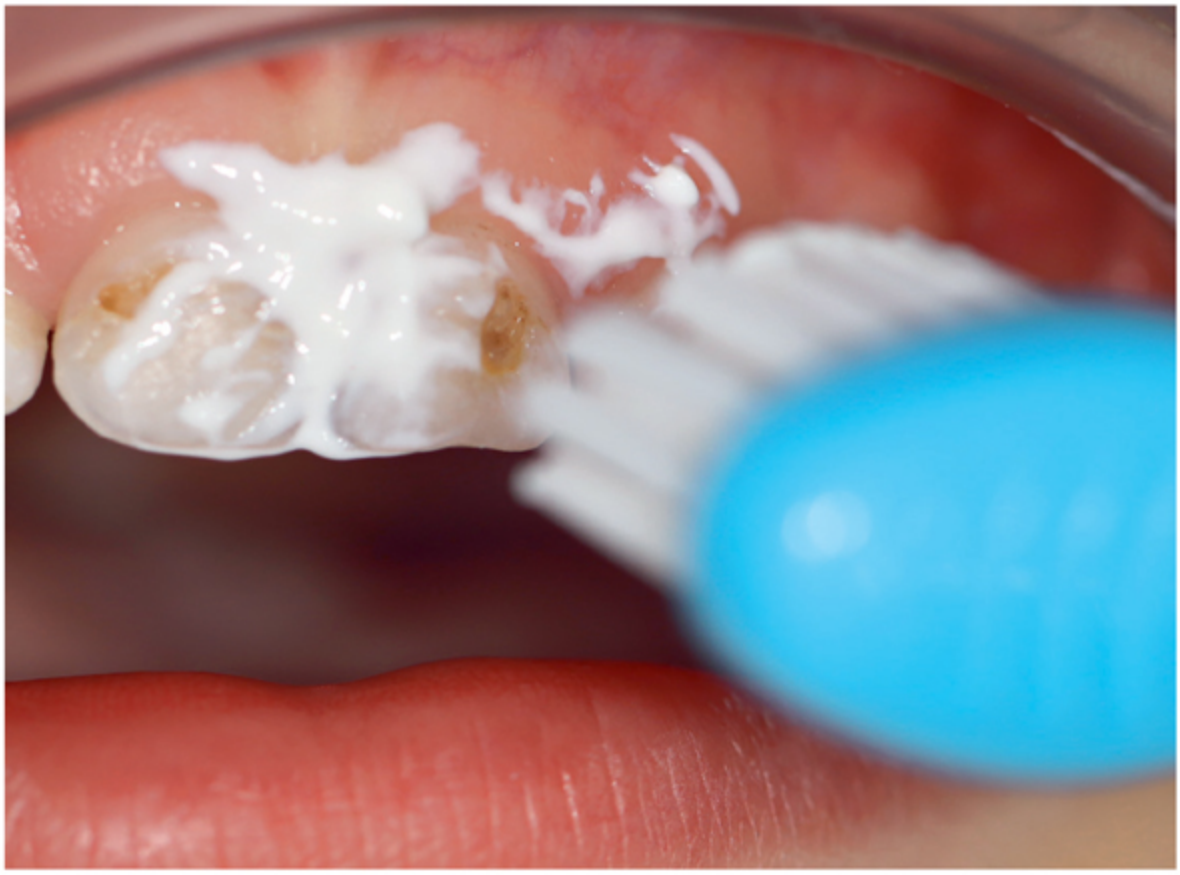


Fig 5-4 Nonoperative caries treatment inactivates caries lesions by improving oral hygiene and fluoride application. Irreversible pulpal inflammation does not allow this approach (image courtesy of R.J.M. Gruythuysen, the Netherlands).

A different approach, using the same infrastructure of well-baby clinics, is the “Toddler Oral Health Project” (translated from the Dutch name “Gezonde Peutermonden”) in the Netherlands.[21] In this project, oral health coaches are detached at well-baby clinics, to provide oral health care and tailored oral health advice according to the NOCTP methodology on the location itself. Results of a randomized controlled trial evaluating the effectiveness of the program are also expected by the end of 2022.

Childsmile in Scotland

In 2006, the Scottish National Health Service (NHS) started an intervention program, named Childsmile, to improve the oral health of children in Scotland and to reduce socioeconomic inequalities in both oral health and access to dental care.[24] Childsmile consists of three programs:

- a core program
- a practice-based program
- a nursery- and school-based program.

The core program includes the provision of free toothbrushes and fluoridated (1,000 to 1,500 ppm) toothpaste on at least six occasions during children's first 5 years, and daily supervised tooth brushing for all children attending nurseries, as well as primary schools in the 20% most deprived areas. In the practice-based program, families of infants at increased risk of developing dental caries are visited by a Dental Health Support Worker (DHSW) on referral by a health visitor. The DHSW gives one-to-one oral health support, makes a first appointment with an NHS dental service, and links families to other community activities or resources that support oral health (eg, food cooperatives). The length and intensity of care is tailored to the family's needs. The nursery- and school-based program is offered to children living in the 20% most deprived area's in Scotland. These children are provided with twice-yearly fluoride varnish applications from the age of 3 years by teams of dental nurses and DHSWs. Furthermore, good oral health is promoted and oral health education is given by these teams.

Long-term results on the cost-effectiveness of the program are expected to be published in due time, but already reported clinical results show that – compared to 10 years earlier – in all categories of deprivation, an increasing percentage of children were found to have no caries into dentin.[23] Preliminary results presented at the European Association of Dental Public Health (EADPH) Congress show that obvious caries experience risk significantly decreased and the frequency of dental practice visits increased from zero contact to more than five contact moments (adjusted odds ratio = 0.5, 95% CI

0.46 to 0.54).[25] Also, the use of DHSWs has recently been studied. This was found to be an effective way of linking children to primary dental care services for prevention at a younger age.[26] Hence, this mixed individual-/community-based approach can be considered successful for the Scottish situation (Fig 5-5).

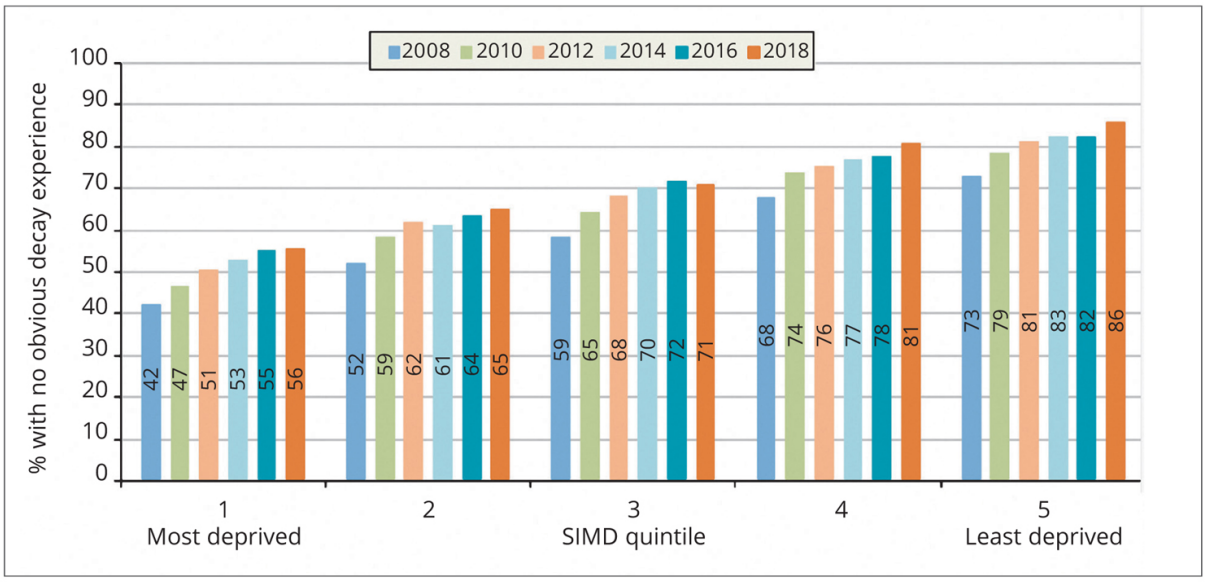


Fig 5-5 Percentage of first year primary school children (approx. 5 years old) in Scotland with no obvious decay between 2008 and 2018 by level of deprivation (Scottish Index of Multiple Deprivation [SIMD] quintile: 1 most deprived, 5 least deprived)(reproduced from National Dental Inspection Programme[27] with permission from Public Health Scotland).

Motivational interviewing

To prevent the development of dental caries, dental health professionals traditionally provide (the caregivers of) their patients with information on an individual basis from a top-down perspective. This means that the dental health professional tries to transfer his/her knowledge and skills on oral hygiene behavior to the patient or his/her care giver by trying to influence (or rather

convince) them. This manner of health promotion is still commonly applied in dentistry. However, evidence of its effectiveness is weak and because of its individual character it can be considered a relatively expensive (and therefore not cost-effective) way of decreasing the caries risk in children. Lack of dental knowledge is one of the identified caries determinants in children.

Alternatively, a more recently introduced, individually delivered way of oral health promotion can be applied as well, using the motivational interviewing (MI) technique. This increasingly applied counseling approach, originally designed for addiction counseling, is based on equivalence between patient/client and health professional. This technique is based on the transtheoretical model of change[22] and is developed by Miller and Rollnick.[23] It is described as a directive client-centered counseling style to change people's behavior intrinsically. This change is achieved by resolving identified ambivalence in behavior in a directive way by first exploring the stage of behavior change the patient (or their caregiver) is in. According to the model, these stages of change are:

- Precontemplation stage: the patient may or may not perceive negative issues but, if present, these issues are not considered serious enough to motivate them to change their behavior. In this stage, he/she has little or no motivation to change since the patient doesn't consider him/herself to have a problem.
- Contemplation stage: the patient is aware that his/her behavior is problematic but he/she is uncertain (ambivalent) about making an actual change in his/her behavior. In this stage, the patient may have considered changing his/her behavior but has not put any effort into changing yet.
- Preparation stage: the patient has decided to change his/her behavior and has made commitment to do so. Positive and negative consequences of their behavior are considered and the patient has concluded that the negative aspects outweigh

the benefits. He/she may have made a plan to change but has not undertaken any action.

- Action stage: the patient is actively involved in changing his/her behavior. The patient understands that he/she is responsible for this change.

From this point on, the patient can either move to:

- Relapse stage: the patient was not successful in continuing the changed behavior and usually enters the contemplation stage of action stage again.
- Maintenance stage/success: the patient has successfully changed his/her behavior for at least 6 months.

The major difference between MI and traditional health promotion strategies is the fact that people are motivated intrinsically by the health professional rather than being persuaded. Furthermore, an important starting point of MI is that it is considered the oral health professional's task to help the patient to identify and resolve their present ambivalence in changing his/her behavior, but not to identify and resolve it for them. MI has been subject to over 200 studies, including in oral health, with promising results. Being able to provide (caregivers of) the patients with all the information they need to go to the next phase in their behavior change, can be considered more effective than providing them with lots of information patients will not process. The principle is of "readiness to change."

Examples of other community-based interventions

In 2016, a Cochrane review was published describing the effectiveness of community-based interventions to promote children's oral health.[28] The review included 38 interventions that were delivered in a variety of settings, including education, community, health care, and home settings. For some of the interventions, interdisciplinary partnerships were established. The

review concluded there is little evidence that oral health education alone is effective for reducing dental caries in children. However, positive impacts have been reported when oral health education was provided in a non-clinical setting and combined with supervised tooth brushing or with professional clinical preventive care. For example, Slade et al[29] reported that a multicomponent community-wide intervention, consisting of bi-annual fluoride varnish application and community health promotion activities at home, health service, and community settings, significantly reduced caries incidence in high-risk children. Vichayanrat et al[30] showed that home visits by lay health workers, access to health services, and community mobilization improved caregivers' oral health knowledge, attitudes, and self-efficacy, but no reductions in children's caries levels were found. Based on the findings of the review, the authors concluded that important elements for oral health promotion are:

- to design integrated interventions combining oral health education with supervised tooth brushing and/or professional preventive care
- to create linkages and collaboration between stakeholders from various community, education, and health care settings
- to incorporate intervention components that consider contextual factors, such as community demographics, access to health care, and environmental conditions.[26]

Integrated interventions to prevent childhood dental caries and obesity

For the past three decades, there has been an increasing interest in studying the relationship between childhood dental caries and obesity. Both conditions are major public health concerns, not only in Western countries, as many low- and middle-income countries are also affected. The prevalence of obesity in children is estimated to be 381 million worldwide.[31] The literature now suggests that these children also have an increased risk of developing dental caries.

Although the evidence is not conclusive, systematic reviews have reported positive associations between childhood dental caries and obesity, particularly in studies that were conducted in Western countries involving normal weight and overweight participants.[32,33] Shared risk factors, such as a sugar-rich diet (which is both cariogenic and obesogenic), and joint social determinants largely contribute to the explanation of this positive relationship. Hence, integrated approaches to promote healthy eating, preferably in the context of the broader social environment, would benefit children's general and oral health.

The CRFA provides opportunities to integrate intervention components for the prevention of childhood dental caries in obesity initiatives, and vice versa. Examples of approaches to promote healthy eating include food labeling, regulating the advertisement of energy-rich foods, school-based nutrition programs, and food policy guidelines addressing costs and access to foods.[10] Schools are excellent venues to promote children's health and increase their prospects for a healthy development. According to Kwan et al,[34] there are several opportunities to promote children's oral health through the WHO's Health Promoting School framework, including: the provision of healthy meals and drinking water; banning sugary foods, vending machines, smoking, and alcohol on school premises; provision of oral health education (and potentially preventive care services) in schools; and the practice of school-based tooth brushing. Another example of an intervention that incorporates oral health is the Women, Infants, and Children program (WIC) in the United States, which provides supplemental foods, (oral) health care referrals, breastfeeding support, and nutrition education, including oral health education, to low-income pregnant and postpartum women, infants, and children up to 5 years of age.[35] Children who participated in WIC had an increased probability of having a dental visit, were more likely to use preventive and restorative services, and were less likely to use emergency services.

CHALO in the United States

Despite the wide acceptance and obvious usefulness of the CRFA, there are only a few studies that have used the CRFA model as a basis for the development of interventions to prevent dental caries and obesity. One example is the CHALO (Child Health Action to Lower Oral Health and Obesity) program in the United States.[36] This program targets South Asian families at high risk for childhood dental caries and obesity. CHALO is a multilevel strategy intervention which addresses common risk factors associated with these two childhood conditions. The intervention consists of culturally tailored home visits by a South Asian community health worker when children are at 6, 8, 10, 12, 14, and 16 months of age. The visits focus on identifying family/household concerns, reviewing cariogenic and obesogenic behaviors, setting concrete and manageable behavior change goals, building skills through active interaction with the child, and providing education and support. The intervention encourages responsive bottle feeding, preparation of age-appropriate self-feeding foods, tummy time and active play, transitioning from naptime milk to water bottles, and oral hygiene practices, such as tooth brushing. A randomized controlled trial is currently being conducted to evaluate the impact of the CHALO program.

Sugar tax

Extensive sugar consumption is considered one of the main causes of NCDs such as obesity and type 2 diabetes. Considering recommendations of the WHO, the intake of sugar should ideally be 5% of a person's total daily energy intake and should not exceed 10% to prevent sugar-related diseases.[37] In 2016, the WHO supported taxing sugary drinks by at least 20% of the retail price to help reduce the total sugar consumption. So far, around 30 countries have already implemented this "sugar tax" and more countries are considering implementation. In Mexico, a drop of 5% in sales of sugar-containing drinks was reported one year after the introduction of this measure, followed by a reduction of 9% in the second year.[38] Highest reductions in purchases of sugared beverages were found in

people with lower SES.[39] Although no empirical studies have yet been published linking the introduction of sugar tax with lower caries prevalence, studies do report on the positive potential impact it may have on health care costs using decision analytic (Markov) modeling.[40] A recent study, using the Netherlands as a reference case, estimated that a total of 1,030,163 caries lesions could be prevented by introducing this tax and that the lifetime estimated tax revenues would easily outweigh the administrative cost for taxation by almost 95 times.[41]

Although these results are quite promising, there are also critical voices. One of the conclusions of a recent paper on sugar and oral health was that the relative cariogenicity of food and drinks is not directly related to the amount of sugar it contains.[42] Furthermore, it was stated that frequency of sugar intake fits the biologic knowledge of the caries process better than the amount, unless this amount is very low. The minimal cariogenic concentration of sugars in food is hard to estimate since this threshold varies with too many factors, with the pH of the oral condition being one of them.[43] However, it is known that the metabolism of cariogenic bacteria is limited to a maximum amount of sugar. This means that if, for example, the production of a certain popular sugar-containing soft drink decreased its sugar content by 50% from 108 g/L to 54 g/L, it would likely not affect the metabolism of oral lactobacilli or *Streptococcus mutans*. Hence, reducing the amount of sugar in sugar-sweetened beverages may have considerable impact on obesity; it may have limited impact on caries reduction unless consumers make a shift towards no-sugar-containing (diet-) products or (preferably) water. Reasoned from this perspective, more positive results can be expected from promoting a healthier lifestyle (drinking soft drinks less frequently and water more frequently) than from decreasing the amount of sugar in recipes. However, if a fair share of the revenues of the sugar tax could be directly spent on oral health promotion activities, a considerable (secondary) dental health gain may be within reach (Fig 5-6).

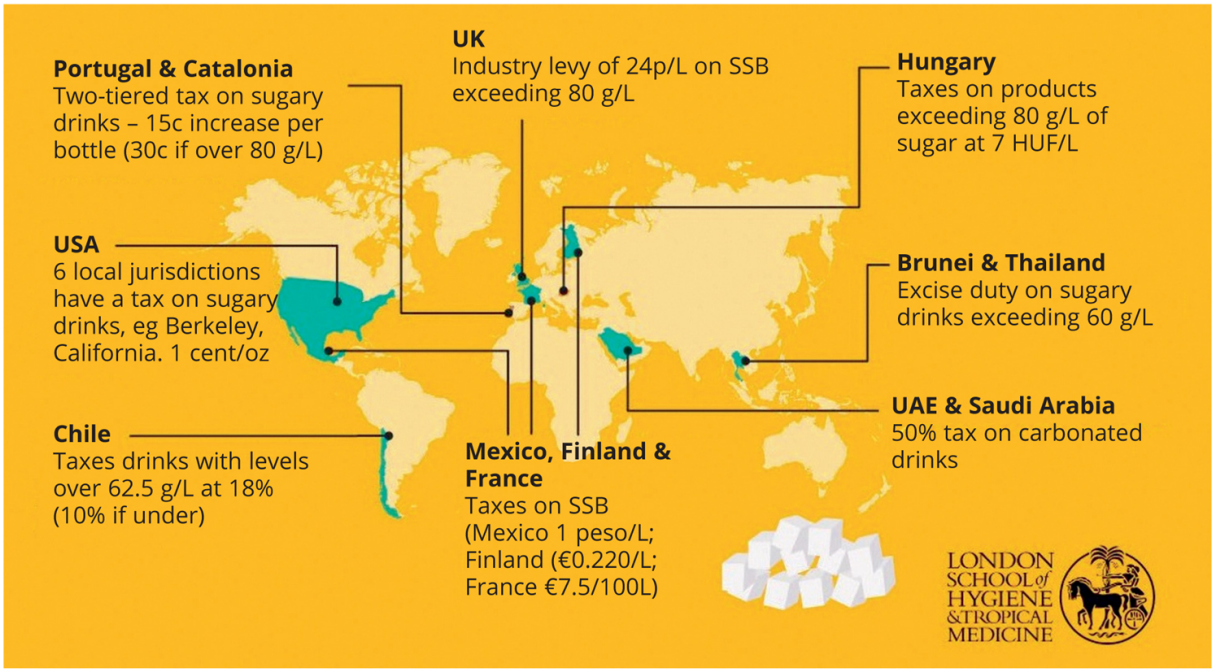


Fig 5-6 Sugar tax around the world (reproduced from London School of Hygiene and Tropical Medicine[44] with permission). SSB, sugar-sweetened beverages.

Integrated interventions to prevent childhood dental caries- and hygiene-related diseases

Apart from NCDs, dental caries is indirectly linked to several infectious diseases. Many children in low- and middle-income countries suffer from a high burden of infectious diseases with hygiene deficiency as a common cause, such as diarrhea, acute respiratory infections, and intestinal worms. These diseases can be prevented on a large scale by effective public health interventions improving access to water, sanitation, and personal hygiene.[45] Such interventions mainly concentrate on creating supportive environments (eg, by providing the necessary infrastructures to perform hygiene behavior, such as handwashing facilities and soap[46]), and on stimulating hygiene behavior change (eg, by using visual cues such as posters and stickers, or environmental “nudges” such as brightly colored handwashing facilities and painted footprints

and handprints.[16,17,47,48] The importance of water, sanitation, and hygiene (WASH) interventions are recognized globally through inclusion in the Sustainable Development Goals (SDGs).[28,49] The SDGs provide a unique opportunity for oral health and allow integration of oral hygiene activities under the umbrella of general hygiene promotion. However, this advocacy opportunity has not yet been systematically used to improve prioritization and integration of oral health in the health, development, and WASH sectors. One of the few exceptions is the Fit for School (FIT) program, which is described below.

Fit for School in Southeast Asia

The FIT approach is an integrated school-based WASH program that has been developed as a response to the serious health problems of Southeast Asian children.[50] The FIT approach aims to improve child health through the institutionalization of simple, evidence-based interventions in primary public schools. Interventions include the practice of daily group handwashing with soap, tooth brushing with toothpaste (containing 1,450 ppm fluoride), and bi-annual deworming. The group hygiene activities are conducted once a day under supervision of a teacher. These activities are complemented by the construction of basic group handwashing facilities in the schools. Recently, the FIT approach was extended with a school sanitation operation and maintenance package, which includes technical support and supplies (eg, cleaning rotas, toilet user kits, cleaning products, and a manual) to improve the quality of school latrines (Fig 5-7).[51] The FIT approach originated in the Philippines in 2007/2008 where it was implemented by the Department of Education as the “Essential Health Care Program” (EHCP). Since 2011, the German Development Cooperation (GIZ), and the South-East Asian Ministers of Education Organization Regional Centre for Educational Innovation and Technology (SEAMEO INNOTECH) partnered to expand the FIT approach to Cambodia, Indonesia, and Lao People’s Democratic Republic as the “Regional Fit for School

Programme." Cohort studies designed to evaluate the impact of the FIT program found a rise in mean BMI and a reduction in the prevalence of moderate to heavy soil-transmitted helminth infections and dental caries.[50,53] Currently, research is being conducted on the impact of the FIT program on the formation of children's independent hygiene habits beyond the school context.

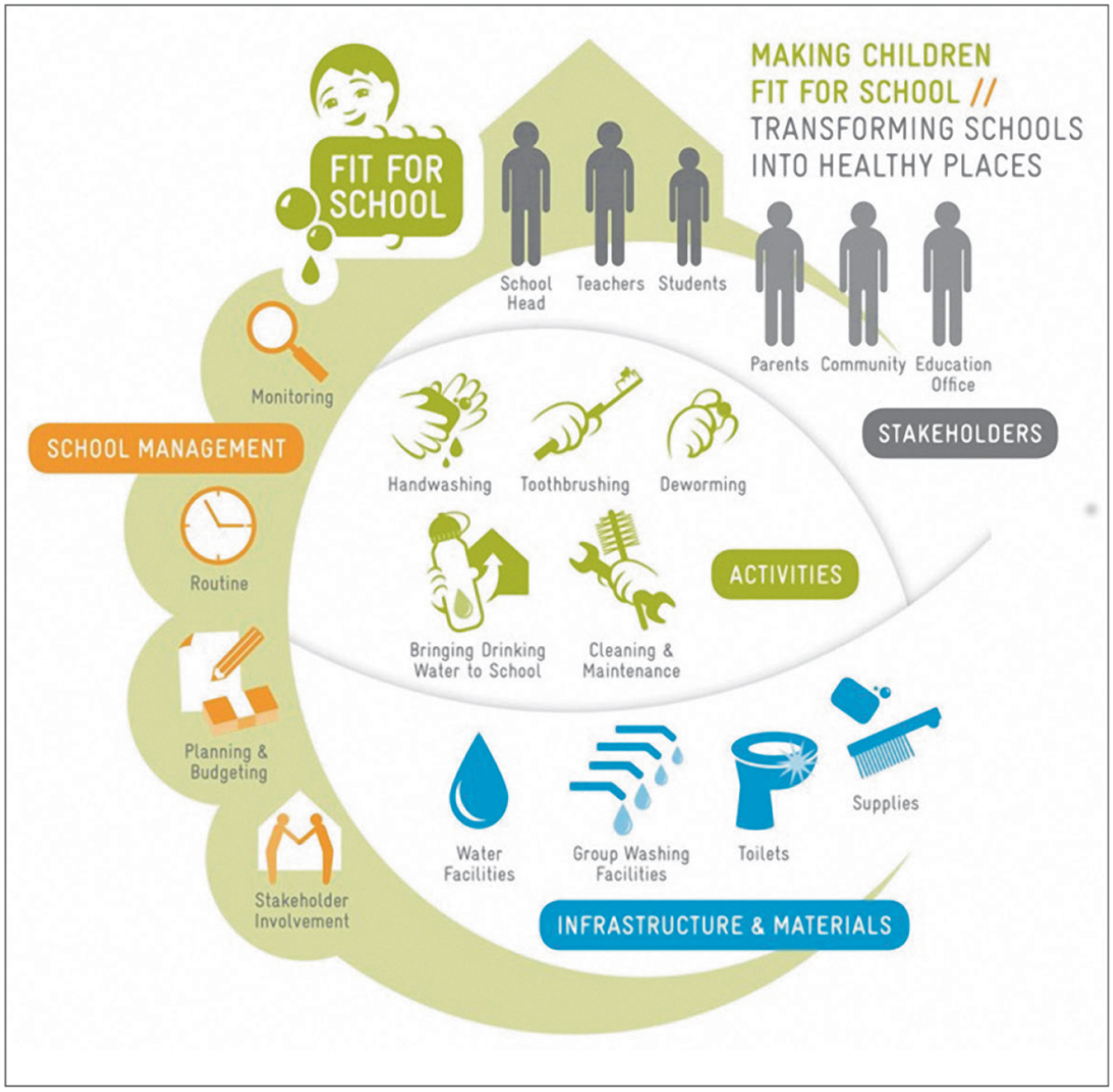


Fig 5-7 The Fit for School framework (reproduced from Internationale Gesellschaft für Internationale Zusammenarbeit [GIZ][52] with permission).

In conclusion, the concept of the CRFA has gained momentum in the last decade. Researchers, public health professionals, and policy makers, not only from the field of oral health, now realize that it is inefficient to target diseases separately when they have similar causes. Clearly, interdisciplinary health promotion strategies that target a number of relevant determinants and/or risk factors will impact on a large number of diseases (including oral diseases) at a lower cost, greater efficiency, and greater effectiveness than disease-specific approaches. This notion has paved the way for closer integration of oral health into general health improvement strategies. This chapter shows that a number of interventions have recently been developed that have incorporated the CRFA and/or acknowledge the importance of interdisciplinary partnerships for children's (oral) health promotion. Studies are currently being conducted to evaluate these interventions, and these will contribute to the evidence-base of such integrated approaches. This, and the continued advocacy to integrate oral health into the broader NCD agenda and SDGs, will provide windows of opportunity to improve children's oral health on a global scale.

References

1. Peres M, Watt RG. Policy solutions for oral health inequalities. International Centre for Oral Health Inequalities Research & Policy (ICOHIRP), Adelaide, September 2017. http://www.icohirp.com/. Accessed 29 December 2019.
2. Marcenes W, Kassebaum NJ, Bernabé E, et al. Global burden of oral conditions in 1990–2010: a systematic analysis. J Dent Res 2013;92:592–597.
3. Schwendicke F, Dörfer CE, Schlattmann P, Foster Page L, Thomson WM, Paris S. Socioeconomic inequality and caries: a

systematic review and meta-analysis. J Dent Res 2015;94:10–18.

4. Jackson SL, Vann Jr WF, Kotch JB, Pahel BT, Lee JY. Impact of poor oral health on children's school attendance and performance. Am J Public Health 2011;101:1900–1906.
5. Harris R, Nicoll AD, Adair PM, Pine CM. Risk factors for dental caries in young children: a systematic review of the literature. Community Dent Health 2004;21(Suppl):71–85.
6. Sabbah W, Tsakos G, Sheiham A, Watt RG. The role of health related behaviors in the socio-economic disparities in oral health. Soc Sci Med 2009;68:298–303.
7. Sanders AE, Spencer AJ, Slade GD. Evaluating the role of dental behaviour in oral health inequalities. Community Dent Oral Epidemiol 2006;34:71–79.
8. Marmot M. For the Commission on Social Determinants of Health. Achieving health equity: from root causes to fair outcomes. Lancet 2007;370:1153–1163.
9. Fisher-Owens SA, Gansky SA, Platt LJ, et al. Influences on children's oral health: a conceptual model. Pediatrics 2010;120:510–520.
10. Watt RG, Sheiham A. Integrating the common risk factor approach into a social determinants framework. Community Dent Oral Epidemiol 2012;40:289–296.
11. World Health Organization. Global Action Plan for the prevention and control of noncommunicable diseases 2013–2020. Geneva: WHO, 2013.
12. Sheiham A, Watt RG. The common risk factor approach: a rational basis for promoting oral health. Community Dent Oral Epidemiol 2000;28:399–406.
13. Ekstrand KR, Christiansen ME. Outcomes of a non-operative caries treatment programme for children and adolescents. Caries Res 2005;39:455–467.
14. Kuzmina I, Ekstrand KR. Outcomes 18 years after implementation of a nonoperative caries preventive program -

the Nexö method - on children in Moscow, Russia. Community Dent Oral Epidemiol 2015;43:308–316.

15. Arrow P. Cost-minimization analysis of two occlusal caries preventive programmes. Community Dent Health 2000;17:85–91.
16. Vermaire JH, Poorterman JHG, van Herwijnen L, van Loveren C. A three year randomized trial in 6-year-old children on caries preventive strategies in a general dental practice in the Netherlands. Caries Res 2014;48:524–533.
17. Vermaire JH. Application of the Nexo method in a general dental practice in the Netherlands: 6-year results of a RCT. Int J Dent Hyg 2018;16:419–425.
18. Ekstrand KR, Qvist V. The impact of a national caries strategy in Greenland after 4 years. Int J Pediatr Dent 2015;25:255–266.
19. Schuller AA, Verlinden DA. Interventies ter bevordering van de mondgezondheid jeugd; stand van zaken GigaGaaf! TNO rapport, 2017. https://publications.tno.nl/publication/34625745/oa6OHl/TNO-2017-R11201.pdf. Accessed 29 December 2019.
20. Verlinden DA, Vermaire JH, Reijneveld SA, Schuller AA. The effectiveness of early referral of children by well-child clinics for their first dental visit. Abstract ORCA 2020 Caries Res (In press).
21. Gezonde Peutermonden: https://husite.nl/gezonde-peutermonden/. Accessed 29 December 2019.
22. Prochaska JO, DiClemente CC. Stages and processes of self-change of smoking: Toward an integrative model of change. J Consult Clin Psychol 1983;51:390–395.
23. Motivational Interviewing, Third Edition: Helping People Change. Miller MR, Rollnick S. New York: The Guilford Press, 2012.
24. Macpherson LM, Ball GE, Brewster L, et al. Childsmile: the national child oral health improvement programme in Scotland.

Part 1: Establishment and development. Br Dent J 2010;209:73–78.

25. Kidd JBR, Conway DI, Mahmoud A, Macpherson LMD, McMahon AD. Evaluation of Childsmile, Scotland's child oral health improvement programme via data linkage. Abstract. Community Dent Health 2018;35:S1–S57.
26. Hodgins F, Sherriff A, Gnich W, Ross AJ, Macpherson LMD. The effectiveness of Dental Health Support Workers at linking families with primary care dental practices: a population-wide data linkage cohort study. BMC Oral Health 2018;18:191.
27. National Dental Inspection Programme (NDIP) 2018. Report of the 2018 Detailed Inspection Programme of Primary1 Children and the Basic Inspection of Primary 1 and Primary 7 children. Scotland: ISD Scotland, NHS National Services Scotland, 23 October 2018. http://www.fitforschool.international. Accessed 16 March 2020.
28. Da Silva AM, Hedge S, Akudo Nwagbara B, et al. Community-based population-level interventions for promoting child oral health. Cochrane Database Syst Rev 2016;9:CD009837.
29. Slade GD, Bailie RS, Roberts-Thomson K, et al. Effect of health promotion and fluoride varnish on dental caries among Australian Aboriginal children: results from a community-randomised controlled trial. Community Dent Oral Epidemiol 2011;39:29–43.
30. Vichayanrat T, Steckler A, Tanasugarn C, Lexomboon D. The evaluation of a multi-level oral health intervention to improve oral health practices among caregivers of preschool children. Southeast Asian J Trop Med Public Health 2012;43:526–539.
31. The Lancet Public Health. Tackling obesity seriously: the time has come. Lancet Public Health 2018;3:e153.
32. Hayden C, Bowler JO, Chambers S, et al. Obesity and dental caries in children: a systematic review and meta-analysis. Community Dent Oral Epidemiol 2013;41:289–308.

33. Hooley M, Skouteris H, Boganin C, Satur J, Kilpatrick N. Body mass index and dental caries in children and adolescents: a systematic review of literature published 2004 to 2011. Syst Rev 2012;1:57.
34. Kwan SY, Petersen PE, Pine CM, Borutta A. Health-promoting schools: an opportunity for oral health promotion. Bull World Health Organ 2005;83:677–685.
35. Women, Infants, and Children program (WIC). https://www.fns.usda.gov/wic. Accessed 29 December 2019.
36. Karasz A, Bonuck K. Reducing pediatric caries and obesity risk in South Asian immigrants: randomized controlled trial of common health/risk factor approach. BMC Public Health 2018;18:680.
37. World Health Organization. Guideline on sugars intake for adults and children. Geneva: WHO, 2015. https://apps.who.int/iris/handle/10665/149782. Accessed 29 December 2019.
38. Bedi R. The sugar tax: a leadership issue for the dental profession and an opportunity to demonstrate that oral health is part of general health. Contemp Clin Dent 2018;9:149–150.
39. Ng SW, Rivera JA, Popkin BM, Colchero MA. Did high sugar-sweetened beverage purchasers respond differently to the excise tax on sugar-sweetened beverages in Mexico? Public Health Nutr 2018;18:1–7.
40. Sonnenberg FA, Beck JR. Markov models in medical decision making. Med Decis Mak 1993;13:322–338.
41. Jevdevic M, Trescher AL, Rovers M, Listl S. The caries-related cost and effects of a tax on sugar-sweetened beverages. Public Health 2019;169:125–132.
42. Loveren van C. Sugar restriction for caries prevention: amount and frequency. Which is more important? Caries Res 2019;53:168–175.
43. Soet de JJ, Nyvad B, Kilian M. Strain-related acid production by oral Streptococci. Caries Res 2000;34:485–490.

44. Robinson R. London School of Hygiene and Tropical Medicine. https://www.lshtm.ac.uk/research/research-action/features/uk-sugar-tax-will-it-work. Accessed 29 December 2019.
45. Fewtrell L, Kaufmann RB, Kay D, Enanoria W, Haller L, Colford JM Jr. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. Lancet Infect Dis 2005;5:42–52.
46. Curtis VA, Danquah LO, Aunger RV. Planned, motivated and habitual hygiene behaviour: an eleven country review. Health Education Res 2009;24:655–673.
47. Dreibelbis R, Kroeger A, Hossain K, Venkatesh M, Pavani KR. Behavior change without behavior change communication: nudging handwashing among primary school students in Bangladesh. Int J Environ Res Public Health 2016;13:E129.
48. Neal D, Vujcic J, Hernandez O, Wood W. The science of habit: creating disruptive and sticky behavior change in handwashing behavior. Washington DC: USAID/WASHplus Project, 2015.
49. United Nations Children's Fund (UNICEF) and World Health Organization (2018). Drinking water, sanitation and hygiene in schools: global baseline report. New York: WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 2018.
50. Monse B, Naliponguit E, Belizario V, Benzian H, Palenstein-Helderman van W. Essential health care package for children—the 'Fit for School' program in the Philippines. Int Dent J 2010;60:85–93.
51. Buxton H, Dimaisip-Nabuab J, Duijster D, Monse B, Benzian H, Dreibelbis R. The impact of an operation and management intervention on toilet usability in schools in the Philippines: a randomised controlled trial. BMC Public Health 2019;19:1680.
52. Internationale Gesellschaft für Internationale Zusammenarbeit (GIZ), Fit for School Programme. http://www.fitforschool.international. Accessed 16 March 2020.

53. Duijster D, Monse B, Dimaisip-Nabuab J, et al. ‘Fit for school’ - a school-based water, sanitation and hygiene programme to improve child health: Results from a longitudinal study in Cambodia, Indonesia and Lao PDR. BMC Public Health 2017;17:302.

6

Oral hygiene: The best route to a healthy mouth?

Elena Figuero, Irene Dige, Vita Mačiulskienė

The dental biofilm is considered to be the major biologic determinant common to the development of dental caries and the periodontal diseases.[1] Prior to discussing the role of oral cleanliness in prevention and control of these diseases, it is important to understand the nature of the dental biofilm and the ways with which it can be interfered.

Definition of the dental biofilm

A dental biofilm is defined as a consortium of microorganisms that is embedded in an extracellular polymeric matrix and sticks to dental surfaces.[1] Most clinicians still use the term dental plaque when referring to dental biofilms. However, the term dental biofilm is becoming more common among clinicians, probably because its role in oral diseases is an important area of study and the term is used in scientific literature. Moreover, dental biofilms are an archetypal example of a multispecies biofilm and share the same characteristics as other natural biofilms. Because of the etiologic role of dental

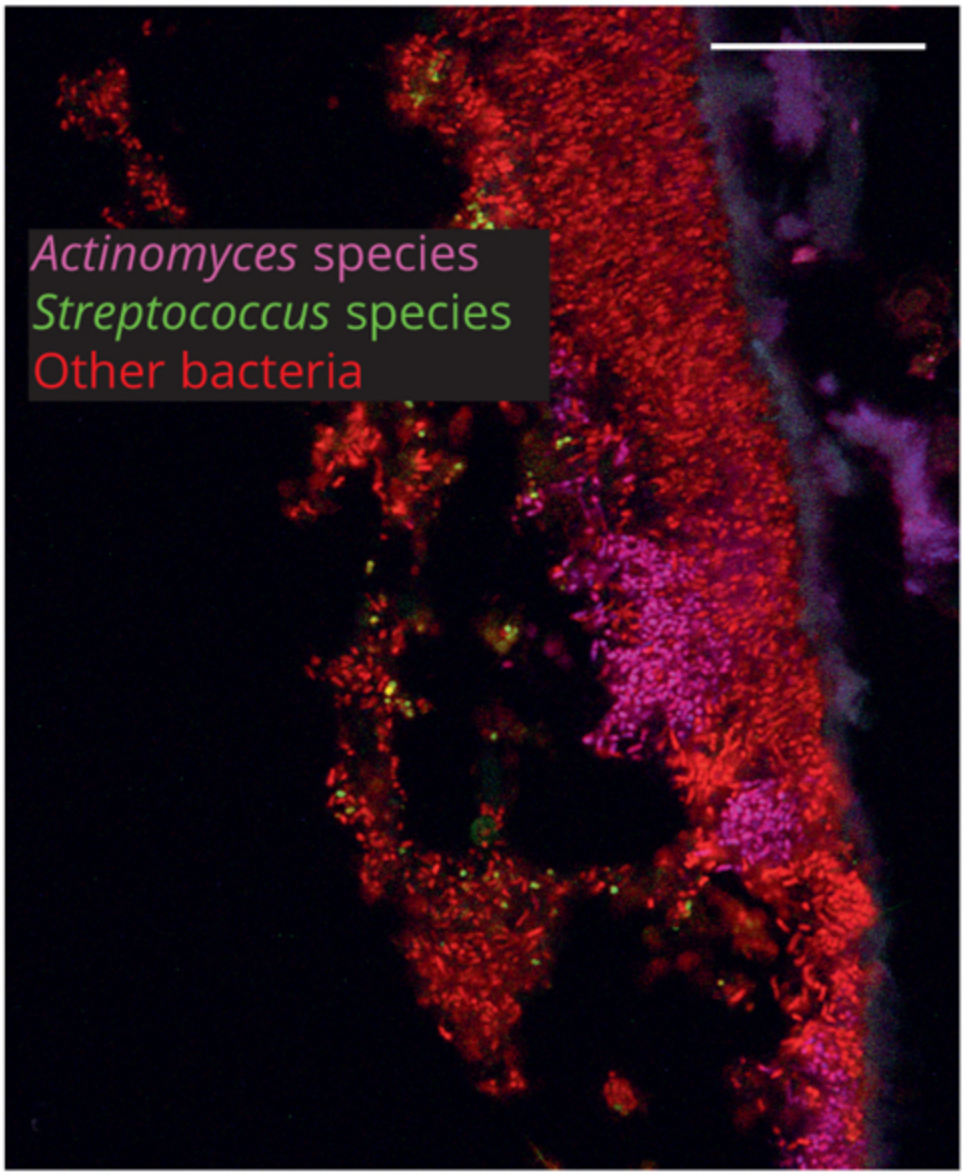
biofilms in dental diseases such as caries, gingivitis, and periodontitis, dental professionals are trained in professional plaque control and to teach their patients to self-perform plaque control in order to prevent and manage biofilm-induced dental diseases. To appreciate the possible value of such interventions it is necessary to understand the biofilm composition and structure, keeping in mind that most dental biofilms live in harmony with the host and only result in dental disease when an ecological shift occurs within the biofilms. Furthermore, since teeth provide nonshedding surfaces with areas that are not easily accessible for mechanical plaque removal, other strategies may be relevant to prevent and control dental diseases.

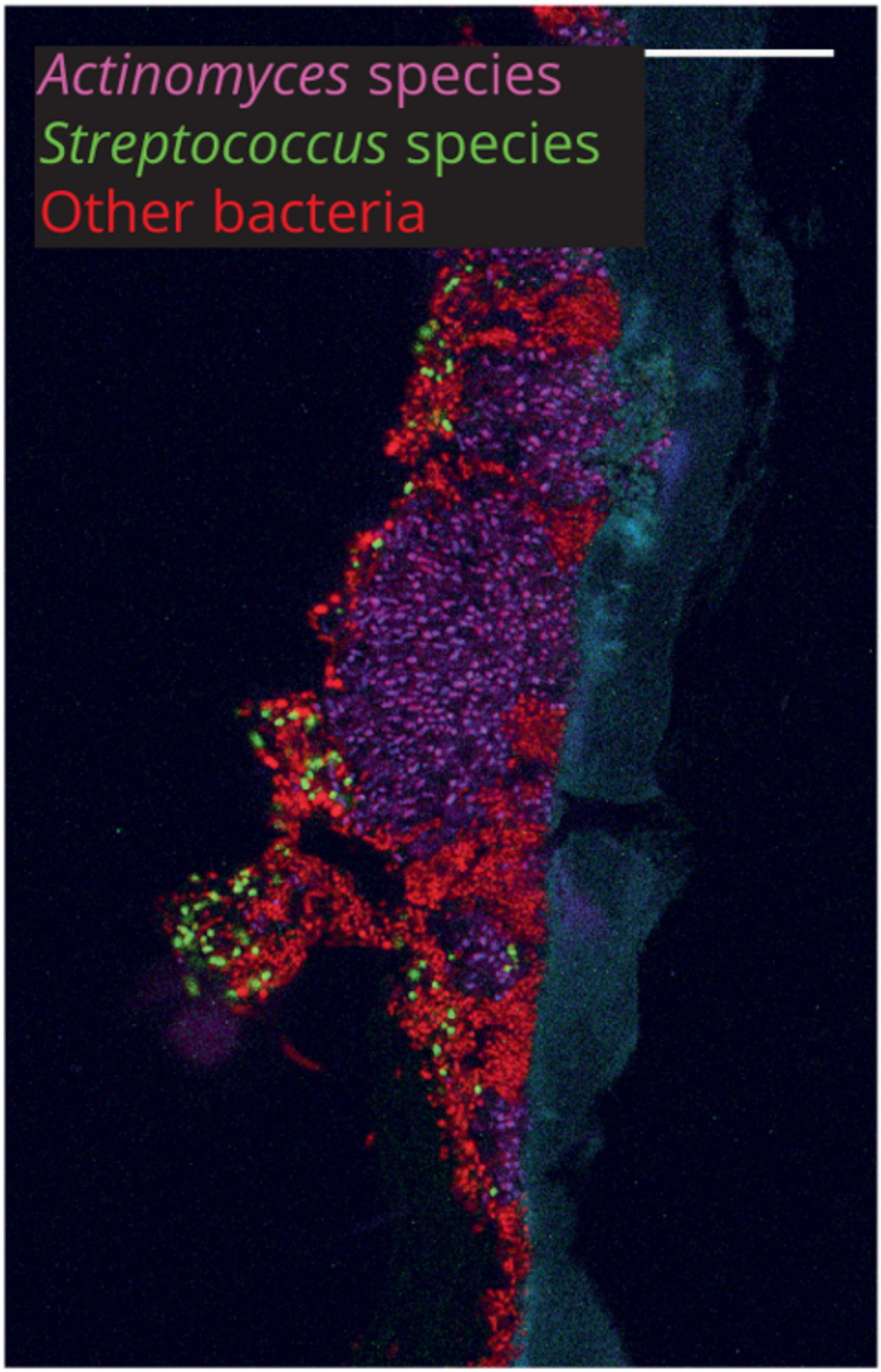
Nature of the dental biofilm

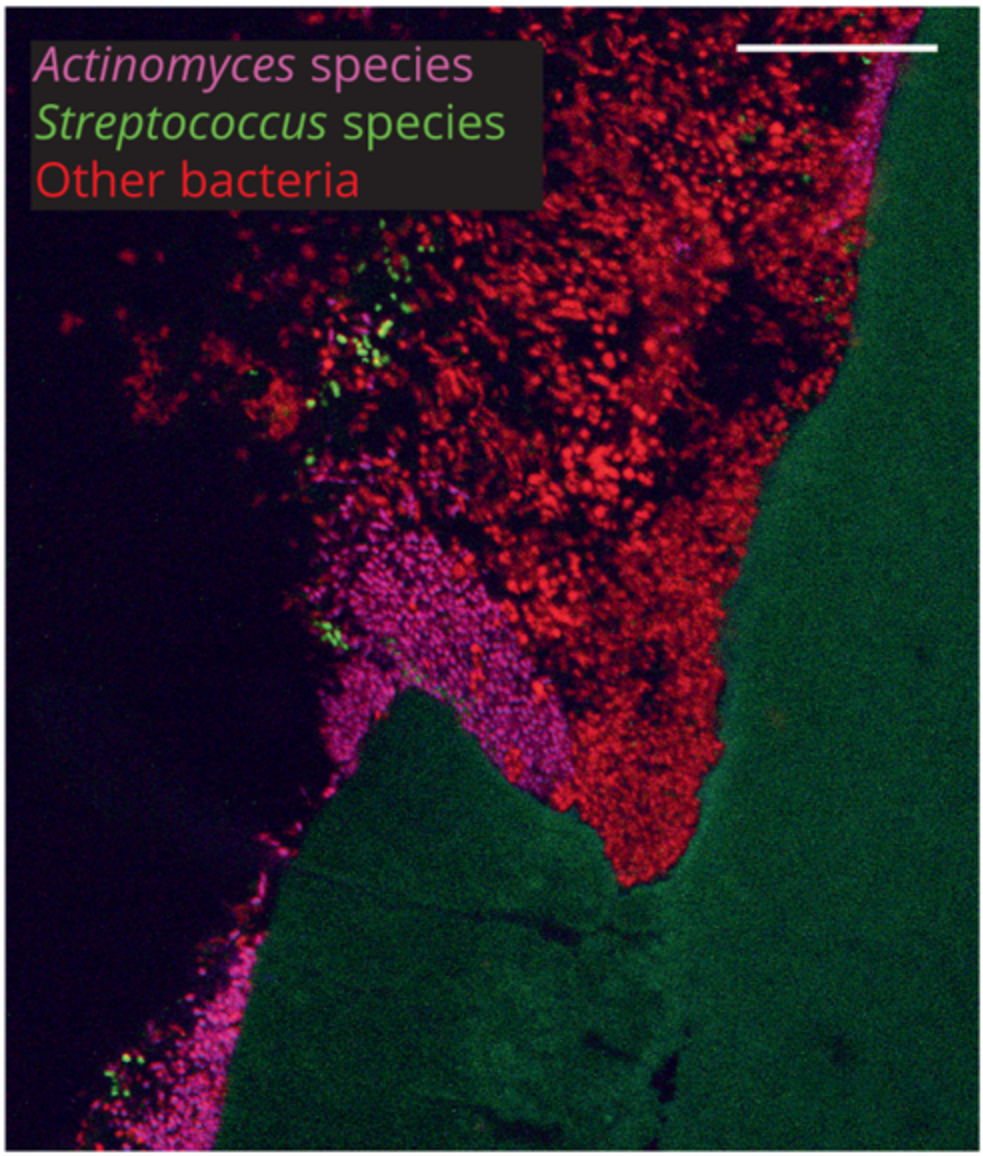
Dental biofilms are well characterized and the development includes several stages, including pellicle formation, initial colonization with attachment of microorganisms, co-adhesion of microorganisms, succession, and growth of attached microorganisms and microcolonies into mature biofilms.[2] Modern molecular techniques have evolved dramatically in recent decades, and added important information to previous culture-based studies. Such techniques have resulted in identification of more than 700 taxa in the oral cavity,[3] from a diverse group of microorganisms including bacteria, viruses, fungi, archaea, and protozoa.[1] In dental biofilm research there has been a focus on the bacteria, but lately understanding the fungus-bacteria interactions and how such cross-kingdom microbial communities influence the biofilm ecology has gained attention.[4,5] An association between microbial profile and oral health and disease has been suggested,[6] but it is beyond the scope of this chapter to go into details of the diverse microbial composition of dental biofilm.

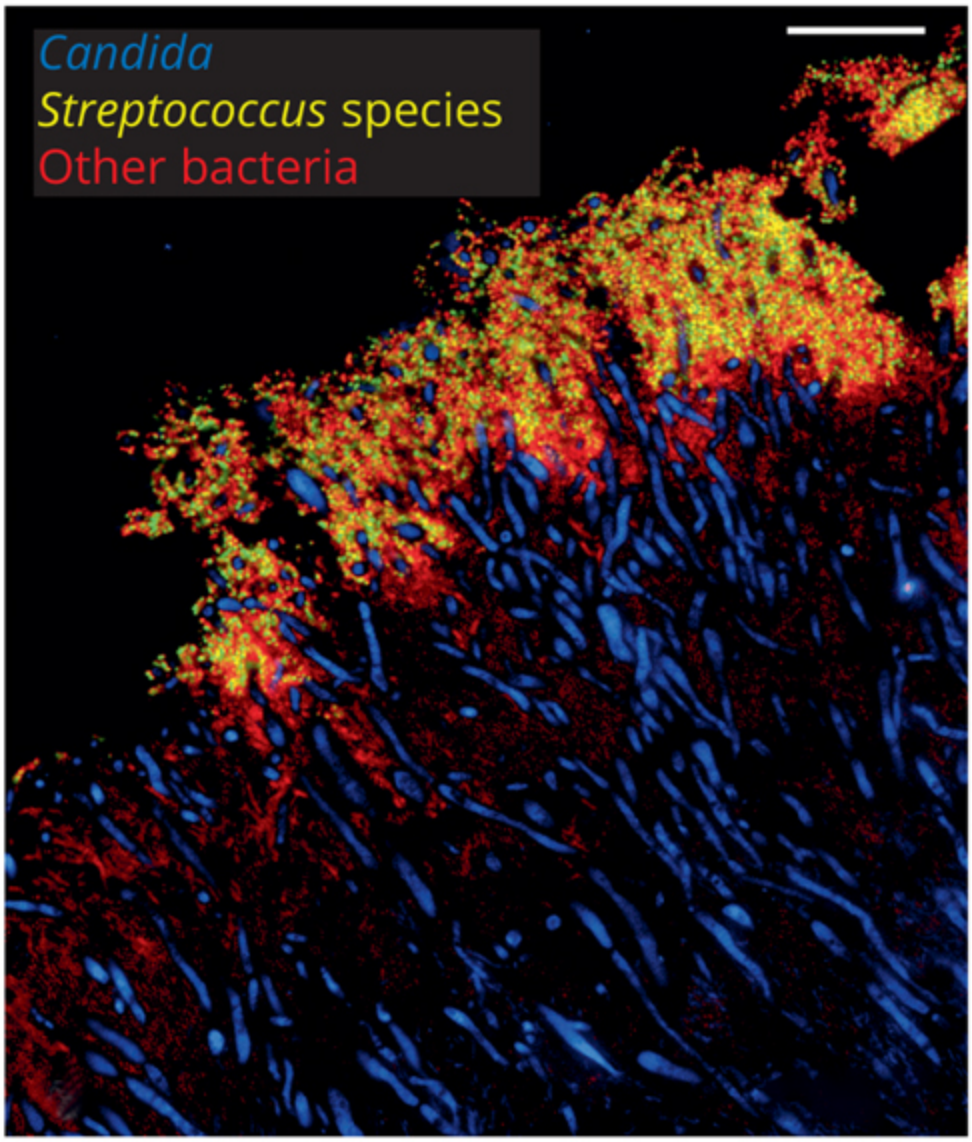
The structure of dental biofilms changes over time, from an initial colonization pattern dominated by adsorption of single bacteria and small multispecies aggregates of bacteria, which form complex multilayered microcolonies and biofilms after 24 to 48 hours.[7]

Molecular studies of mature biofilms from supra- and subgingival biofilms[8] and occlusal surfaces[9] using confocal microscopy and fluorescence in situ hybridization have demonstrated interesting structural features of such dental biofilms (Fig 6-1). For example, these studies have demonstrated in vivo biofilms comprise of a dense basal layer with a preferential localization of *Actinomyces* species (Figs 6-1b and c). In contrast, the outer layers seem to be more loosely structured (Figs 6-1a and c). Fungal species have recently been shown to be an important part of dental biofilm architecture, demonstrating hyphal networks with bacteria (Fig 6-1d).[5] Co-localization of *Candida* species and bacteria such as streptococci suggest beneficial interactions that may affect the ecology of the biofilm.









Figs 6-1a to d Images of microbial colonization patterns of in vivo biofilms on occlusal surfaces **(a and b)** and root surfaces **(c and d)**. The fluorescent colors of the respective bacterial and fungal organisms are marked on each image. The outermost part of the biofilms are located to the left **(a to c)** and **(d)** top. Note that the biofilm is divided into an inner compact layer covered with a looser structured layer **(a and c)**. *Candida* hyphal networks with bacteria are demonstrated **(d)**. Scale bars: 25 µm. (The copyright of these images remains with the author Irene Dige.)

The extracellular matrix is another important part of dental biofilms and consists of different types of biopolymers called extracellular polymeric substances (EPS), which include polysaccharides, extracellular DNA, proteins, and lipids. The EPS act as a scaffold that provides the mechanical stability of the biofilm by establishing a three-dimensional (3D) polymer network.[10] Several functions of EPS have been ascertained involving adhesion, cohesion, nutrient source, and protective barrier against chemical and biologic substances. Despite the growing interest in exploring the role of the extracellular matrix and the development of new methods, there is still a need for deeper insight into the spatial structure and function of the matrix.[11] For example, it is not known how the EPS synthesis among oral bacteria can facilitate environmental and biologic niches. From studies of mixed-species oral biofilm models, it is understood that areas with low pH reside inside complexes of exopolysaccharides.[12] In addition, identification of acidogenic hot spots within 3D dental in situ biofilms support the existence of heterogenous pH landscapes in dental biofilms.[13]

Recognition that microorganisms grow in structural communities that differ phenotypically from their counterparts growing in planktonic phase, and understanding how they interact through communication and production of the biofilm matrix, is fundamental to prevent and treat biofilm-induced dental diseases. The finding that bacteria in biofilms can be up to 1,000 times more resistant to antimicrobials than the same bacteria growing in planktonic phase[14] supports this view. Shifts in the balance of the resident microbiota driven by local environmental conditions, as described by the ecological plaque hypothesis,[1,15] can lead to demineralization in caries[16] or loss of alveolar bone in periodontal disease.[17]

How to interfere with the dental biofilm

The common goal for the dental practitioner is to help the patient maintain good oral health and thereby avoid imbalance in dental

biofilms. This has traditionally been endeavored by teaching patients good oral hygiene measures. From clinical observations it is known that if clinically biofilm-free conditions are obtained, caries lesion progression can be arrested, but there is no evidence of the threshold of biofilm quantity.[18] However, the age of the biofilm may play a role. For example, dental biofilms need to be well established, exceeding 2 days, to be able to cause pH drops below the critical pH resulting in demineralization of enamel.[19] Increased biofilm accumulation has also been shown to increase inflammation, the risk of gingivitis and halitosis, and suppression of beneficial bacteria.[1] Therefore, the strategy could be to aim at preventing biofilms from maturing. When the biofilm becomes thicker, a shift in the biofilm composition can take place, caused, for example, by reductions in oxygen and nutrients from saliva that favor specific micro-organisms.

The purpose of mechanical plaque removal is prevention of initial colonization of oral microorganisms, mechanical disruption of the biofilm, and possible removal of the biofilm. There is limited information on the effect of tooth brushing on biofilm. In order to investigate the effectiveness of different plaque removal methods, in vitro studies have been used to investigate the efficacy of various types of toothbrushes. One in vitro study showed that 16-hour-old biofilms adhered more tenaciously than initial biofilms,[20] which may be explained by the fact that adhering bacteria need time to anchor themselves to the surface and grow. The same study also demonstrated that the bacteria in the inner part of the biofilms were the most difficult to remove and required direct contact with the toothbrush bristles. Another study showed that complete removal of the biofilm cannot be achieved and biofilm will always be left behind.[21] A recent study investigated the impact of oral hygiene discontinuation on supragingival microbiomes.[22] This study demonstrated that the microbial composition of supragingival biofilm samples collected after 4, 7, and 10 days of oral hygiene cessation differed significantly from the baseline samples. Even though the data were collected from healthy individuals and not correlated with change in clinical endpoints, the data suggest that cessation of tooth

brushing may change the composition of the microbiota and thereby alter the ecology of the biofilm in favor of disease.[22]

Evidence on the combined effect of mechanical and chemical plaque removal is also lacking, and one study of 4-day biofilm grown intraorally on titanium disks showed incomplete biofilm removal.[23] The use of antibacterial agents is intended to achieve the same goal as mechanical plaque removal, including inhibition of bacterial adhesion and colonization, as well as disturbance of mature biofilms. However, certain agents such as chlorhexidine and essential oils could potentially also inhibit bacterial growth and metabolism and modify biofilm biochemistry and ecology. The fact that part of the dental biofilm is difficult to remove can be explained by the biofilm structure described above, with compact inner layers of biofilm.[8,9] Future research should provide deeper knowledge of the various components of the biofilm matrix, and a possible approach could be to develop inhibitors to disrupt the stability of the 3D matrix.[11]

On the other hand, as described above oral biofilms in dynamic balance with the host may not constitute a health problem. In fact, the resident microflora may prevent colonization of exogenous microorganisms that could drive the ecological balance towards disease development. Black pigmented dental biofilms are examples of biofilms that are difficult to remove but have a suggested positive association with lower caries experience.[24] In appreciation of ecological principles, an alternative approach to eliminate the biofilm is to try to control or even manipulate the biofilm to maintain a healthy balance with the host; for example, by introducing replacement strategies including pre- and probiotics (see Chapter 11). It has been argued that the practitioner should not only focus on elimination of the biofilm but rather maintain good oral health through a harmonious coexistence between the oral resident microbiota and the host.[25]

Both prevention and control/treatment of biofilm-induced dental disease are best achieved by teaching patients to perform

effective plaque control, supplemented with educating the patients on appropriate lifestyle choices and helping to reduce environmental factors that might lead to dysbiosis.

Clinical effect of biofilm control on dental caries

By definition, dental caries is a multifactorial, biofilm-mediated disease that develops in the sites favoring accumulation and maturation of the microbial deposits.[26] Thus, it is apparent that regular removal of the biofilm should act as a prerequisite for the control of caries development. However, many other determinants (see Chapter 17) might take a role in the caries process, by interacting with the metabolic processes in the biofilm, or by affecting the fluctuations of minerals at the interface with the tooth surface. Such a complex interplay of different variables determines the likelihood for caries lesion progression as well as the rate at which this occurs at any plaque-covered site.[27] Therefore, the impact of oral cleanliness alone is difficult to evaluate.

The role of fluoride

Presence of fluoride in the oral cavity, due to its well-recognized therapeutic effect, masks the effect of mechanical plaque removal. The majority of clinical studies that focused on plaque removal and showed inhibition of the caries process were performed using fluoridated dentifrices. A series of Cochrane systematic reviews provide solid evidence collected from a number of clinical trials, that regular tooth brushing with fluoride-containing toothpaste is associated with a clear reduction of caries increments.[28,29] Moreover, supervised procedures of oral care among children lead to greater benefits as compared to self-performance. Although these benefits

could be attributed to the improved delivery of fluoride to the oral cavity on a regular basis, the biologic effect of tooth cleaning should not be rejected. It is interesting to note that the remarkable decline of dental caries that occurred in the last decades of the 20th century in many Western European countries, was not associated with any particular preventive strategy; the emphasis on oral hygiene education, along with the regular use of fluoride toothpaste, proved to be as successful a method as education combined with additional fluoride delivery, other than toothpaste.[30]

The effect of tooth brushing separately from that of fluoride was investigated in the 1970s.[31,32] Koch and Lindhe[31] reported the results of a 3-year clinical trial in 9- to 11-year-old children involved in a preventive program based on daily supervised tooth brushing with nonfluoride dentifrice ("placebo"), or on other preventive regimes such as tooth brushing with NaF toothpaste, fortnightly mouth rinsing with 0.5% NaF solution, and fortnightly mouth rinsing with distilled water. They found that supervised daily brushing without fluoride significantly contributed to oral cleanliness, and reduced the plaque levels as well as gingival inflammation, but was of little value for control of dental caries. Those children who brushed their teeth under supervision with NaF dentifrice experienced about 50% lower caries increment than those in the placebo brushing group. It is important to note, however, that the number of new caries lesions that developed over the study period was significantly lower in children using NaF toothpaste than in those rinsing their mouth with 0.5% NaF solution (Fig 6-2). The other interesting observation was that smooth surfaces (the buccal surfaces, in particular) benefited from brushing most of all, most likely due to the easy access for cleaning as well as for the delivery of fluoride. The study by Horowitz et al[32] came to a similar conclusion, that the supervised use of the nonfluoride toothpaste had only marginal effect on the caries rates over the 2-year period; however, certain limitations of the study design, such as interrupted interventions during the summer periods, limit the value of their findings.

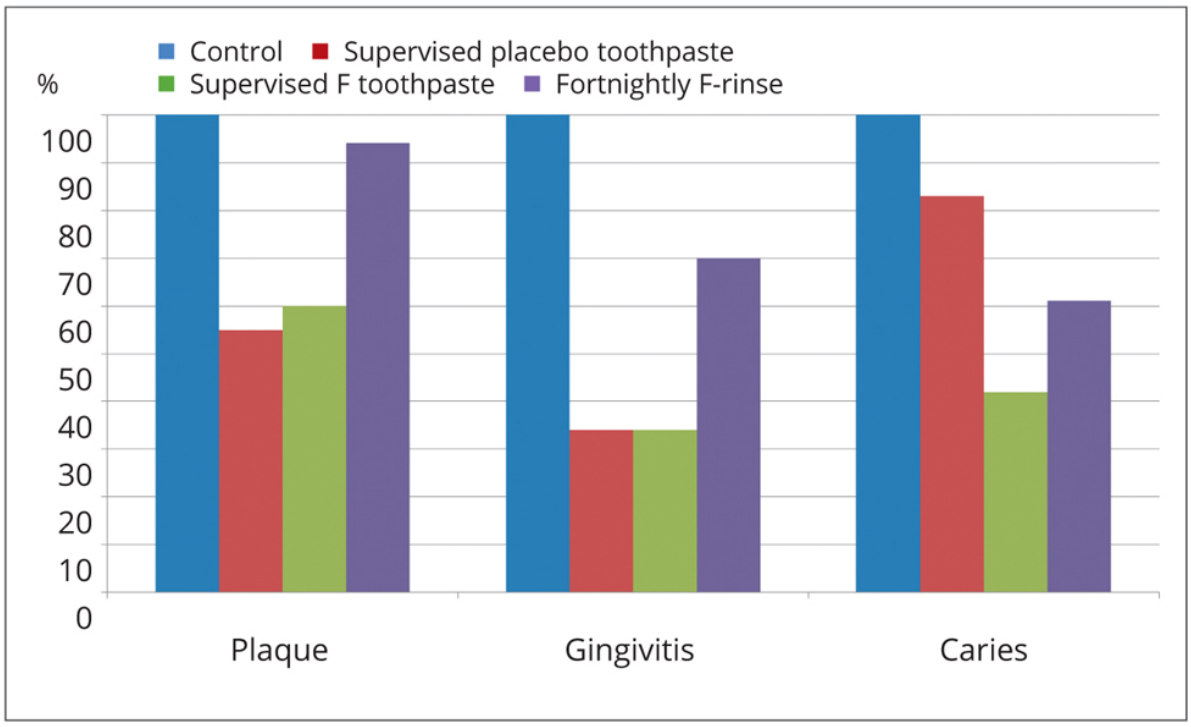


Fig 6-2 Three-year results of different preventive measures including supervised tooth brushing with nonfluoride toothpaste ("placebo") (according to Koch and Lindhe[31]).

The effect of supervised versus individually performed tooth cleaning

The second important point is that oral cleanliness is a behavior-dependent factor.[33] The usual methods to control accumulation of the dental biofilm on the dental surfaces are tooth brushing and interdental flossing. The quality of the biofilm removal makes a difference: a number of studies have shown that although fluoride is present, the caries experience is lower in the individuals with good oral hygiene.[34-36] Professionally performed or supervised tooth cleaning has been shown to be effective in caries reduction by a number of research groups.[36-38] In particular, an emphasis of the mechanical plaque control on the erupting surfaces has been shown to have an effect.[39,40] However, in all of these studies fluoride in

different formulations was involved. Interestingly, in a study focused on the plaque removal from proximal surfaces,[41] a caries-inhibiting effect of the regular supervised interdental flossing procedure in children was demonstrated in comparison with the self-performed unsupervised flossing. However, the use of fluoridated toothpaste under unsupervised conditions of interdental flossing did not have a superior effect to that of nonfluoridated toothpaste.[41]

Individually performed tooth brushing combines many variables, such as frequency and duration of brushing, the brushing method, and the toothbrush used, and these may affect the efficacy of the plaque removal.[42] Thus, infrequent brushers demonstrated a higher incidence of caries lesions than frequent brushers, particularly in the primary dentition.[43] A considerable variety in the choice of toothbrushes (manual or powered; varying in bristle shape, bristle size, and number of filaments) as well as in the tooth brushing methods implies that these may play a role in the oral cleanliness. However, no single tooth brushing technique or toothbrush design has been demonstrated to be superior. The most important principle is to access all available tooth surfaces, and to spend sufficient time for plaque removal, regardless of the basic method of tooth brushing that is used.[44] Unfortunately, not all tooth surfaces are equally accessible to cleaning; interproximal spaces or deep occlusal fissures are relatively inaccessible to the toothbrush filaments. The use of dental floss is a widely accepted measure for plaque removal from the interproximal space; however, there is very limited evidence regarding the anti-caries effect of unsupervised interdental cleaning, in permanent or in primary dentition.[45,46] Although a few early studies demonstrated a significant reduction of proximal caries in primary teeth as a result of supervised flossing,[41,47] the professional-quality flossing is a hardly achievable goal. Moreover, the topical fluoride exposure combined with tooth brushing may override the effectiveness of flossing.[48]

In summary, there is insufficient evidence regarding the clinical effect of the dental biofilm removal alone, in the management of dental caries. Nevertheless, meticulous tooth cleaning should be encouraged as it helps to control the biofilm accumulation in conjunction with the delivery of fluoride, provided fluoridated toothpaste is used. Regular tooth brushing with fluoride-containing toothpaste is associated with reduction of caries increments. Moreover, the quality of the biofilm removal plays a role in the control of dental caries.

Clinical effect of biofilm removal on periodontal and peri-implant diseases

Periodontal (gingivitis and periodontitis) and peri-implant (peri-implant mucositis and peri-implantitis) diseases are highly prevalent worldwide. Since there is parallelism between gingivitis and peri-implant mucositis and periodontitis and peri-implantitis, in order to simplify the reading, only references to gingivitis and periodontitis will be made in this chapter.

From an etiologic point of view, gingivitis is associated with the amount of periodontal biofilm present, while this etiology is more complex in the case of periodontitis. Periodontitis is a chronic inflammatory disease triggered by a dysbiotic biofilm and characterized by the destruction of the supporting periodontal tissues. *Porphyromonas gingivalis* has been identified as a keystone pathogen triggering the dysbiosis state, by altering the community of commensal microorganisms and, thus, leading to an unresolved chronic inflammation.[1] Therefore, periodontal biofilm play a critical role in the onset and development of periodontal diseases.

In the 11th European Workshop on Periodontology (European Federation of Periodontology) it was considered that although not all patients with gingivitis will develop periodontitis, management of gingivitis is considered a primary prevention strategy for periodontitis

and a secondary prevention strategy in successfully treated periodontitis cases[49] in order to prevent disease recurrence.[50]

Self-performed mechanical biofilm control

Prevention and treatment of periodontal diseases predominantly depend on high standards of mechanical biofilm control and this can be achieved through professional or self-performed strategies.[50,51] Professional mechanical biofilm removal as the sole element of professional preventive care is inappropriate since it is ineffective in the long term if high standards of daily patient-delivered oral hygiene are missing. This requires a patient-centered approach to education, motivation, and behavioral changes, and a good knowledge of the most effective methods of plaque removal,[52] mainly toothbrushes and interdental devices.

Toothbrushes

Toothbrushes might be manual or power. Manual toothbrushes have various designs, from flat-trim bristle designs (24% to 47% reduction in plaque scores from baseline scores), multilevel bristles (33% to 54% plaque level reduction), or crisscross designs (39% to 61% plaque reduction),[50] without statistically significant differences in effectiveness among them.

Several techniques for using manual toothbrushes have been described, and include vertical, horizontal, circular, Bass (Fig 6-3), modified Bass, Charles, Stillmann, and modified Stillmann,[53] with the modified Bass technique significantly more effective in removing supragingival biofilm than the other tooth brushing practices in both buccal and lingual sites.[54]

Figs 6-3a and b Tooth brushing using the Bass technique in the vestibular and lingual aspects.

Power toothbrushes can be divided based on the type of power (a rechargeable power or replaceable batteries) or the type of movement (rotating, oscillating, oscillating-rotating, side-to-side action). Higher biofilm level reduction has been demonstrated with toothbrushes with rechargeable power and an oscillating-rotating

effect.[50] Among power toothbrushes, sonic technology was introduced to produce fluid turbulent activity that might assist in biofilm removal. These devices can be divided according to the frequency and amplitude (high or low) of the sonic waves.

One single episode of tooth brushing allows the reduction of 42% and 46% of biofilm scores, for manual and powered tooth brushing, respectively. This has been confirmed in a recent systematic review on the topic, demonstrating a statistically significantly higher reduction in Quigley and Hein Plaque Index (0.16) for powered toothbrushes.[55] However, the use of these products should be tested in daily use.

The use of power toothbrushes on an everyday basis also reduces biofilm levels to a higher level than manual toothbrushes, in both the short and long term (11% at 1 to 3 months, 21% at ≥ 3 months). At present there are insufficient data to refute or accept any association between the use of power tooth brushing and oral side effects.[50]

When talking about sonic toothbrushes, they have been compared to both manual and oscillating-rotating toothbrushes, demonstrating superiority over manual technology[56] and inferiority when compared to oscillating-rotating toothbrushes.[57]

On the other hand, infrequent tooth brushing has been associated with an increased probability of developing periodontitis in a systematic review of cross-sectional studies (odds ratio = 1.41; $P < .001$).[58] Furthermore, an 11-year prospective study demonstrated that subjects reporting brushing twice or more a day develop 1.99 less teeth with probing depths greater or equal to 4 mm than subjects without this behavior.[59]

In summary, it can be concluded that tooth brushing with manual or powered toothbrushes is efficacious in removing biofilm, treating gingivitis, and, therefore, preventing the onset of periodontitis.

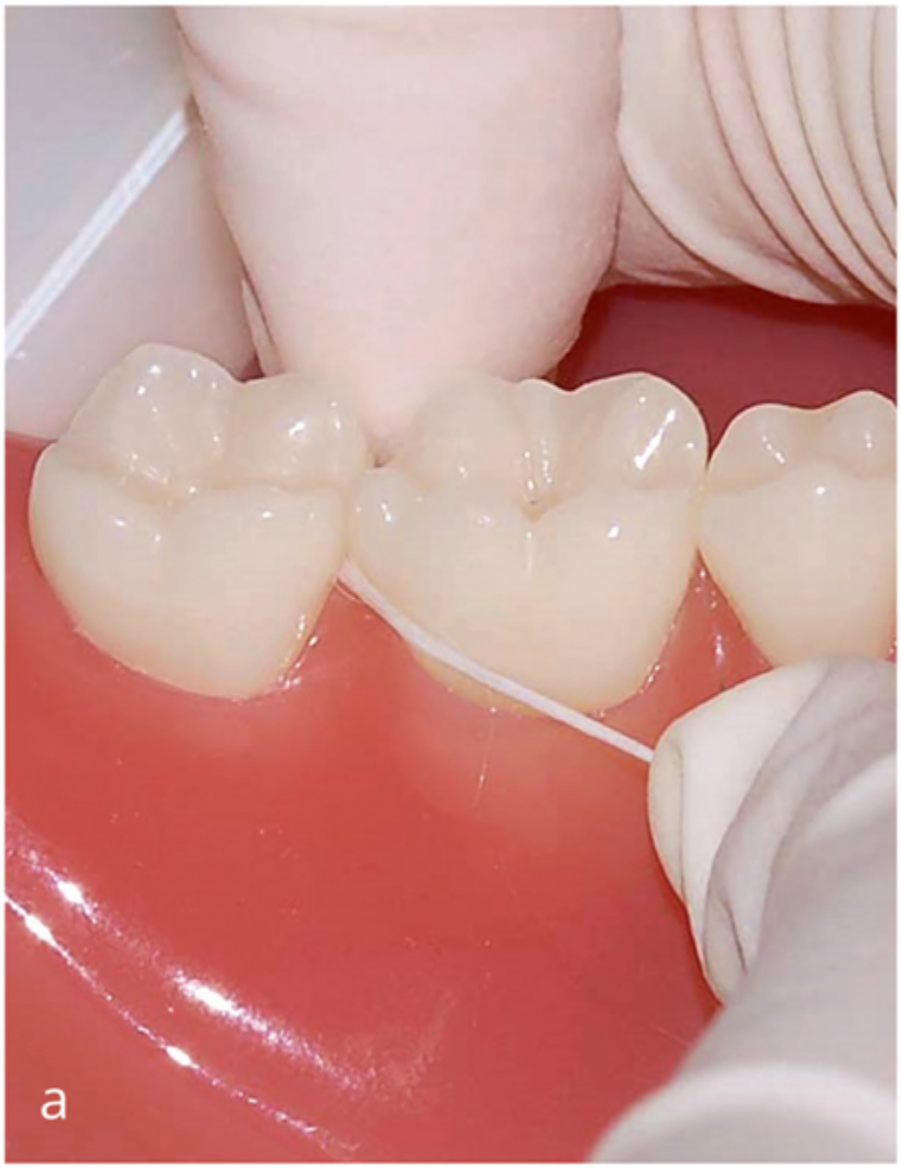
In terms of peri-implant diseases, there are no studies available for primary prevention of peri-implant mucositis, in contrast to gingivitis; however, it has been considered that self-performed plaque control (by means of manual or power toothbrushes) in conjunction with professional administered plaque removal is effective in the treatment of peri-implant mucositis. Although complete resolution

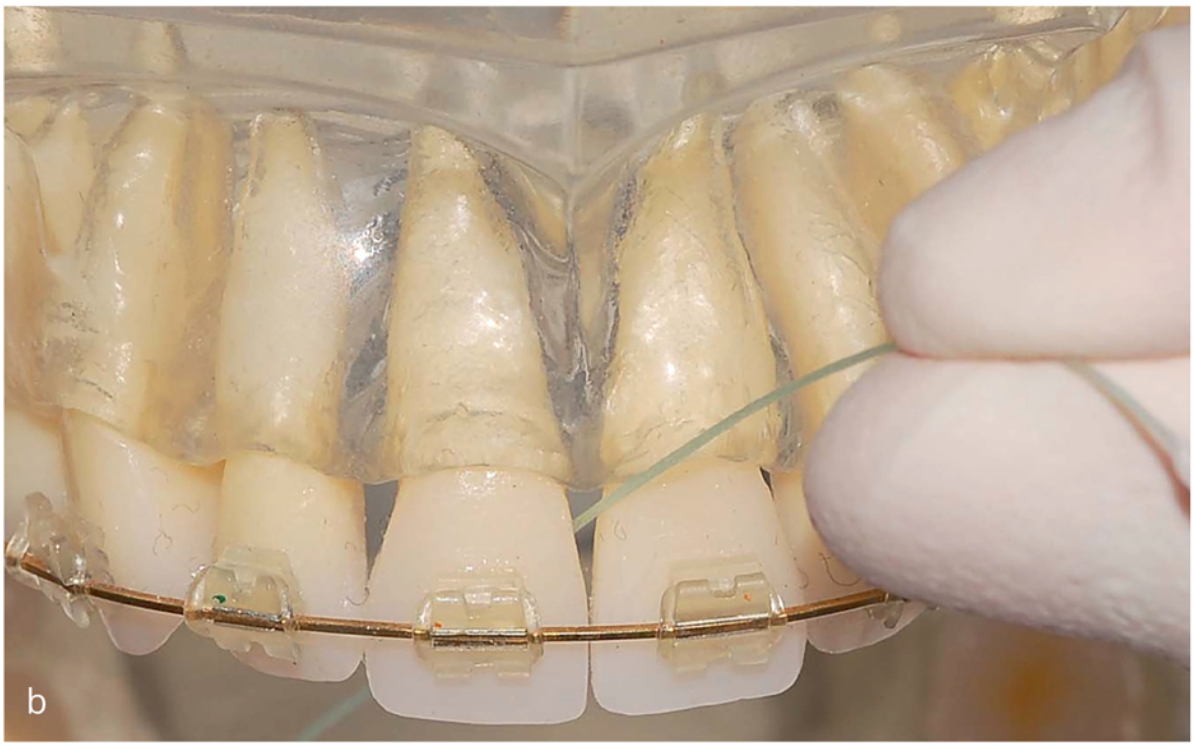
has not always been reported, a reduction in clinical signs of inflammation is evident.[60]

Interdental devices

Toothbrushes are not able to penetrate into interdental spaces, where periodontal diseases first develop. Therefore, some interdental devices have been described to be used in conjunction with tooth brushing, such as dental floss, toothpicks, water jet irrigation devices, or interdental brushes.[61]

Dental floss is able to remove interproximal plaque, and is effective in the management of periodontal diseases when performed in conjunction with toothbrushing.[50] However, patient compliance to dental floss is low and patients usually perceive it as difficult to use (Fig 6-4).[46] This results in a misperception of lack of efficiency with dental floss for the prevention of periodontal diseases (see Chapter 7).



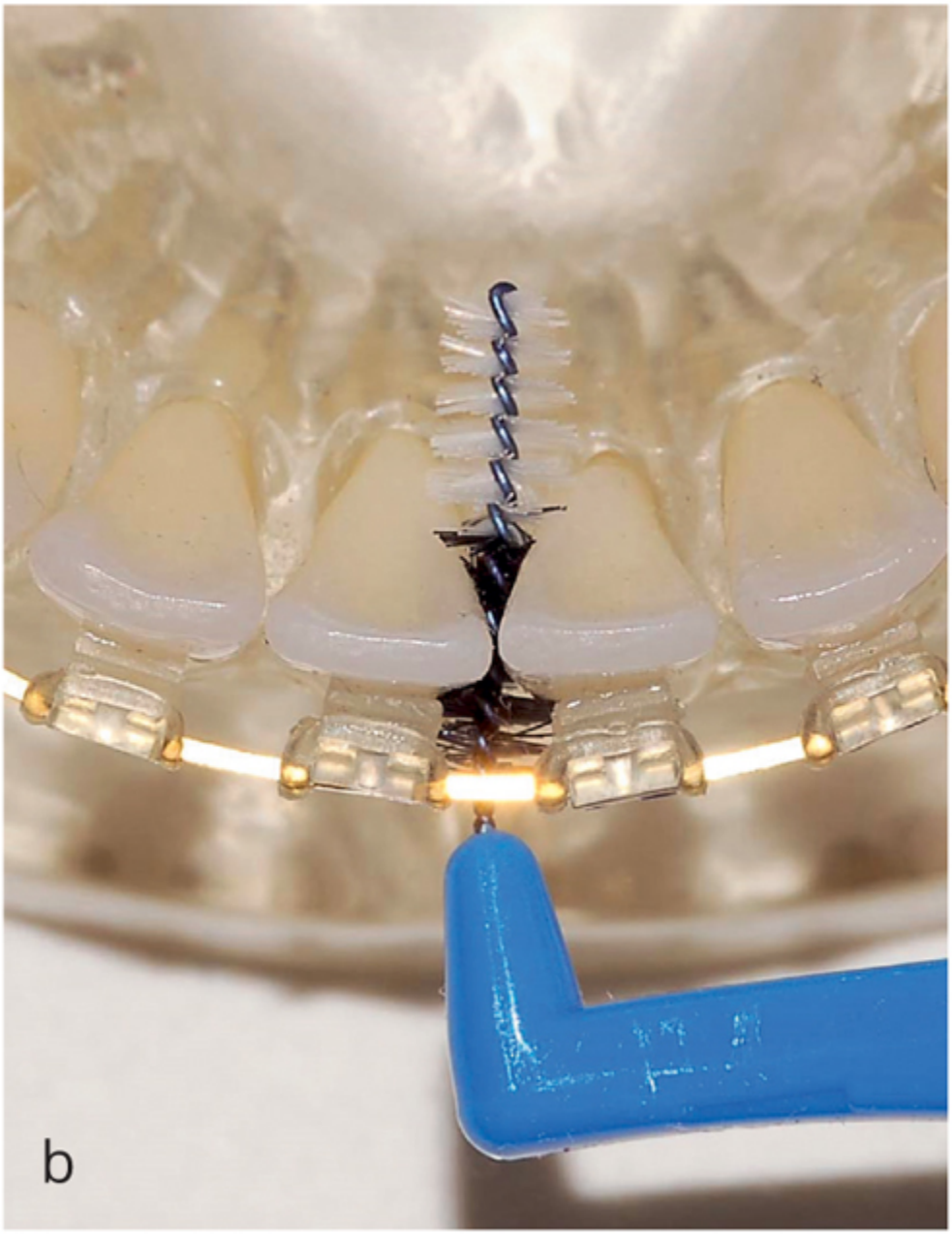


Figs 6-4a and b (a) Use of dental floss for cleaning the mesial and distal aspect of proximal narrow spaces. **(b)** Threading is needed if the proximal space is closed.

Toothpicks have been used historically for cleaning tooth surfaces. Nowadays they are still used in older age groups in the United States, Eastern Europe, China, Korea, and Japan, usually to eliminate food debris interproximally. Interdental rubber tips are also used to stimulate blood flow.

Water jet irrigators work with water under pressure in order to remove dental biofilm. There are different tips in order to use them supra- or subgingivally.

Interdental brushes consist of a central thin wire with small cylindrical or cone-shaped bristles (Fig 6-5). They can be found in a range of different widths, known as “passage hole diameter” (PHD), which is the smallest interdental space where the interdental brush can be inserted. They are easier to use than dental floss, and are effective in removing interdental plaque, although there has been some controversy regarding their reduction of clinical parameters.



Figs 6-5a and b Use of interdental toothbrushes: the biggest brush fitting into the proximal space is selected.

Dental floss and water jet irrigation devices can be used in all interdental spaces, whereas interdental brushes and toothpicks can only be used in those interdental spaces wide enough to allow the device.[46]

There have been two recent systematic reviews dealing with the efficacy of interdental devices on periodontal diseases: a Cochrane systematic review using pairwise traditional meta-analyses compared active products versus control groups,[46] and another using network meta-analyses to allow the integration of data from direct (treatments compared within a trial) and indirect comparisons (treatments compared among trials through a common comparator treatment).[61] The following conclusions can be highlighted:

- Flossing or using an interdental brush, in addition to tooth brushing, may reduce gingivitis (in term of Gingival Index) at 1, 3, or 6 months, although there was no clear difference in bleeding sites.
- Interdental brushes may reduce biofilm more than tooth brushing alone.
- Using wooden cleaning sticks or rubber/elastomeric interdental cleaning sticks, plus tooth brushing, may reduce bleeding sites at 3 months or plaque at 1 month.
- Oral irrigators may reduce gingivitis at 1 month but not at 3 or 6 months. They did not reduce bleeding sites at 1 or 3 months, or plaque at 1, 3, or 6 months, more than tooth brushing alone.
- When comparing between different interdental devices as adjuncts to tooth brushing, interdental brushes demonstrated the largest reduction in gingival inflammation, followed by oral irrigators, with toothpicks demonstrating the worst results.
- Only minor adverse effects, such gingival irritation, have been associated with the use of interdental devices.

Chemical biofilm control

As self-performed mechanical plaque removal is not always performed to an optimal or even adequate standard,[62] adjunctive chemical biofilm control procedures have been proposed, such as the use of antiseptics and other chemotherapeutics delivered in

various formats including mouth rinses, dentifrices, or gels. Chemical agents can be classified as antimicrobials (bactericidal or bacteriostatic effect), plaque inhibitors (have an effect on biofilm, but no effect on gingivitis), anti-plaque (have an effect on biofilm and gingivitis), or anti-gingivitis agents (have an effect on gingivitis, without an effect on biofilm levels).

A recent systematic review, including only 6-month randomized controlled clinical trials, demonstrated that the adjunctive use of anti-plaque agents provided statistically significant improvements in Gingival, Bleeding, and Plaque Indexes, when compared to a negative control.[63] More recently, data on the Turesky modification of the Quigley and Hein Plaque Index[64] and on gingival inflammation,[65] based on the previous systematic review, was analyzed using network meta-analysis. The results revealed that, despite the high variability in the number of studies comparing each active agent and the different risks of bias (when comparing among products and formulations), chlorhexidine and essential oils within mouth rinses, and chlorhexidine and triclosan-copolymer, within dentifrices, appeared to be the most effective active agents for plaque control. In terms of gingival inflammation, no clear differences were found within dentifrices, while mouth rinses containing essential oils or chlorhexidine showed the greatest effect.

Following the latest clinical guidelines from the European Federation of Periodontology (EFP)[66] for the treatment of periodontitis stages I to III, it is important to remark that the basis of the management of gingival inflammation is self-performed mechanical removal of biofilm. For this supragingival dental biofilm control by the patient the following aspects have been recommended[66]:

- repeated individually tailored instructions
- considering patient's need and preferences when choosing a toothbrush or an interdental brush design
- if anatomically possible, toothbrushing should be supplemented by the use of interdental brushes.

In terms of adjunctive therapies for gingival inflammation,[66] adjunctive measures, including antiseptic, may be considered in specific cases, as part of a personalized treatment approach.

Understanding the composition and structure of dental biofilm is fundamental to prevent and treat biofilm-induced dental diseases. It is important to acknowledge the nature of dental biofilms and the need to establish an ecological balance within the multispecies microbial community organized in a three-dimensional network of extracellular matrix. In case of dysbiosis within the biofilm and consequent development of dental caries and periodontal and peri-implant diseases, the strategy must be to teach patients to perform effective plaque control.

References

1. Sanz M, Beighton D, Curtis MA, et al. Role of microbial biofilms in the maintenance of oral health and in the development of dental caries and periodontal diseases. Consensus report of group 1 of the joint EFP (ORCA workshop on the boundaries between caries and periodontal diseases. J Clin Periodontol 2017;44(Suppl 18):5–11.
2. Nyvad B. Microbial colonization of human tooth surfaces. APMIS Suppl 1993;32:1–45.
3. Dewhirst FE, Chen T, Izard J, et al. The human oral microbiome. J Bacteriol 2010;192:5002–5017.
4. Diaz PI, Strausbaugh LD, Dongari-Bagtzoglou A. Fungal-bacterial interactions and their relevance to oral health: linking the clinic and the bench. Front Cell Infect Microbiol 2014;4:101.
5. Dige I, Nyvad B. *Candida* species in intact in vivo biofilm from carious lesions. Arch Oral Biol 2019;101:142–146.

6. Takahashi N. Oral microbiome metabolism: from “who are they?” to “what are they doing?” J Dent Res 2015;94:1628–1637.
7. Dige I, Raarup MK, Nyengaard JR, Kilian M, Nyvad B. *Actinomyces naeslundii* in initial dental biofilm formation. Microbiology 2009;155:2116–2126.
8. Zijnge V, van Leeuwen MB, Degener JE, et al. Oral biofilm architecture on natural teeth. PloS One 2010;5:e9321.
9. Dige I, Gronkjaer L, Nyvad B. Molecular studies of the structural ecology of natural occlusal caries. Caries Res 2014;48:451–460.
10. Flemming HC, Wingender J. The biofilm matrix. Nat Rev Microbiol 2010;8:623–633.
11. Cugini C, Shanmugam M, Landge N, Ramasubbu N. The role of exopolysaccharides in oral biofilms. J Dent Res 2019;98:739–745.
12. Xiao J, Klein MI, Falsetta ML, et al. The exopolysaccharide matrix modulates the interaction between 3D architecture and virulence of a mixed-species oral biofilm. PLoS Pathog 2012;8:e1002623.
13. Dige I, Baelum V, Nyvad B, Schlafer S. Monitoring of extracellular pH in young dental biofilms grown in vivo in the presence and absence of sucrose. J Oral Microbiol 2016;8:30390.
14. Davies D. Understanding biofilm resistance to antibacterial agents. Nat Rev Drug Discov 2003;2:114–122.
15. Marsh PD. Microbial ecology of dental plaque and its significance in health and disease. Adv Dent Res 1994;8:263–271.
16. Takahashi N, Nyvad B. The role of bacteria in the caries process: ecological perspectives. J Dent Res 2011;90:294–303.
17. Moore WEC, Moore LVH. The bacteria of periodontal diseases. Periodontol 2000 1994;5:66–77.

18. Nyvad B, Fejerskov O. Assessing the stage of caries lesion activity on the basis of clinical and microbiological examination. Community Dent Oral Epidemiol 1997;25:69–75.
19. Imfeld T, Lutz F. Intraplaque acid formation assessed in vivo in children and young adults. Pediatr Dent 1980;2:87–93.
20. Verkaik MJ, Busscher HJ, Rustema-Abbing M, Slomp AM, Abbas F, van der Mei HC. Oral biofilm models for mechanical plaque removal. Clin Oral Investig 2010;14:403–409.
21. Jongsma MA, van de Lagemaat M, Busscher HJ, et al. Synergy of brushing mode and antibacterial use on in vivo biofilm formation. J Dent 2015;43:1580–1586.
22. Belstrøm D, Sembler-Møller ML, Grande MA, et al. Impact of oral hygiene discontinuation on supragingival and salivary microbiomes. JDR Clin Trans Res 2018;3:57–64.
23. Charalampakis G, Ramberg P, Dahlén G, Berglundh T, Abrahamsson I. Effect of cleansing of biofilm formed on titanium discs. Clin Oral Implants Res 2015;26:931–936.
24. Żyła T, Kawala B, Antoszewska-Smith J, Kawala M. Black stain and dental caries: a review of the literature. Biomed Res Int 2015;2015:469392.
25. Kilian M. The oral microbiome - friend or foe? Eur J Oral Sci 2018;126(Suppl 1):5–12.
26. Fejerskov O, Nyvad B, Kidd E (eds). Dental caries: The disease and its clinical management, 3rd edn. Oxford: Wiley Blackwell, 2015:7–10.
27. Fejerskov O. Concepts of dental caries and their consequences for understanding the disease. Community Dent Oral Epidemiol 1997;25:5–12.
28. Marinho VCC, Higgins J, Logan S, Sheiham A (deceased). Fluoride toothpastes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2003;1:CD002278.
29. Marinho VCC, Higgins JPT, Sheiham A, Logan S. One topical fluoride (toothpastes, or mouthrinses, or gels, or varnishes)

versus another for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2004;1:CD002780.

30. Källestål C, Wang NJ, Petersen PE, Arnadottir IB. Caries-preventive methods used for children and adolescents in Denmark, Iceland, Norway and Sweden. Community Dent Oral Epidemiol 1999;27:144–151.
31. Koch G, Lindhe J. The state of the gingivae and the caries increments in schoolchildren during and after withdrawal of various prophylactic measures. In: McHugh WD (ed). Dental plaque. Edinburgh: Livingstone, 1970:271–281.
32. Horowitz AM, Suomi JD, Peterson JK, Lyman BA. Effects of supervised daily dental plaque removal by children: II. 24 months' results. J Public Health Dent 1977;37:180–188.
33. Ebel S, Blättermann H, Weik U, Margraf-Stiksrud J, Deinzer R. High plaque levels after thorough toothbrushing: what impedes efficacy? JDR Clin Trans Res 2019;4:135–142.
34. Mathiesen AT, Ogaard B, Rolla G. Oral hygiene as a variable in dental caries experience in 14-year-olds exposed to fluoride. Caries Res 1996;30:29–33.
35. Chestnutt IG, Schafer E, Jacobson APM, Stephen KW. The influence of toothbrushing frequency and postbrushing rinsing on caries experience in a caries clinical trial. Community Dent Oral Epidemiol 1998;26:406–411.
36. Machiulskiene V, Richards A, Nyvad B, Baelum V. Prospective study of the effect of post-brushing rinsing behavior on dental caries. Caries Res 2002;36:3031–3037.
37. Axelsson P, Lindhe J. The effect of a preventive programme on dental plaque, gingivitis and caries in schoolchildren. Results after one and two years. J Clin Periodontol 1974;1:123–138.
38. Kjaerheim V, von der Fehr, Pulsen S. Two-year study on the effect of professional toothcleaning on children in Oppergaard, Norway. Community Dent Oral Epidemiol 1980;8:401–406.
39. Carvalho JC, Thylstrup A, Ekstrand KR. Results after 3 years of non-operative occlusal caries treatment of erupting permanent

first molars. Community Dent Oral Epidemiol 1992;20:187–192.

40. Ekstrand KR, Kuzmina IN, Kuzmina E, Christiansen ME. Two and a half -year outcome of caries-preventive programs offered to groups of children in the Solntsevsky district of Moscow. Caries Res 2000;34:8–19.
41. Wright GZ, Feasby WH, Banting DVB. The effectiveness of interdental flossing with and without fluoride dentifrice. Pediatr Dent 1980:2:1059.
42. Slot DE, Wiggelinkhuizen L, Rosema NA, Van der Weijden GA. The efficacy of manual toothbrushes following a brushing exercise: a systematic review. Int J Dent Hyg 2012;10:187–197.
43. Kumar S, Tadakamadla J, Johnson NW. Effect of toothbrushing frequency on incidence and increment of dental caries: a systematic review and meta-analysis. J Dent Res 2016;95:1230–1236.
44. Baruah K, Thumpala VK, Khetani P, Baruah Q, Tivari R, Dixit H. A review on toothbrushes and tooth brushing methods. Int J Pharm Sci Invent 2017;6:29–38.
45. de Oliveira KMH, Nemezio MA, Romualdo PC, et al. Dental flossing and proximal caries in the primary dentition: a systematic review. Oral Health Prev Dent 2017;15:427–434.
46. Worthington HV, MacDonald L, Poklepovic Pericic T, et al. Home use of interdental cleaning devices, in addition to toothbrushing, for preventing and controlling periodontal diseases and dental caries. Cochrane Database Syst Rev 2019;4:CD012018
47. Wright GZ, Banting DW, Feasby WH. The Dorchester dental flossing study: final report. Clin Prev Dent 1979;1:23–26.
48. Hujoel PP, Cunha-Cruz J, Banting DW, Loesche WJ. Dental flossing and interproximal caries: a systematic review. J Dent Res 2006;85:2098–2305.
49. Chapple ILC, Mealey BL, Van Dyke TE, et al. Periodontal health and gingival diseases and conditions on an intact and a reduced periodontium: Consensus report of workgroup 1 of the

2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Clin Periodontol 2018;45(Suppl 20):S68–S77.

50. Chapple IL, Van der Weijden F, Doerfer C, et al. Primary prevention of periodontitis: managing gingivitis. J Clin Periodontol 2015;42(Suppl 16):S71–S76.
51. Figuero E, Nobrega DF, Garcia-Gargallo M, Tenuta LM, Herrera D, Carvalho JC. Mechanical and chemical plaque control in the simultaneous management of gingivitis and caries: a systematic review. J Clin Periodontol 2017;44(Suppl 18):S116–S134.
52. Tonetti MS, Chapple IL, Jepsen S, Sanz M. Primary and secondary prevention of periodontal and peri-implant diseases: Introduction to, and objectives of the 11th European Workshop on Periodontology consensus conference. J Clin Periodontol 2015;42(Suppl 16):S1–S4.
53. Wainwright J, Sheiham A. An analysis of methods of toothbrushing recommended by dental associations, toothpaste and toothbrush companies and in dental texts. Br Dent J 2014;217:E5.
54. Poyato-Ferrera M, Segura-Egea JJ, Bullon-Fernandez P. Comparison of modified Bass technique with normal toothbrushing practices for efficacy in supragingival plaque removal. Int J Dent Hyg 2003;1:110–114.
55. Elkerbout TA, Slot DE, Rosema NAM, Van der Weijden GA. How effective is a powered toothbrush as compared to a manual toothbrush? A systematic review and meta-analysis of single brushing exercises Int J Dent Hyg 2020;18:17–26.
56. de Jager M, Rmaile A, Darch O, Bikker JW. The effectiveness of manual versus high-frequency, high-amplitude sonic powered toothbrushes for oral health: a meta-analysis. J Clin Dent 2017;28:A13–A28.
57. Cahuana-Vasquez RA, Conde E, Grender JM, Cunningham P, Qaqish J, Goyal CR. An eight-week clinical evaluation of an oscillating-rotating power toothbrush with a brush head utilizing

angled bristles compared with a sonic toothbrush in the reduction of gingivitis and plaque. J Clin Dent 2015;26:80–85.

58. Zimmermann H, Zimmermann N, Hagenfeld D, Veile A, Kim TS, Becher H. Is frequency of tooth brushing a risk factor for periodontitis? A systematic review and meta-analysis. Community Dent Oral Epidemiol 2015;43:116–127.
59. Joshi S, Suominen AL, Knuuttila M, Bernabe E. Toothbrushing behaviour and periodontal pocketing: an 11-year longitudinal study. J Clin Periodontol 2018;45:196–203.
60. Jepsen S, Berglundh T, Genco R, et al. Primary prevention of peri-implantitis: managing peri-implant mucositis. J Clin Periodontol 2015;42(Suppl 16):S152–S157.
61. Kotsakis GA, Lian Q, Ioannou AL, Michalowicz BS, John MT, Chu H. A network meta-analysis of interproximal oral hygiene methods in the reduction of clinical indices of inflammation. J Periodontol 2018;89:558–570.
62. van der Weijden GA, Hioe KP. A systematic review of the effectiveness of self-performed mechanical plaque removal in adults with gingivitis using a manual toothbrush. J Clin Periodontol 2005;32(Suppl 6):214–228.
63. Serrano J, Escribano M, Roldan S, Martin C, Herrera D. Efficacy of adjunctive anti-plaque chemical agents in managing gingivitis: a systematic review and meta-analysis. J Clin Periodontol 2015;42(Suppl 16):S106–S138.
64. Escribano M, Figuero E, Martin C, et al. Efficacy of adjunctive anti-plaque chemical agents: a systematic review and network meta-analyses of the Turesky modification of the Quigley and Hein plaque index. J Clin Periodontol 2016;43:1059–1073.
65. Figuero E, Herrera D, Tobías A, et al. Efficacy of adjunctive anti-plaque chemical agents in managing gingivitis: a systematic review and network meta-analyses. J Clin Periodontol 2019 46:723–739.
66. Sanz M, Herrera D, Kebschull M, et al. Treatment of stage I-III periodontitis: The EFP S3 level clinical practice guideline. J Clin

Periodontol 2020;47(Suppl 22):4–60.

7

Interdental oral hygiene: To floss, or not to floss?

Falk Schwendicke, Christian H. Splieth

The two main dental diseases, caries and periodontal disease, are associated with biofilms and dysbiosis.[1] For caries, a repeated provision of fermentable carbohydrates leads to a change in supragingival biofilm composition, from nonacidogenic and nonaciduric to acidogenic, aciduric, and hence cariogenic bacteria, resulting in the generation of relevant organic acids leading to mineral loss of the hard tissues. For periodontal disease, pathogenic supragingival and, more so, subgingival biofilms are similarly characterized by a dysbiosis, provoking an inflammation of the periodontal tissue, ie gingivitis or, in later stages, periodontitis.

Mechanical biofilm removal is one main, causal strategy in prevention of both diseases, and in managing them. This mechanical biofilm removal is mainly performed via tooth brushing: Tooth brushing removes biofilm, and also serves to deliver fluoride as one main preventive strategy for caries prevention (see Chapter 3). However, tooth brushing is, even if performed with high quality, not able to remove biofilm sheltered in dental niches, mainly in interdental areas.[2,3] To allow mechanical biofilm removal in these

interdental areas, interdental oral hygiene using either floss or interdental brushes has been recommended.

Flossing is performed by moving a dental floss, either waxed or nonwaxed, up- and downwards along the interdental tooth surfaces (Fig 7-1). Floss should not be used in a saw-like action. The application of floss into the interdental space is not easy for most patients, as some dexterity and training is needed. Conventionally, flossing is recommended for interdental cleaning of either very narrow interdental spaces (eg, crowded anterior mandibular region) or, more often, for interdental spaces with an intact gingival papilla. Interdental brushing, in contrast, is slightly easier to use for most patients, especially in anterior areas (up to premolars). The interdental brush should fill out the interdental space, and should not be too small, as its bristles need to be in contact with the dental surfaces to realize any cleaning effect. The brush is then used in a bottle-cleaning like motion of mainly fore and back movements, and also minimal rotations. Interdental brushes are available in different sizes to allow application in narrower and wider spaces; very small sizes can also be used in interdental areas with only minimal gingival recession.

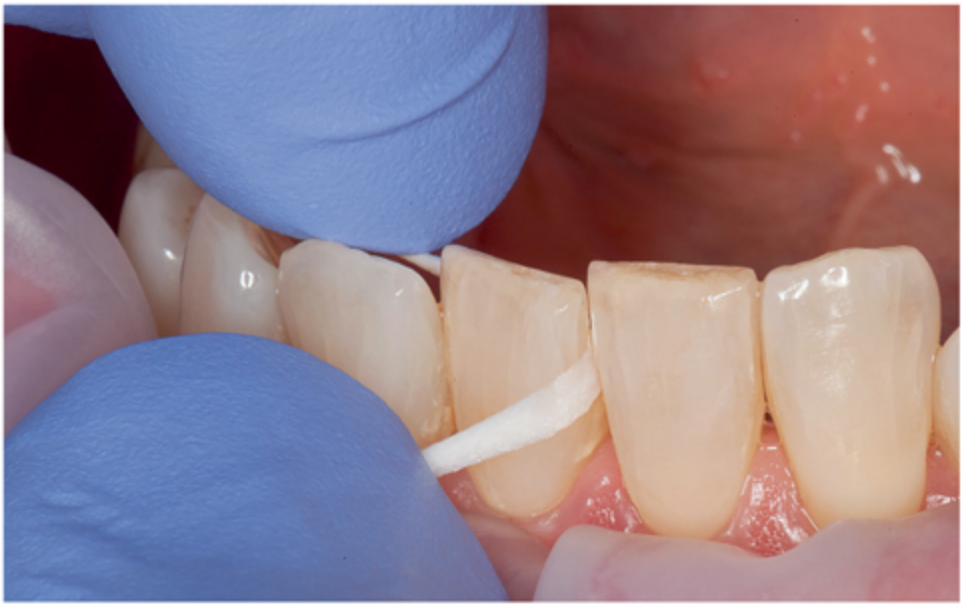


Fig 7-1 Flossing is supported by only low levels of evidence. However, patients should not be discouraged when they use floss, but properly instructed for using soft horizontal movements. This may help to avoid damage like “flossing clefts” due to saw-like vertical actions.

The evidence for flossing

Recently, the evidence base of flossing has been re-examined after two systematic reviews questioned its preventive effect for caries, for plaque removal, and for the prevention of gingivitis.[4,5] In the case of caries, the plausibility of flossing as a preventive measure is generally accepted (see Chapter 4). There is evidence that the additional plaque removal induced by flossing generates only low caries-preventive effects, which are mainly conferred by fluoride toothpaste instead (see Chapter 6, Fig 6-2).[6] There is ample evidence that plaque removal itself may have only limited preventive effectiveness, especially when fluoridated toothpaste is not a key part.[7]

Two more recent systematic reviews on interdental cleaning and its effect on plaque, gingivitis, and caries stress that no relevant studies on caries can be found, and that flossing is less effective for plaque removal than interdental brushes.[8,9] There is weak evidence that flossing, in addition to tooth brushing, may reduce gingivitis.[9]

From a practical point of view, flossing is one of the least adapted oral preventive measures: Both the sales figures for dental floss as well as the self-reported use of floss remain disappointing after decades of promoting its use.[10,11] Even in clinical trials on proximal caries lesion management, where patients are specifically instructed how to use floss, only a limited number of patients truly adopt,[11] and consequently, interproximal plaque and gingivitis scores do not improve.[12]

A more detailed look into the evidence on flossing was provided by a systematic review on the effect of dental flossing on interproximal

caries.[4] The review included six randomized clinical trials, which are preferable over cohort studies, where patients were assigned randomly to the test or control group, hence reducing the risk of a selection bias. For example, groups where dental floss is used regularly could also have a higher dental awareness and health literacy and overall lower caries risk. The different studies were conducted in various settings, which allow for a judgement of potential cofactors (Table 7-1):

- Professional flossing on schooldays shows clear caries preventive effects and feasibility.
- High-frequency professional flossing in schools would, however, be cost-intensive. On the other hand, a reduced frequency of flossing only every 3 months does not have a clinically relevant effect any more.
- Self-performed and even supervised flossing does not lead to relevant caries reductions, potentially due to inadequate application.

Table 7-1 Randomized clinical trials on the efficacy of dental flossing on interproximal caries (Hujoel et al[4])

	No. analyzed/age; duration; risk group in control vs flossing	Intervention	Control group	Outcome (relative risk [confidence interval]; measurement)	Fluoride exposure
Wright et al[13]	88/mean 5.8 y; 1.7 y; 14% vs 7%	Professional flossing on school days	Split-mouth; contralateral side	46% (0.3–0.7); DFS/dfs including x-ray	No information; no water fluoridation
Wright et al[14]	147/1st grade; 1.7 y; 12% vs 8%	Professional flossing in school	Split-mouth; contralateral side	67% (0.5–0.9); DFS including x-ray	No water fluoridation; self-report on F or non-F toothpaste
Gisselsson et al[15]	148/11 y; 3 y; 10% vs 8%	Professional flossing every 3rd month	Parallel group; no flossing instructions	81% (0.6–1.2); DFS including x-ray	Water fluoride 0.3 ppm; weekly 0.2% NaF rinse
Gisselsson et al[16]	174/4 y; 3 y; 27% vs 28%	Professional flossing every 3rd month	Parallel group; no flossing instructions	105% (0.8–1.5); def including x-ray	Water fluoride 0.2 ppm; recommended 250 ppm F toothpaste and F tablets
Granath et al[17]	140/12–13 y; 2 y; 25% vs 25%	Supervised flossing on school days	Split-mouth; contralateral side	101% (0.9–1.27); DFS including x-ray	F-toothpaste and every 6th week 0.2% NaF solution
Gisselsson et al[18]	35/10–11 y; 2 y; 14% vs 10%	Unsupervised flossing with instruction and re-instruction	Parallel group; no flossing instructions	102% (0.3–1.9); DFS of incisors and 1st molars	Weekly 0.2% NaF solution and semi-annual topical F

In addition, it may be added that flossing has some effectiveness to remove plaque and prevent gingivitis, again depending on patients' compliance and application.

The evidence for interdental brushes

A recent systematic review found very limited evidence supporting the use of interdental brushes.[9] For caries prevention, no study could be included at all. There are two studies on a total of 93 individuals demonstrating that these brushes are more effective in plaque removal than tooth brushing (Table 7-2). Consequently, gingivitis, measured by Gingival Index or Bleeding Index, was significantly reduced by interdental brushing; again, the same two studies (93 individuals) assessed these outcomes. Interdental brushes have also

been found more effective than flossing for plaque removal and gingivitis prevention.

Table 7-2 Comparison of interdental brushes plus tooth brushing versus tooth brushing alone (from Worthington et al[9] including references)

Study	Risk of bias	Assessment	Results	Adverse events
Graziani et al[2]	Unclear	Bleeding at 1 month; plaque	Interdental brushing reduced plaque levels by around 60%, whereas in the control group, the reduction was only around 30%. Gingival health (bleeding) was also significantly improved.	None assessed/ reported.
Jared et al[19]	Unclear	Gingival health at 1 month; plaque	Interdental brushing reduced plaque levels 30%–40% compared with the control. Gingival health also showed significantly higher improvements in the interdental brushing than in the control group.	Adverse events were assessed, but not reported.

Clinical considerations

It seems that under ideal conditions, flossing can reduce dental plaque and subsequently also gingivitis. For caries, this association between plaque reduction and caries prevention seems less clear. However, the major problem of dental flossing is the compliance and performance. Children are generally not able to perform flossing at a decent quality and although data on adults are not available, controlled trials on caries lesion arrest in proximal areas demonstrate low motivation, adherence, and performance quality of flossing in adults.[12,20]

Flossing was, in the past, mainly recommended for children, adolescents, and young adults with intact interproximal papillae. It is likely that these individuals will show limited caries increment anyway, at least in countries with effective caries-preventive systems or water fluoridation.[21] Hence, for most low-risk individuals, it is generally questionable if dental flossing will have any preventive effect. On the other hand, improper use of flossing has been found to come with the risk of inducing "flossing clefts."[22,23]

For the remaining population of high-risk individuals, who bear the majority of caries experience, more basic oral hygiene measures including regular tooth brushing with fluoridated toothpaste[24] often needs to be implemented first. Flossing will have limited priority in these groups.

In cases with existing initial caries lesion on proximal surfaces, flossing can be a component of noninvasive caries treatment, possibly together with the application of fluoride varnishes, especially in case of lesions restricted to enamel or more compliant individuals.[12] Otherwise, micro-invasive measures (sealing, infiltration) may need to be applied.

If flossing is practiced by patients, it should not be demotivated by dental professionals, but monitored to increase its effectiveness and reduce the risk of harm.

For interdental brushes, there is evidence supporting their use to remove plaque and prevent gingivitis. For caries, but also for periodontitis, studies have not found any beneficial effect, likely due to too short follow-up periods or, for caries, also a limited plausibility. Interdental brushes further provide a more effective plaque removal and gingivitis prevention than flossing. Overall, the evidence supporting interdental brushes is more consistent than that on flossing. Dental practitioners should instruct patients on using interdental brushes, especially for patients who already suffer from periodontal diseases. For high-risk caries patients, other measures such as like fluoride provision may be prioritized, if needed, over the use of interdental brushes. Again, the use of interdental brushes requires professional training, including motivation and instruction/demonstration.

Recommendation for interproximal hygiene at home

- Flossing is not first priority in children and adolescents. Parents should be trained in brushing their children's teeth with a fluoride toothpaste and avoid frequent snacking or sugary drinks. Erupting teeth carry a greater caries risk than proximal

surfaces and should be cleaned with a cross-brushing technique. The reason for rampant caries in children or adolescents as well as generalized gingivitis is infrequent or inadequate tooth brushing. The introduction of regular tooth brushing with fluoride toothpaste is also a greater priority than dental flossing.

- In case of (initial) proximal caries lesions, nonoperative treatment with flossing and additional proximal fluoride use can be the first option.
- Use of interdental brushes for removal of plaque and prevention and management of periodontal diseases (gingivitis) is grounded in evidence. There is, however, no evidence supporting interdental brushes to prevent caries lesions.
- Interdental brushes are easier to use than floss for most patients. Floss should only be recommended in case of very narrow interdental spaces.
- The effectiveness of interdental oral hygiene is greatly dependent on patients' compliance and application.

References

1. Sanz M, Beighton D, Curtis MA, et al. Role of microbial biofilms in the maintenance of oral health and in the development of dental caries and periodontal diseases. Consensus report of group 1 of the Joint EFP/ORCA workshop on the boundaries between caries and periodontal disease. J Clin Periodontol 2017;44(Suppl 18):S5–S11.
2. Graziani F, Palazzolo A, Gennai S, et al. Interdental plaque reduction after use of different devices in young subjects with intact papilla: a randomized clinical trial. Int J Dent Hyg 2018;16:389–396.

3. Jepsen S, Blanco J, Buchalla W, et al. Prevention and control of dental caries and periodontal diseases at individual and population level: consensus report of group 3 of joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases. J Clin Periodontol 2017;44(Suppl 18):S85–S93.
4. Hujoel PP, Cunha-Cruz J, Banting DW, Loesche WJ. Dental flossing and interproximal caries: a systematic review. J Dent Res 2006;85:298–305.
5. Sambunjak D, Nickerson JW, Poklepovic Pericic T, et al. Flossing for the management of periodontal diseases and dental caries in adults. Cochrane Database Syst Rev 2019;4:CD008829.
6. Koch G, Lindhe J. The state of the gingivae and the caries-increment in schoolchildren during and after withdrawal of various prophylactic measures. In: McHugh WD (ed). Dental plaque. Livingstone: Edinburgh & London, 1970:271–281.
7. Cooper AM, O'Malley LA, Elison SN, et al. Primary school-based behavioural interventions for preventing caries. Cochrane Database Syst Rev 2013;31:CD009378.
8. Richards D. The effectiveness of interproximal oral hygiene aids. Evid Based Dent 2018;19:107–108.
9. Worthington HV, MacDonald L, Poklepovic Pericic T, et al. Home use of interdental cleaning devices, in addition to toothbrushing, for preventing and controlling periodontal diseases and dental caries. Cochrane Database Syst Rev 2019;4:CD012018.
10. Mattos-Silveira J, Matos-Lima BB, Oliveira TA, et al. Why do children and adolescents neglect dental flossing? Eur Arch Paediatr Dent 2017;18:45–50.
11. Carvalho JC, Schiffner U. Dental caries in European adults and senior citizens 1996–2016: ORCA Saturday Afternoon Symposium in Greifswald, Germany - Part II. Caries Res 2019;53:242–252.

12. Alkilzy M, Berndt C, Splieth CH. Sealing proximal surfaces with polyurethane tape: three-year evaluation. Clin Oral Investig 2011;15:879–884.
13. Wright GZ, Banting DW, Feasby WH. The Dorchester dental flossing study: final report. Clin Prev Dent 1979;1:23–26.
14. Wright GZ, Feasby WH, Banting D. The effectiveness of interdental flossing with and without a fluoride dentifrice. Pediatr Dent 1980;2:105–109.
15. Gisselsson H, Birkhed D, Björn AL. Effect of professional flossing with chlorhexidine gel on approximal caries in 12- to 15-year-old schoolchildren. Caries Res 1988;22:187–192.
16. Gisselsson H, Birkhed D, Björn AL. Effect of a 3-year professional flossing program with chlorhexidine gel on approximal caries and cost of treatment in preschool children. Caries Res 1994;28:394–399.
17. Granath LE, Martinsson T, Matsson L, Nilsson G, Schroder U, Söderholm B. Intraindividual effect of daily supervised flossing on caries in schoolchildren. Community Dent Oral Epidemiol 1979;7:147–150.
18. Gisselsson H, Björn AL, Birkhed D. Immediate and prolonged effect of individual preventive measures in caries and gingivitis susceptible children. Swed Dent J 1983;7:13–21.
19. Jared H, Zhong Y, Rowe M, Ebisutani K, Tanaka T, Takase N. Clinical trial of a novel interdental brush cleaning system. J Clin Dent 2005;16:47–52.
20. Martignon S, Ekstrand KR, Ellwood R. Efficacy of sealing proximal early active lesions: an 18-month clinical study evaluated by conventional and subtraction radiography. Caries Res 2006;40:382–388.
21. Mejàre I, Stenlund H, Zelezny-Holmlund C. Caries incidence and lesion progression from adolescence to young adulthood: a prospective 15-year cohort study in Sweden. Caries Res 2004;38:130–141.

22. Hallmon WW, Waldrop TC, Houston GD, Hawkins BF. Flossing clefts. Clinical and histologic observations. J Periodontol 1986;57:501–504.
23. Walters JD, Chang EI. Periodontal bone loss associated with an improper flossing technique: a case report. Int J Dent Hyg 2003;1:115–119.
24. IDZ (Institut der Deutschen Zahnärzte): Fünfte Deutsche Mundgesundheitsstudie – DMS V. Köln: Institut der Deutschen Zahnärzte, 2016.

8

Tooth brushing: Myth and science

Stefan Zimmer

In many countries, caries prevalence has considerably declined in several age groups during the past 40 years. However, there is little evidence that oral hygiene per se has remarkably contributed to this oral health improvement.[1] This raises the question whether techniques and means usually recommended for daily oral hygiene are appropriate and validated by the best available evidence. The present chapter will restrict this question to manual toothbrushes and techniques and scrutinize the design of manual toothbrushes and usual oral hygiene procedures.

Classic criteria of a manual toothbrush

Until a few years ago, there was a generally accepted idea of what a “good” manual toothbrush would look like. It should have a short head, a flat bristle field with many bristle tufts (multitufted) arranged in parallel, and end-rounded nylon bristles (Fig 8-1). However, this toothbrush shape did not originate from scientific evidence, but from tradition and as a result of the available manufacturing techniques.

Basically, a toothbrush in its development is nothing more than a small broom used to clean small things, namely the teeth. Looking at a broom or even a clothes brush, they have essentially the same shape as the toothbrush described above: parallel bristles, many tufts, and a flat bristle field (Fig 8-2). However, a broom has been designed to clean even surfaces, such as floors. In contrast, when looking at a dental arch, it becomes clear that such a broom is basically unsuitable for cleaning the convex surfaces of teeth with fissures, interproximal spaces, and the gingival sulcus (Fig 8-3).

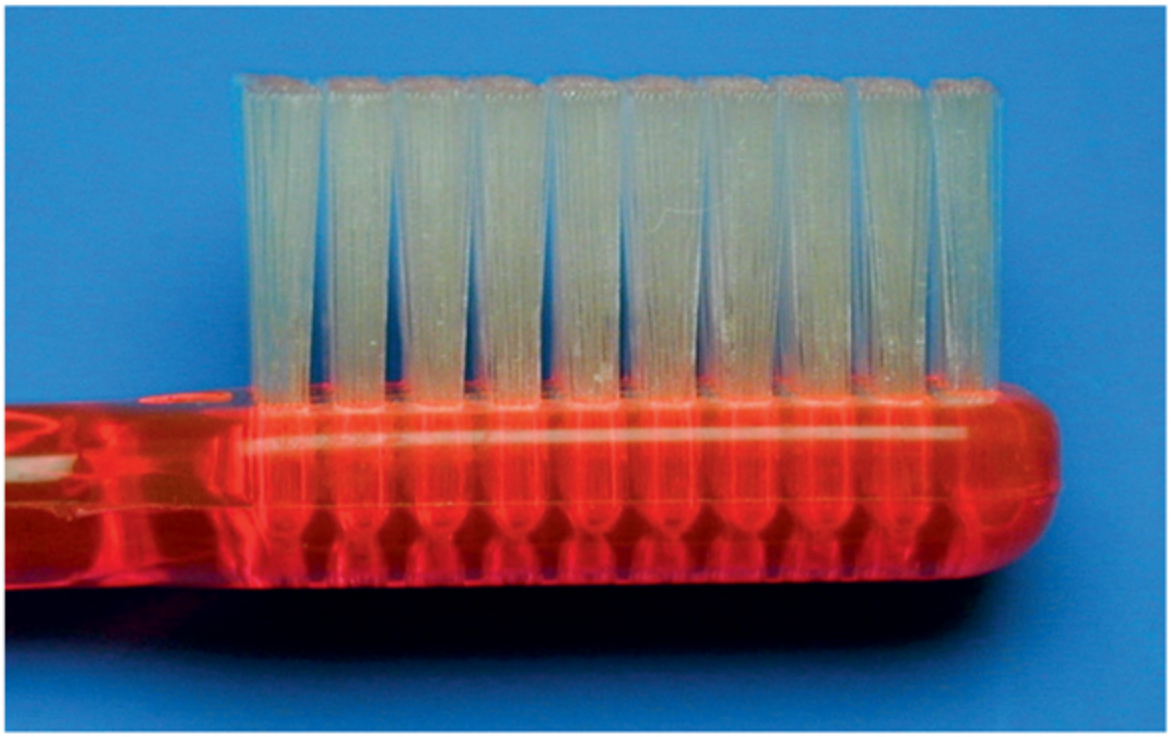


Fig 8-1 Appearance of a classic manual toothbrush: short head, flat multitufted bristle field and parallel end-rounded nylon bristles.

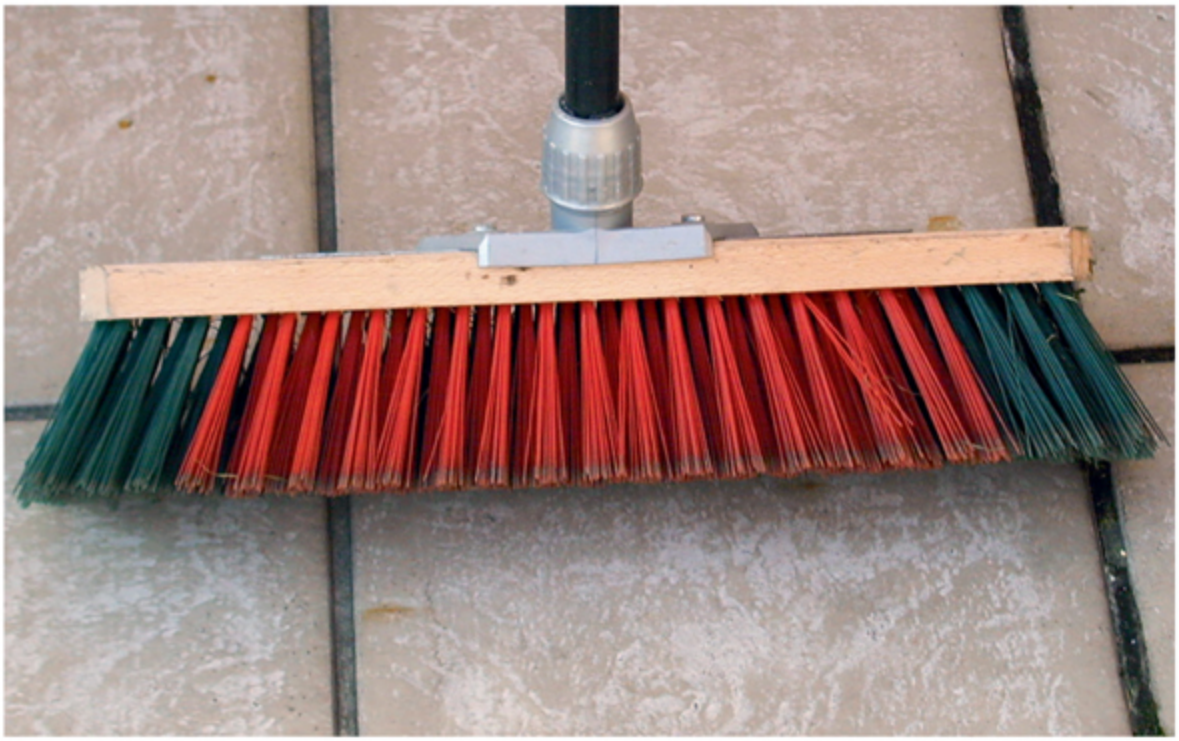


Fig 8-2 The bristle field of a broom has substantially the same shape as that of a conventional toothbrush.

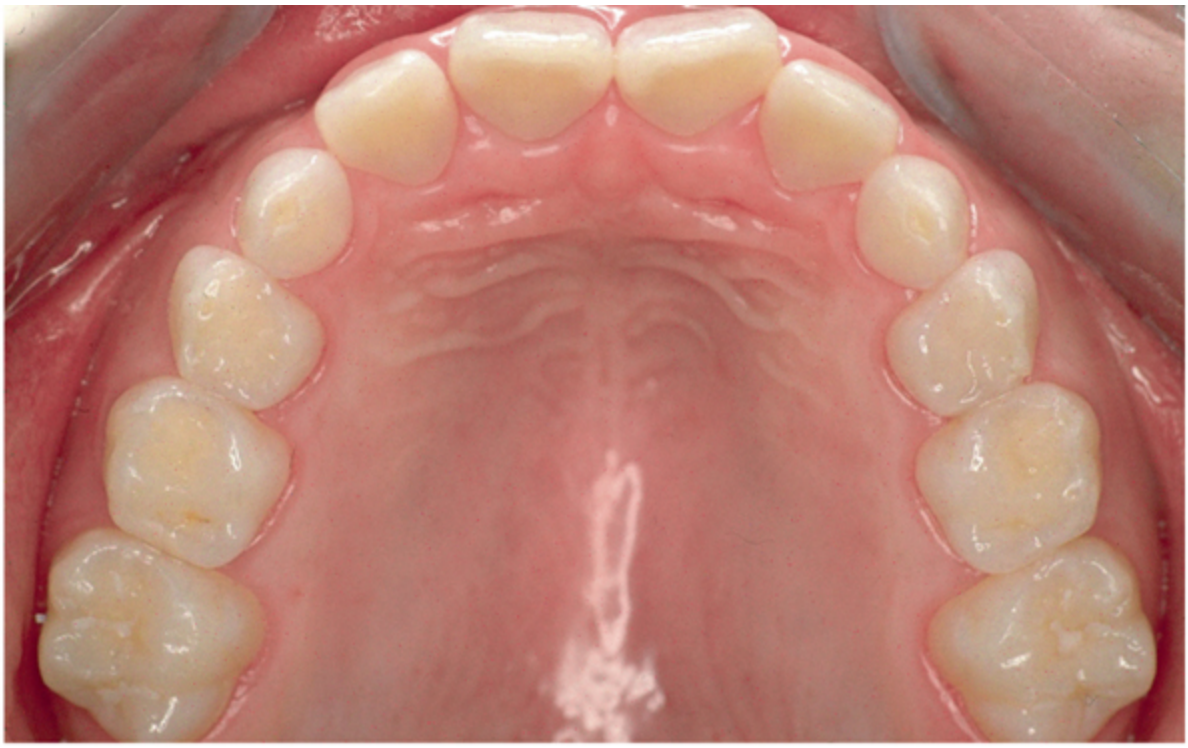


Fig 8-3 A dental arch is composed of convex surfaces and is characterized by difficult-to-clean cleft spaces, eg, interproximal area, fissure, and sulcus.

Production of toothbrushes

Developments in production technology today enable the manufacture of differently designed toothbrushes. This in particular relates to the bristle field. Although toothbrushes with V-shaped bristle field were also produced earlier, with the technique available at that time, it was not possible to round off the bristle ends that stood in the “valleys” of the bristle field. Therefore, the so-called V-toothbrushes were rejected at that time. For several years, however, the toothbrush industry has been able to round off the bristle ends in the “valleys.” In addition, it is now possible to round the bristle ends first and then attach them in the brush head. Various methods are available for this: In the injection molding process, the bristles are first brought into the correct position and then the brush head is sprayed around the bristles. In the insertion process, the bristles are pressed into the heated and thus soft material of the brush head. When the brush head has cooled, the bristles are firmly and substantially bonded to it, in the same way as by injection molding. In the welding process, bristles and brush head, which must then consist of the same material, are welded together by simultaneous heating. These new joining techniques not only allow new designs of bristle fields, but also a virtually gap-free fastening of the bristles in the brush head (Fig 8-4). This is important in view of the recurring discussion of the toothbrush as a germ reservoir. In the conventional method, the bristle tufts are anchored in the brush head with the aid of metal staples, which is not possible without a gap.

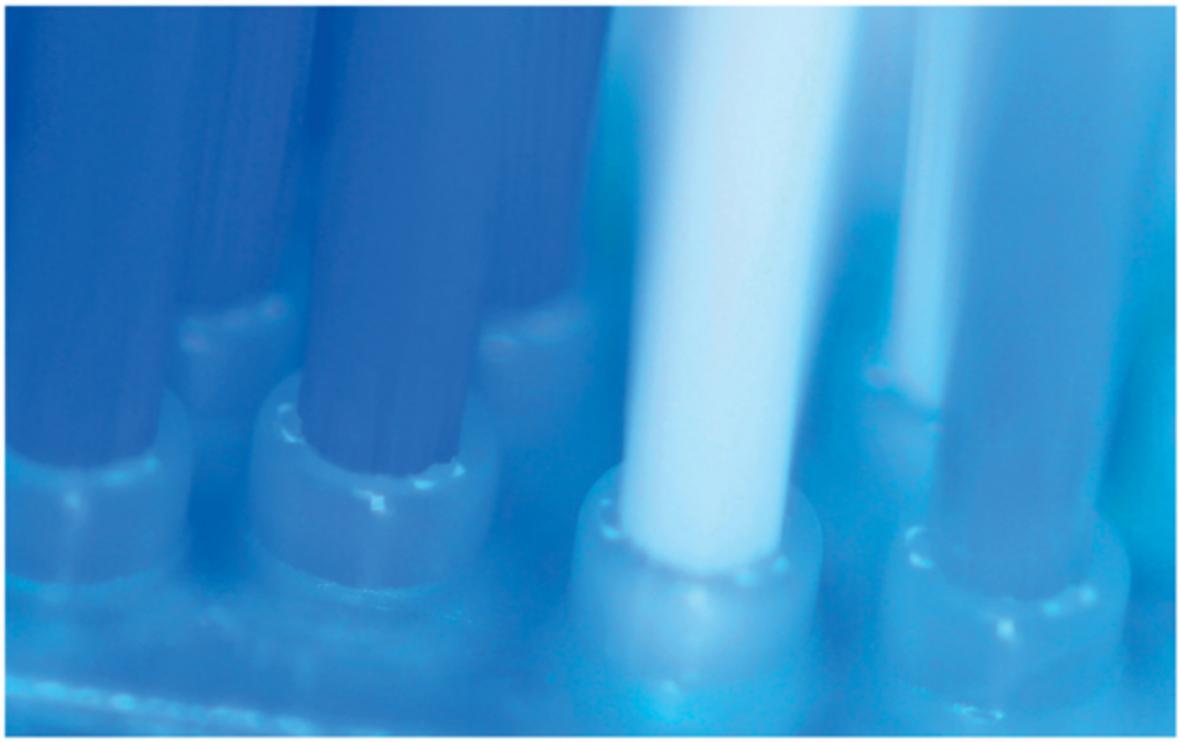


Fig 8-4 Anchorless gap free fixation of tufts.

Evidence-based criteria for manual toothbrushes

In this section, the classic criteria of manual toothbrush design are questioned and, if justified by evidence, replaced by new ones.

Rounded nylon bristles

Although there is no scientific research, it is now agreed that the bristles of a toothbrush should be made of nylon or a similar plastic. Natural bristles are rejected for hygienic reasons (bacterial colonization of the marrow channels of the bristle hairs) and because they splice quickly. Many descriptive in vitro studies have been done with respect to the end-rounding quality of toothbrush bristles. However, there is little evidence of the importance of bristle end-

rounding with respect to the prevention of soft-tissue trauma. Only one study showed that the extent of gingival lesions was by 30% greater when not-end-rounded bristles were used.[2] In conclusion, end-rounded nylon bristles are recommended even if scientific evidence is low because there is no convincing alternative (Fig 8-5).

Fig 8-5 Example of a toothbrush with less dense and different length bristle tufts.

Flat multitufted bristle field

The flat bristle field of a toothbrush, which has long been regarded as ideal, generally seems less suitable for cleaning teeth. Since a tooth surface has no flat, but only convex surfaces and the optimum cleaning is achieved by maximum contact between the brush and the tooth, a good toothbrush should rather have a concave bristle field, ie, a form matching to the dental arch. One possibility to achieve this is that the outer bristles are longer than the inner ones

(Fig 8-6). The present author's investigations have also shown that using a toothbrush with a dense, flat bristle field makes it difficult to clean the fissures. When the toothbrush is placed on the chewing surface of the tooth, a wedging effect occurs which prevents the bristles from penetrating deeper into the fissure (Fig 8-7). If the bristles are packed less densely, this works much better (Fig 8-8), even if the bristles of a toothbrush hardly succeed in reaching the fundus of a fissure perfectly. The same applies to the likewise very narrow interdental spaces and the gingival sulcus, a critical area especially with regard to the development of gingivitis and periodontitis. A toothbrush that has compact shorter bristles with more protruding less dense thin bristles has also been shown to clean these hard-to-reach areas better than a conventional brush (Fig 8-9).[3,4]

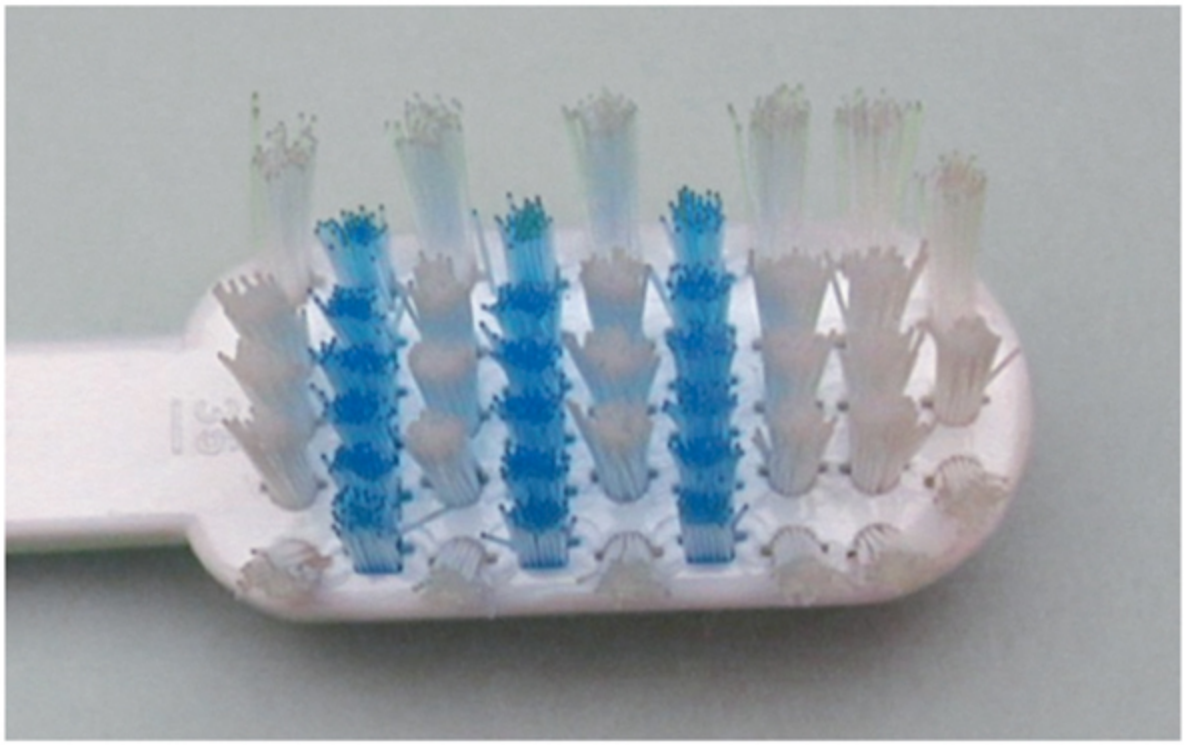


Fig 8-6 End-rounded nylon bristles.

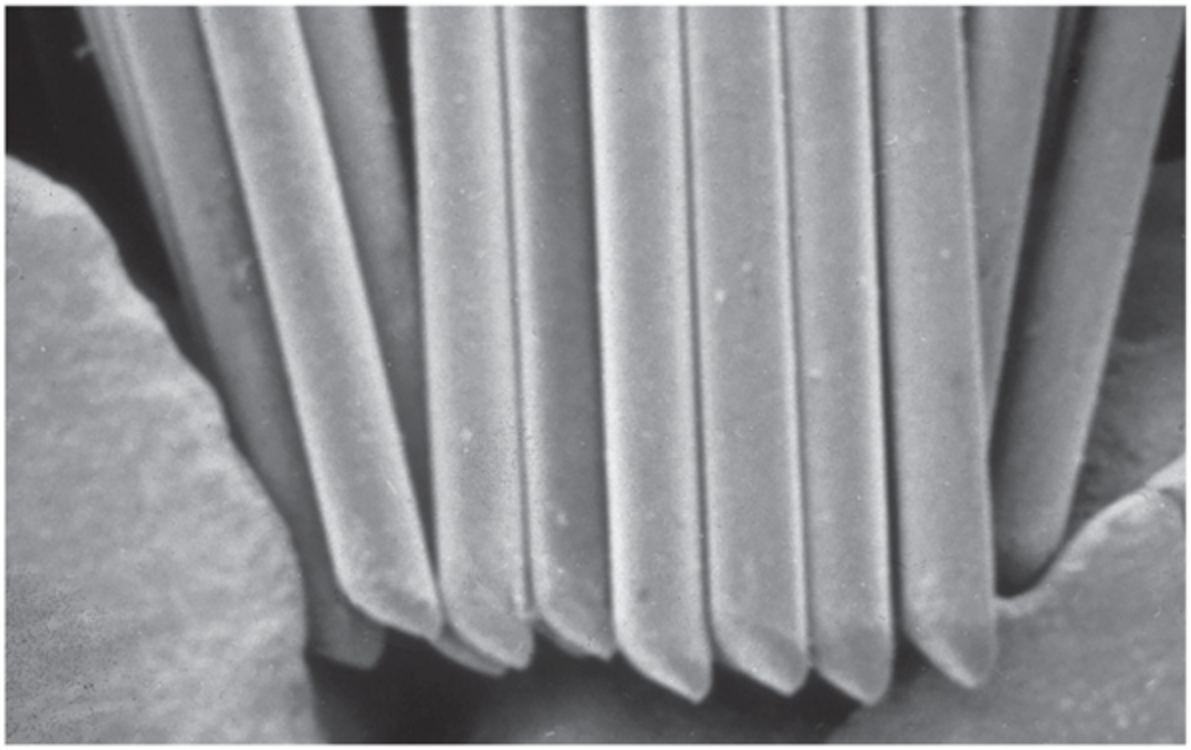


Fig 8-7 Scanning electron micrograph of a toothbrush with a flat and dense bristle field, firmly pressed onto the occlusal surface of a molar. The fundus of the fissure cannot be reached due to a wedging effect.

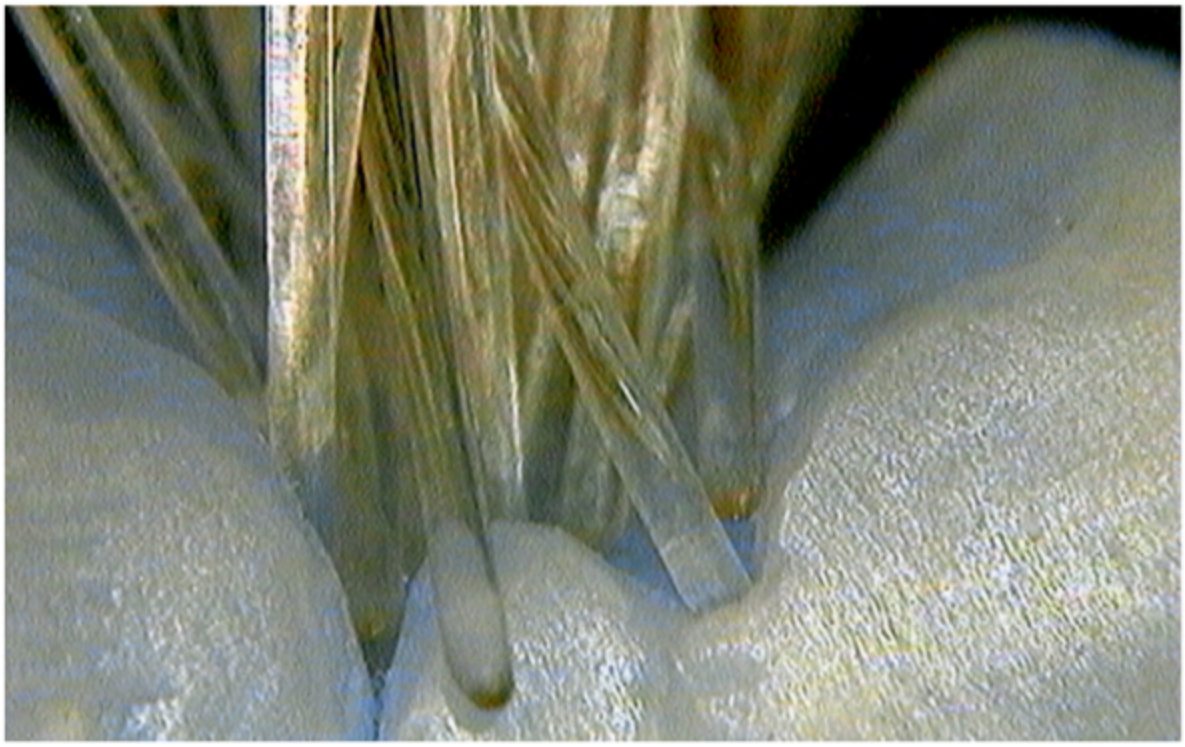


Fig 8-8 Light micrograph of a toothbrush with “scattered” less dense bristles. It can be seen in comparison to Fig 8-7 that the depth of the fissure can be achieved much better.

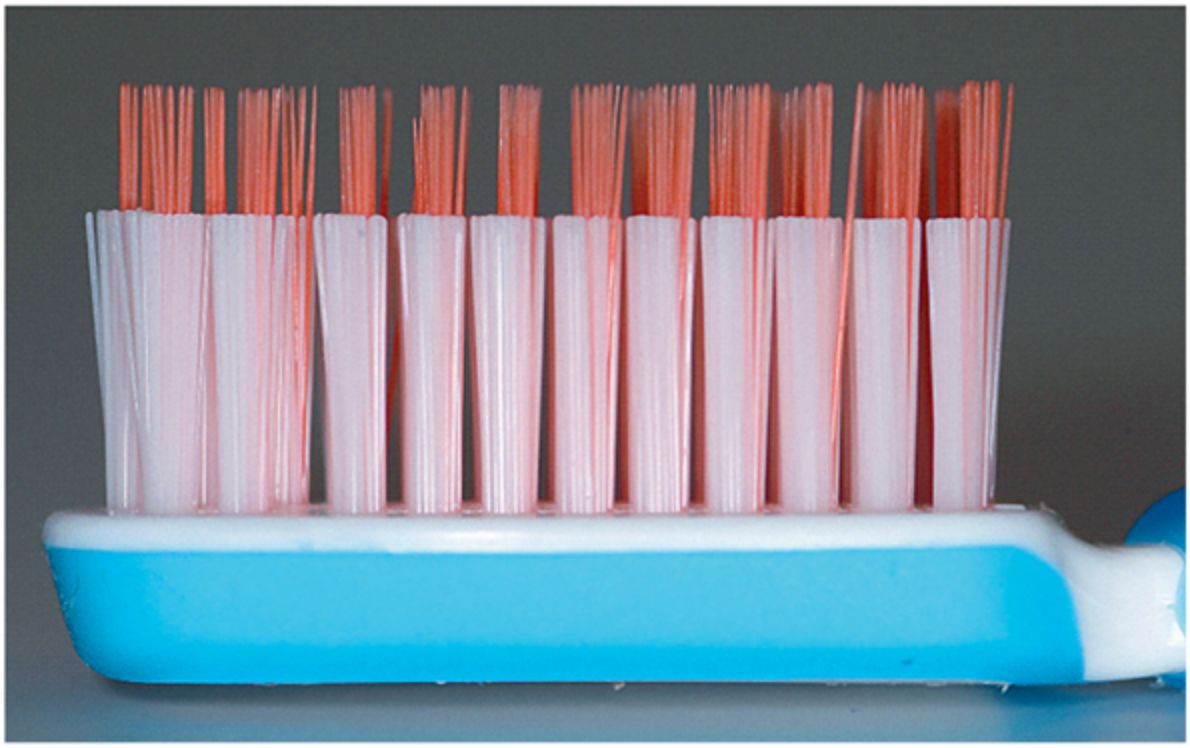


Fig 8-9 A toothbrush with thinner bristles extending beyond the normal bristle field can better clean interdental spaces, fissures, and the gingival sulcus than a conventional brush.

These are only two examples of modern hand toothbrushes with improved cleaning effect. Another aspect that is becoming important in the development of new toothbrushes is that it is increasingly clear that good oral hygiene can also have side effects: hypersensitive teeth, visible hard tissue defects, and trauma to the gingiva and mucosa are increasing. This is largely due to false and with-too-much-force-applied tooth brushing techniques. First and foremost, therefore, the user must be trained in the most careful but also gentle care technology possible. The toothbrush industry can also help tackle this problem by providing a range of toothbrushes with different properties. Here arises, for example, the question about bristle stiffness, eg, whether a toothbrush should have rather hard or soft bristles.

Bristle stiffness

In former times, hard toothbrushes in particular were preferred and then a change to the medium-hard variant took place. Increasingly, soft toothbrushes were recommended in the recent past under the impression of a more intensive mechanical oral hygiene and associated side effects. In fact, some of these toothbrushes have been shown to clean as well as the compared medium-hard toothbrushes with less gum trauma.[5,6] Since these comparisons of toothbrushes differed not only in bristle stiffness but also in the shape of the bristle field, the equally good cleaning effectiveness could not be unequivocally justified by the degree of hardness of the toothbrushes. For this reason, the present author evaluated similar toothbrushes with different degrees of hardness (hard, medium, soft) in vivo in terms of cleaning effectiveness and gingival trauma. The result was unambiguous. Toothbrushes with hard bristles caused more gingiva injuries, but they also showed a much better cleaning effect. Toothbrushes with medium-hard bristles were in the middle for both parameters.[7] A recent in vitro study by the present author's working group has also shown that soft toothbrushes lead to more abrasion of dentin than hard or medium-hard toothbrushes.[8] This sounds surprising at first, but is due to the fact that the bristles of the soft toothbrush bend at the ends and thereby lead to a more flat surface contact with the tooth surface than is the case with hard bristles. Due to the surface contact with the tooth surface, the toothpaste, which is indeed the abrasive, is brought more intensively into surface contact with the dental hard tissue and thus is more abrasive. This observation was confirmed by a study by Wiegand et al.[9]

Size of the brush head

One of the key requirements for the design of a manual toothbrush used to be a short brush head. That sounds reasonable, because the oral cavity is a narrow space with hard-to-reach areas, where it is

easier to maneuver with a small brush head than with a large one. On the other hand, it is obvious that a larger broom can clean a larger area at the same time. Since the time spent for brushing teeth is one of the most crucial factors and is usually not long enough,[10,11] it seems questionable whether a small toothbrush head really is an advantage. In a clinical study over 8 weeks, the present author examined two toothbrushes that differed only in the size of their brush head with respect to biofilm removal and improvement of gingivitis (Fig 8-10). For biofilm removal, there was a tendency for superiority of the toothbrush with the larger head after 8 weeks, but this was not statistically significant. However, with regard to the reduction of gingivitis as measured by the Papillary Bleeding Index (PBI), the larger toothbrush was significantly superior. There was an improvement of 0.426 in relation to 0.178, which is also a clinically significant difference.[12]

Fig 8-10 In a clinical study over 8 weeks, two toothbrushes that differed only in the size of their brush heads were examined for plaque removal and gingivitis enhancement.

Recommendations

From the findings presented so far, the following desired design features for a manual toothbrush can be derived:

- A toothbrush should have end-rounded nylon bristles to prevent gingival injury.
- A toothbrush should have a bristle field that is adapted to the shape of the tooth and the dental arch for optimal cleaning (shape congruence). Single bristle tufts and a less densely packed bristle field improve the biofilm removal in hard-to-reach areas.
- Patients with poor oral hygiene who do not show soft tissue injuries should use a hard toothbrush.
- Patients with good oral hygiene and existing soft tissue injuries should use a soft toothbrush.
- Patients with brushing abrasions on dental hard tissue should use low abrasive toothpaste, preferably in combination with a hard toothbrush (unless they have soft tissue defects at the same time). In addition, it is of course particularly important to establish a gentle brushing technique with not too much contact pressure.
- A slightly larger brush head seems to clinically improve cleaning performance.

Manual toothbrushes for children

When using a manual toothbrush, two toothbrushes should always be kept in the first 4 to 5 years of life: one for the child to use themself, and one with which the parents clean. There are two reasons for this. On the one hand, small children usually chew on the toothbrush when brushing their own teeth, rendering them

unusable very quickly for good cleaning. Second, the child grips the toothbrush with a fist handle and therefore needs a brush with a thick, short handle. However, a toothbrush with a longer, narrow handle is more suitable for re-cleaning by the parents. According to the child's growth, the toothbrush should "grow along." Some manufacturers therefore offer graduated age-adapted children's toothbrushes. The brush head of the child's toothbrush should be short enough to allow a good maneuverability in the infantile oral cavity and the bristles should be soft so as not to injure the child's sensitive mucosa.

Tooth brushing technique

In a study by Wainwright and Sheiham,[13] the recommendations on tooth brushing techniques provided by dental societies, toothpaste and toothbrush manufacturers, and in textbooks worldwide were examined. Of a total of 66 sources, 19 recommended the modified Bass techniques, 11 the "classic" Bass technique,[14] 10 the Fones,[15] five the scrub technique, and two the Stillman technique.[16] Nineteen of these professional sources had not recommended any cleaning techniques. Overall, the Bass or the modified Bass technique with a total of 30 out of 47 mentions was most commonly represented. The Bass technique is probably the most recommended technique in Germany as well. In a survey carried out in cooperation with the market research institute Forsa, however, only 4% of respondents had named the Bass technique as the technique used.[17] Much more common were circular (Fones technique, 57%), scrubbing (no described technique, 33%) and sweeping movements (Stillman technique, 28%). Consequently there is a clear discrepancy between what professionals recommend as the right brushing technique and what is actually being implemented in the population.

In their study on 46 students, Poyato-Ferrera et al[18] examined the effectiveness of the modified Bass technique in comparison to the "usual" brushing technique over 21 days. Between the brushing

technique that the study participants had previously exercised and the intensively instructed modified Bass technique there was a significant difference in favor of the Bass technique. This difference was 27.8%, based on the Quigley-Hein index with the modification of Turesky.[18] Although the study design (no instruction vs intensive instruction, placebo vs verum procedure in an open-label design) had favored the modified Bass technique, the study nevertheless found that a well-implemented modified Bass technique produced a very good result. However, this technique is manually demanding. In order to clarify whether the theoretically best toothbrush technique under the same conditions is also the best in comparison with one that is considered less effective, Harnacke et al[19] compared the simple but not particularly effective Fones technique with the modified Bass technique and a negative control group. A total of 67 subjects were randomized to the three groups and received PC-based general information on oral hygiene (all groups) as well an intensive education with practical exercises in the respective oral hygiene techniques (only Bass and Fones group). After 6, 12, and 28 weeks, not only parameters for biofilm and gingivitis were examined, but also how well the learned technique could be reproduced. Significant superiority of the Fones over the modified Bass technique was observed with regard to gingivitis at 12 weeks and reproducibility at 6, 12, and 28 weeks. These results showed that the Fones technique could be taught more successfully and that it led to partly better but never worse results than the Bass technique, although the former is considered inferior in principle. Interesting in this context is the investigation of the adherence to the taught toothbrush technique. In the Bass group, 18 subjects were included in the final analysis, 19 in the other two groups. Of these, 11 people (61%) in the Bass group reported that because of various difficulties, they did not stay with the technique over the entire study period; in the other two groups there were only five subjects not adhering to the instructed technique (26.3%).[19] Again, this may explain why the modified Bass technique has not proven to be as effective as expected. It may also explain why so few people use Bass or modified Bass technique, although, as the study by Wainwright and

Sheiham[13] shows, they are the techniques most widely recommended by professionals.

It can be seen from the cited studies that the Bass or the modified Bass technique is the most effective method of mechanical oral hygiene in principle, but is not successfully implemented in reality. Therefore, it must be considered which brushing technique should be recommended alternatively in the dental practice. Using a manual toothbrush, Stillmann's sweeping technique could be the most suitable technique for most people because it is simple. However, its effectivity still has to be demonstrated in clinical field studies. In the Stillmann technique, it is important that the toothbrush is aligned with the bristle ends at an angle of about 45 degrees to the gingiva so that about half of the bristle field is on the gingiva and the other on the teeth. Then it is swept from red to white (Fig 8-11). Per tooth or group of teeth this movement should be performed about four to five times.

Fig 8-11 In the sweeping technique, the toothbrush is set with the bristle ends at an angle of about 45 degrees to the gingiva, in the

maxilla up and in the mandible down. Care should be taken that the bristle field covers about half of the tooth and gingiva. Then the brush is unrolled from the gingiva to the tooth ("from red to white"). This procedure should be performed about four to five times per tooth or group of teeth.

Tooth brushing time

Clinical studies in both hand and electric toothbrushes show that a longer brushing time correlates significantly with better plaque removal.[20-22] However, it has also been shown that the time spent on oral hygiene is usually clearly misjudged,[23] which generally leads to a significant reduction of the recommended tooth brushing time.[10]

For each individual, a different efficiency of the biofilm removal and also different dental conditions have to be taken into account. Therefore, it is not possible to give a uniform recommendation for tooth brushing duration. There is no scientific evidence for the usually recommended 2 or 3 minutes. It is also to be assumed that the time actually required for an optimal result is significantly higher. Hawkins et al[11] demonstrated an optimum "average" cleaning time of 5.1 minutes for manual brushes. However standard deviation was high. For these reasons, it seems appropriate for each person to determine their own individual cleaning time. For this purpose, the oral biofilm can first be stained with a commercial plaque staining tablet. Thereafter, the patient should stop the time it takes to completely remove all stained deposits. Finally, she or he should stain the teeth again to make sure that all the deposits were actually removed. This determined individual cleaning time is a realistic guideline for the time that has to be spent twice daily for a good oral hygiene.

In conclusion, some traditional dogma on mechanical oral hygiene must be considered obsolete today. This affects almost

all design features of a manual toothbrush. Also the usually recommended cleaning technique according to Bass must be reconsidered. Although there is little evidence for the recommendation of a manual tooth brushing technique, it is clear that the Bass technique or the modified Bass technique have not succeeded under realistic field conditions. Two or three minutes should not stereotypically be recommended as a brushing time. Rather, each person should determine their individually appropriate cleaning time. Until now, the primary strategy of dental practitioners and their prophylaxis staff has been to motivate their patients to change their behavior in the presence of insufficient oral hygiene. Sustainably effective behavioral changes are difficult to realize. Therefore, the efforts of dentistry and the dental industry in the future should be designed to develop products that meet the already practiced behavior. The maxim should be to develop tools and techniques for people's established behaviors, not the other way round, to adapt people's behavior to existing devices and techniques.

References

1. Jordan R, Micheelis W. Fünfte Deutsche Mundgesundheitsstudie DMS V 1-617. Cologne: Deutscher Zahnärzte Verlag, 2016.
2. Breitenmoser J, Mormann W, Muhlemann HR. Damaging effects of toothbrush bristle end form on gingiva. J Periodontol 1979;50:212–216.
3. Stiller S, Bosma ML, Shi X, Spirgel CM, Yankell SL. Interproximal access efficacy of three manual toothbrushes with extended, x-angled or flat multitufted bristles. Int J Dent Hyg 2010;8:244–248.
4. Yankell SL, Shi X, Spirgel CM, Stiller S. Interproximal access efficacy of one vibrating and two powered oscillating-rotating

toothbrushes. J Clin Dent 2011;22:55–58.

5. Dorfer CE, von Bethlenfalvy ER, Kugel B, Pioch T. Cleaning efficacy of a manual toothbrush with tapered filaments. Oral Health Prev Dent 2003;1:111–118.
6. Gallob J, Petrone DM, Mateo LR, et al. Comparative efficacy of a soft toothbrush with tapered-tip bristles to an ADA reference toothbrush on gingival abrasion over a 12-week period. J Clin Dent 2016;27:48–53.
7. Zimmer S, Ozturk M, Barthel CR, Bizhang M, Jordan RA. Cleaning efficacy and soft tissue trauma after use of manual toothbrushes with different bristle stiffness. J Periodontol 2011;82:267–271.
8. Bizhang M, Schmidt I, Chun YP, Arnold WH, Zimmer S. Toothbrush abrasivity in a long-term simulation on human dentin depends on brushing mode and bristle arrangement. PloS One 2017;12:e0172060.
9. Wiegand A, Kuhn M, Sener B, Roos M, Attin T. Abrasion of eroded dentin caused by toothpaste slurries of different abrasivity and toothbrushes of different filament diameter. J Dent 2009;37:480–484.
10. Saxer UP, Barbakow J, Yankell SL. New studies on estimated and actual tootbrushing times and dentifrice use. J Clin Dent 1998;9:49–51.
11. Hawkins BF, Kohout FJ, Lainson PA, Heckert A. Duration of toothbrushing for effective plaque control. Quintessence Int 1986;17:361–365.
12. Zimmer S, Pohlmann S. Effektivität zweier Handzahnbürsten mit unterschiedlich großen Bürstenköpfen. Prophylaxe Impuls 2019;23.
13. Wainwright J, Sheiham A. An analysis of methods of toothbrushing recommended by dental associations, toothpaste and toothbrush companies and in dental texts. Br Dent J 2014;217:E5.

14. Bass CC. An effective method of personal oral hygiene. J Louisiana State Med Soc 1954;106:57–73.
15. Fath S. Zahnpasten. In: Roulet J-F, Fath S, Zimmer S (eds). Lehrbuch Prophylaxeassistentin, 4th edn. Munich: Elsevier, 2012:186–189.
16. Stillman P. A philosophy of treatment of periodontal disease. Dent Digest 1932;38:315–322.
17. Zimmer S, Lieding L. Gewohnheiten und Kenntnisse zur Mundhygiene in Deutschland - Ergebnisse einer bevölkerungsrepräsentativen Befragung. Dtsch Zahnärztl Z 2014;69:584–593.
18. Poyato-Ferrera M, Segura-Egea JJ, Bullon-Fernandez P. Comparison of modified Bass technique with normal toothbrushing practices for efficacy in supragingival plaque removal. Int J Dent Hyg 2003;1:110–114.
19. Harnacke D, Mitter S, Lehner M, Munzert J, Deinzer R. Improving oral hygiene skills by computer-based training: a randomized controlled comparison of the modified Bass and the Fones techniques. PloS One 2012;7:e37072.
20. Honkala E, Nyyssonen V, Knuuttila M, Markkanen H. Effectiveness of children's habitual toothbrushing. J Clin Periodontol 1986;13:81–85.
21. Weijden van der FA, Timmerman MF, Snoek IM, Reijerse E, Velden van der U. Toothbrushing duration and plaque removing efficacy of electric toothbrushes. Am J Dent 1996;9:31–36.
22. Weijden van der GA, Timmerman MF, Nijboer A, Lie MA, Van der Velden U. A comparative study of electric toothbrushes for the effectiveness of plaque removal in relation to toothbrushing duration. Timer study. J Clin Periodontol 1993;20:476–481.
23. McCracken GI, Janssen J, Steen N, DeJager M, Heasman PA. A clinical evaluation of a novel data logger to determine compliance with the use of powered toothbrushes. J Clin Periodontol 2002;29:838–843.

9

Guidance for healthy dental and oral behavior: Multilevel prevention of early childhood caries

Julian Schmoeckel

Early childhood caries (ECC) is a preventable oral disease in young children, but still highly prevalent worldwide (23% to 90% in 5-year-olds).[1] Distribution of caries experience, also in the case of ECC, is polarized, resulting in higher caries rates in children from lower socioeconomic families or lower parental educational background, reflecting strong parental influences.[2] Especially in severe cases ECC affects the children's and their parent's quality of life. The Specific affected Caries Index (SaC), describing the mean caries experience in children with a decayed, missing, or filled teeth (dmft) > 0,[3] is in this age group of 3-year-olds in Germany already 3.6 dmft (Fig 9-1).[4] In many cases the care index of ECC is low, eg in 3-year-olds in Germany it is only about 25%, even though all restorative treatment including general anesthesia is covered by health insurance in Germany (Fig 9-1).[4] In addition, the low care index in primary teeth is very low, which is presumably due, among other

reasons, to lack of knowledge in dental practitioners,[5] and to the low ability and willingness of these small children to cooperate for invasive dental treatment.[6]

Though the treatment of ECC usually improves the oral health-related quality of life (OHRQoL),[7] invasive approaches pose not only risks and efforts on the children or families, but also a considerable burden for the health systems, as general anesthesia might be needed for restorative and surgical interventions.[8,9]

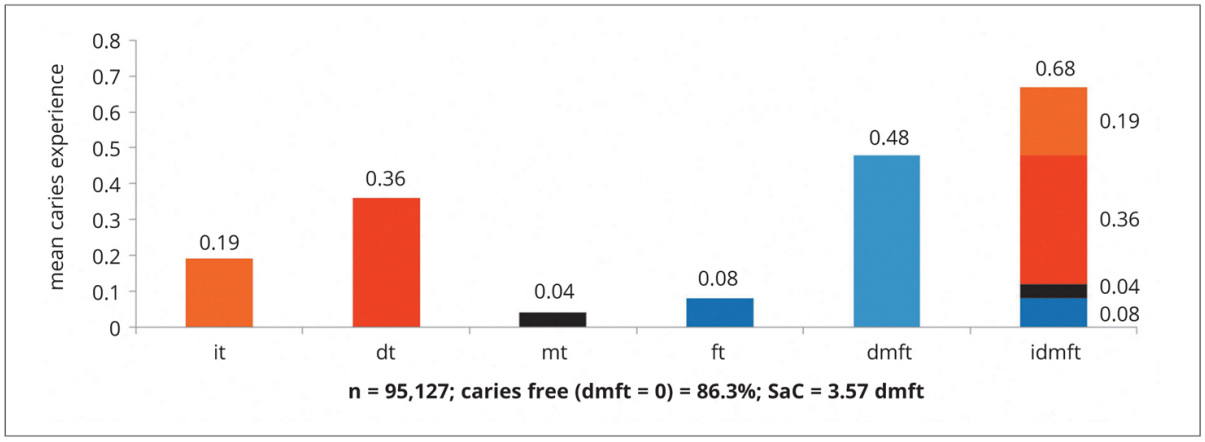


Fig 9-1 Caries experience (dmft) and its single components as well as initial lesions (it) in a representative sample of 3-year-olds (n = 95,127) in kindergarten in Germany, 2016 (modified from Team DAJ[4]).

Main aspects in the etiology of ECC and, therefore, measures for its prevention are known: Regular tooth brushing with fluoride toothpaste in children starting with the first tooth, which usually erupts arounds the age of 6 months, and no use of nursing bottles containing sugary drinks.[10] Despite this knowledge on the most important home measures of preventing ECC, transposing this

information for the implementation of these measures for a healthy dentition in early childhood still remains a great challenge.

Communicating beneficial information and its transformation into an actual change of behavior is not simple, and its effectiveness can quickly be overrated.[11] This means that health care providers (eg, dental practitioners) need to consider psychologic components in the communication with patients (eg, behavior change techniques and theory) as it is in general a far step from "knowledge" towards "attitude" and finally to a long-term change of behavior.[12]

The primary aim of pediatric dentistry is the achievement of a high OHRQoL, to which a healthy dentition via a working prevention of ECC can significantly contribute.

How do we learn: different theories

Social cognitive theory: learning from a model

Social cognitive theory (SCT) describes that a person (model) is observed, and if it appears to be meaningful and if it is possible for the imitator (learner) to imitate this behavior, the behavior is imitated. Often the model and/or the imitator (the learner) are not aware of his or her position. Learning from the model, therefore, includes both a thinking (conscious) imitation, and an unconscious imitation (imitation without explicitly thinking about it).[13] There are certain requirements for learning according to the SCT[14]:

- the learner must have an emotional relationship with the model and/or the model must be important in some way (eg, parent, teacher, employer)
- the behavior must be attainable and comprehensible

- model behavior must have been successful and reinforced
- the learner must be strengthened to show the adopted behaviors.

This means in the specific case of ECC prevention that children may or will adopt the behavior of regular tooth brushing from their parents and/or older sibling, if they observe them brushing their teeth every time before bedtime, especially when this behavior is positively reinforced.[15] In addition, the diet of the child is influenced and shaped in childhood, likely due to the availability of certain (sugary) food and the observation of parental dietary habits.

Similarly, in the kindergarten setting the educators and other/older children may be models that have an influence on young children's behavior, eg a kindergarten teacher brushes teeth with fluoride toothpaste with a group of children (also her own teeth) on a daily basis after lunch. This might be used as a public health approach to compensate for parents who don't brush their children's teeth. Attained behavior in early childhood is thought to be a key factor also for behavior later in life, and in adulthood, which is highly important for prevention of a lifestyle disease like caries.[16]

Behaviorism: learning through reinforcement and success

Behaviorism refers to the concept in scientific theory of investigating and explaining the behavior of humans and animals using scientific methods, ie without introspection or empathy.[17] This paradigm of operant conditioning, also called "learning by success" describes a learning of stimulus-response patterns. The findings of behaviorist research are the basis for various behavioral therapeutic procedures, including the so-called systematic desensitization of patients with a phobia.[18] This is also highly relevant in pediatric dentistry as young children receiving an invasive dental treatment in a carious tooth but

without help or guidance in coping positively with this situation might gain a negative or even painful experience in the dental office, resulting in dental anxiety and negative stimulus-response patterns.

Cognitivism: learning through insight and cognition

Cognitivism is a learning theory that should be distinguished from behaviorism and constructivism. It describes the learning process like a classic “data computing process” and regards each person as an individual who is not “controlled” by others and with ability to think, as human beings stand out from the animal world.[19]

Constructivism: learning through personal experience and interpretation

Constructivist “learning is a cognitively structuring acquisition of novel events in the systemic environment.”[20] “The constructivist orientation can only help in the sense that it emphasizes the basic autonomy of the ‘learner’ and points out that in all circumstances it is only the ‘learner’ themselves who can construct their conceptual structures.”[21]

Learning is in principle “self-directed learning.” This means that learning cannot be taught directly. It is true that information can be conveyed, but everyone has to “understand” it. “Understanding” means: to integrate new knowledge into existing patterns, to consider it personally important and relevant, and also to “occupy” knowledge emotionally and to formulate it “with one’s own words,” to provide it with meanings. It’s like the proverb, “You can lead a horse to water but you can’t make it drink!”[20,22]

Learning and the potential role of sensory perception

Despite different learning theories it is clear that not all information received will be retained and especially not processed further for

behavioral changes – if at all. Our brain capacity and functionality is extremely high, but still limited. Via sensory organs (eye, ear, etc), we absorb information that is processed and stored in the brain in ultra-short-, short-, or long-term memory depending on the quality of the information, the importance of the information, and on how the information got into the brain in the first place. A rough distinction is made between the probability of retaining information via different ways of intake (Table 9-1), which should be considered for the approach of parental counseling, eg on prevention of ECC in dental office.[23]

Table 9-1 Rough assessment of the probability of retaining information via different ways of intake[23]

Information intake	Probability of retaining
Do it yourself	90%
Tell / explain to somebody	70%
Listen & see	50%
See	30%
Listen	20%

Ethical considerations in modern patient-doctor relationships

In the past decades a change from a rather so-called “paternalistic” approach to more participative approaches with informed consent has occurred in medicine and dentistry.[24] In contrast to the traditional (“paternalistic”) asymmetric patient-doctor relationship, contemporary

medicine relies on the mature patient and a symmetric, partnership-based relationship that is oriented towards the autonomy of the patient and includes his or her competencies.[25] A schematic diagram illustrates the roles of the patient and dental practitioner (Fig 9-2).

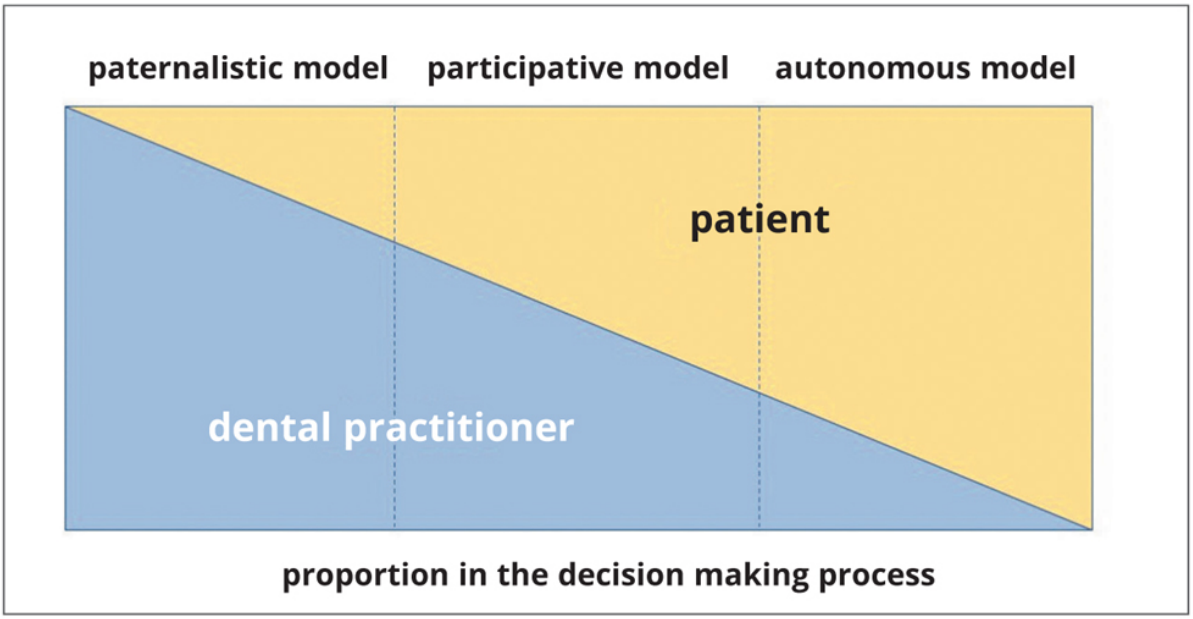


Fig 9-2 Depending on the model of patient-doctor relationship, the proportion in the decision making process varies. In the participative model, dental practitioner and patient have a symmetric, partnership-based relationship.

According to Beauchamp and Childress[26] there are four basic principles in medical ethics which are to be considered and balanced against each other for decision taking in medicine:

- respect for autonomy
- beneficence
- non-maleficence
- justice.

Why do we need informed consent?

Modern society acknowledges the individual in medicine, and with "informed consent" (Table 9-2) authority on decision is given to the individual (patient or the research participant) who may be a single non-expert, to veto power over some interventions, even against the will of many expert physicians.[27]

Table 9-2 Arguments for informed consent in medicine (modified from Eyal[27])

Main arguments for informed consent	Comment
Protection	Protection of study participants
Autonomy	"The autonomous individual acts freely in accordance with a self-chosen plan"[28]
Prevention of abusive conduct	Informed consent sets a bulwark against offenses such as assault, deceit, coercion, and exploitation
Trust	Trust is needed in any patient-doctor relationship. The process of informed consent contributes to the restoration of trust.
Self-ownership	The patient holds "proprietary" rights over themselves and their body
Non-domination	Patients retain a high degree of control over what happens to them
Personal integrity	Protection of patients' sense of personal integrity

The process or the approach of informed consent relies on certain requirements and main elements in the process of clarification and decision making,[29] presented in Table 9-3.

These aspects are essential in the understanding of the modern patient in an equal partnership-based relationship and for approaches improving the health literacy, which is needed in the areas of disease management, as prevention and health promotion for oneself, and for people for whom one bears responsibility.[30] The support of the caregivers' self-efficacy[31] and of their health literacy via intrinsic motivation may have long-term effects. In the case of ECC, (oral) health literacy (of the guardian) may lay the foundation to maintain a healthy (primary) dentition and a high (oral health-related) quality of life from early childhood onward.

Table 9-3 Elements in the process and approach of informed consent[29]

1	The patient's ability to understand and to decide	Requirements
2	Voluntarity	
3	The explanation of the relevant information	Process of clarification
4	A recommendation of a procedure	
5	Understanding of (3) and (4)	
6	The decision for a procedure	Decision taking
7	The acceptance of the treatment request	

Health literacy and belief in self-efficacy

Self-efficacy mechanisms describe the expectation of a person to be able to perform desired actions successfully on the basis of his/her own competencies. This means "the higher the level of induced self-efficacy, the higher the performance accomplishments."[32]

In principle, the caregiver's oral health literacy is an important success factor for caries prevention in pediatric dentistry. Measures such as parental training in oral hygiene for toddlers and improving health literacy and at best also self-efficacy are important aspects, so that preventing ECC by brushing the primary teeth with fluoride toothpaste in the home setting is performed sufficiently and starts early.

Posing questions may help to guide parents, and puts the responsibility to answer on the "learning parent," decreasing the hierarchy in the "teacher-learner" or "patient-doctor" relationship (Fig 9-2):

- What do you wish for your children's teeth?
- What do you think you need for a good oral health of your child?
- What do you think you need to keep your child's teeth healthy?

According to the "Rubicon model of action phases,"[33] there are steps between the motivational process of the predecisional phase and the volitional processes of the postdecisional phase, which means that there are "clear boundaries between motivational and action phases."[33]

In the context of ECC prevention, parents may first consider in the motivational phase "what and how to achieve oral health in their child" and then secondly act (eg, brush with fluoride toothpaste regularly) and reflect on their actions (postdecisional phase, to see that it is working – or not).

Already in 12-year-old children in Germany the lack of self-efficacy shows an impact on the oral health of permanent teeth (Table 9-4). Health professionals should therefore consider for the parents (individually) how they may be able to address their conviction of self-efficacy, and later on also in the growing child.

Table 9-4 Relationships between categorized caries experience and self-efficacy conviction in 12-year-olds in Germany (modified from Institute of German Dentists [IDZ][34])

Conviction of self-efficacy*	DMFT 0, n = 1,192	DMFT 1–2, n = 182	DMFT > 2, n = 91
"Very much" or "much"	86.1%	85.5%	84.7%
"Some"	12.2%	13.7%	5.9%
"Little" or "nothing"	1.7%	0.5%	5.5%

* How much can you do yourself to maintain or improve the health of your teeth?

Evidence of different aspects in counseling for preventing ECC

Tooth brushing with fluoride toothpaste and a low frequency of sugar intake are the basis for preventing and managing caries not only in children.[16]

Three aspects (oral hygiene, diet/carbohydrate intake, fluorides) may therefore be the target of counseling approaches to prevent ECC (Fig 9-3).

Nonetheless, the level of evidence for and the effectiveness of different caries preventive measures differ (Table 9-5).

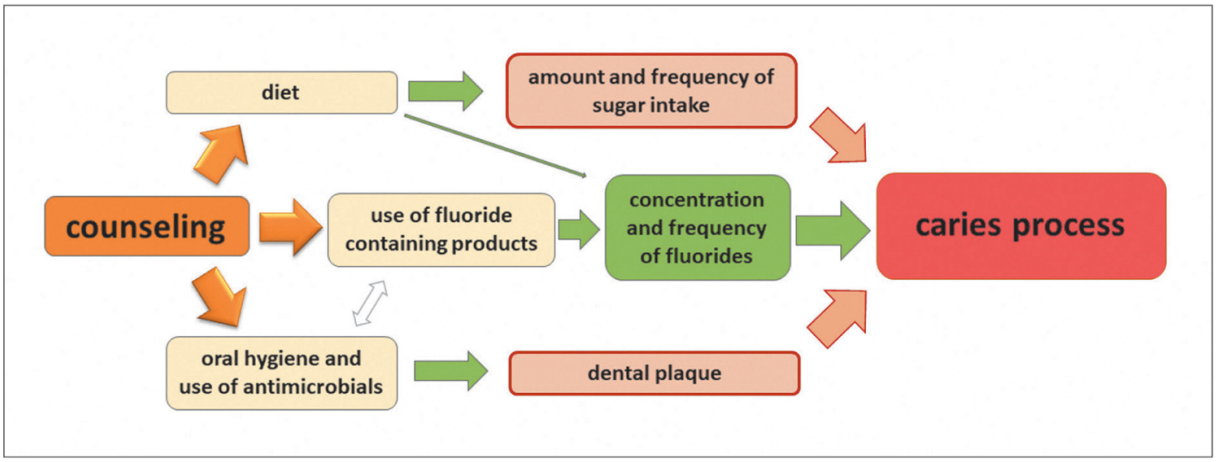


Fig 9-3 Possibilities to intervene in the carious process by counseling (orange arrow).

Table 9-5 Evidence-based catalog of measures for caries prevention in the primary teeth (modified from Public Health England[35])

Advice (for all 0- to 3-year-olds)	Level of evidence*
Parents/caregivers should brush (or supervise) tooth brushing	I
Use of toothpaste containing at least 1,000 ppm fluoride	I
From the breakthrough of the first tooth, a fluoride toothpaste should be brushed with	I

Advice (for all 0- to 3-year-olds)	Level of evidence*
twice a day	
Breastfeeding provides the best nutrition for babies	I
The frequency of consumption and the amount of sugary foods and beverages should be reduced	III, I
Teeth should be brushed before bedtime and once a day	III
From an age of 6 months a free-flow cup should be introduced and from 1 year it is not advisable to feed from a bottle anymore	III
Sugar-free medication should be recommended	III
When weaning, sugar should not be added to the porridge or drinks	V
A very small amount of toothpaste should be used when brushing your teeth	Clinical practice

* Evidence levels range from I (very high) to V (very low).

The following catalog of measures should be recommended in an individual setting to promote healthy primary teeth.[35]

In addition, the method of counseling may play an essential role. Dental practitioners should be aware that there is a difference in the likelihood of behavioral change after the bare telling of the information on how domestic prevention of ECC regarding tooth brushing, fluoride use, and nutrition (nursing bottle and content) should be performed compared to, for example, the use of a certain communication technique like motivational interviewing (MI).

MI describes a non-authoritative approach aiming at serving people to detect their intrinsic motivations and resources in order to overcome the ambivalence in knowledge and behavior.[36] In the case of ECC, “a MI-style intervention shows promise to promote preventive behaviors in mothers of young children at high risk for caries.”[37] Furthermore, there is substantial evidence that emotional events are remembered better and for longer periods of time than are neutral events.[38] As mentioned before, the relationship and emotional connotation as well as the kind and the combination of senses involved in the process influence the probability of retaining information. This should always be considered when counseling is performed in the dental office:

Learning and retention of information is usually stimulated more when multiple senses are involved simultaneously (eg, sight, hearing, touch, smell, taste) in the process (Table 9-2). Additionally, active information recording (eg, retelling) is more effective than passive information recording (eg, seeing). This leads to the important conclusion that parents must clean their children’s teeth in the dental practice themselves (training – do it yourself), and not just hear (being told about preventive measures) and see (being shown “how to brush”) to increase the likelihood of learning and retention.

This is in line with findings from a study from Iran, which found that in addition to educational interventions (lecture), group discussions significantly reduced the incidence of ECC in 1- to 3-year-old children without dental caries (13% in the experimental group and 35% in the control group).[39]

Studies on prevention of ECC often unfortunately describe imprecisely their way of counseling and the exact information given. Clinicians experience frequently that despite the same information given to two different patients, not only the parents' intellectual ability but especially the way of counseling may lead to large differences in understanding. This is well described in the so-called "four-sides model," also known as the "communication square" or "four-ears model," which is a communication model introduced in 1981 by Schulz von Thun.[40] This model describes that every message has four facets, which are all simultaneously present[40]:

- factual level
- self-disclosure
- relationship-layer
- appeal.

The emphasis of each facet in one sentence may differ in the transmitter and receiver, potentially leading to misunderstandings and a disturbed communication.[40]

Transferring techniques of other fields of psychology and medicine is advisable;[41] "teach-back" may additionally be used to track what information is stored after patient instruction on the prevention of ECC.

Evidence of oral hygiene counseling

Regarding the usually performed oral hygiene instructions in dental offices, there is "insufficient high-quality evidence to recommend any specific one-to-one oral hygiene advice."[42] The studies considered in this Cochrane review looked at the reduction of gingivitis or plaque; unfortunately, none of the randomized controlled trials (RCTs)

measured the outcome dental caries.[42] It should be considered that a reduction of plaque scores does not necessarily lead to a reduction in caries rates (in early childhood), though this is biologically plausible. The level of knowledge can usually be improved by oral health advice, but whether these changes in knowledge really lead to lasting changes in behavior or the reduction of clinical indices of the caries disease has not been proven.[43]

Regarding MI, results suggest that behavioral aspects may be affected, but the effect of behavioral changes on caries development remain rather uncertain. Scientific evidence shows that, on the one hand, MI appeared to have some impact on some parental behaviors contributing to ECC,[44,45] but on the other hand it has failed to reduce the number of new untreated caries/ECC.[45] In another study the authors also found "some evidence that using an MI approach when delivering oral health information had a positive effect on parent/caregiver oral health knowledge, attitudes, and behaviors compared to traditional dental health education."[46] MI should be consequently regarded as "a promising approach that warrants further attention in a variety of dental contexts."[47]

A different approach using a brief multicomponent theory-based intervention among mothers of 1- to 2-year-old children showed moderate effect in improving cognitions and self-reported cleaning of children's teeth,[48] but also here the effect on ECC is still unclear. Similarly an educational program was regarded as a "practical and effective method for increasing oral hygiene practice, but was not sufficient to prevent the development of ECC,"[49] showing that it is a far step from advice to actual lasting behavioral change leading to a caries-preventive effect.

As yet, there is moderate quality evidence showing a benefit of oral health education for caregivers,[50] when a combination of brushing and fluoride instruction is considered. This means that, conceivably, oral hygiene counseling might only be effective in ECC prevention if fluoride toothpaste (eg, ≥ 1,000 ppm) is not

only recommended but used, because then the increased number of times that the children's teeth are brushed[44] may gain an impact on children's oral health.

In addition, repetition is known to promote motor learning,[51] which leads to the conclusion that repeated brushing instruction combined with training at each visit may help to promote oral health.

Evidence of diet counseling

Although there is "some evidence that one-to-one dietary interventions in the dental setting can change behavior,"[52] the effect of this intervention on the prevention of ECC is not clearly proven.[53] It is biologically plausible that sugar reduction reduces caries risk, but the evidence for the role of dietary intervention in preventing ECC is low. To eliminate or at least to limit the frequency of intake of sugars in nursing bottles should still be part of the educational intervention.[50] The effect of traditional dental health education of caregivers regarding the diet of preschool children to prevent ECC is questionable. For instance no change in parental behavior after intense dietary counseling, which consisted of a scripted counseling, including also the presentation pictures of severe ECC, was found in a study from the USA.[54]

Nonetheless, the evidence is clear that sugars play an essential role in the caries process. Furthermore, the frequency of sugar consumption and the duration of sugars staying in the mouth are more powerful determinants of caries risk than the quantity of sugar consumption.[55] Nonetheless, the high correlation between the amount and frequency of sugars makes it difficult to say which is of more importance in caries prevention. Along with the very low or absent relation between sugar consumption and caries when fluoride is appropriately used, the relevance of emphasizing diet counseling decreases.[56] For the consumption of sugars in bottles as well as for

prolonged breastfeeding, there is (low-quality) evidence of increased risk of ECC.[50]

Despite low evidence for a low caries preventive effect of dietary and brushing advice, it may have an impact on the change of behavior if proper techniques and mechanism of learning are considered. Regular tooth brushing at home and a healthy dental diet will play an important role in the management of caries in the primary dentition if lasting dental health is to be achieved.

Evidence of fluoride counseling

In contrast to oral hygiene and dietary counseling, a chairside oral health counseling containing the use of fluoride was found to be effective for reducing caries.[43]

This is plausible as studies on the preventive effect of tooth brushing before introduction of fluoride toothpaste show lower plaque scores and gingivitis but almost no decrease in caries incidence.[57]

Regarding the use of the technique of MI for fluoride counseling, a protective effect with regard to the development of ECC was shown.[47] One reason for this clinical effect is most likely the “greater compliance with recommended fluoride varnish treatment regimens in families who received MI counseling compared with families who received traditional education.”[47]

Fluoride varnish has been shown to be effective in ECC prevention as the caries incidence was higher in a study comparing “counseling only” vs “counseling + fluoride varnish assigned once/year” (odds ratio [OR] = 2.20) and “twice/year” (OR = 3.77).[58] At the same time these study results show also that standard

counseling regarding dietary habits and domestic oral hygiene has a low caries preventive effect.

Therefore, fluoride varnish should be applied to compensate for lack of healthy behavior. Nonetheless, adequate time-effective techniques for counseling focusing on fluoride use should still be applied in the prevention of caries in early childhood.

Consultation during pregnancy: primary-primary prevention of ECC

A smart and early approach in the prevention of ECC is to target the expectant mothers in this special emotional phase of life and to address oral health issues.

Especially in first time mothers, pregnancy being a new experience, information on how to deal with their future baby is of interest. Therefore, it is not surprising that “oral health promotion information during pregnancy, and later when the child reached 6 and 12 months of age has been shown to be successful in reducing the incidence of severe ECC in very young children.”[59] In addition, “providing new mothers with guidance on caries prevention helps to reduce ECC” but also “has a sustainable effect up to school age.”[60] Regarding toothache, which is an important factor in OHRQoL of children, this study showed that children in the intervention groups suffered significantly less from toothache than those in the comparison group.[60] Prevention at this early stage even showed to be effective in reducing caries in preschool children, when a population is already profiting from community water fluoridation (Chile). The conducted prenatal and postnatal caries prevention program resulted in 97% of

the children (1 to 3.5 years of age) being caries free compared to the 77% in the control group.[61]

Another interesting aspect of primary-primary prevention of ECC may be to advise the use of xylitol chewing gum for mothers with high salivary mutans streptococci (MS) levels. A study from Finland has shown that maternal use of xylitol chewing gum can prevent dental caries in their children by inhibiting "the transmission of MS from mother to child."[62] Nonetheless, this chewing gum approach does not implement a long-term healthy behavior to care for the children's teeth, but due to reduced levels of MS may still help to reduce bacterial levels and possibly ECC.

Access to children: prevention on individual, group, and collective level

Aside the widespread knowledge on the etiology and prevention of ECC, the reduced interest and access to that information along with lower health literacy and belief in self-efficacy in particular groups may be a barrier for successful prevention of ECC in vulnerable social groups. This is why caries prevalence and incidence especially in children is usually distributed non-normally, as indices like the Significant Caries Index (SiC)[63] and SaC^3 depict. The parental educational or socioeconomic status (SES) usually plays an essential role in caries risk and prediction (OR of 4.6 for parental university degree and a low 10-year caries increment in the child).[64]

As mentioned before, early contact to caregivers, during pregnancy or early after birth, regarding healthy behavior may be a key for effective prevention of ECC.

Population-based programs inviting every parent with their newborn child to visit a dental office to receive comprehensive oral health advice, free fluoride toothpaste, and a free toothbrush along with risk-related recall intervals for fluoride varnish

applications was shown to be highly successful in reducing the incidence of ECC.[64]

Despite the fact that children from lower SES profited most (5.6 vs 0.3 dmfs [decayed, missing, and filled surfaces], Table 9-6), still non-participation in the program poses a problem especially for the vulnerable infants from lower SES, as participation was voluntary.[65]

Table 9-6 Caries experience differentiated by socioeconomic status and group affiliation in a birth cohort study from Jena, Germany, after 3 years running the caries preventive program (adopted and modified according to Wagner and Heinrich-Weltzien[65])

Group		Socioeconomic status		
		High	Middle	Low
Children	Total (n = 755)	200	491	64
	Prevention group (n = 377)	114	228	35
	Control group (n = 378)	86	263	29
Mean $d_{1-4}mfs$ (total)	Total	1.0	1.6	4.4
	Prevention group	0.5	0.7	1.5
	Control group	1.3	2.4	7.9
Mean $d_{3-4}mfs$ (total)	Total	0.3	0.7	2.7
	Prevention group	0.1	0.1	0.3
	Control group	0.5	1.2	5.6

This means that either a political will and decision is necessary to implement an obligatory early dental visit by law or that vulnerable groups need to receive specific visits at home as, for example, in Denmark,[66] as they (mostly children from low SES) may not consider going to the dentist for regular check-ups in order to receive effective caries preventive measures (fluoride varnish) despite free dental care.

As far as accessibility is concerned, the additional group prophylaxis approach, ie the setting approach, offers great opportunities and advantages, especially for balancing social differences in (oral) health. This, however, requires concentration and intensification in risk groups via the proposed concept of proportionate universalism.[67] This means that preventive actions aiming at caries reductions must be "universal but with a scale and intensity that is proportionate to the level of disadvantage."[67] For the prevention of ECC and the generally too-high caries prevalence in the primary teeth worldwide,[1] the implementation of a combination of different approaches in prevention of ECC is needed.

Along with early contact and invitation for individual prevention including early examinations for detection of ECC in the dental office from the first tooth onwards, group prophylaxis and home visits would also be important. The Nexø method is a great example: This program is based on very early access to all children of the community (from the eighth month of life) and high-quality oral hygiene with fluoride application. This is achieved by training the parents to clean the teeth from the first tooth onwards, and risk-based recall intervals. The success of the Nexø method or slight modifications is well documented in different countries and settings.[66,68,69]

The Common Risk Factor Approach[70] and the setting approach offer a theoretical concept to address the socioeconomic influences on oral health within the framework of group prophylaxis for caries prevention. The advantage is that no primary drive of the "clients" is necessary, so that the remaining risk group with probably lower social status, less self-efficacy, or lower health literacy can be addressed via "risk kindergartens." In addition, a network with other official institutions can be built to provide home visits or telephone calls for preventive measures.

It is known that availability and use of fluoride through different means (eg, water, salt, and toothpaste) has a clear effect on caries levels,[71-73] and according to experts fluorides play the most important role in caries prevention.[74] It is known that children in areas with fluoride-containing water have a lower risk for ECC,[50] but also that already the distribution of free fluoride toothpaste (1,450 ppm) with dental health messages to the homes of 1-year-old children has a caries preventive effect on population level in this age group.[75] An increase of fluoride concentrations in toothpaste for children – as a measure of collective prophylaxis – therefore, most likely will lead to caries reductions regardless of a change in oral health behavior, as long as there is at all a widespread habit of tooth brushing in the community. On the level of group prophylaxis, "supervised tooth brushing for preschool children was found to be an effective prevention technique for use in underprivileged groups."[76]

Still, regardless of an effective health intervention to reduce ECC, caries levels in non-participants in a deprived population were particularly high.[77] This shows that reaching out to risk groups is of utmost importance.

Fortunately, "home visits for dietary advice appear to help reducing dental caries in infants."[78,79] In addition, in a population approach in Australia, a controlled 2-year cohort study found that home visits or telephone contacts conducted every 6 months from birth prevent ECC effectively, as only 1.5% of the children developed caries in the home-visit group, 6.8% in the telephone-contact group, but 22.5% in the control group.[80] Regarding efforts and benefits in this study, the telephone contact should be of particular interest, as they are less time-consuming than home visits. This demonstrates that home visits or other ways of contact might be needed to reach an effect in these vulnerable groups at particularly high risk.

In another study on home nutritional advice during the first year of life, caries incidence and severity at 4 years of age in a low-income community was decreased as well. Interestingly, the “intervention produced a greater reduction in the frequency of ECC in children from one-parent families than in those from two-parent families.”[81] Nonetheless, they still had a four-times higher risk than children from two-parent families, showing that single parents are a decisive factor in the risk of ECC,[81] which should be kept in mind by dental professionals also in the context of individual prevention in dental offices. Possibly, in high-risk groups there should be more proportionate prevention with effective measures like fluorides, and less space may be given for behavioral prevention.

In conclusion, for effective prevention of ECC, a combination of approaches in individual, group, and collective settings is needed. The access to vulnerable groups via home visit or telephone contact and during susceptive phases (eg, pregnancy – primary-primary prevention), or as public health approaches via kindergartens, applying the concept of proportionate universalism, are a key factor, as ECC is highly prevalent in risk groups of predominantly lower socioeconomic background. Fortunately, dentistry has highly effective caries prevention options, such as fluorides, which can largely compensate for competence deficits in plaque removal or diet for a certain period of time. Close-together preventive dental check-ups for the early detection of caries lesions including preventive measures, such as additional fluoride applications in children at caries risk, are advisable. Dental practitioners likely overestimate the impact of their preventive advice on behavioral change, as diet and oral hygiene advice have not been shown to be effective in preventing ECC. Only when fluorides play a role in the counseling some effect may be depicted. The bare telling of evidence-based effective preventive measures (tooth brushing with fluoride toothpaste and a low frequency of sugar intake) is

most likely not enough to achieve a long-lasting effect, because it is a far step from “knowledge” towards “attitude” and finally to a long-term change into healthy behavior. Therefore, in the context of modern patient-doctor relationships “informed consent” is essential and techniques like MI or “teach back” should be used. In counseling approaches, it should always be considered by the health professionals “how people learn” (eg, learning from the model) and that the way of information transmission affects learning (training vs telling). Nonetheless, daily tooth brushing with fluoride-containing toothpaste from the first tooth onwards remains irreplaceable for lasting good oral health and should therefore be primary advocated content, despite compensatory prevention or management options.

References

1. Chen KJ, Gao SS, Duangthip D, Lo ECM, Chu CH. Prevalence of early childhood caries among 5-year-old children: a systematic review. J Investig Clin Dent 2019;10:e12376.
2. Hooley M, Skouteris H, Boganin C, Satur J, Kilpatrick N. Parental influence and the development of dental caries in children aged 0–6 years: a systematic review of the literature. J Dent 2012;40:873–885.
3. Schmoeckel J, Santamaría RM, Basner R, Schüler E, Splieth CH. Introducing a specific term to present caries experience in populations with low caries prevalence: specific affected caries index (SaC). Caries Res 2019;53:527–531.
4. Team DAJ. Epidemiologische Begleituntersuchungen zur Gruppenprophylaxe 2016. 1st ed. Bonn: Deutsche Arb.-Gemeinsch. f. Jugendzahnpflege, 2017.
5. Basner R, Hirsch C, Splieth C. Lehre im Fach Kinderzahnheilkunde im Grundstudium Zahnmedizin in Deutschland. Curriculum for the undergraduate programme in

paediatric dentistry in Germany. Deutsche Zahnärz Zeitsch 2012(67):708–715.

6. Splieth CH, Bünger B, Pine C. Barriers for dental treatment of primary teeth in East and West Germany. Int J Paed Dent 2009;19:84–90.
7. Vollú AL, da Costa MdEPR, Maia LC, Fonseca-Gonçalves A. Evaluation of oral health-related quality of life to assess dental treatment in preschool children with early childhood caries: a preliminary study. J Clin Ped Dent 2018;42:37–44.
8. Thomson WM. Public health aspects of paediatric dental treatment under general anaesthetic. Dent J (Basel) 2016;4:E20.
9. Rashewsky S, Parameswaran A, Sloane C, Ferguson F, Epstein R. Time and cost analysis: pediatric dental rehabilitation with general anesthesia in the office and the hospital settings. Anesthes Prog 2012;59:147–153.
10. Avila WM, Pordeus IA, Paiva SM, Martins CC. Breast and bottle feeding as risk factors for dental caries: a systematic review and meta-analysis. PLoS One 2015;10:e0142922.
11. Valéra M-C, Aragon I, Monsarrat P, Vaysse F, Noirrit-Esclassan E. Oral health education in children before dental treatment under general anesthesia. J Clin Paed Dent 2016;40:417–421.
12. Matvienko-Sikar K, Toomey E, Delaney L, et al. Behaviour change techniques and theory use in healthcare professional-delivered infant feeding interventions to prevent childhood obesity: a systematic review. Health Psych Rev 2019;13:277–294.
13. Bandura A (ed). Psychological modeling: Conflicting theories. Chicago: Aldine-Atherton, 1971.
14. Schmitt G. Lernen und Verhaltensänderung. Essen: Skript, 1999.
15. Puri S, Vasthare R, Munoli R. The impact of sibling behavior on oral health: a narrative review. J Int Soc Preventive Community Dent 2019;9:106–111.

16. Meyer-Lueckel H, Ekstrand KR, Paris S. Caries management: Science and clinical practice. Stuttgart: Thieme, 2013.
17. Skinner BF. About Behaviorism. New York: Random House US, 2011.
18. Hofmann SG, Hildebrandt A, Schnell T (eds). Einführung in die moderne kognitive Verhaltenstherapie: Psychotherapeutische Lösungsansätze. Berlin: Springer VS, 2013.
19. Willig W (ed). Psychologie, Sozialmedizin, Rehabilitation: Ein Lehrbuch für die Ausbildung in der Krankenpflege. 2nd ed. Balingen: W. Willig, 2002.
20. Schäffter O. Bildung zwischen Helfen, Heilen und Lehre. In: Krüger H-H, Olbertz JH (eds). Bildung zwischen Staat und Markt. Wiesbaden: VS Verlag für Sozialwissenschaften, 1997:691.
21. Glasersfeld EV. Aspekte einer konstruktivistischen Didaktik: Aspects of constructivist didactics. http://www.vonglasersfeld.com/179. Accessed 29 December 2019.
22. Siebert H. Konstruktivismus: Konsequenzen für Bildungsmanagement und Seminargestaltung. Frankfurt: DIE, 1998.
23. Schroer K. Die Psychologie des Lernens – Wie funktioniert Lernen? https://www.fernstudieren.de/im-studium/effektives-lernen/die-psychologie-des-lernens. Accessed 29 December 2019.
24. Klemperer D. Vom Paternalismus zur Partnerschaft: Der Arztberuf im Wandel. In: Pundt J (ed). Professionalisierung im Gesundheitswesen: Positionen, Potenziale, Perspektiven, 1st ed. Bern: Huber, 2006:61–75.
25. Geisler L. Arzt-Patient-Beziehung im Wandel. Stärkung des dialogischen Prinzips. In: Abschlussbericht der Enquête-Kommission “Recht und Ethik der modernen Medizin”. Berlin: Medien- und Kommunikations, 2002:216–220.

26. Beauchamp TL, Childress JF. Principles of biomedical ethics. New York: Oxford University Press, 2013.
27. Eyal N. Informed Consent. https://plato.stanford.edu/archives/spr2019/entries/informed-consent/. Accessed 29 December 2019.
28. Beauchamp TL, Childress JF. Principles of biomedical ethics. 6th ed. New York: Oxford University Press, 2009.
29. Beauchamp TL. Informed Consent. In: Post SG (ed). Encyclopedia of bioethics, 3rd ed. New York: Macmillan Reference, 2004:1271–1313.
30. Sørensen K, Pelikan JM, Röthlin F, et al. Health literacy in Europe: comparative results of the European health literacy survey (HLS-EU). Eur J Public Health 2015;25:1053–1058.
31. Bandura A. Self-efficacy: The exercise of control. 11th ed. New York: WH Freeman. 2010.
32. Bandura A. Self-efficacy mechanism in human agency. Am Psychologist 1982;37:122–147.
33. Achtziger A, Gollwitzer PM. Motivation and volition in the course of action. In: Heckhausen J, Heckhausen H (eds). Motivation und Handeln, 4th ed. Berlin, Heidelberg: Springer-Verlag, 2010.
34. IDZ. Fünfte Deutsche Mundgesundheitsstudie – DMS V. Cologne: IDZ, 2016.
35. Public Health England. Delivering better oral health: an evidence-based toolkit for prevention. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/605266/Delivering_better_oral_health.pdf. Accessed 29 December 2019.
36. Miller WR, Moyers TB. Motivational interviewing and the clinical science of Carl Rogers. J Consult Clinical Psychol 2017;85:757–766.
37. Harrison R, Benton T, Everson-Stewart S, Weinstein P. Effect of motivational interviewing on rates of early childhood caries: a randomized trial. Pediatr Dent 2007;29:16–22.

38. Tyng CM, Amin HU, Saad MNM, Malik AS. The Influences of emotion on learning and memory. Front Psychol 2017;8:1454.
39. Basir L, Rasteh B, Montazeri A, Araban M. Four-level evaluation of health promotion intervention for preventing early childhood caries: a randomized controlled trial. BMC Public Health 2017;17:767.
40. Schulz von Thun F. Störungen und Klärungen: Allgemeine Psychologie der Kommunikation. 55th edn. Reinbek bei Hamburg: Rowohlt Taschenbuch Verlag, 2018.
41. Peter D, Robinson P, Jordan M, Lawrence S, Casey K, Salas-Lopez D. Reducing readmissions using teach-back: enhancing patient and family education. J Nurs Admin 2015;45:35–42.
42. Soldani FA, Lamont T, Jones K, et al. One-to-one oral hygiene advice provided in a dental setting for oral health. Cochrane Database Syst Rev 2018;10:CD007447.
43. Kay E, Locker D. A systematic review of the effectiveness of health promotion aimed at improving oral health. Community Dent Health 1998;15:132–144.
44. Freudenthal JJ, Bowen DM. Motivational interviewing to decrease parental risk-related behaviors for early childhood caries. J Dent Hyg 2010;84:29–34.
45. Ismail AI, Ondersma S, Jedele JMW, Little RJ, Lepkowski JM. Evaluation of a brief tailored motivational intervention to prevent early childhood caries. Community Dent Oral Epidemiol 2011;39:433–448.
46. Naidu R, Nunn J, Irwin JD. The effect of motivational interviewing on oral healthcare knowledge, attitudes and behaviour of parents and caregivers of preschool children: an exploratory cluster randomised controlled study. BMC Oral Health 2015;15:101.
47. Weinstein P, Harrison R, Benton T. Motivating mothers to prevent caries: confirming the beneficial effect of counseling. J Am Dent Assoc 2006;137:789–793.

48. Makvandi Z, Karimi-Shahanjarini A, Faradmal J, Bashirian S. Evaluation of an oral health intervention among mothers of young children: a clustered randomized trial. J Res Health Sci 2015;15:88–93.
49. Vachirarojpisan T, Shinada K, Kawaguchi Y. The process and outcome of a programme for preventing early childhood caries in Thailand. Community Dent Health 2005;22:253–259.
50. Moynihan P, Tanner LM, Holmes RD, et al. Systematic review of evidence pertaining to factors that modify risk of early childhood caries. JDR Clin Trans Res 2019;4:202–216.
51. Kimura T, Nakano W. Repetition of a cognitive task promotes motor learning. Hum Mov Sci 2019;66:109–116.
52. Harris R, Gamboa A, Dailey Y, Ashcroft A. One-to-one dietary interventions undertaken in a dental setting to change dietary behaviour. Cochrane Database Syst Rev 2012;3:CD006540.
53. Sälzer S, Alkilzy M, Slot DE, Dörfer CE, Schmoeckel J, Splieth CH. Socio-behavioural aspects in the prevention and control of dental caries and periodontal diseases at an individual and population level. J Clin Periodontol 2017;44(Suppl 18):S106–S115.
54. Franco S, Theriot J, Greenwell A. The influence of early counselling on weaning from a bottle. Community Dent Health 2008;25:115–118.
55. Gustafsson BE, Quensel CE, Lanke LS, et al. The Vipeholm dental caries study; the effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. Acta Odont Scand 1954;11:232–264.
56. van Loveren C. Sugar restriction for caries prevention: amount and frequency. Which is more important? Caries Res 2019;53:168–175.
57. Koch G, Lindhe J. The state of the gingivae and caries increment in schoolchildren during and after withdrawal of various prophylactic measures. In: McHugh WD (ed). Dental Plaque. Edinburgh: Livingstone, 1970:271–281.

58. Weintraub JA, Ramos-Gomez F, Jue B, et al. Fluoride varnish efficacy in preventing early childhood caries. J Dent Res 2006;85:172–176.
59. Plutzer K, Spencer AJ. Efficacy of an oral health promotion intervention in the prevention of early childhood caries. Community Dent Oral Epidemiol 2008;36:335–346.
60. Plutzer K, Spencer AJ, Keirse MJNC. Reassessment at 6-7 years of age of a randomized controlled trial initiated before birth to prevent early childhood caries. Community Dent Oral Epidemiol 2012;40:116–124.
61. Gomez SS, Weber AA. Effectiveness of a caries preventive program in pregnant women and new mothers on their offspring. Int J Paediatr Dent 2001;11:117–122.
62. Isokangas P, Söderling E, Pienihäkkinen K, Alanen P. Occurrence of dental decay in children after maternal consumption of xylitol chewing gum, a follow-up from 0 to 5 years of age. J Dent Res 2000;79:1885–1889.
63. Bratthall D. Introducing the Significant Caries Index together with a proposal for a new global oral health goal for 12-year-olds. Int Dent J 2000;50:378–384.
64. Schmoeckel J, Santamaría RM, Splieth CH. Long-term caries development in schoolchildren and the role of educational status. Quintessence Int 2015;46:409–415.
65. Wagner Y, Heinrich-Weltzien R. Evaluation of an interdisciplinary preventive programme for early childhood caries: findings of a regional German birth cohort study. Clin Oral Investig 2016;20:1943–1952.
66. Ekstrand KR, Christiansen MEC, Qvist V. Influence of different variables on the inter-municipality variation in caries experience in Danish adolescents. Caries Res 2003;37:130–141.
67. The Marmot review. Fair society, healthy lives: The Marmot review. London: UCL, 2010.
68. Kuzmina I, Ekstrand KR. Outcomes 18 years after implementation of a nonoperative caries preventive program –

the Nexö-method – on children in Moscow, Russia. Community Dent Oral Epidemiol 2015;43:308–316.

69. Vermaire JH. Application of the Nexø method in a general dental practice in the Netherlands: 6-year results of a RCT. Int J Dent Hyg 2018;16:419–425.
70. Watt RG, Sheiham A. Integrating the Common Risk Factor Approach into a social determinants framework. Community Dent Oral Epidemiol 2012;40:289–296.
71. Walsh T, Worthington HV, Glenny A-M, Marinho VC, Jeroncic A. Fluoride toothpastes of different concentrations for preventing dental caries. Cochrane Database Syst Rev 2019;3:CD007868.
72. Marinho VCC, Chong LY, Worthington HV, Walsh T. Fluoride mouthrinses for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2016;7:CD002284.
73. Weyant RJ, Tracy SL, Anselmo TT, et al. Topical fluoride for caries prevention: executive summary of the updated clinical recommendations and supporting systematic review. J Am Dent Assoc 2013;144:1279–1291.
74. Bratthall D, Hänsel-Petersson G, Sundberg H. Reasons for the caries decline: what do the experts believe? Eur J Oral Sci 1996;104:416–422.
75. Davies GM, Worthington HV, Ellwood RP, et al. A randomised controlled trial of the effectiveness of providing free fluoride toothpaste from the age of 12 months on reducing caries in 5-6 year old children. Community Dent Health 2002;19:131–136.
76. Skeie MS, Klock KS. Dental caries prevention strategies among children and adolescents with immigrant - or low socioeconomic backgrounds- do they work? A systematic review. BMC Oral Health 2018;18:20.
77. Davies GM, Duxbury JT, Boothman NJ, Davies RM. Challenges associated with the evaluation of a dental health promotion programme in a deprived urban area. Community Dent Health 2007;24:117–121.

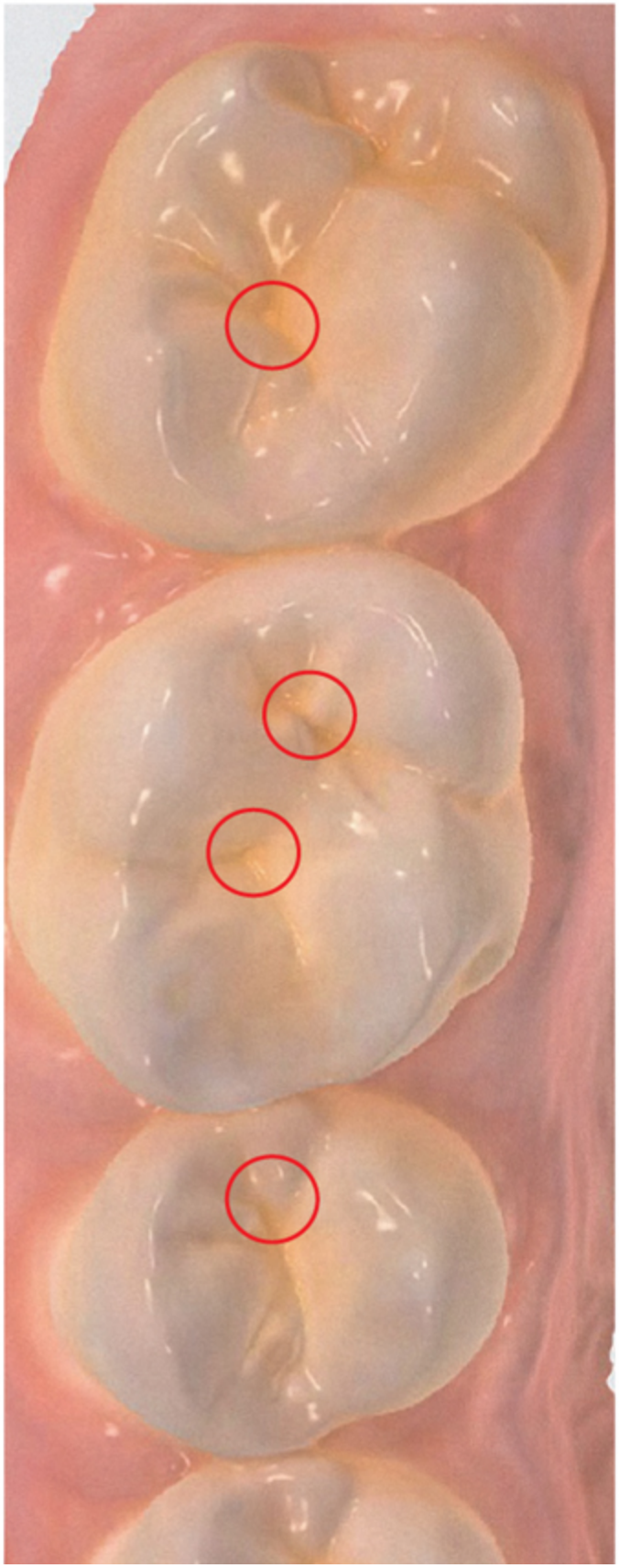
78. Feldens CA, Vítolo MR, Drachler MdL. A randomized trial of the effectiveness of home visits in preventing early childhood caries. Community Dent Oral Epidemiol 2007;35:215–223.
79. Feldens CA, Giugliani ERJ, Duncan BB, Drachler MdL, Vítolo MR. Long-term effectiveness of a nutritional program in reducing early childhood caries: a randomized trial. Community Dent Oral Epidemiol 2010;38:324–332.
80. Plonka KA, Pukallus ML, Barnett A, Holcombe TF, Walsh LJ, Seow WK. A controlled, longitudinal study of home visits compared to telephone contacts to prevent early childhood caries. Int J Paediatr Dent 2013;23:23–31.
81. Plutzer K, Keirse MJNC. Incidence and prevention of early childhood caries in one- and two-parent families. Child Care Health Dev 2011;37:5–10.

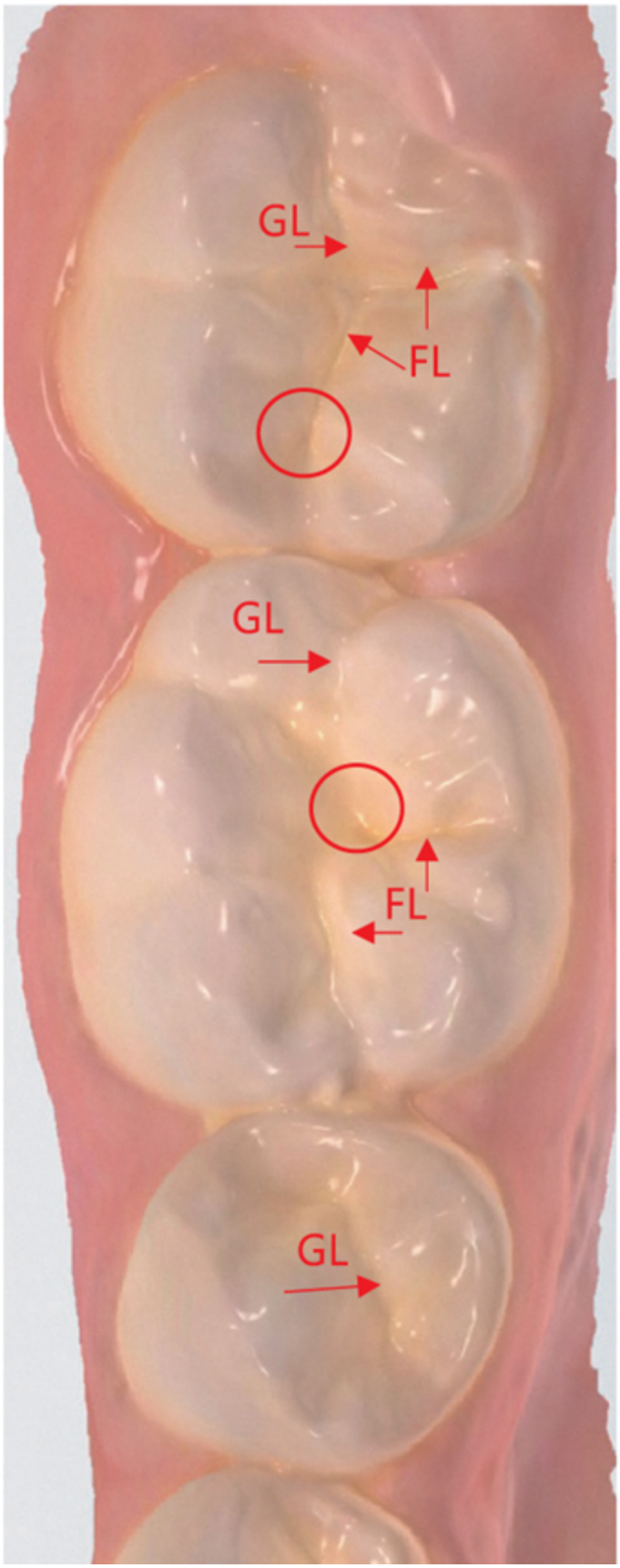
10

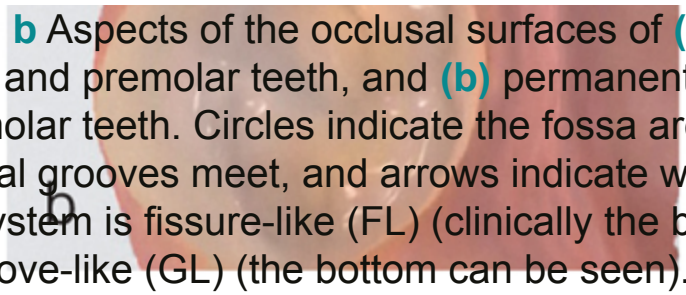
Fissure sealing: Still to be recommended?

Kim R. Ekstrand, Azam Bakshandeh, Christian H. Splieth

Due to their macromorphologic structure, occlusal surfaces on molars are extremely caries prone (Fig 10-1). In older literature, it was hypothesized that the narrow and deep pits and fissures on the occlusal surfaces (Fig 10-1, site FL) are to be blamed for the caries development on these surfaces, as they are uncleansable.[1,2] More recently, authors stress the importance of the more open fossa areas (Fig 10-1, circled),[3,4] together with a long-lasting eruption period of these teeth without function from the antagonists.[5] This promotes plaque accumulation, and thus leads to a high caries susceptibility of these surfaces. The interaction of the two latter problems is the hypothesis mainly accepted today. It is supported by the fact that the occlusal surfaces in the maxillary premolars (Fig 10-1a), which present with a deep and narrow fissure system, hardly ever develop caries or have to be restored in countries with low caries prevalence.







Figs 10-1a and b Aspects of the occlusal surfaces of **(a)** permanent maxillary molar and premolar teeth, and **(b)** permanent mandibular molar and premolar teeth. Circles indicate the fossa area where several interlobal grooves meet, and arrows indicate where the groove-fossa system is fissure-like (FL) (clinically the bottom cannot be seen) or groove-like (GL) (the bottom can be seen). (Occlusal pictures of 3D models are shown. Software: Trios, 3Shape. Intraoral scanner: Trios 4, 3Shape. Images courtesy of Dr S Michou.)

Fissure sealants were suggested as a management for caries on the occlusal surface by Buonocore in the 1950s to 1970s.[6,7] Since then, sealants have been used extremely often in countries where there is a well-established dental system caring for children and adolescents.[8] It is tempting to suggest that fissure sealants played a major part in the caries decline observed in many countries, such as in Denmark.[9] Contrary to this assumption, the inter-municipality variation in the number of sealed teeth among children does not mirror the respective caries levels in the different municipalities in Denmark.[10] With the Nexö method, which includes special attention for tooth brushing of erupting molars and therefore limits the indication of sealants to progressing initial caries lesions, one of the lowest caries rates in the world was achieved for adolescents up to 18 years of age.[11] Thus sealants seem to be a valuable preventive measure, with the indication and technique discussed later in the chapter. The main aim of this chapter is to examine if fissure sealants can be recommended as a general preventive measure for all children, in the same way that dental practitioners recommend tooth brushing twice a day with fluoridated toothpaste to their patients, or if sealants should be used risk-related. In order to answer this question, the following topics are addressed:

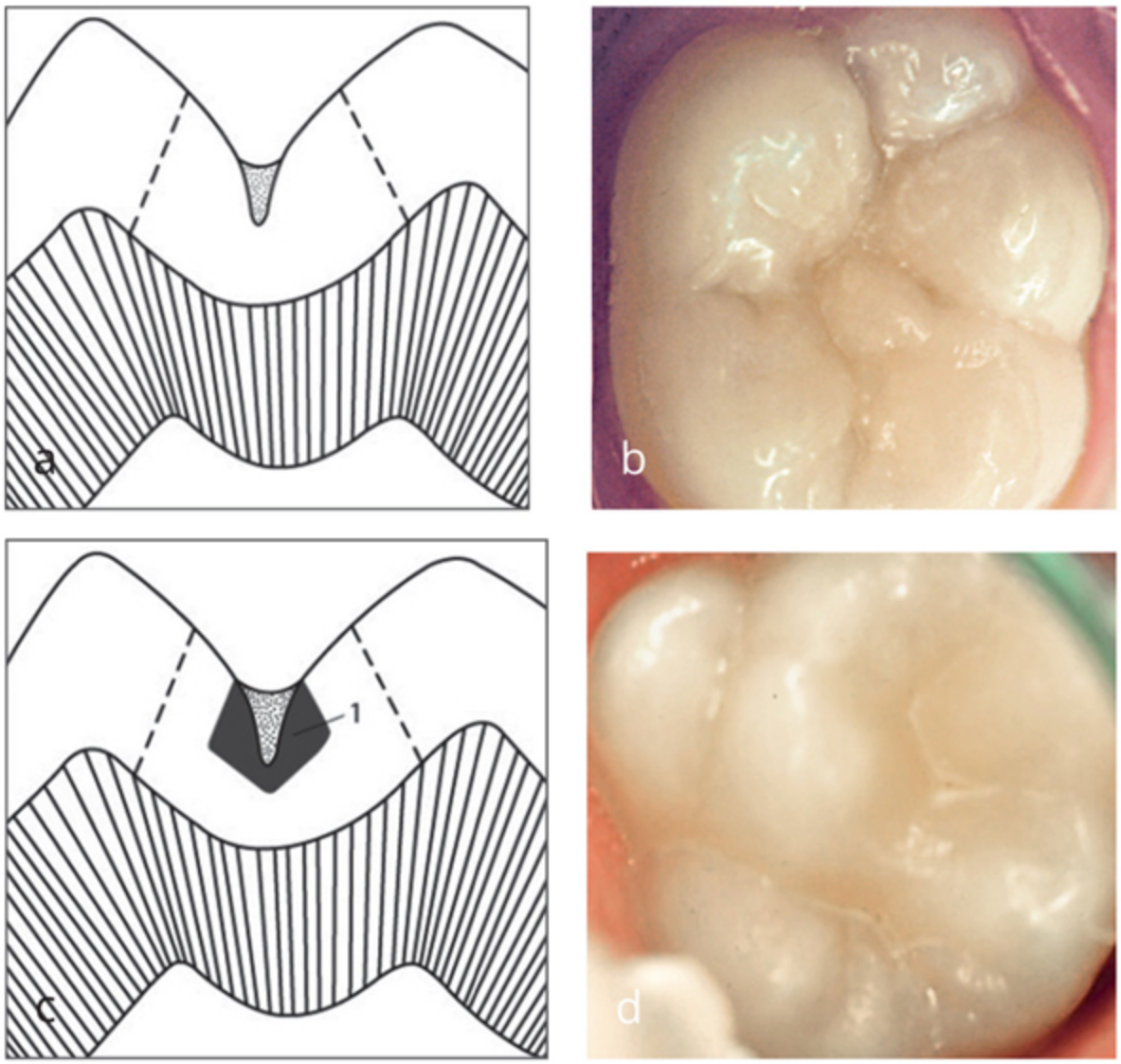
- the progression of the caries demineralization on the occlusal surface and the reactions of the pulp dentin organ, including the radiologic appearances of the different caries stages on the occlusal surface

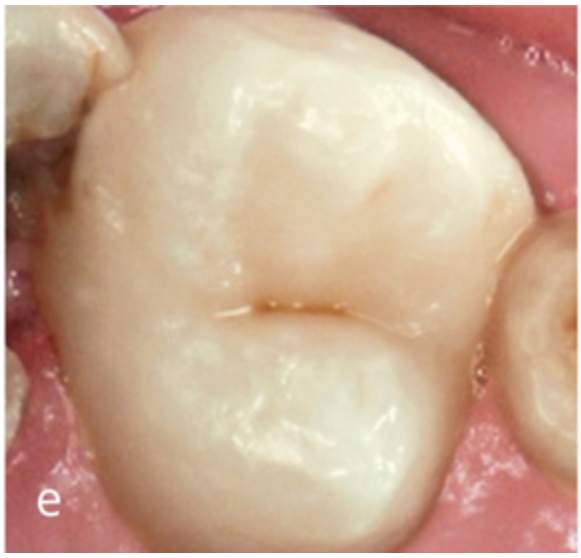
- at what stage of caries (no caries, initial, moderate, or extensive staged caries) sealants are indicated
- differences between preventive and therapeutic sealing and consequences for indication and technique
- how the effectiveness of fissure sealing compares to basic prevention or to fluoride treatment
- if there are differences in the effectiveness of different materials used as fissure sealants (glass-ionomer cement [GIC], composite resin)
- what recommendations can be made for proper fissure sealing technique.

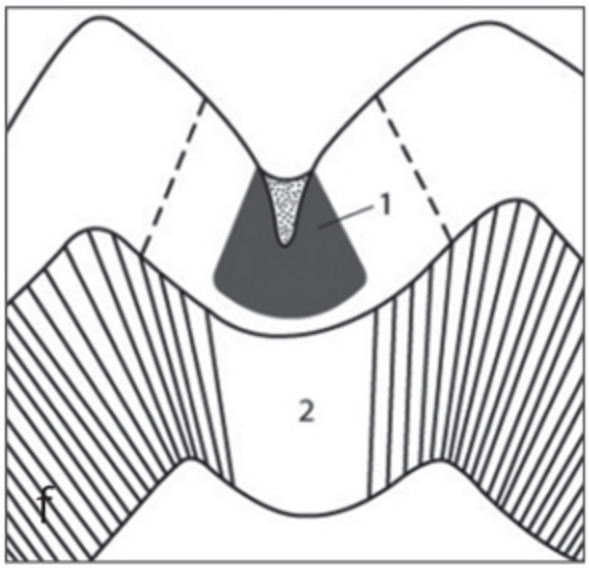
Caries progression on occlusal surfaces

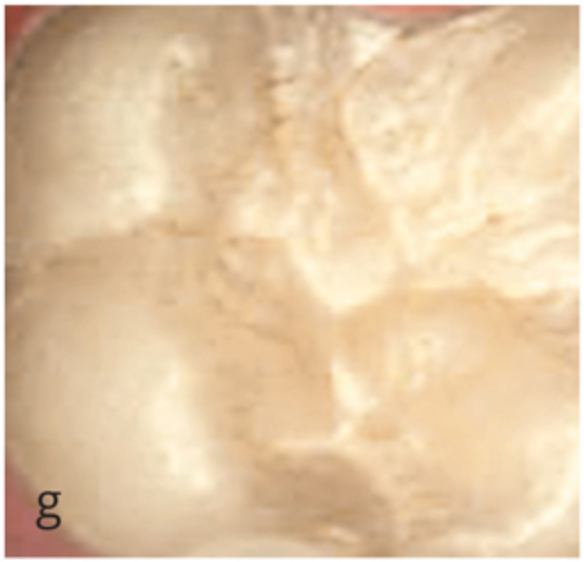
Based on several studies,[3,12,13] the illustrations in Figs 10-2 and Table 10-1 highlight the caries development observed clinically and radiographically. In Fig 10-2, progressive stages of caries on the occlusal surface are illustrated on sections on the occlusal surfaces with the reactions of the dentin pulp organ. Caries spreads along the direction of the rods (Figs 10-2a and c), and progresses in a pulpal direction on the occlusal surface. The bacteria in the groove-fossa system, the modern term for pits and fissure system,[14] are most metabolically active in the upper part of the relatively narrow parts of the groove-fossa system and in the bottom part of the more open parts of the groove-fossa system.[3,15] The progression rate is, therefore, fastest at the upper part of the narrow grooves, as illustrated in Fig 10-2c. Just before the lesion reaches the enamel dentin boarder, the dentin below reacts with tubular sclerosis, resulting in hypermineralization (Fig 10-2f). If the lesion continues to progress, this hypermineralized dentin will demineralize and there will be a further reaction at the pulp side, where tertiary dentin is formed (Fig 10-2i). In most cases, the surface is still unbroken and the color of the lesion is whitish, yellowish, or brownish (Figs 10-2d, e, g, h, j, and k). If the dentinal de¢mineralization penetrates deeper,

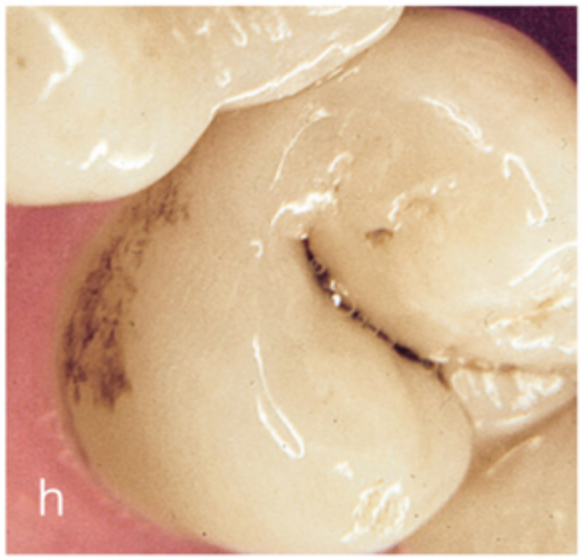
either a breakdown will occur in the enamel and/or a shadow will appear clinically (Figs 10-2l to n). With further progression of the lesion, the final step will be the formation of a cavitation into dentin (Figs 10-2o and p), followed by massive invasion of bacteria into the enamel and dentin (Figs 10-2l to p).

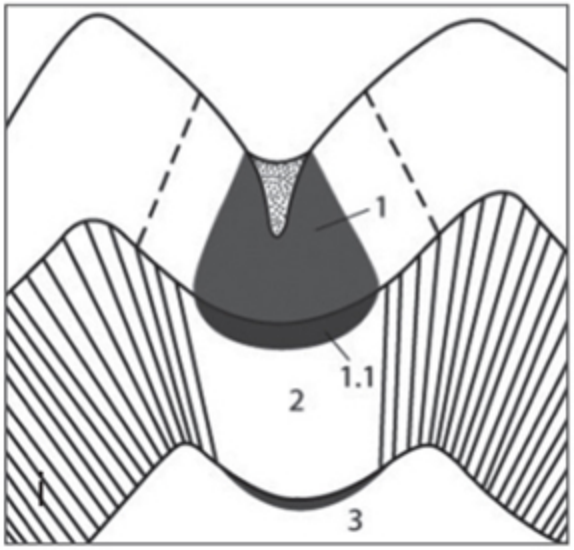


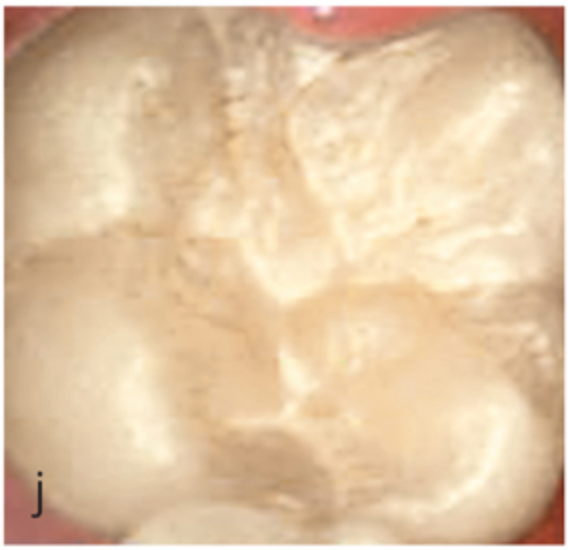


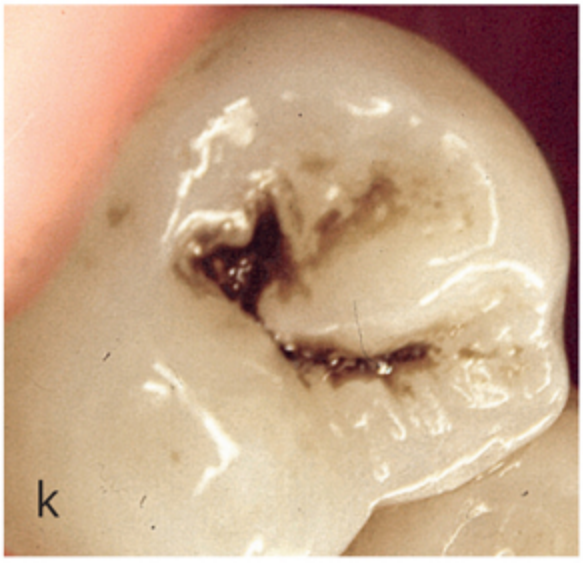


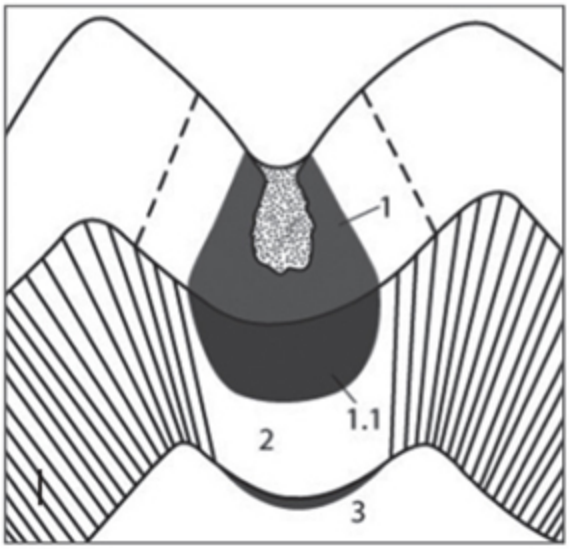


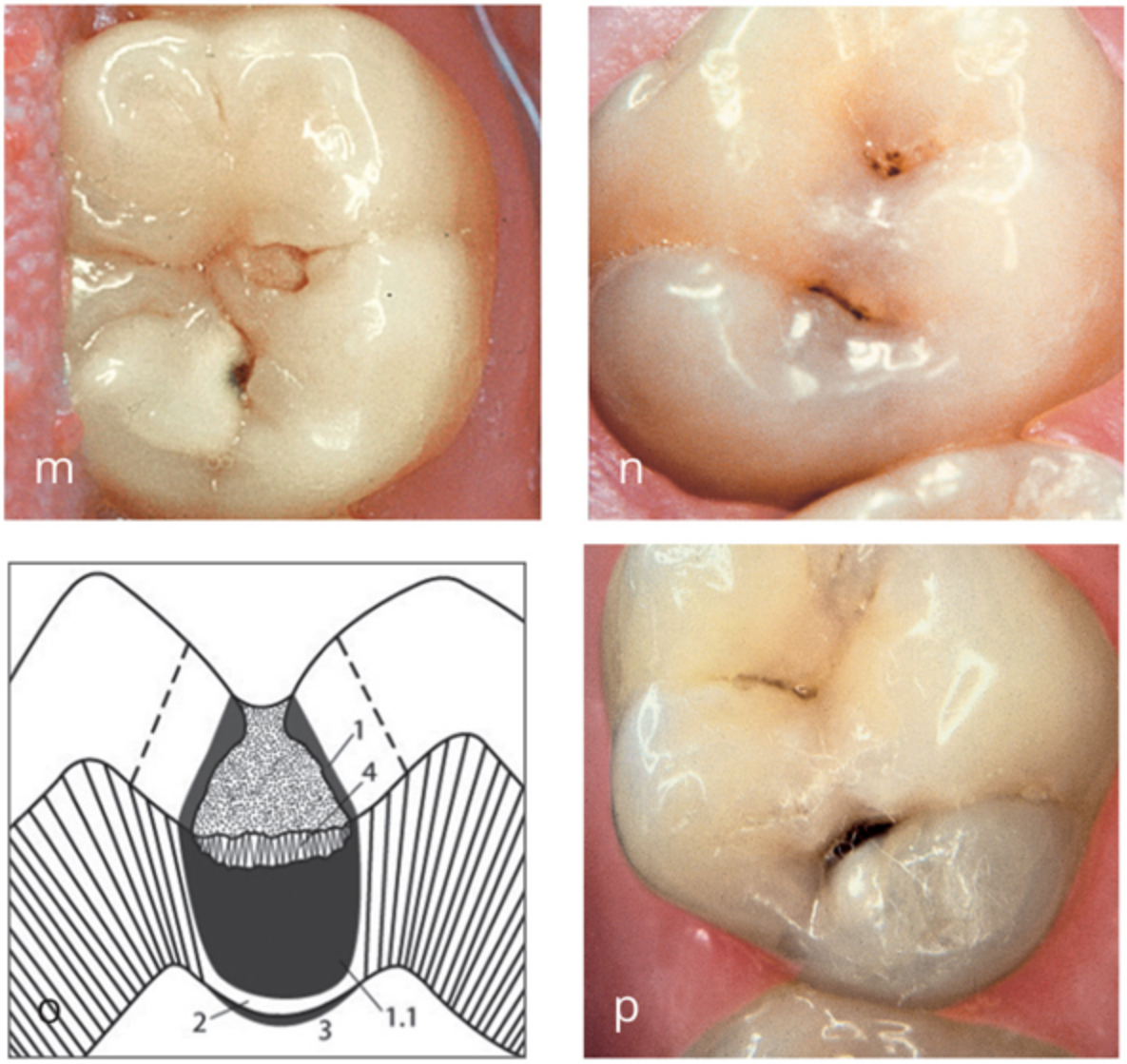








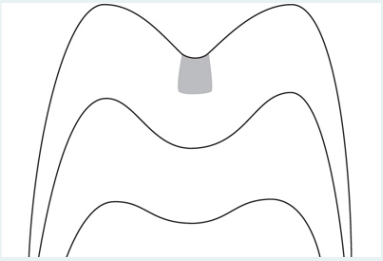
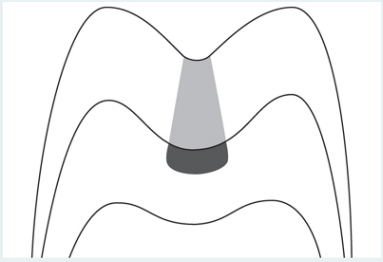


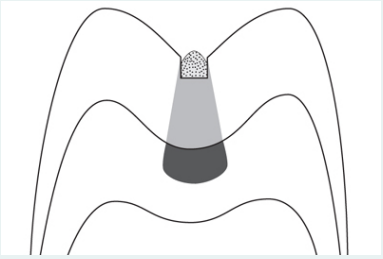
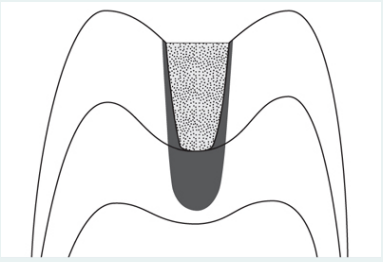


Figs 10-2a to p Illustrations and clinical examples of the relationship between the underlying histologic reactions and the clinical stages of occlusal caries. **(a and b)** No histologic lesion, no clinical caries. **(c to e)** Initial lesion (A): Demineralization (c, 1) limited to the outer half of the enamel, requiring air-drying to identify the white spot lesions, or recognized by brown spot lesions located in the morphology of the groove. **(f to h)** Initial lesion (B): Before the lesion reaches the enamel dentin border, the dentin below reacts with tubular sclerosis (f, 2), resulting in hypermineralization. **(i to k)** Initial lesion (C): Hypermineralized dentin demineralizes (i, 1.1) with further reaction at the pulp side, where tertiary dentin is formed (i, 3). Clinically initial

lesions B and C are recognized by white spot lesions that do not require air-drying to be identified or brown spot lesions that extend beyond the groove morphology (g, h, j, k). Clinically it is not possible to differentiate if the lesion, histologically, is a B or a C lesion. **(l to n)** Moderate lesion: Demineralization entering to the middle third of the dentin; breakdown occurs in the enamel and/or a shadow appears clinically. **(o and p)** Extensive lesion: Demineralization into the inner third of the dentin or even into the pulp and clinically formation of a cavitation into dentin, followed by massive invasion of bacteria into the enamel and dentin.

Table 10-1 Relation between clinical, radiographic, and histologic stages of occlusal caries

Visual occlusal aspect	Radiograph	Histology
Initial caries	No radiolucency in dentin	
Initial caries	Radiolucency in outer third of dentin towards the pulp	

Visual occlusal aspect	Radiograph	Histology
Moderate caries	Radiolucency in middle third of dentin towards the pulp	
Extensive caries	Radiolucency in inner third of dentin towards the pulp or already into the pulp	

In Table 10-1, the radiologic appearance of progressive clinical stages of occlusal caries is shown. Due to sound enamel on the buccal and lingual surface, it is rarely possible to identify an initial *enamel* lesion of the occlusal caries on radiographs (Table 10-1, first row). Thus, the first radiographic appearance is a radiolucent area just below the enamel-dentin junction, caused by the demineralization in the dentin (Table 10-1, second row). If the lesion progresses, the radiolucent area will move towards the pulp and when it reaches the middle third (Table 10-1, third row), clinical breakdown of the enamel surface will often appear and/or a shadow will be seen clinically on the occlusal surface. When the radiolucency reaches the inner third of the dentin, dentin cavitation is usually seen clinically, and histologically the demineralization is also in the inner third of the dentin or already in the pulp (Table 10-1, fourth row).[16]

The terminology used for staging coronal lesions, including lesions on the occlusal surface, both clinically (Fig 10-2) and radiographically (Table 10-1) is:[16-20]

- no lesions
- initial lesions
- moderate lesions
- extensive lesions.

Preventive and therapeutically placed fissure sealants

In the literature, two different indications for fissure sealants are discussed: preventive fissure sealing and therapeutic fissure sealing.

According to current ORCA/IADR (European Organisation for Caries Research/International Association for Dental Research) terminology, preventive sealing is "the application of a thin physical barrier over a clinically sound caries predilection site, in order to prevent the initiation of a caries lesion. These can be applied to pits, fissures, and fossae using composite resin or glass-ionomer cement."[21] Thus, preventive sealing is used on a risk indication basis and is placed on molar teeth that clinically appear sound, but histologic changes might already have happened (Figs 10-2a to c and Table 10-1, first row).

Therapeutic sealing is "the application of a thin physical barrier over a caries lesion in order to prevent its progression. These can be applied to pits, fissures, fossae, and smooth surfaces using composite resin or glass-ionomer cement." This is applied on teeth with clinically visible caries stages (Figs 10-2c to k and Table 10-1 second row) as established techniques, and on advanced stages (Figs 10-2l to n and Table 10-1 third row) at a research level.[22]

Thus, sealants can be applied at all stages of caries lesion and also all levels of caries management from primary prevention on

healthy teeth through secondary prevention on initial lesions and, potentially, also as tertiary prevention in moderate lesions.

Qvist et al[22] recently assessed if it was possible to postpone restorative intervention on initial and moderate staged occlusal caries lesions in the permanent dentition, by sealing as a tertiary preventive approach. In this randomized clinical trial, 521 occlusal lesions in 521 patients aged 6 to 17 years were included. Based on the clinical and radiographic diagnosis, all lesions were assessed to require restorative treatment, which was randomly provided as sealant or composite resin restorations (ratio 2:1) by 68 dental practitioners in nine municipalities in Denmark. The annual clinical and radiographic controls over a 7-year period revealed that 46% of the fissure sealants were still functioning after 7 years while 31% were replaced by restorations. Of the baseline restorations, 7% were repaired or renewed. No endodontics had to be performed, either in the sealed or in the restored teeth. Similar results were found for sealing dentin lesions in adults.[23]

Survival of the therapeutic sealants increased in patients with low caries risk and/or excellent oral hygiene, in second molars compared with first molars, and in lesions not extending to the middle third of the dentin, corresponding to the moderate staged lesions (Table 10-1, third row).[22] Thus, it can be assumed that besides sealing fissures with initial enamel caries lesions, cases where the dentin involvement on radiographs are limited to the outer third of the dentin (Table 10-1 second row) can be treated with sealants as well. Still, repair of fissure sealants may be needed, but regular checkups allow for caries control, re-sealing, and potential replacement with restorations.[22,24,25]

The results underline that it is possible to postpone or avoid restorative intervention of occlusal dentin caries lesions in young permanent teeth with therapeutic sealants. The suggestion by Qvist et al[22] that the term “fissure sealant” should be used for cases without clinical and dentinal radiographic changes, and “SEAL” treatment could be used for cases with dentinal radiolucency, is in line with the new ORCA/IADR terminology.[21]

Effectiveness of fissure sealants

The effectiveness of sealants and their cost-benefit ratio has become an important topic since the caries decline, especially for approaches to preventive sealing in children in countries with nationalized health caries systems. The evaluation of this problem follows established procedures of public health and health economics.

Table 10-2 shows an example: in a group of 100 control patients without sealants, 90 (b) develop caries during a 3-year period, while the 100 patients with a sealed first permanent molar present only 20 (a) caries cases. In order to calculate the effectiveness of sealants, the risk of getting caries in not-sealed teeth is calculated (using the example in Table 10-2) as b / (b + d) = 0.9, meaning 90% caries development; the risk of getting caries in sealed teeth is a / (a + c) = 0.2, therefore only 20%.

Table 10-2 Hypothetical example for calculating the effectiveness of fissure sealants

	Caries	No caries	No. of teeth
Sealed	20 (a)	80 (c)	100
Not sealed	90 (b)	10 (d)	100
Total	110	90	200

a to d, see text for calculations of relative risk and odds ratio.

The relative risk (RR), which expresses the risk of an adverse outcome (caries) when receiving a medical treatment (sealing) versus no treatment (or placebo), is calculated as (a / b) divided by (a + c)/(b + d) = 0.22, then divided by 1 = 0.22. Thus, the risk of caries is 0.22 (22%) if the teeth are sealed compared to the unsealed surfaces, and the risk of caries is reduced by almost 80%.

The odds ratio (OR) is calculated by (a / c) divided by (b / d) = 20/80 divided by 90/10, which yields about 0.03. If the outcome of both treatments is the same, the OR will be 1. If the OR is < 1, the intervention is better than the control; in the above example, there is a 33-times higher risk (0.03 × 33 ≈ 1) of getting caries on unsealed teeth compared to sealed teeth.

The confidence interval (CI) describes an estimate of the range for the true value of an unknown population parameter. An OR of 0.03 and a 95% CI of 0.02 to 0.04 shows a large effect with a narrow range.

Bias means there is a systematic difference between the results obtained from a study and the true state of affairs, eg by a nonrepresentative selection of the patients or treating clinicians, nonrandomized assignment of the treatment and control group, the age of the children, problems with drop-outs from the study, or difficulties in the caries diagnosis.

For comparing fissure sealants versus no sealants,[26] a systematic review used data from randomized controlled trials (RCTs) comparing sealants with no sealant for preventing caries of occlusal

surfaces of premolar or molar teeth in children and adolescents aged up to 20 years (Table 10-3).

Table 10-3 Overview of data on the effectiveness of fissure sealants compared to no sealant over various time periods[26]

Duration and no. of studies	Pooled no. of participants	Materials	Effectiveness	Bias
24 mo, n = 15	1,548	Second-, third-, and fourth-generation resin-based sealants	OR = 0.12; 95% CI 0.08 to 0.19	Low, only blinding was a systematic problem
48–56 mo, n = 4	482		OR = 0.21; 95% CI 0.16 to 0.28	Low, only blinding was a systematic problem
24 mo, n = 3	NS	Low-viscosity glass-ionomer (2 studies) and resin-modified glass-ionomer (1 study)	Inconclusive	High

NS, not specified.

The data from 15 studies revealed that unsealed surfaces had about a 5- to 12-times greater risk of developing caries compared to resin sealed surfaces, and the trustworthiness of the data was high due to low levels of bias (Table 10-3). This decreased over time to 3.5- to 6.3-times greater risk at 4 to nearly 5 years of observation. It is questionable whether the treatment outcomes in RCTs under controlled conditions are transferrable to measures implemented as public health measures or in a community/national health system. Heyduck et al[27] found considerably higher rates for loss of sealant retention and caries development in a long-term observational study of the German National Health System, as clinical reality showed lower effectiveness in comparison to RCTs.

In addition, the underlying caries prevalence determines the benefit of a sealant. According to Ahovuo-Saloranta et al,[26] for a prevalence of 70% in the control group, sealants would reduce the prevalence to 19% (−51%) during a 2-year period; for a baseline prevalence of 19% this would be reduced to 5.2% (−14%). The effect could be even smaller when the observational period is extended or if there is an increase in the failure rate of sealants in a practice- or community-based setting. Thus, with low caries prevalence, the question of cost-effectiveness of general sealant application, especially in community or national health systems, arises and

mostly leads to serious concerns for a non-risk-based scheme.[28] For GIC sealants versus no sealants, the evidence is inconclusive, mostly owing to the very few studies with a high risk of bias (Table 10-3); this is also true for comparison of different sealant materials (mostly GIC versus composite resin).[26]

Ahovuo-Saloranta et al[26] concluded that "resin-based sealants applied on occlusal surfaces of permanent molars are effective for preventing caries in children and adolescents. The review found moderate-quality evidence that resin-based sealants reduced caries by between 11% and 51% compared to no sealant, when measured at 24 months. Similar benefit was seen at time points up to 48 months; after longer follow-up, the quantity and quality of evidence was reduced. There was insufficient evidence to judge the effectiveness of glass-ionomer sealant or the relative effectiveness of different types of sealants. Information on adverse effects was limited but none occurred where this was reported. Further research with long follow-up is needed."

The direct comparison of sealants versus fluoride varnish application is based on very few studies (Table 10-4),[29] and these indicate that occlusal surfaces receiving topical fluoride varnish applications have an up to two-times higher risk of developing caries over a 2- or 9-year-period compared to sealed surfaces. No adverse events were found for either treatment. The trustworthiness of the data, however, is low due to high levels of bias (Table 10-4). The authors concluded that "currently, scarce and clinically diverse data are available on the comparison of sealants and fluoride varnish applications; therefore it is not possible to draw clear conclusions about possible differences in effectiveness for preventing or controlling dental caries on occlusal surfaces of permanent molars. The conclusions of this updated review remain the same as those of the last update (in 2010). We found some low-quality evidence suggesting the superiority of resin-based fissure sealants over fluoride varnish applications for preventing caries."[29] Regarding the cost-effectiveness, the mode of application determines the benefit of both preventive measures. In school-based settings, there seems to

be evidence that the clinical superiority of sealants is clearly lost when considering the lower costs of varnish applications.[28]

Table 10-4 Effectiveness of sealants compared to fluoride varnish treatment over 2 and 9 years[29]

Duration and no. of studies	Pooled no. of participants	Materials	Effectiveness	Bias
2 y, n = 2	358	Fluoride vanish versus resin types of sealants	OR 0.69; 95% CI 0.50 to 0.94	High
9 y, n = 1	75		26.6% of sealed teeth and 55.8% of fluoride-varnished teeth had developed caries	High

Clinical application

The following sealant technique is based on the protocol given by the University of Copen-hagen.[30]

Diagnosis and indication

Preventive sealants should only be applied to high-risk individuals, groups, or populations, whereas an active initial caries lesion where arrest is unlikely or a moderate caries lesion both indicate a therapeutic sealant.

Cleaning

The occlusal surface is cleaned with toothpaste/powder paste and a rigid micro-motor prophylactic brush. A solo brush/normal brush can also be used.

Rinsing and drying

Rinsing is with water spray, and followed by drying with air. A probe is used carefully to ensure that the fissure system is clean.

Saliva control

The work area is kept dry by using rubber dam[31] or suction/cotton rolls/absorbent paper points.

Etching

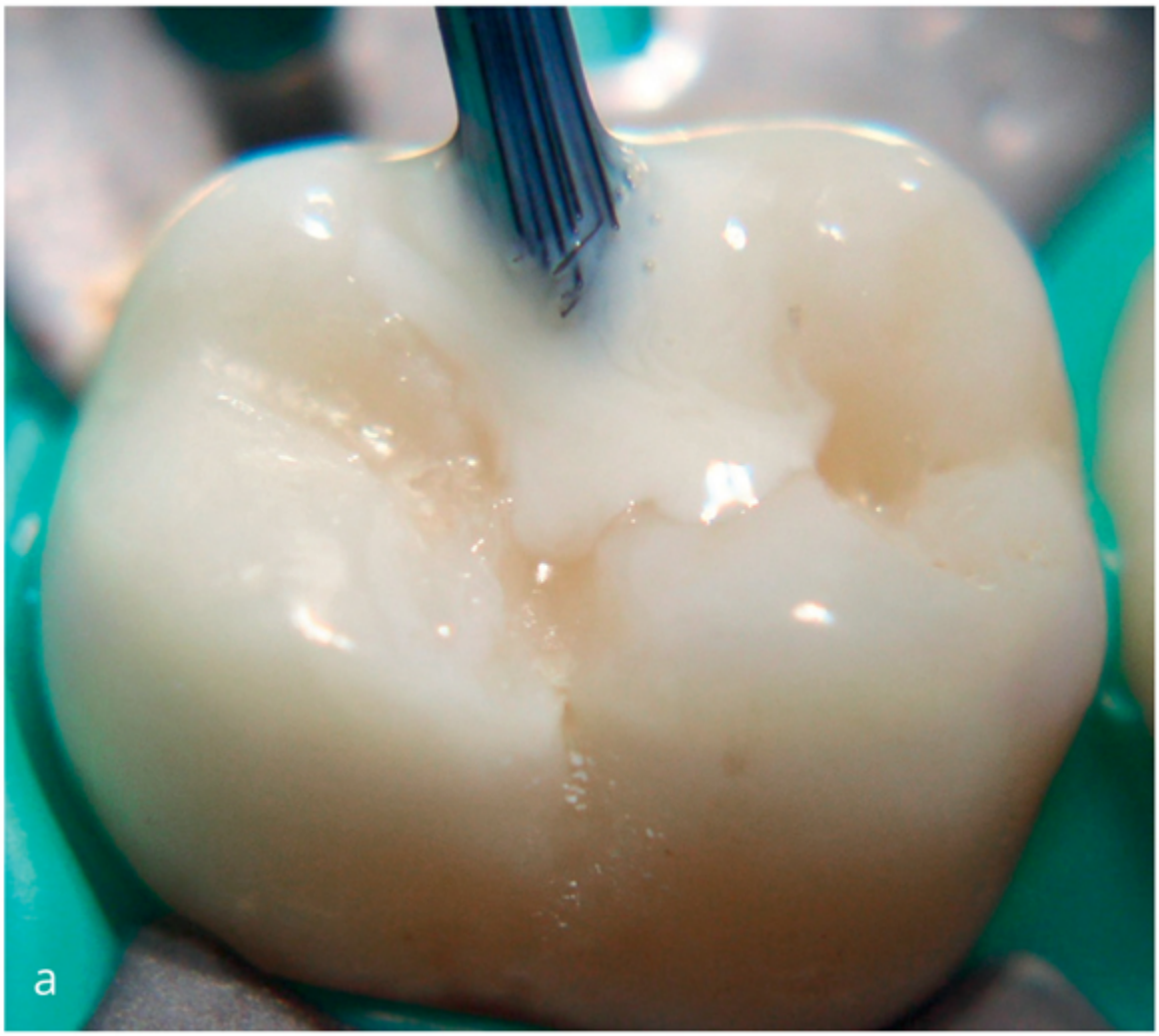
The parts of the fissure system to be sealed are etched with 35% phosphoric acid according to the manufacturer's instructions (usually between 20 and 60 seconds). The gel may be rubbed into the fissures during etching with a microbrush or a probe. By etching, a microrelief is formed, which allows micromechanical retention of the sealant material to the enamel. In a therapeutic seal and a SEAL treatment, the sound enamel around the caries lesion must also be etched. The durability of the seal is enhanced by binding to sound enamel.

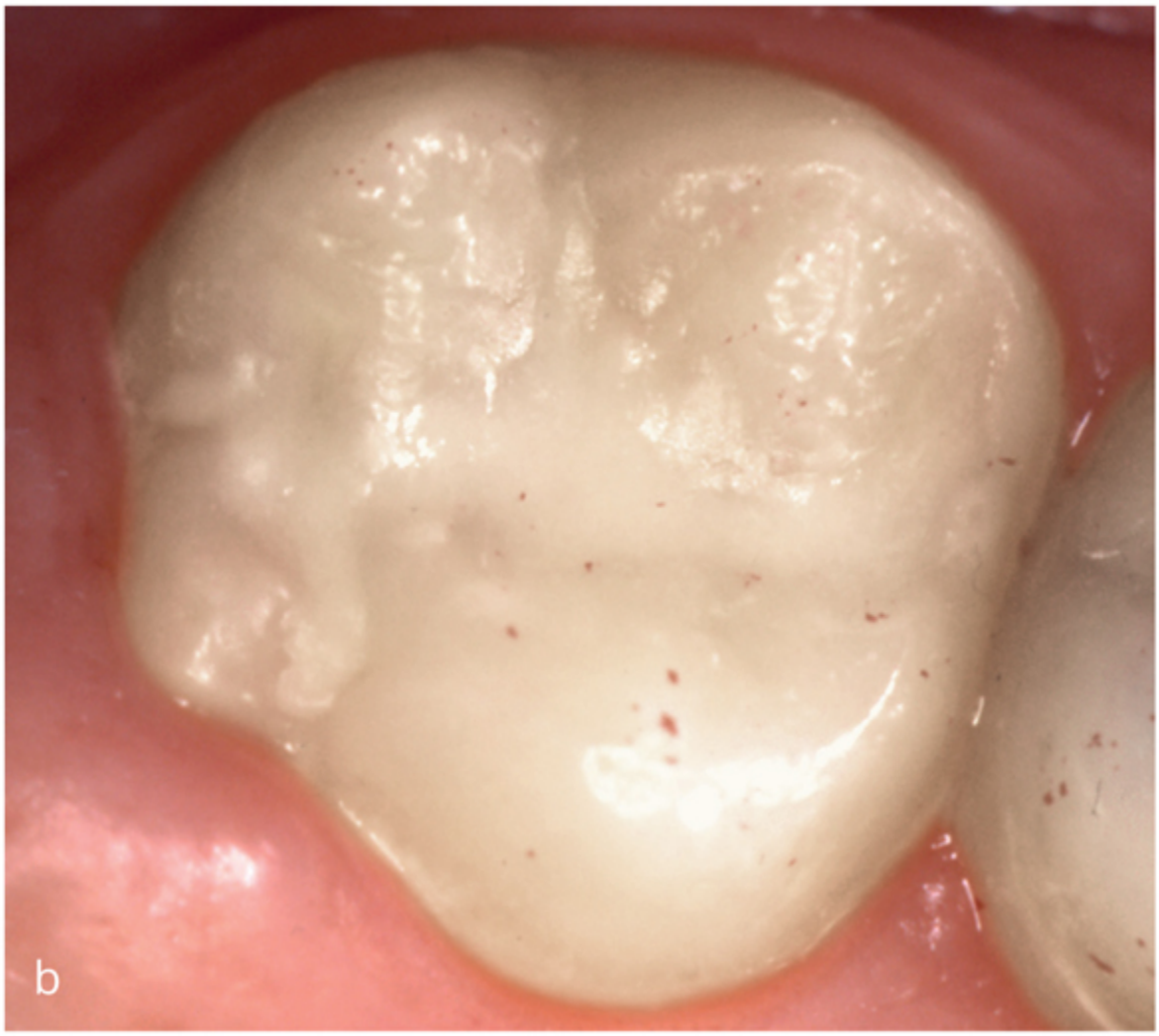
Rinsing and drying

Rinsing is via water spray for 20 seconds, and the occlusal surface is air-dried. It should be remembered to check that there are no water droplets in the air flow. Cotton rolls should be replaced, and the surface dried again until it is chalky white; otherwise drying can be repeated, or etching used if necessary. If the etched surface has been contaminated with saliva, the surface is re-etched for 10 seconds and water-sprayed for 5 seconds. The reduced etching and rinsing time is due to the fact that only a short time is needed to remove the proteins in saliva from an already etched enamel surface. Absolute alcohol (99%) should be used in order to dehydrate the etched surface.

Application of the fissure sealant material

The composite-based sealing material is applied with knot probe/microbrush/disposable brush/disposable tubes on the etched and dehydrated area (Fig 10-3). It is important that resin is only applied to the etched part of the fissure system because overfilling causes edges to break off. Poor edge closure increases the risk of plaque accumulation, thereby making the seal more damaging than beneficial. Resin excess is removed with a dry microbrush before polymerization.





Figs 10-3a and b Composite resins should preferably be used for preventive or therapeutic sealants **(a)**, whereas GIC sealants **(b)** are placed in case of problems with moisture control or cooperation, especially in high-risk children during tooth eruption.

Penetration

The sealing material should have time to penetrate the etched enamel, so that it is first polymerized after 20 seconds.

Polymerization

The sealant is polymerized for at least 20 seconds. The lamp should be kept perpendicular and close to the occlusal surface and the appropriate power of the lamp checked regularly.

Control of adaptation, occlusion, and articulation

The transition between sealant and tooth is controlled by a probe. There must be no gaps or porosities. Occlusion and articulation are controlled by articulation paper. Excessive occlusion and articulation points are to be removed with diamond powder because they can cause fracture of the seal. After fitting, the surface is polished.

Removal of oxygen-inhibited layer

If there is no need for adjustment of the sealant, the oxygen-inhibited layer should be removed with 99% alcohol on a cotton roll.

Patient file record

Statement of the treatment is recorded in the file recording system.

Control appointment

Time for recall is planned.

From science to clinical recommendations

Occlusal surfaces, including the foramen cecum on oral and buccal surfaces of molar teeth and on incisors, are highly prone to caries.[1,2,5,10,32] A large number of preventive options have been suggested over the years,[1,2,33] and sealants were brought to the attention of the dental world with the development of adhesive composite materials in the 1950s.[6,7] The recent Cochrane review[26]

demonstrates that sealants are effective in controlling caries development on occlusal surfaces compared to no treatment at a level to 1:10 over a 2-year period, dropping to about 1:4 over 5 years. The trustworthiness of the data from the studies is moderate (Table 10-3). Comparisons of sealing materials regarding their effectiveness to control caries are rare and highly biased, but high-quality data on the effectiveness of GICs as preventive sealant materials are also inconclusive (Table 10-3). Fluoride varnish applications are an effective preventive measure in pits and fissures, but compared to sealants their effectiveness drops to 1:2 over a 2- to 9-year-period, with only very few studies and a high risk of bias (Table 10-4). Thus, the overall caries prevalence in a population, the individual caries risk of molar occlusal surfaces in patients, the cost of application in the according setting, and alternative costs for fluoride varnish applications have to be taken into account before choosing sealant application. Thus, after the caries decline a risk-related strategy rather than a population-based strategy is important when it comes to the use of sealants. However, in countries with very high caries prevalence it can be effective to use a population strategy, using sealants for a fixed period, simply to win time to establish other caries-care methods. For example, Greenland has, for many years, been regarded as a country with very high caries prevalence, even though Greenland has a quite well-established dental care system for children and adolescents.[34] In 2008, a caries-preventive strategy was implemented in Greenland advocating a population approach for sealing all permanent molar teeth in children, together with other caries-preventive measures. During a 10-year period, the caries prevalence dropped significantly.[35]

There is also an experimental trend for the use of sealants as tertiary prevention in moderate dentin lesions. SEAL treatment covers cases where not more than the outer third of the dentin towards the pulp is carious on a radiograph (an initial lesion). Moderate lesions should not be sealed in general. Still, data show that when such lesions are sealed, they fail more often than when initial lesions are sealed.[22]

Concerning materials to be used as sealants, there is no doubt that modern composite resin materials should be used preferably over GICs, but they require adequate moisture control. For erupting teeth and where there are problems with moisture control, GICs can be used (Fig 10-3b).

In conclusion, fissure sealants are still to be recommended for controlling caries on occlusal surfaces and on pits and grooves on buccal and lingual surfaces, but they should be used risk-related or therapeutically on clinically and/or radiographically staged initial caries lesions. Especially in low prevalence countries, the cost-effectiveness in comparison to other noninvasive preventive measures has to be taken into account.

References

1. Bodecker C. Eradication of enamel fissures. Dent Items Int 1929;51:859–866.
2. Hyatt TP. Prophylactic odontotomy: The cutting into the tooth for the prevention of disease. Dent Cosmos 1923;65:234–241.
3. Ekstrand KR, Bjørndal L.Structural analyses of plaque and caries in relation to the morphology of the groove-fossa system on erupting mandibular third molars. Caries Res 1997;31:336–348.
4. Ekstrand KR, Ricketts DN, Kidd EA. Reproducibility and accuracy of three methods for assessment of demineralization depth of the occlusal surface: an in vitro examination. Caries Res 1997;31:224–231.
5. Carvalho JC, Ekstrand KR, Thylstrup A. Dental plaque and caries on occlusal surfaces of first permanent molars in relation to stage of eruption. J Dent Res 1989;68:773–779.

6. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res 1955;34:849–853.
7. Buonocore M. Adhesive sealing of pits and fissures for caries prevention, with use of ultraviolet light. J Am Dent Assoc 1970;80:324–330.
8. Splieth CH, Ekstrand KR, Alkilzy M, et al. Sealants in dentistry: outcomes of the ORCA Saturday Afternoon Symposium 2007. Caries Res 2010;44:3–13.
9. World Health Organization (WHO) Collaboration Center for Education, Training and Research in Oral Health. Who Oral Health Country/Area Profile Project (CAPP). Country Oral Health Profiles http://www.whocollab.od.mah.se. Accessed 29 December 2019.
10. Nørrisgaard PE, Qvist V, Ekstrand K. Prevalence, risk surfaces and inter-municipality variations in caries experience in Danish children and adolescents in 2012. Acta Odontol Scand 2016;74:291–297.
11. Ekstrand KR, Christiansen MEC. Outcomes of a non-operative caries treatment programme for children and adolescents. Caries Res 2005;39:455–467.
12. Ekstrand KR, Kuzmina I, Bjørndal L, Thylstrup A. Relationship between external and histologic features of progressive stages of caries in the occlusal fossa. Caries Res 1995;29:243–250.
13. Ekstrand KR, Ricketts DN, Kidd EA, Qvist V, Schou S. Detection, diagnosing, monitoring and logical treatment of occlusal caries in relation to lesion activity and severity: an in vivo examination with histological validation. Caries Res 1998;32:247–254.
14. Carlsen O. Dental morphology. Copenhagen: Munksgaard, 1987.
15. Dige I, Grønkjær L, Nyvad B. Molecular studies of the structural ecology of natural occlusal caries. Caries Res 2014;48:451–460.

16. Ricketts DN, Ekstrand KR, Kidd EA, Larsen T. Relating visual and radiographic ranked scoring systems for occlusal caries detection to histological and microbiological evidence. Oper Dent 2002;27:231–237.
17. Ekstrand KR, Martignon S, Ricketts DJ, Qvist V. Detection and activity assessment of primary coronal caries lesions: a methodologic study. Oper Dent 2007;32:225–235.
18. Pretty IA, Ekstrand KR. Detection and monitoring of early caries lesions: a review. Eur Arch Paediatr Dent 2016;17:13–25.
19. Kühnisch J, Ekstrand KR, Pretty I, et al. Best clinical practice guidance for management of early caries lesions in children and young adults: an EAPD policy document. Eur Arch Paediatr Dent 2016 17:3–12.
20. Pitts NB, Zero DT, Marsh PD, et al. Dental caries. Nat Rev Dis Primers 2017;3:17030.
21. Machiulskiene V, Campus G, Carvalho JC, et al. Terminology of dental caries and dental caries management: Consensus Report of a Workshop Organized by ORCA and Cariology Research Group of IADR. Caries Res 2019;7:1–8.
22. Qvist V, Borum MK, Møller KD, Andersen TR, Blanche P, Bakhshandeh A. Sealing occlusal dentin caries in permanent molars: 7-year results of a randomized controlled trial. JDR Clin Trans Res 2017;2:73–86.
23. Bakshandeh A, Qvist V, Ekstrand KR. Sealing occlusal lesions in adults referred for restorative treatment: 2-3 years of follow-up. Clin Oral Investig 2012;16:521–529.
24. Griffin SO, Gray SK, Malvitz DM, Gooch BF. Caries risk in formerly sealed teeth. J Am Dent Assoc 2009;140:415–423.
25. Naaman R, El-Housseiny AA, Alamoudi N. The use of pit and fissure sealants: a literature review. Dent J 2017;5:E34.
26. Ahovuo-Saloranta A, Forss H, Walsh T, Nordblad A, Mäkelä M, Worthington HV. Pit and fissure sealants for preventing dental decay in permanent teeth. Cochrane Database Syst Rev 2017;7:CD001830.

27. Heyduck C, Meller C, Schwahn C, Splieth CH. Effectiveness of sealants in adolescents with high and low caries experience. Caries Res 2006;40:375–381.
28. Neidell M, Shearer B, Lamster IB. Cost-effectiveness analysis of dental sealants versus fluoride varnish in a school-based setting. Caries Res 2016;50(Suppl 1):78–82.
29. Ahovuo-Saloranta A, Forss H, Hiiri A, Nordblad A, Mäkelä M. Pit and fissure sealants versus fluoride varnishes for preventing dental decay in the permanent teeth of children and adolescents. Cochrane Database Syst Rev 2016;1:CD003067.
30. Bakhshandeh A, Ekstrand KR, Qvist V. https://odont.ku.dk/fagomr/cariologi_endodonti/vejledninger-undervisn/Plast_rest_BA_5._Fissurforsegl_SEAL_0818.pdf. Accessed 29 December 2019.
31. Borges AB, Torres CRG, Benetti AR, Bakshandeh A. Isolation of the operating field. In: Torres CRG (ed). Modern operative dentistry: Principles for clinical practice (Textbooks in Contemporary Dentistry). New York: Springer, 2020:224–260.
32. Ekstrand KR, Carvalho JC, Thylstrup A. Restorative caries treatment patterns in Danish 20-year-old males in 1986 and 1991. Community Dent Oral Epidemiol 1994;22:75–79.
33. Black GV. Operative Dentistry. Vol 1: Pathology of the hard tissues of teeth. Chicago: Medico-Dental Publising, 1908
34. Petersen PE, Christensen LB. Dental health status and development trends among children and adolescents in Greenland. Int J Circumpolar Health 2006;65:35–44.
35. Ekstrand KR, Abreu-Placeres N. The impact of a national caries strategy in Greenland 10 years after implementation. A failure or a success? Int J Circumpolar Health 2020;79:1804260.

11

Prebiotics, probiotics, and synbiotics: A revolution in preventive dentistry?

Svante Twetman, Jukka H. Meurman, Egija Zaura

Recent insights in the oral microbiome have brought new understanding of its critical role in maintaining oral health. The microbiome and the human body function as an integrated superorganism, affected by genetics as well as lifestyle factors such as sugar consumption, tobacco smoking, oral hygiene, and use of antibiotics.[1] A rich, diverse, and balanced oral microbiome in symbiosis with the host is associated with health, while persisting environmental stress may induce a dysbiotic shift resulting in caries, periodontal diseases, or candidiasis (Fig 11-1). Therefore, measures to promote a balanced microbiome to maintain (primary prevention) or restore oral health (secondary prevention) have gained evolving interest in recent years. The most established methods to interfere with the drivers of dysbiosis towards caries are daily exposure to fluoride, regular oral hygiene practices, reduced intake of sucrose, and stimulation of saliva.[2] In addition, regular ingestion of pre-, pro-, and synbiotics, as defined in Table 11-1, may exert beneficial effects on general and oral health. Prebiotics interfere primarily with events

associated with the caries process while probiotics have been linked to treatment of both caries and periodontal disease, as well as with bad breath and *Candida* overgrowth. This chapter will briefly review the role and evidence of using prebiotic supplements and probiotic bacteria in preventive dentistry. An immediate remark is that these strategies are adjuncts, rather than alternatives, to the established knowledge and can boost the effect of the common evidence-based preventive technologies.

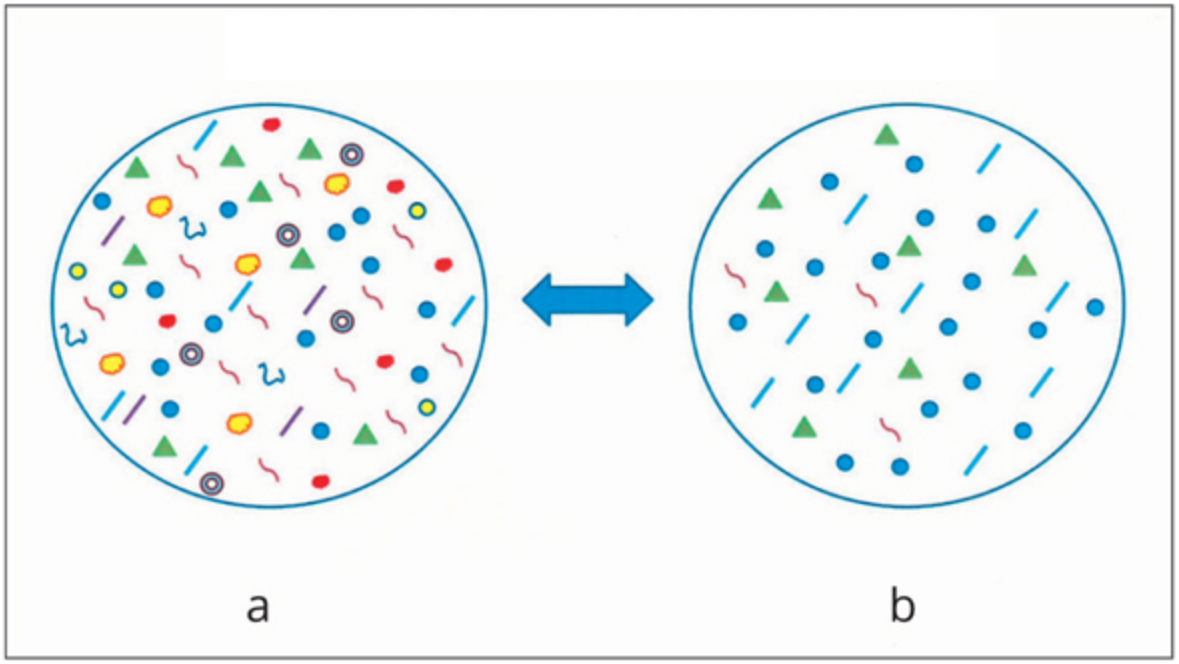


Fig 11-1 Illustration of the ecological shift from a symbiotic **(a)** to a dysbiotic **(b)** biofilm with reduced diversity and abundance of aciduric species. Note that the process can go both ways; by dealing with the drivers of dysbiosis, a stable health-associated biofilm may be reestablished.

Table 11-1 Common definitions of prebiotics, probiotics, and synbiotics

	Definition
Prebiotics	Substrate that is selectively utilized by host microorganisms conferring a health benefit.[3]
Probiotics	Live microorganisms which, when administered in adequate amounts, confer a health benefit on the host.[4] In order to be labeled a probiotic, scientific evidence for the health benefit would have to be documented.
Synbiotics	Food ingredients or dietary supplements combining probiotics and prebiotics in a form of synergism.[5]

Oral prebiotics

Arginine

Arginine is a naturally occurring amino acid in parotid saliva and probably the most investigated prebiotic for oral care. Arginine is hydrolyzed into ammonia through the arginine deiminase system (ADS) pathway by major commensal (health-associated) members of the oral microbiota, such as *Streptococcus sanguinis*, *Streptococcus gordonii*, *Streptococcus parasanguinis*, and *Streptococcus mitis*. In addition, certain *Lactobacillus* and *Actinomyces* strains are ADS-positive.[6] The ammonia production from arginine metabolism offers ecological, such as pH increase, and bio-energetic advantages to ADS-positive bacteria and favors their growth.[7] Arginine may also increase the penetrability of the biofilm through interference with the bacterial production of exopolysaccharides that glue the matrix community together.[8] The relationship between the ADS activity and caries has been evaluated in adults as well as in children, and one example is shown in Fig 11-2. In this study, the ADS activity in saliva and plaque was

significantly higher in caries-free young adults (DMFT [decayed, missing, or filled teeth] = 0) compared to those with at least four active caries lesions.[9] Furthermore, a recent systematic review based on seven studies concluded that low ADS activity in saliva and plaque could be a potential caries risk indicator for adults, while this relationship was inconclusive in children.[10]

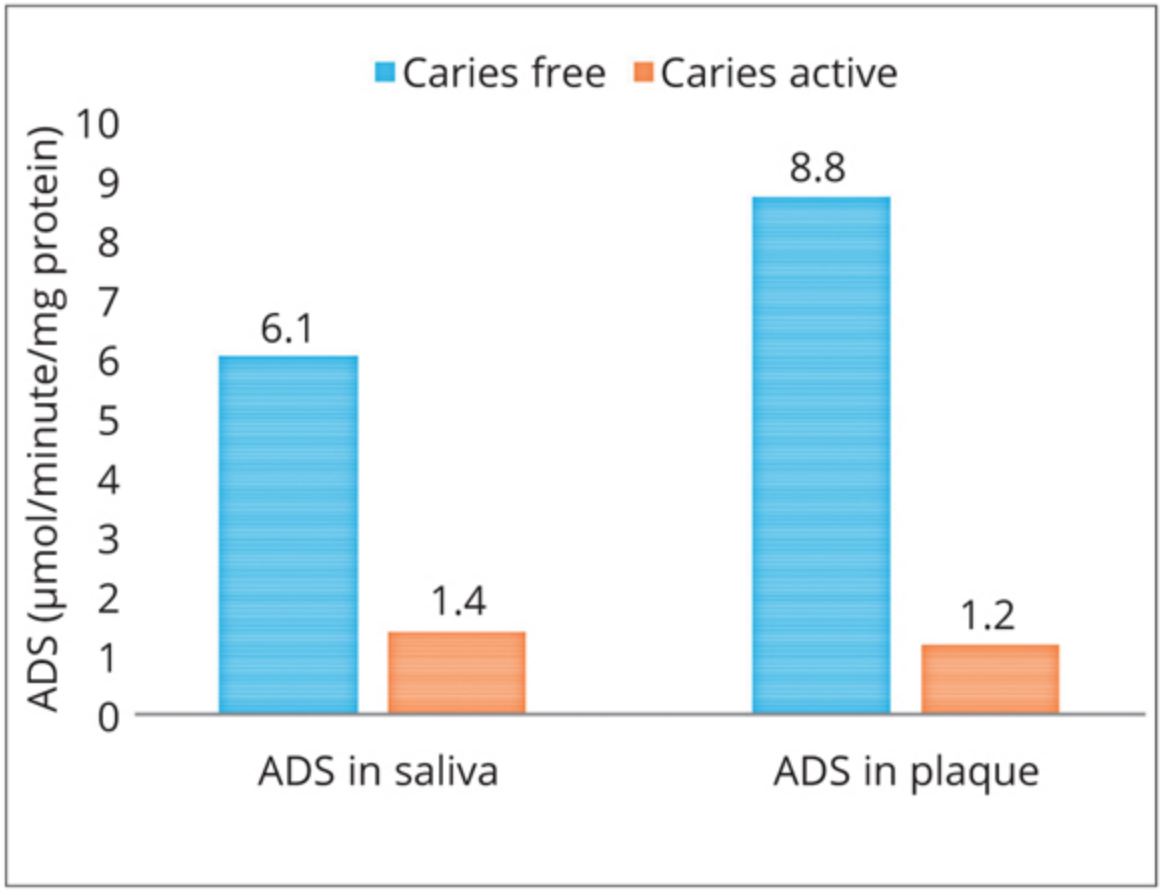


Fig 11-2 Average arginine deiminase system (ADS) activity in saliva and plaque from caries-free and caries-active subjects (data from Reyes at al[9]).

One important question is, however, whether arginine interventions can modulate the composition of the oral microbiota and actually prevent caries. Studies have suggested that the use of a 1.5% arginine toothpaste with and without fluoride twice daily for 2

to 8 weeks may induce a health-associated microbial shift in volunteers and in caries-active individuals,[11,12] thereby confirming findings from multi-species biofilm models in vitro.[13] In clinical trials, arginine has been added to toothpaste and mint confection and the anti-caries effects have been compiled in several systematic and narrative reviews (Table 11-2). The studies were conducted on permanent teeth in schoolchildren, middle aged adults, or elderly patients, and the vast majority compared a fluoride toothpaste with 1.5% w/w arginine vs a standard fluoride toothpaste. Collectively, evidence suggested that arginine in combination with calcium bases and fluoride provided a superior reduction of caries increment and progression compared with fluoride alone.[14] The prevented fraction ranged from 15% to 25% but the confidence in the effect estimates was very low.[14,15] The downgrading was motivated because only a few trials, with low risk of performance bias, were available. There was also an obvious risk of publication bias since studies were conducted and, in many cases co-authored, by employees of the industry. Thus, further independent studies according to the principles of good clinical practice are needed to gain knowledge and avoid downgrading and perception of low trust. Large clinical randomized trials are very expensive to perform, but the industry should limit their involvement solely to financial support.

Table 11-2 Summary of reviews on arginine toothpaste with caries lesion as the endpoint

Study (type of review)	Material, sample size	Conclusion according to authors
Li et al[14] (systematic)	10 studies, n = 15,545	When used with calcium, a superior anti-caries effect compared to fluoride alone, but high risks of bias and potential publications bias

Study (type of review)	Material, sample size	Conclusion according to authors
Ástvaldsdóttir et al[15] (systematic)	4 studies, n = 6,947	Insufficient evidence in support of a caries-preventive effect for arginine in toothpastes
Fontana[16] (conference paper)	8 studies, n = 10,378	Has the potential to boost fluoride toothpaste, but independent studies are welcome
Wolff and Schenkel[17] (narrative)	8 studies	Significant clinical research shows that 1.5% arginine combined with fluoride toothpaste has superior anti-caries efficacy to toothpaste containing fluoride alone
Bijle et al[18] (meta-evaluation)	2 systematic reviews	Arginine-containing dentifrice with insoluble calcium base and fluoride promising for primary and secondary caries prevention but more non-industry-supported data could provide better insights

Many foods are rich in arginine, and arginine is generally regarded as safe for use in toothpaste. Recently, a novel toothpaste formula containing 1.5% L-arginine and zinc (0.96% zinc oxide and zinc citrate) was claimed to provide superior effects on the reduction of the amount of plaque, presence of gingivitis, and oral malodor compared with a regular fluoride toothpaste.[19] However, not all

subjects may benefit from arginine supplements. Zaura et al[20] recently categorized the salivary microbiome, metabolome, and the biochemical properties of saliva from young healthy adults into five ecological types. Three of the five ecological types were termed “adaptive” while two were “specialized,” either saccharolytic (pro-caries) or proteolytic (pro-periodontal diseases).[20] Enhancing pH recovery by generating alkali from prebiotic supplements such as arginine would theoretically be highly beneficial in the former group, whereas an additional arginine may lead to unwanted effects in individuals with an already predominantly proteolytic microbiome. This illustrates that the concept “one size for all” is untrue concerning preventive strategies. Hence, individually tailored measures are called for in the future.

In summary, arginine fulfills the criteria for an oral prebiotic. It is selectively utilized by oral microbiota and the conferred health benefit to the host in terms of inhibitory effects on the caries process has been shown in multiple studies. It should, however, be noted that the possible effect of arginine on dentin hypersensitivity is not based on its prebiotic properties. In addition, there is evidence to show that some prebiotics also exert direct effects on the host, independent of their effects on resident bacterial populations.[21] Such direct effects include stimulation of expression of interleukin (IL)-10 and interferon γ, enhancement of immunoglobulin A (IgA) secretion, and modulation of inflammatory responses to pathogens. Thus, it is possible that prebiotic therapies that promote the growth of certain bifidobacteria and lactobacilli also can have a systemic influence on periodontal health.

Urea

Urea is formed in the liver and naturally occurs in saliva. Some common oral bacteria, for example *Streptococcus salivarius*, *Actinomyces naeslundii*, and *Haemophilus* species, have the capacity to convert urea to ammonia/ammonium and bicarbonate that may increase pH in dental plaque.[6] Consequently, clinical studies have associated reduced levels of urease in plaque with increased caries activity.[9,22] The clinical effect of urea as a caries preventive agent has been investigated in two clinical trials[23,24] in which schoolchildren were supplied with sugar-free chewing gums supplemented with urea for daily use during 3 years. However, the results were disappointing as no major effects on caries increment were obtained compared with non-urea controls. It is nevertheless possible that the results were somewhat biased by the stimulation of saliva through the mechanical chewing itself. A possible drawback for wider implementation of urea-containing products could be its unattractive name and the commonly perceived unpleasant taste.

Xylitol

Xylitol is a five-carbon sugar substitute with anti-caries properties but its clinical use has been accompanied by scientific controversies over the past decades. Recent systematic reviews have displayed contrasting conclusions on its efficacy, from “effective”[25] to “uncertain.”[26] The question is whether xylitol can be regarded as an oral prebiotic. Studies on the gut microbiota have shown that some polyols, including xylitol, can be absorbed by passive diffusion and reach the large bowel and increase the number of bifidobacteria in humans.[27] In the oral environment, xylitol cannot be fermented by bacteria and may therefore hamper the metabolic activity in the oral biofilm and reduce the low-pH stress. The in vivo effect on the oral microbial communities, however, remains to be established.

So far, there is clear evidence that daily intake of xylitol can reduce the number of mutans streptococci in dental plaque and

saliva when several grams per day are consumed, but no major changes in the composition of the oral microbiome have been unveiled.[28-30] Further studies seem motivated to elucidate the prebiotic-like properties of xylitol and other polyols in the oral cavity.

Other prebiotics

Besides the existing prebiotics described above, a search for new compounds that might confer prebiotic properties regarding oral health has been initiated.[31,32] By performing simple in vitro screening assays with over 700 compounds and selecting the most promising compounds for more complex in vitro biofilm models, three potential prebiotic candidates have been identified; N-acetyl-D-mannosamine, succinic acid, and methyl-beta-D-galactoside.[32] However, their use in vivo requires further investigations.

Oral probiotics

The most commonly used probiotic strains for oral health belong to the *Lactobacillus* and *Bifidobacterium* genera, but also some *Streptococcus* species express probiotic properties. The beneficial effects are thought to be strain specific[33] but this is challenged by the fact that the oral health benefits addressed below have been achieved by a blend of various strains and doses. Another intriguing issue is that only few strains in the clinical trials are of oral origin. The common use of gastrointestinal strains may be suboptimal for the unique and complex environment in the oral cavity. One example of an orally derived probiotic strain is *Limosilactobacillus reuteri* (Fig 11-3), which was isolated from the dental plaque of a young woman with uncompromised oral health. Similarly, two commensal streptococcal strains have recently been isolated from the supragingival plaque of healthy individuals: *Streptococcus*

dentisani[34] and *Streptococcus* A12.[8] Both strains are potential anti-caries probiotics due to their inhibitory activity against *Streptococcus mutans* and their ability to metabolize arginine.

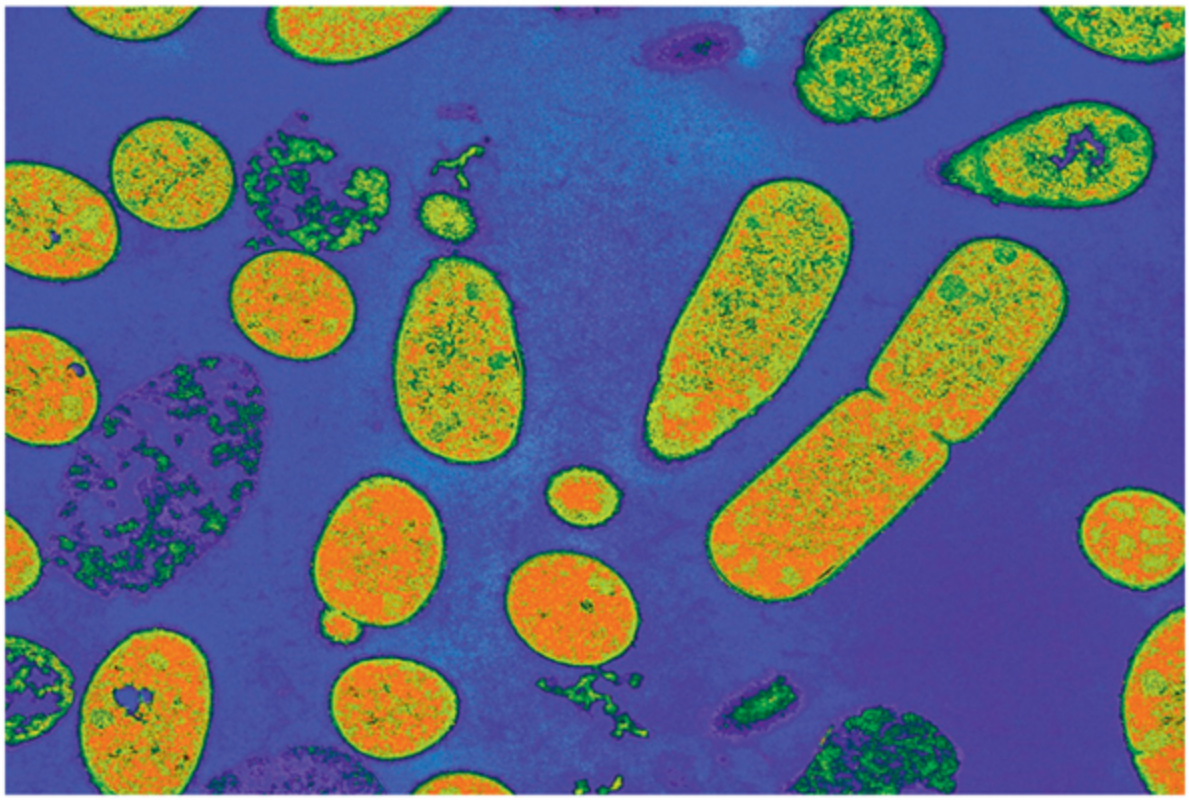


Fig 11-3 The probiotic strain *Limosilactobacillus reuteri* Prodentis (ATCC PTA 52899) was isolated from a 30-year-old Japanese woman with excellent oral health.

Probiotics have both preventive and therapeutic effects, and the mechanisms of action involve both local and systemic events. The local events include prevention of adhesion of pathogens to host tissues and growth inhibition of pathogens through production of bacteriocins, acids, or peroxide.[35] The systemic effects are based on stimulation and modulation of the mucosal immune system, for example by reducing pro-inflammatory cytokines, increasing anti-inflammatory cytokines and host defense peptides (β-defensin 2), and by enhancing IgA output in saliva.[21,35] A common observation is

that the intake of probiotics must be regular and at least 4 to 5 days per week. The administration alternatives are dairy products, baby gruel, or chewable tablets, lozenges, or drops. For dairy products such as yoghurt or kefir with 10^5 to 10^8 live bacteria/mL, around 100 to 150 mL per day is advocated. The commonly utilized dose for tablets or lozenges (10^8 live bacteria/tablet) is 1 to 2 tablets daily. Most importantly, no serious adverse events have been reported in the studies conducted in dentistry. Adverse systemic effects of probiotics are also very rare and those observed have mainly been immunocompromised cases.[36]

Dental caries

There is good evidence from systematic reviews that interventions with probiotic bacteria result in significant reductions of caries-associated mutans streptococci in saliva and dental plaque.[37-39] The impact on the composition of the oral microbiome is less well studied. Two studies have shown increased diversity and a transient shift to common commensals with reduced levels of pathogens.[40,41] Other researchers have failed to show a major impact on the oral microbiome after short-term interventions with probiotic strains from the *Bifidobacterium* and *Lactobacillus* genera.[42,43] There are clearly insufficient data as yet to firmly answer the question of whether the composition and function of the oral microbiome can be modulated with the aid of beneficial bacteria.

The clinical effect of probiotic supplements on caries increment and remineralization has recently been reviewed by Zaura and Twetman.[44] The results based on 12 clinical trials are summarized in Table 11-3. The most outstanding finding was that probiotic interventions conducted in day care or nursery school settings resulted in significantly reduced caries increment in the primary dentition. The average prevented fraction from five studies was 34%. Three studies were post-trial evaluations; the intervention was given early in life with medical endpoints but the caries prevalence was investigated several years thereafter. The results were mixed and

inconclusive due to different kinds of bias. The effect on schoolchildren was also mixed but promising when only those with high caries risk were considered. A single study addressed the reversal of primary root caries lesions in elderly patients after a 14-month daily intake of milk supplemented with probiotic lactobacilli.[49] The test group showed significantly more reversals, verified by visual scoring and electric resistance, when compared with the control group consuming milk without probiotic bacteria. This may be of significant importance in future, since root caries is a growing problem globally and is demanding to treat.

Table 11-3 Anti-caries effects of probiotic therapy obtained in clinical trials (data from Zaura and Twetman[44])

Age group	No. of studies; participants	Caries-preventive effect	*P*
Preschool children	5 studies; 1,273 children	RRR 0.65 (95% CI 0.47–0.90)	< .05
Preschool intervention, follow-up at school age	3 studies; 474 children	RRR 0.68 (95% CI 0.42–1.09)	NS
Schoolchildren	3 studies; 182 children	RRR 0.70 (95% CI 0.45–1.09)	NS
Elderly	1 study; 80 subjects	RRR 0.61 (95% CI 0.46–0.81)	< .05

NS, not statistically significant; RRR, relative risk reduction with 95% confidence interval (CI).

An important remark is that significant improvements on general health were obtained in four of the caries trials identified above, in terms of reduced respiratory tract infections, reduced prescription of antibiotics, reduced days with sick leave, and reduced incidence of IgE-associated eczema.[44] Such health benefits for the individual as well as the economic gains for the society could also be taken into account in future trials with pre- and probiotic interventions in dentistry.

Periodontal diseases

The most investigated “probiotic domain” in dentistry is the effect of lactobacilli-derived supplements in the comprehensive treatment of chronic and aggressive periodontitis. The intervention is commonly applied as an adjunct to conventional scaling and root planing and

typical clinical endpoints are Plaque Index, Gingival Bleeding Index, bleeding on probing (BOP), pocket probing depth (PD), and clinical attachment level. Several systematic reviews and meta-analyses have evaluated the clinical effects, and the main conclusions are listed in Table 11-4. A common result was that oral administration of probiotics improved the recognized clinical signs of chronic and aggressive periodontitis, such as PD, BOP, and attachment loss, with a concomitant reduction in the levels of major periodontal pathogens but without affecting the amount of plaque.[45] Additional claims were that probiotic interventions could reduce the need for periodontal surgery and antibiotics.[45,46] The systematic reviews highlighted that a continuous probiotic administration was necessary to maintain these benefits. However, most studies were small and short term, which reduced the strength of these conclusions.

Table 11-4 Summary of reviews on probiotics and periodontal disease

Study (type of review)	Material	Conclusion according to authors
Gruner et al[38] (systematic and meta-analysis)	10 studies	Current evidence is supportive towards managing gingivitis or periodontitis with probiotics
Matsubara et al[45] (systematic)	12 studies	Oral administration of probiotics is a safe and effective adjunct to conventional mechanical treatment in the management of periodontitis, especially the chronic disease entity
Martin-Cabezas et al[46] (systematic	4 studies	Findings seem to support the adjunctive use of *L reuteri* to

Study (type of review)	Material	Conclusion according to authors
and meta-analysis)		scaling and root planing in chronic periodontitis treatment in the short-term, especially in deep pockets
Jayaram et al[47] (systematic)	13 studies	Probiotics in the treatment of periodontal disease produce only short-term clinical and microbiologic benefits
Ikram et al[48] (systematic and meta-analysis)	7 studies	Adjunctive probiotics could result in additional benefits in clinical attachment level in chronic periodontitis

Probiotic bacteria have also recently been applied for the prevention and treatment of peri-implant mucositis and peri-implantitis, with contrasting results. In two studies, the administration of a daily lozenge of *L reuteri* for 30 days, together with mechanical debridement, improved the clinical parameters of implants with mucositis or peri-implantitis over a 90-day period.[50,51] Other researchers have failed to demonstrate a significantly enhanced outcome when probiotic adjuncts were compared with placebo.[52,53] Thus, it seems likely that probiotics prevent inflammation by affecting host responses rather than by affecting selected pathogenic microbiota in peri-implantitis patients,[54] but studies addressing the effects on the entire microbiome are still to be performed.

Candidiasis

Candida albicans is a minor component of the oral microbiota in health but it may, as an opportunistic pathogen, take advantage of an immunocompromised host, causing mucositis and candidiasis. Oral candidiasis is a particularly common problem among fragile elderly patients and denture wearers. It has been shown that probiotic lactobacilli have the ability to co-aggregate with various *Candida* species, interfere with hyphae formation, and inhibit growth via production of bacteriocins.[55] Consequently, randomized controlled clinical trials have demonstrated reduced salivary counts of *C albicans* in frail elderly patients and in patients with dentures after use of probiotic supplements.[56,57] A meta-analysis based on four trials in elderly patients has concluded that probiotic products have a preventative effect on oral *Candida* infections.[56] This may be of importance in the light of an increasing occurrence of drug-resistance in *Candida* species strains due to overuse of antifungal medications, systemic toxicity, and cross-reactivity with other drugs.

Halitosis

The main reason for oral malodor/halitosis is the production of volatile sulfur compounds (VSC) from Gram-negative bacteria mainly located on the dorsum of the tongue. A number of placebo-controlled clinical studies have been conducted to investigate the effect of probiotic supplements on oral malodor with an organoleptic endpoint or by measuring the concentration of VSC.[35] A meta-analysis revealed that organoleptic scores were significantly lower in subjects who received probiotics than placebo, but no significant differences were observed concerning the VSC concentrations.[58] Although current evidence is supportive of recommending probiotics for the management of halitosis, the studies were of short duration and heterogenous with respect to the intervention. Halitosis may also occur in association with severe periodontitis and it is suggested that probiotics may be a valuable adjunct to the comprehensive management of the disease with reductions in oral malodor.[59] It is,

however, important to further elucidate whether the improvements in malodor are stable over time.

Oral synbiotics

The effect of combining oral prebiotics, such as arginine, with oral probiotic strains into one synbiotic product is a challenge for the future. As an example, it has been recently suggested that arginine supplementation in combination with ADS-positive probiotics may constitute a nonpharmaceutical advancement in caries prevention.[7] To the present authors' knowledge, there are not yet any clinical trials with synbiotics retrievable in the scientific databases with endpoints associated with oral health. However, a few pioneering studies on caries and gingivitis are registered as ongoing trials. Both pre- and probiotics are natural and inexpensive food additives with small or even negligible risk of side effects. Thus, the concept may have the potential to be accepted by consumers, be health-economically favorable, and play a role in the causal management of oral diseases. The potential "spill-over" effect to other noncommunicable conditions such as overweight, diabetes, and cardiovascular disease may further enhance the awareness of the pre- and probiotic concepts among dental practitioners and health professionals in general.

Along with the novel insights on the importance of a healthy oral microbiome, the concept of pre- and probiotics has entered preventive dentistry. The various modes of action rely on sound principles but further research is required to optimize clinical applications and to confirm the efficacy in randomized controlled trials.

References

1. Kilian M, Chapple IL, Hannig M, et al. The oral microbiome: an update for oral healthcare professionals. Br Dent J 2016;221:657–666.
2. Twetman S. Prevention of dental caries as a non-communicable disease. Eur J Oral Sci 2018;126:19–25.
3. Gibson GR, Hutkins R, Sanders ME, et al. Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nat Rev Gastroenterol Hepatol 2017;14:491–502.
4. Sanders ME. Probiotics: definition, sources, selection, and uses. Clin Infect Dis 2008;46:S58–S61.
5. Pandey KR, Naik SR, Vakil BV. Probiotics, prebiotics and synbiotic: a review. J Food Sci Technol 2015;52:7577–7587.
6. Liu Y-L, Nascimento M, Burne RA. Progress toward understanding the contribution of alkali generation in dental biofilms to inhibition of dental caries. Int J Oral Sci 2012;4:135–140.
7. Nascimento MM. Potential uses of arginine in dentistry. Adv Dent Res 2018;29:98–103.
8. Huang X, Zhang K, Deng M, et al. Effect of arginine on the growth and biofilm formation of oral bacteria. Arch Oral Biol 2017;82:256–262.
9. Reyes E, Martin J, Moncada G, et al. Caries-free subjects have high levels of urease and arginine deiminase activity. J Appl Oral Sci 2014;22:235–240.
10. Bijle MNA, Yiu CKY, Ekambaram M. Can oral ADS activity or arginine levels be a caries risk indicator? A systematic review and meta-analysis. Clin Oral Investig 2018;22:583–596.
11. Koopman JE, Hoogenkamp MA, Buijs MJ, et al. Changes in the oral ecosystem induced by the use of 8% arginine toothpaste. Arch Oral Biol 2017;73:79–87.

12. Nascimento MM, Browngardt C, Xiaohui X, Klepac-Ceraj V, Paster BJ, Burne RA. The effect of arginine on oral biofilm communities. Mol Oral Microbiol 2014;29:45–54.
13. Zheng X, He J, Wang L, et al. Ecological effect of arginine on oral microbiota. Sci Rep 2017;7:7206.
14. Li J, Huang Z, Mei L, Li G, Li H. Anti-caries effect of arginine-containing formulations in vivo: a systematic review and meta-analysis. Caries Res 2015;49:606–617.
15. Ástvaldsdóttir Á, Naimi-Akbar A, Davidson T, et al. Arginine and caries prevention: a systematic review. Caries Res 2016;50:383–393.
16. Fontana M. Enhancing fluoride: clinical human studies of alternatives or boosters for caries management. Caries Res 2016;50:22–37.
17. Wolff MS, Schenkel AB. The anticaries efficacy of a 1.5% arginine and fluoride toothpaste. Adv Dent Res 2018;29:93–97.
18. Bijle MNA, Yiu CKY, Ekambaram M. Calcium-based caries preventive agents: a meta-evaluation of systematic reviews and meta-analysis. J Evid Based Dent Pract 2018;18:203–217.
19. Cummins D, Marsh PD. Changing the paradigm of daily prevention to achieve whole mouth health in the 21st Century. J Clin Dent 2018;29(Spec No A):A1–A9.
20. Zaura E, Brandt BW, Prodan A, et al. On the ecosystemic network of saliva in healthy young adults. ISME J 2017;11:1218–1231.
21. Devine DA, Marsh PD. Prospects for the development of probiotics and prebiotics for oral applications. J Oral Microbiol 2009;1:10.3402/jom.v1i0.1949.
22. Morou-Bermudez E, Elias-Boneta A, Billings RJ, et al. Urease activity as a risk factor for caries development in children during a three-year study period: a survival analysis approach. Arch Oral Biol 2011;56:1560–1568.
23. Machiulskiene V, Nyvad B, Baelum V. Caries preventive effect of sugar-substituted chewing gum. Community Dent Oral

Epidemiol 2001;29:278–288.

24. Petersen PE, Razanamihaja N. Carbamide-containing polyol chewing gum and prevention of dental caries in schoolchildren in Madagascar. Int Dent J 1999;49:226–230.
25. Janakiram C, Deepan Kumar CV, Joseph J. Xylitol in preventing dental caries: a systematic review and meta-analyses. J Nat Sci Biol Med 2017;8:16–21.
26. Marghalani AA, Guinto E, Phan M, Dhar V, Tinanoff N. Effectiveness of xylitol in reducing dental caries in children. Pediatr Dent 2017;39:103–110.
27. Ruiz-Ojeda FJ, Plaza-Díaz J, Sáez-Lara MJ, Gil A. Effects of sweeteners on the gut microbiota: a review of experimental studies and clinical trials. Adv Nutr 2019;10(Suppl 1):S31–S48.
28. Rafeek R, Carrington CVF, Gomez A, et al. Xylitol and sorbitol effects on the microbiome of saliva and plaque. J Oral Microbiol 2019;11:1536181.
29. Söderling E, ElSalhy M, Honkala E, et al. Effects of short-term xylitol gum chewing on the oral microbiome. Clin Oral Investig 2015;19:237–244.
30. Takeuchi K, Asakawa M, Hashiba T, Takeshita T, Saeki Y, Yamashita Y. Effects of xylitol-containing chewing gum on the oral microbiota. J Oral Sci 2018;60:588–594.
31. Slomka V, Hernandez-Sanabria E, Herrero ER, et al. Nutritional stimulation of commensal oral bacteria suppresses pathogens: the prebiotic concept. J Clin Periodontol 2017;44:344–352.
32. Slomka V, Herrero ER, Boon N, et al. Oral prebiotics and the influence of environmental conditions in vitro. J Periodontol 2018;89:708–717.
33. de Vrese M, Schrezenmeier L. Probiotics, prebiotics and synbiotics. Adv Biochem Engin/Biotechnol 2008;111:1–66.
34. López-López A, Camelo-Castillo A, Ferrer MD, Simon-Soro Á, Mira A. Health-associated niche inhabitants as oral probiotics: The case of *Streptococcus dentisani*. Front Microbiol 2017;8:379.

35. Twetman S, Jørgensen M, Keller M. Fifteen years of probiotic therapy in the dental context: what has been achieved? J Calif Dent Assoc 2017;45:539–545.
36. Doron S, Snydman DR. Risk and safety of probiotics. Clin Infect Dis 2015;60(Suppl 2):S129–S134.
37. Cagetti MG, Mastroberardino S, Milia E, Cocco F, Lingstrom P, Campus G. The use of probiotic strains in caries prevention: a systematic review. Nutrients 2013;5:2530–2550.
38. Gruner D, Paris S, Schwendicke F. Probiotics for managing caries and periodontitis: systematic review and meta-analysis. J Dent 2016;48:16–25.
39. Laleman I, Detailleur V, Slot DE, Slomka V, Quirynen M, Teughels W. Probiotics reduce mutans streptococci counts in humans: a systematic review and meta-analysis. Clin Oral Investig 2014;18:1539–1552.
40. Dassi E, Ballarini A, Covello G, et al. Enhanced microbial diversity in the saliva microbiome induced by short-term probiotic intake revealed by 16S rRNA sequencing on the IonTorrent PGM platform. J Biotechnol 2014;190:30–39.
41. Romani Vestman N, Chen T, Lif Holgerson P, Öhman C, Johansson I. Oral microbiota shift after 12-week supplementation with *Lactobacillus reuteri* DSM 17938 and PTA 5289; a randomized control trial. PLoS One 2015;10:e0125812.
42. Keller MK, Brandsborg E, Holmstrom K, Twetman S. Effect of tablets containing probiotic candidate strains on gingival inflammation and composition of the salivary microbiome: a randomised controlled trial. Benef Microbes 2018;9:487–494.
43. Toiviainen A, Jalasvuori H, Lahti E, et al. Impact of orally administered lozenges with *Lactobacillus rhamnosus* GG and *Bifidobacterium animalis* subsp. lactis BB-12 on the number of salivary mutans streptococci, amount of plaque, gingival inflammation and the oral microbiome in healthy adults. Clin Oral Investig 2015;19:77–83.

44. Zaura E, Twetman S. Critical appraisal of oral pre- and probiotics for caries prevention and care. Caries Res 2019;53:514–526.
45. Matsubara VH, Bandara HM, Ishikawa KH, Mayer MP, Samaranayake LP. The role of probiotic bacteria in managing periodontal disease: a systematic review. Expert Rev Anti Infect Ther 2016;14:643–655.
46. Martin-Cabezas R, Davideau JL, Tenenbaum H, Huck O. Clinical efficacy of probiotics as an adjunctive therapy to non-surgical periodontal treatment of chronic periodontitis: a systematic review and meta-analysis. J Clin Periodontol 2016;43:520–530.
47. Jayaram P, Chatterjee A, Raghunathan V. Probiotics in the treatment of periodontal disease: a systematic review. J Indian Soc Periodontol 2016;20:488–495.
48. Ikram S, Hassan N, Raffat MA, Mirza S, Akram Z. Systematic review and meta-analysis of double-blind, placebo-controlled, randomized clinical trials using probiotics in chronic periodontitis. J Investig Clin Dent 2018;9:e12338.
49. Petersson LG, Magnusson K, Hakestam U, Baigi A, Twetman S. Reversal of primary root caries lesions after daily intake of milk supplemented with fluoride and probiotic lactobacilli in older adults. Acta Odontol Scand 2011;69:321–327.
50. Flichy-Fernández AJ, Ata-Ali J, Alegre-Domingo T, et al. The effect of orally administered probiotic *Lactobacillus reuteri*-containing tablets in peri-implant mucositis: a double-blind randomized controlled trial. J Periodontal Res 2015;50:775–785.
51. Galofré M, Palao D, Vicario M, Nart J, Violant D. Clinical and microbiological evaluation of the effect of *Lactobacillus reuteri* in the treatment of mucositis and peri-implantitis: a triple-blind randomized clinical trial. J Periodontal Res 2018;53:378–390.
52. Hallström H, Lindgren S, Widén C, Renvert S, Twetman S. Probiotic supplements and debridement of peri-implant

mucositis: a randomized controlled trial. Acta Odontol Scand 2016;74:60–66.

53. Mongardini C, Pilloni A, Farina R, Di Tanna G, Zeza B. Adjunctive efficacy of probiotics in the treatment of experimental peri-implant mucositis with mechanical and photodynamic therapy: a randomized, cross-over clinical trial. J Clin Periodontol 2017;44:410–417.
54. Tada H, Masaki C, Tsuka S, Mukaibo T, Kondo Y, Hosokawa R. The effects of *Lactobacillus reuteri* probiotics combined with azithromycin on peri-implantitis: a randomized placebo-controlled study. J Prosthodont Res 2018;62:89–96.
55. Jørgensen MR, Kragelund C, Jensen PØ, Keller MK, Twetman S. Probiotic *Lactobacillus reuteri* has antifungal effects on oral *Candida* species in vitro. J Oral Microbiol 2017;9:1274582.
56. Ai R, Wei J, Ma D, et al. A meta-analysis of randomized trials assessing the effects of probiotic preparations on oral candidiasis in the elderly. Arch Oral Biol 2017;83:187–192.
57. Miyazima TY, Ishikawa KH, Mayer M, Saad S, Nakamae A. Cheese supplemented with probiotics reduced the *Candida* levels in denture wearers-RCT. Oral Dis 2017;23:919–925.
58. Yoo JI, Shin IS, Jeon JG, Yang YM, Kim JG, Lee DW. The effect of probiotics on halitosis: a systematic review and meta-analysis. Probiotics Antimicrob Proteins 2019;11:150–157.
59. Soares LG, Carvalho EB, Tinoco EMB. Clinical effect of *Lactobacillus* on the treatment of severe periodontitis and halitosis: a double-blinded, placebo-controlled, randomized clinical trial. Am J Dent 2019;32:9–13.

12

Silver fluorides: The new magic bullet?

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Antimicrobial silver seems to have returned to dentistry, causing a paradigm shift in the management of caries lesions in children, and surpassing invasive dentistry and costly surgeries, in which a relapse is not uncommon.

Historical background

The historical use of silver in medicine can be seen as early as the 1800s, when the antimicrobial effect of silver was established in previous Mediterranean and Asian civilizations' use of silver foil to disinfect wounds. It was also exhibited in the act of dropping silver coins in water containers of American travelers in the 1880s in order to set back the growth of bacteria and algae.[1] Following successful practices in medicine, the dawn of silver in dentistry arose in 1891 when Stebbins declared the arrest of caries lesions by applying silver nitrates.[2] On the scent of these findings, the combination was further developed by Howe, who enhanced and stabilized the

antimicrobial effect by adding ammonia to the silver nitrate, making it more applicable to early cavitated lesions and even to infected root canals;[3] the solution came to be known as “Howe’s solution.”

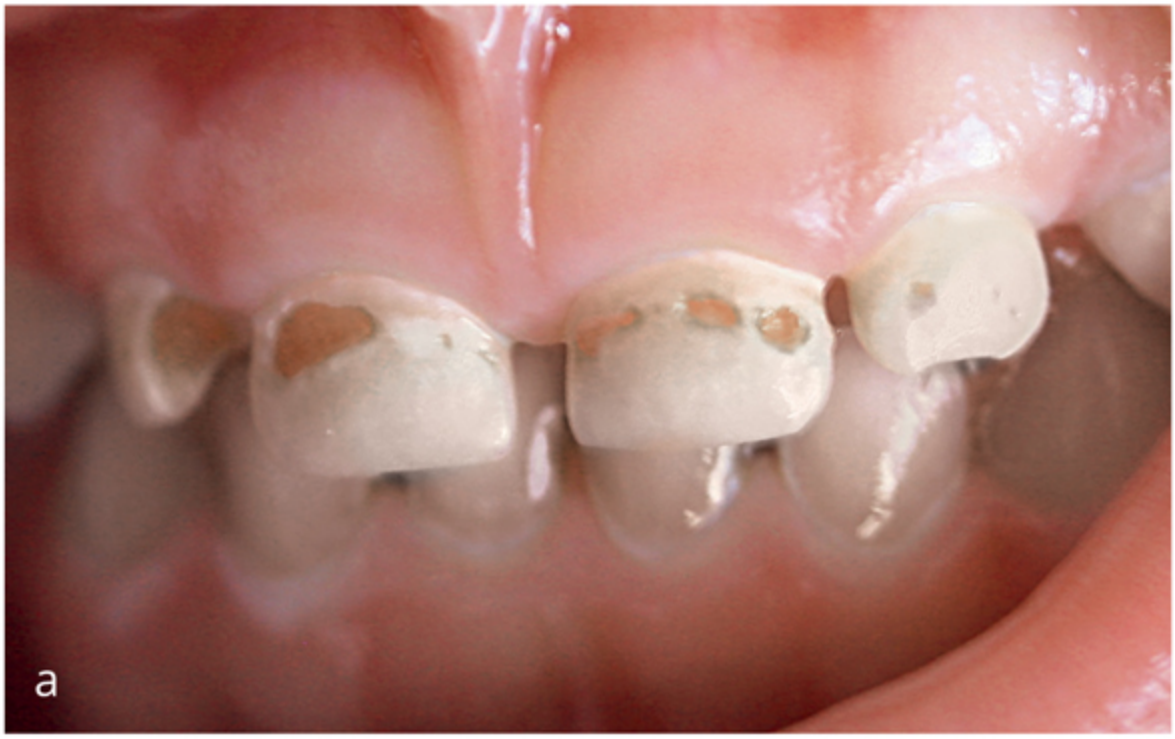
Silver diammine fluoride (SDF) was originally hypothesized in Japan in 1969 as a PhD thesis.[4] The powerful combination of silver antimicrobial properties with high fluoride doses produced a precipitate that plugs the dentinal terminals and, furthermore, diminished hypersensitivity.[5]

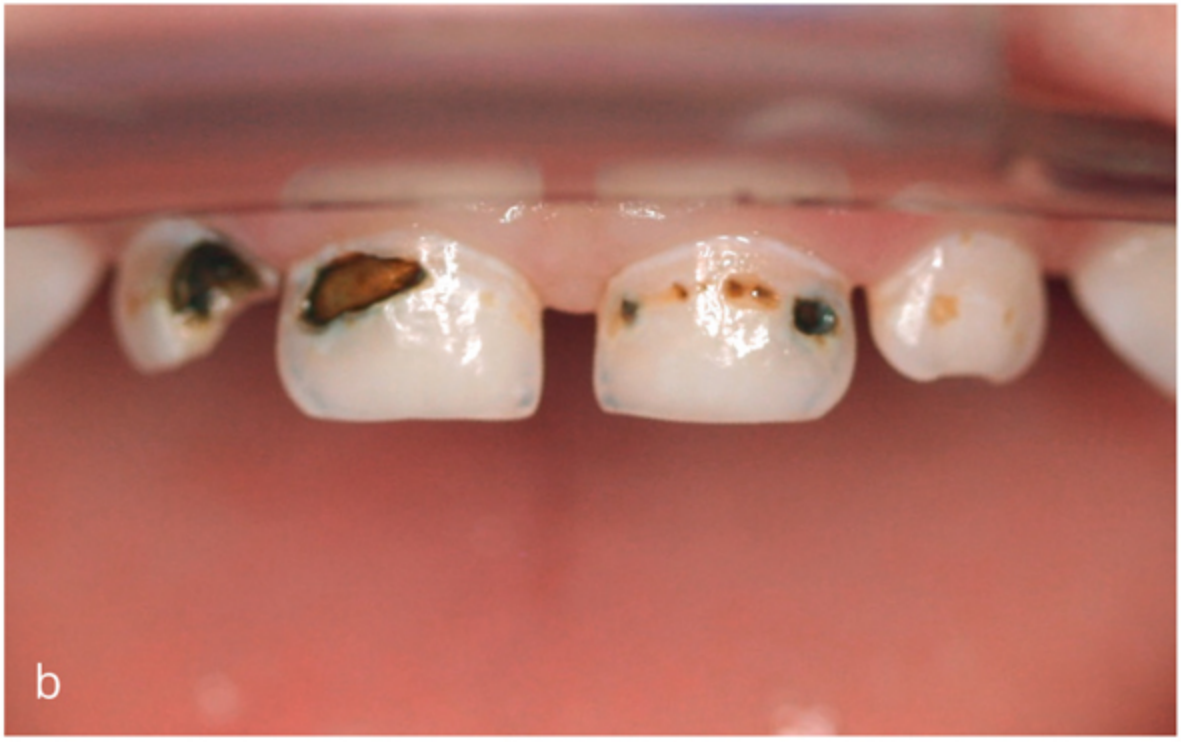
Composition

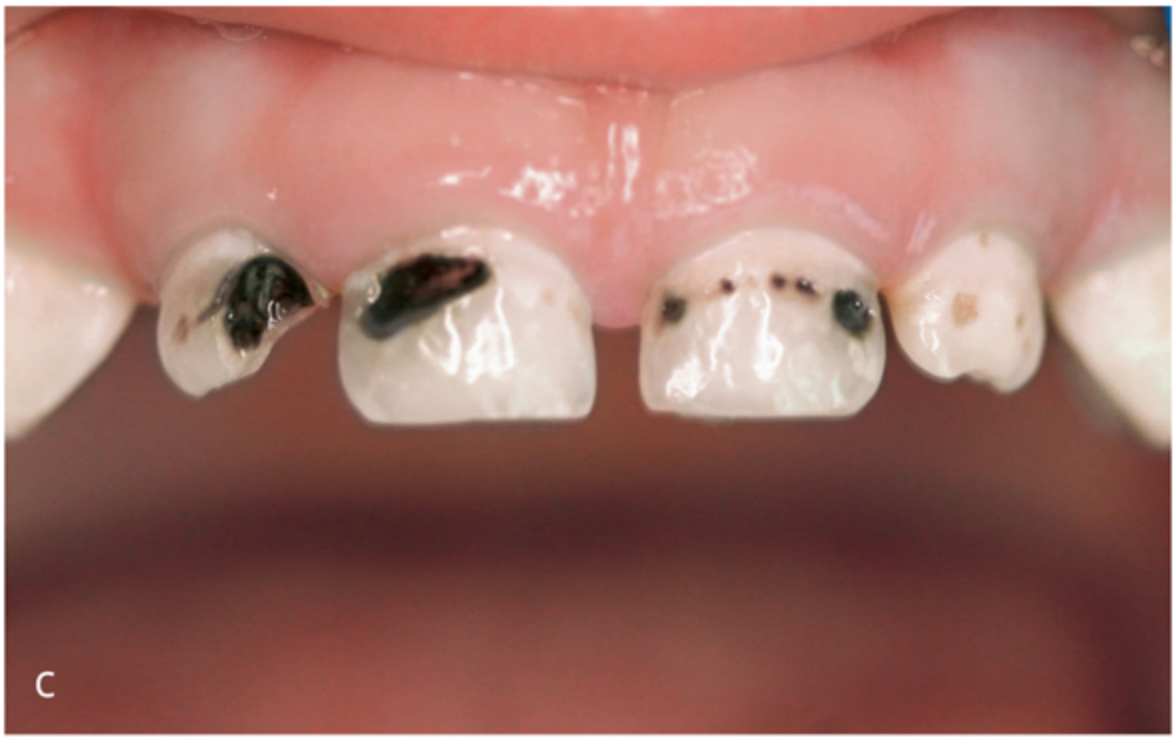
The combination of silver and fluoride is present in various formulas and concentrations. Silver fluoride and SDF are similar in their silver and fluoride contents, but differ as the latter contains ammonia, which plays an important role in keeping the concentration steady.[6] SDF is available at various concentrations (Table 12-1). However, results of a randomized clinical trial in 2018 showed that SDF potency to arrest caries lesions at 38% concentration is superior to lower concentrations,[7] but that an increase in staining was positively associated with higher concentrations and frequent applications (Fig 12-1).[8] In order to counter the staining effect of SDF, a few studies have reported promising results by applying a saturated solution of potassium iodide immediately after SDF application. Potassium iodide is believed to minimize staining of dentin caries while the caries-arresting effect of SDF remains unaffected.[9,10]

Table 12-1 Various SDF products, manufacturers, SDF concentrations, and main ingredients

Product	Manufacturer/country	SDF concentration (%)	Main components
Advantage Arrest	Elevate Oral Care/USA	38%	Silver diammine fluoride
Cariestop	Biodinamica/Brazil	12%	Fluoridic acid, silver nitrate, ammoniahydroxide, deionized water
Fagamin	Tedequim/Argentina	38%	Silver diammine fluoride
Saforide	Toyo Seiyaku Kasei/ Japan	38%	Silver diammine fluoride
Riva Star	SDI/Australia	35–40%	Unit 1: silver, fluoride, ammonia; Unit 2: potassium, iodine







Figs 12-1a to c (a) Dentin caries lesions in primary anterior teeth in a 3-year-old patient diagnosed with early childhood caries. **(b)** Same lesions showing staining after 2 weeks, and **(c)** 3 months after silver diammine fluoride application.

Mechanism of action

The mechanism of action of SDF has long been a topic of debate. In 1972, it was suggested that SDF's potency against caries lesions stems from the silver antibacterial traits embedded in the end product of the SDF reaction at the tooth level. The reaction precipitates silver phosphate (Ag_3PO_4) and calcium fluoride (CaF_2), with the latter being responsible for the delivery of high doses of fluoride, enhancing the chances of successful caries arrest.[5] A recent review proposed three modes of actions of SDF in favor of caries arrest and prevention (Fig 12-2).[11] The first action was backed by a few studies where a lower number and suppression of growth of bacterial colonies were reported after SDF application,[12,13] thus

supporting the hypothesized bactericidal effect of silver ions on cariogenic bacteria. More broadly, the second and third actions of SDF were evidenced with studies denoting its contribution to remineralization and inhibition of demineralization in enamel and dentin surfaces,[14,15] and its aid in preventing dentin collagen matrix collapse.[16,17]

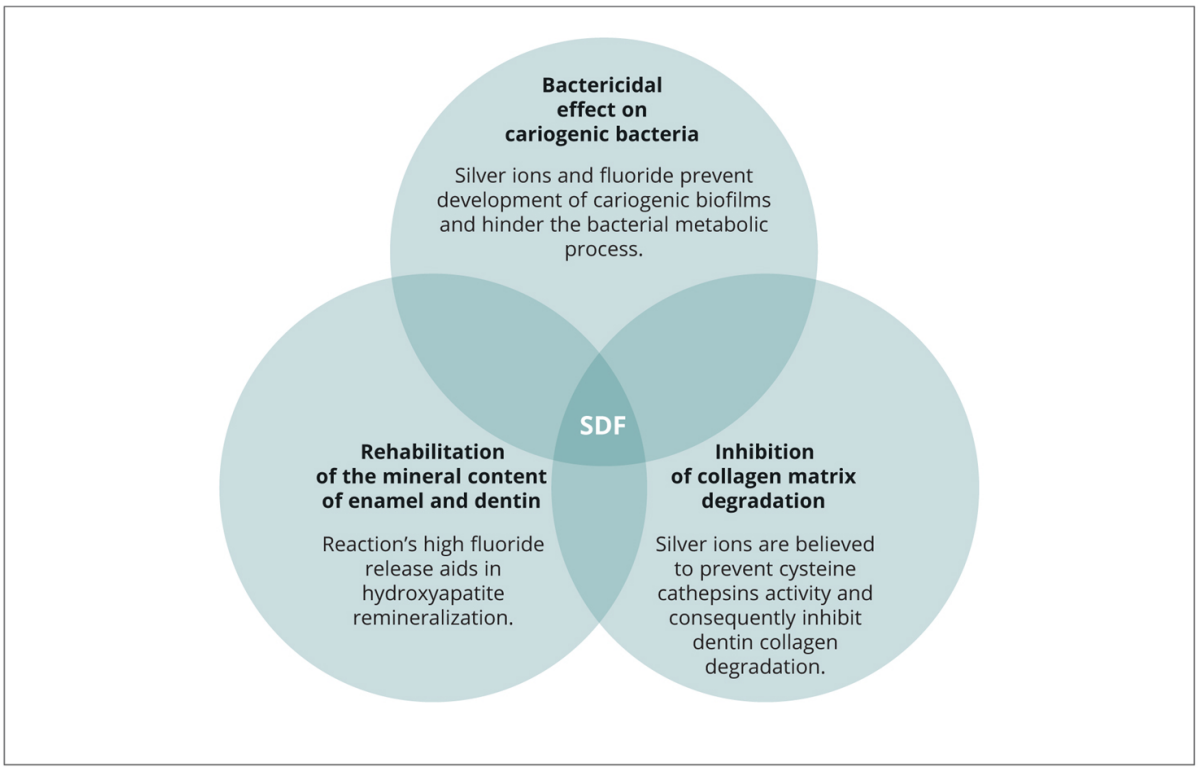


Fig 12-2 Mechanism of action of silver diammine fluoride (SDF) as proposed by Zhao et al.[11]

Indications

In 2014, SDF was cleared by the US Food and Drug Administration primarily as a treatment for dentinal sensitivity,[18] which is also the primary indication of the only SDF product available in Europe. Its efficiency in reducing dentin hypersensitivity is also helpful in pediatric dentistry for management of hypersensitivity in teeth

diagnosed with molar incisor hypomineralization (MIH), through sole application or in combination with high-viscosity glass-ionomer cement, an approach known as the silver modified atraumatic restorative technique (SMART).[19] However, further research on its effectiveness for treatment of MIH is still needed.

SDF has a well-reputed history in arresting caries. Since its utilization does not require caries removal, the ease of its application and acceptance by young children or elderly patients has been praised in many studies,[20-23] and this motivated the off-label use on the grounds of caries management, also providing relief in tackling the caries process in disabled children.[24] A recent guideline from a workgroup formed by the American Academy of Pediatric Dentistry (AAPD) recommended the use of 38% SDF to treat caries.[25] Regardless, the beneficial use of SDF is strongly dependent on case selection at the patient and tooth levels. The AAPD panel listed recommendations for case selection for application of SDF (Table 12-2).[25]

Table 12-2 Recommendations for case selection according to the American Academy of Pediatric Dentistry (AAPD) guidance[25]

Patient level	Tooth level
High caries risk patients presenting with active cavitated caries lesions in anterior or posterior teeth	Teeth with no reports of spontaneous pain or clinical signs of pulpal involvement
Behaviorally and medically challenging patients with cavitated caries lesions	Deeply cavitated lesions not horning the pulp (radiograph

Patient level	Tooth level
	should be taken to assess depth of the lesion)
Patients with difficult access or without access to proper dental care	Teeth with possible access to proximal lesions that allows use of brush for SDF applications (orthodontic separators can be used to gain access prior to SDF application)
Patients with numerous caries lesions, which cannot be treated in a single visit without the use of general anesthesia	Prior to restoration placement and as part of caries control therapy

Contraindications and side effects

Despite the scarce data on the prevalence of allergy to silver,[26] children with a known chemical allergy to silver should not be treated with SDF. Additionally, the requirement for pulpal treatment of teeth undergoing irreversible pulpitis or necrosis contraindicates the therapeutic use of SDF in the line of treatment.[25] It is also preferable to avoid SDF contact with sensitive open mouth sores (eg, herpetic gingivostomatitis, ulcerative gingivitis) until symptoms diminish.

The high fluoride concentration (44,800 ppm) of SDF at 38% may raise a concern regarding safety, as well as the risk of inducing dental fluorosis. Contrarily, a randomized clinical trial conducted in 2017 reached a safe verdict on treatment with SDF at different concentrations for preschool children as it did not result in any serious hazards or systemic illness.[8] Reports of gingival swelling and pain were rare, and all bleached gingivae after SDF contact resolved

without interference within 2 days.[8] In favor of minimizing such events, it is reasonable to recommend proper isolation of the treatment area and avoidance of oversaturation of the microbrush with SDF solution in order to minimize gingival contact during application.

On the other hand, researchers identified the main flaw of treatment with SDF: permanent black staining of the caries lesions.[8,21,27] Many efforts have been made to reduce this nonesthetic drawback of SDF. Alongside the previously mentioned positive reports of minimizing discoloration by the additional use of potassium iodide following SDF application,[10,28] an innovative form of silver fluoride called nano silver fluoride (NSF) is believed to be an effective anti-caries agent without the staining consequences.[29]

Under the scope of parental acceptability and satisfaction, opinions of parents can be controversial following treatment of their children with SDF due to different cultures and esthetic priorities. However, a recent survey among a diverse group of parents recorded high rates of parents who prefer dental health to dental esthetics in their children, while those who perceived the staining effect of SDF as unacceptable still agreed to the esthetic compromise in favor of avoiding the hazards of treatment under general anesthesia.[30] Informed consent, detailing the predicted staining of treated lesions, is recommended.[25]

Clinical application

The application of SDF is technically a simple procedure to perform in terms of clinical dexterity. Nevertheless, the suitability of this treatment modality for the specific patient/caregiver and tooth should be carefully considered, taking into account the indications previously mentioned.

For successful treatment using SDF the following steps are recommended:

- Acquisition of informed consent from parent/caregiver is fundamental. In case of concern, use of SDF should be avoided in anterior teeth.
- In case of limited access to the caries lesion(s) for SDF application, accessibility can be established by rotary instrumentation or hand removal of overhanging enamel.
- Removal of any food debris using a dental bristle brush or a toothbrush.
- Achievement of a dry treatment field using cotton-rolls or air.
- SDF solution application using a microbrush, following the specific instructions of the manufacturer. Usually application of SDF takes 30 to 60 seconds with air drying.
- The patient should be rescheduled to return for caries activity assessment of treated lesions, mainly considering color and lesion appearance. Treated caries lesions should look dark brown or black with a shiny appearance (Fig 12-1). For further information on characteristics of lesion activity, see Chapter 14, Table 14-3.
- Individual assessment is essential if restoration of the SDF-treated teeth is esthetically advantageous or desired by the patient/caregiver. Whenever necessary, the patient should be rescheduled for a restorative procedure (mainly using preformed metal crowns), or wait for teeth to exfoliate.
- Involvement of the child/caregiver in a caries control program (see Chapter 14) and settlement of regular recall visits allowing lesion activity to be monitored and if necessary, reapplication of SDF (maximum biannually).

Existing evidence

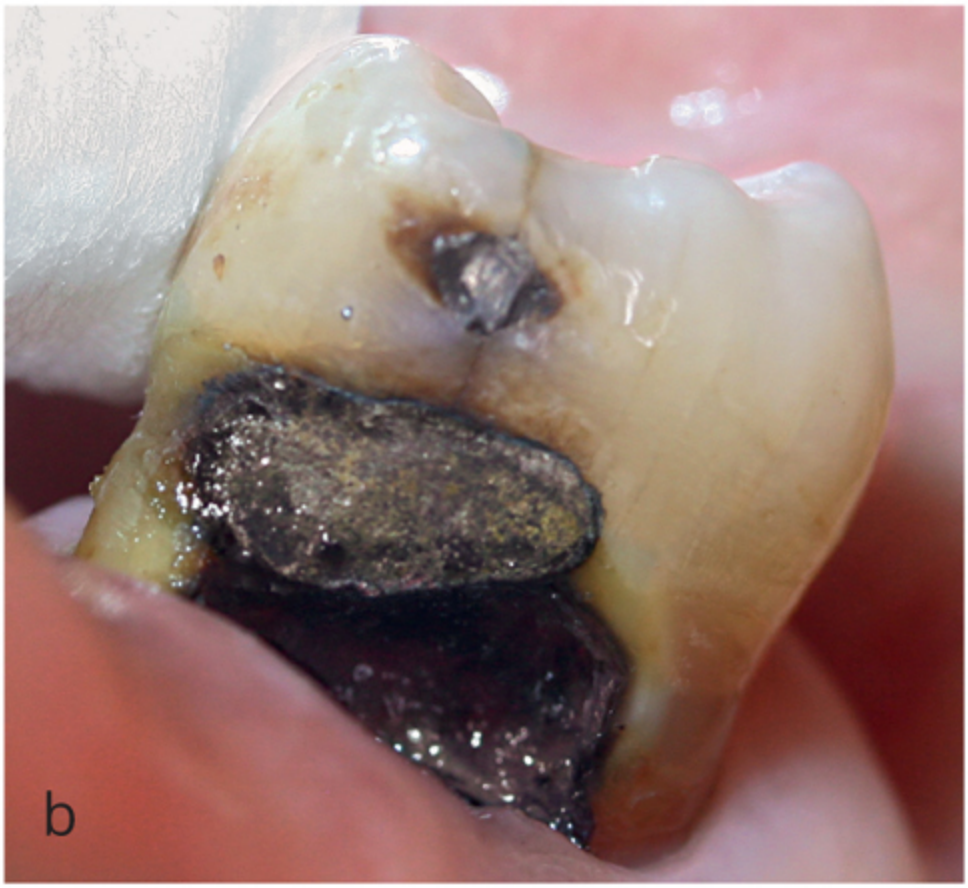
There is evidence from high-quality systematic reviews and meta-analyses showing the effectiveness of SDF to control caries lesions in primary and permanent teeth.[27,31,32]

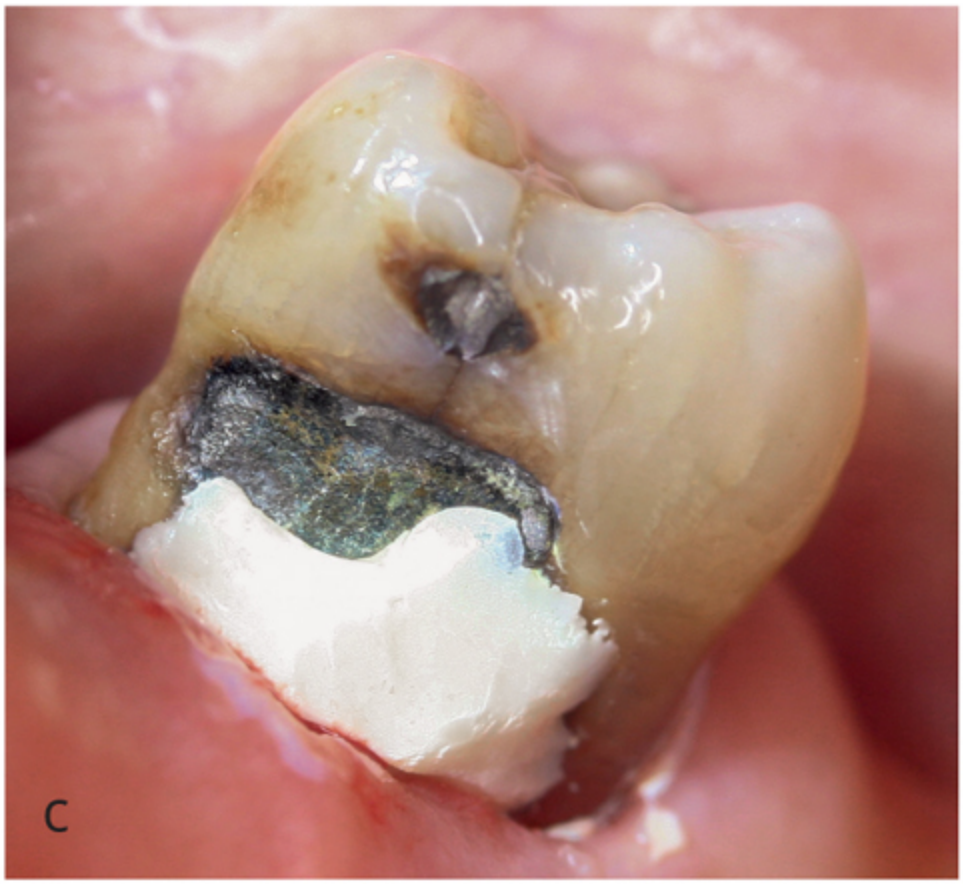
In general, all studies reach a similar conclusion supporting the efficacy of SDF to arrest caries lesions in primary teeth. A meta-analysis of randomized clinical trials reported an overall percentage of 81% (95% confidence interval 68% to 89%; $P < .001$) of active caries that became arrested.[32] Data adapted from Gao et al[32] show randomized controlled trials supporting the evidence for SDF, some of which are presented in Table 12-3. The consistently high caries-arrest potency of SDF, regardless of the country and setting where it has been used, speak for themselves.

Table 12-3 Overall success rates among eight randomized control trials using SDF versus other interventions according to Gao et al[32]

Study	Country	Sample/intervention	Follow-up period	Main findings
Duangthip et al[20]	Hong Kong	Primary teeth; Group 1: 30% SDF, annually (n = 458); Group 2: 30% SDF, one-off (n = 426); Group 3: 5% sodium fluoride, one-off (n = 523)	18 mo	Caries-arresting rate: Group 1: 40%; Group 2: 35%; Group 3: 27%
dos Santos et al[33]	Brazil	Primary teeth; Group 1: 30% SDF, one-off (n = 183); Group 2: glass ionomer, one-off (n = 162)	12 mo	Caries-arresting rate: Group 1: 67%; Group 2: 39%
Zhi et al[34]	China	Primary teeth; Group 1: 38% SDF, annually (n = 218); Group 2: 38% SDF, semiannually (n = 239); Group 3: glass ionomer, annually (n = 262)	24 mo	Caries-arresting rate: Group 1: 79%; Group 2: 91%; Group 3: 82%
Yee et al[35]	Nepal	Primary teeth; Group 1: 38% SDF, one-off (n = 3,396); Group 2: 12% SDF, one-off (n = 1,652); Group 3: no treatment (n = 1,590)	24 mo	Caries-arresting rate: Group 1: 31%; Group 2: 22%; Group 3: 15%
Llodra et al[36]	Cuba	Group 1: 38% SDF, semiannually (n = 675); Group 2: no treatment (n = 658)	36 mo	Caries-arresting rate: Group 1: 85%; Group 2: 62%
Yang and Wei[37]	China	Primary teeth; 38% SDF, one-off (n = 158)	6 mo	Caries-arresting rate: 94%
Chu et al[38]	Hong Kong	Primary teeth; Group 1: 38% SDF, annually (n = 641); Group 2: 5% sodium fluoride, every 3 months (n = 576); Group 3: no treatment (n = 273)	30 mo	Caries-arresting rate: Group 1: 65%; Group 2: 41%; Group 3: 34%
Ye[39]	China	Primary teeth; 38% SDF, one-off (n = 300)	12 mo	Caries-arresting rate: 92%

Older adults also have their share of SDF benefits. Existing reports of trials and reviews reveal the significant effect of SDF in arresting exposed root caries and prevention of new lesions.[40,41] Moreover, a systematic review with similar conclusions noted no esthetic concerns in the included studies' populations.[42] A possible explanation could be that despite the staining of exposed root lesions after SDF application (Fig 12-3), ease of the procedure or importance of retaining existing teeth are perhaps more important than esthetics in older populations. However, evidence of SDF in geriatric dentistry is limited, and further research assessing acceptability and application frequency of this treatment modality is required.





Figs 12-3a to c Difficult teeth in compromised patients, eg root caries with uncertain margins **(a)**, can effectively be treated with silver diammine fluoride **(b)** even bed-side with hand excavation and glass-ionomer cement restorations **(c)**, if no irreversible pulpal involvement is present.

In conclusion, there is clear evidence supporting the effectiveness of SDF in managing active caries lesions in children. The easy application and instant arrest of caries in conventionally unmanageable cases presents an alternative option in caries management for practitioners. Case selection prior to treatment with SDF is vital for a satisfactory outcome and acceptability of the staining effect. Further research is needed to

provide evidence on how to minimize or eliminate the staining, and whether SDF could be a valid option for MIH or root caries.

References

1. Barillo DJ, Marx DE. Silver in medicine: A brief history BC 335 to present. Burns 2014;40(Suppl 1):S3–S8.
2. Stebbins E. What value has argenti nitras as a therapeutic agent in dentistry? Int Dent J 1891;12:661–670.
3. Howe P. A method of sterilizing and at the same time impregnating with a metal affected dentinal tissue. Dent Cosmos 1917;59:891–904.
4. Nishino M, Yoshida S, Sobue S, Kato J, Nishida M. Effect of topically applied ammoniacal silver fluoride on dental caries in children. J Osaka Univ Dent Sch 1969;9:149–155.
5. Yamaga R, Nishino M, Yoshida S, Yokomizo I. Diammine silver fluoride and its clinical application. J Osaka Univ Dent Sch 1972;12:1–20.
6. Mei ML, Chu CH, Lo ECM, Samaranayake LP. Fluoride and silver concentrations of silver diammine fluoride solutions for dental use. Int J Paediatr Dent 2013;23:279–285.
7. Fung MHT, Duangthip D, Wong MCM, Lo ECM, Chu CH. Randomized clinical trial of 12% and 38% silver diammine fluoride treatment. J Dent Res 2018;97:171–178.
8. Duangthip D, Fung MHT, Wong MCM, Chu CH, Lo ECM. Adverse effects of silver diamine fluoride treatment among preschool children. J Dent Res 2018;97:395–401.
9. Knight GM, McIntyre JM, Craig GG, Mulyani. Ion uptake into demineralized dentine from glass ionomer cement following pretreatment with silver fluoride and potassium iodide. Aust Dent J 2006;51:237–241.

10. Nguyen V, Neill C, Felsenfeld J, Primus C. Potassium iodide. the solution to silver diamine fluoride discoloration? Adv Dent Oral Heal 2017;5:5555655.
11. Zhao IS, Gao SS, Hiraishi N, et al. Mechanisms of silver diamine fluoride on arresting caries: a literature review. Int Dent J 2018;68:67–76.
12. Chu CH, Mei L, Seneviratne CJ, Lo ECM. Effects of silver diamine fluoride on dentine carious lesions induced by *Streptococcus mutans* and *Actinomyces naeslundii* biofilms. Int J Paediatr Dent 2012;22:2–10.
13. Knight GM, McIntyre JM, Craig GG, Mulyani, Zilm PS, Gully NJ. An in vitro model to measure the effect of a silver fluoride and potassium iodide treatment on the permeability of demineralized dentine to *Streptococcus mutans*. Aust Dent J 2005;50:242–245.
14. Mei ML, Ito L, Cao Y, Lo EC, Li QL, Chu CH. An ex vivo study of arrested primary teeth caries with silver diamine fluoride therapy. J Dent 2014;42:395–402.
15. Wu L, Yang F. The effects of three fluoride-containing agents on the remineralization of deciduous teeth in vitro. J Pr Stomatol 2002;347–349.
16. Mei ML, Ito L, Cao Y, Li QL, Chu CH, Lo EC. The inhibitory effects of silver diamine fluorides on cysteine cathepsins. J Dent 2014;42:329–335.
17. Mei ML, Li QL, Chu CH, Yiu CK, Lo EC. The inhibitory effects of silver diamine fluoride at different concentrations on matrix metalloproteinases. Dent Mater 2012;28:903–908.
18. US Food and Drug Administration. Diammine silver fluoride dental hypersensitivity varnish [510(k) premarket notification]. Silver Spring: US Food and Drug Administration, 2017. Accessed 14 March 2019.
19. MacLean J. Minimally invasive treatment for molar incisor hypomineralization. Decis Dent 2018;4:18–20,22–23.

20. Duangthip D, Chu CH, Lo ECM. A randomized clinical trial on arresting dentine caries in preschool children by topical fluorides - 18 month results. J Dent 2016;44:57–63.
21. Gao SS, Zhang S, Mei ML, Lo EC-M, Chu C-H. Caries remineralisation and arresting effect in children by professionally applied fluoride treatment: a systematic review. BMC Oral Health 2016;16:12.
22. Mei ML, Lo EC, Chu C-H. Clinical use of silver diamine fluoride in dental treatment. Compend Contin Educ Dent 2016;37:93–98.
23. Sharma G, Puranik MP, Sowmya KR. Approaches to arresting dental caries: an update. J Clin Diagnostic Res 2015;9:ZE08–ZE11.
24. Travis M. Nelson-Jessica RW. Dental care for children with special needs: a clinical guide. Geneva: Springer Nature Switzerland, 2019.
25. Crystal YO, Marghalani AA, Ureles SD, et al. Use of silver diamine fluoride for dental caries management in children and adolescents, including those with special health care needs. Pediatr Dent 2017;39:135–145.
26. Lansdown AB. Silver in health care: antimicrobial effects and safety in use. Curr Probl Dermatol 2006;33:17–34.
27. Trieu A, Mohamed A, Lynch E. Silver diamine fluoride versus sodium fluoride for arresting dentine caries in children: a systematic review and meta-analysis. Sci Rep 2019;9:2115.
28. Garg S, Sadr A, Chan D. Potassium iodide reversal of silver diamine fluoride staining: a case report. Oper Dent 2019;44:221–226.
29. dos Santos VE, Filho AV, Ribeiro Targino AG, et al. A new “silver-bullet” to treat caries in children – nano silver fluoride: a randomised clinical trial. J Dent 2014;42:945–951.
30. Crystal YO, Janal MN, Hamilton DS, Niederman R. Parental perceptions and acceptance of silver diamine fluoride staining. J Am Dent Assoc 2017;148:510–518.e4.

31. Chibinski AC, Wambier LM, Feltrin J, Loguercio AD, Wambier DS, Reis A. Silver diamine fluoride has efficacy in controlling caries progression in primary teeth: a systematic review and meta-analysis. Caries Res 2017;51:527–541.
32. Gao SS, Zhao IS, Hiraishi N, et al. Clinical trials of silver diamine fluoride in arresting caries among children: a systematic review. JDR Clin Transl Res 2016;1:201–210.
33. dos Santos VE, de Vasconcelos FMN, Ribeiro AG, Rosenblatt A. Paradigm shift in the effective treatment of caries in schoolchildren at risk. Int Dent J 2012;62:47–51.
34. Zhi QH, Lo ECM, Lin HC. Randomized clinical trial on effectiveness of silver diamine fluoride and glass ionomer in arresting dentine caries in preschool children. J Dent 2012;40:962–967.
35. Yee R, Holmgren C, Mulder J, et al. Efficacy of silver diamine fluoride for arresting caries treatment. J Dent Res 2009;88:644–647.
36. Llodra JC, Rodriguez A, Ferrer B, Menardia V, Ramos T, Morato M. Efficacy of silver diamine fluoride for caries reduction in primary teeth and first permanent molars of schoolchildren: 36-month clinical trial. J Dent Res 2005;84:721–724.
37. Yang Q, Wei BYZ. Clinical effectiveness of using silver diamine fluoride to treat caries on primary anterior teeth (in Chinese). Heilongjiang Med Pharmacol 2002;3:66–67.
38. Chu CH, Lo ECM, Lin HC. Effectiveness of silver diamine fluoride and sodium fluoride varnish in arresting dentin caries in Chinese pre-school children. J Dent Res 2002;81:767–770.
39. Ye Z. The use of 38% silver diamine fluoride in dental caries (in Chinese). Chin J Conserv Dent 1995;1:32.
40. Li R, Lo EC, Liu BY, Wong MC, Chu CH. Randomized clinical trial on arresting dental root caries through silver diamine fluoride applications in community-dwelling elders. J Dent 2016;51:15–20.

41. McReynolds D, Duane B. Systematic review finds that silver diamine fluoride is effective for both root caries prevention and arrest in older adults. Evid Based Dent 2018;19:46–47.
42. Oliveira BH, Cunha-Cruz J, Rajendra A, Niederman R. Controlling caries in exposed root surfaces with silver diamine fluoride: a systematic review with meta-analysis. J Am Dent Assoc 2018;149:671–679.e1.

13

Self-assembling peptides: A perfectly engineered preventive and therapeutic tool?

Mohammad Alkilzy, Christian H. Splieth

Despite the caries decline over the last five decades in many countries,[1,2] dental caries is still the most prevalent disease in the world.[2,3] Caries occurs when an imbalance between re- and demineralization takes place at the site of loss of minerals in hard dental tissue. Therefore, the classic “treatment” of cavities by drilling and filling constitutes repair of the damage, but does not treat the disease itself (see Chapter 1). “Real” caries treatment would consist of shifting the equilibrium to remineralization, for instance by improving the daily oral hygiene regime and fluoride utilization. Furthermore, the traditional invasive restorative interventions lead to destruction of healthy tooth tissue, destabilizing the tooth structure and leading to a cycle of new restorations, more removal of dental tissue to replace existing restorations by larger ones, and so on.

The caries decline and a subsequently slow progression of caries lesions allow the use of preventive treatment strategies instead of

restorative treatments.[4]

Based on the new understanding of caries kinetics, monitoring the de-/remineralization equilibrium is the first step in applying and controlling measures for correcting the mineralization balance. In the early stages of caries, prior to the cavitation of the enamel surface, many non- and minimally invasive treatments have been suggested to avoid placing a restoration. The primary aim of noninvasive treatments is to inactivate or arrest the caries (see Chapter 1). This can be achieved by diet control and plaque removal, which allow the caries lesions to remineralize naturally through saliva,[5] as described in other chapters of this book. The presence of fluorides clearly enhances remineralization and prevents further demineralization,[6-8] but this is less effective in manifest cavities (see Chapter 3).[9,10]

Thus, most preventive approaches rely on changes in the patient's behavior. A possible alternative is mechanically sealing caries risk surfaces,[11] but sealants are prone to microleakage and subsequent caries in the long run.[12]

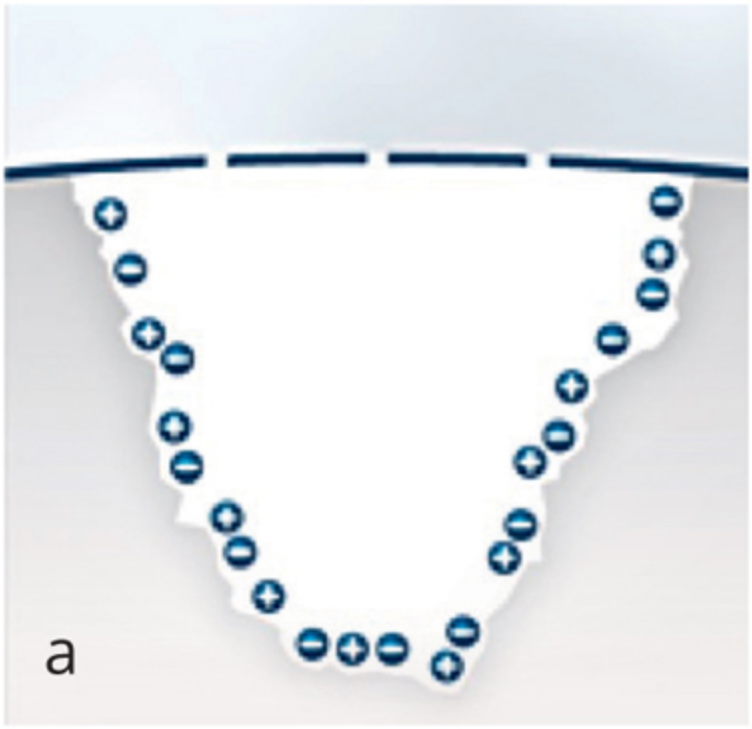
The caries decline and preventive approaches result in a relatively slow progression of many caries lesions, allowing the use of nonoperative treatment strategies.

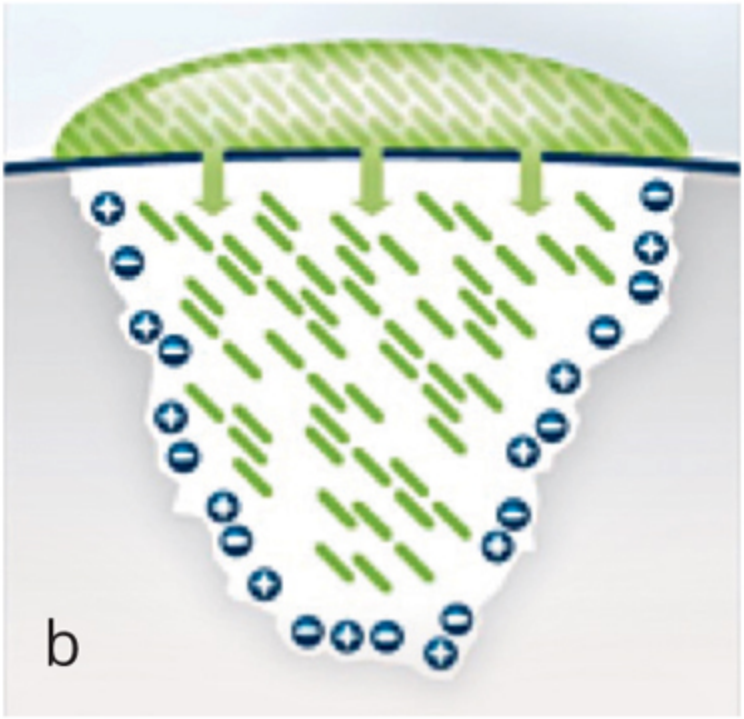
Regenerative medicine enables the replacement of damaged or diseased tissues. The shift from reparative to regenerative dentistry reflects the current trend in medicine,[13] and also mirrors the new understanding of caries as a chronic disease.[1] Similar to the guided regeneration of bone and periodontal tissue (long-established procedures in dentistry), the subsurface caries lesion presents a unique compartment, in which a biomimetic scaffold can support natural hard tissue formation through saliva,[14] resulting in guided enamel regeneration (GER) analogous to guided tissue regeneration (GTR) and guided bone regeneration (GBR).[15,16]

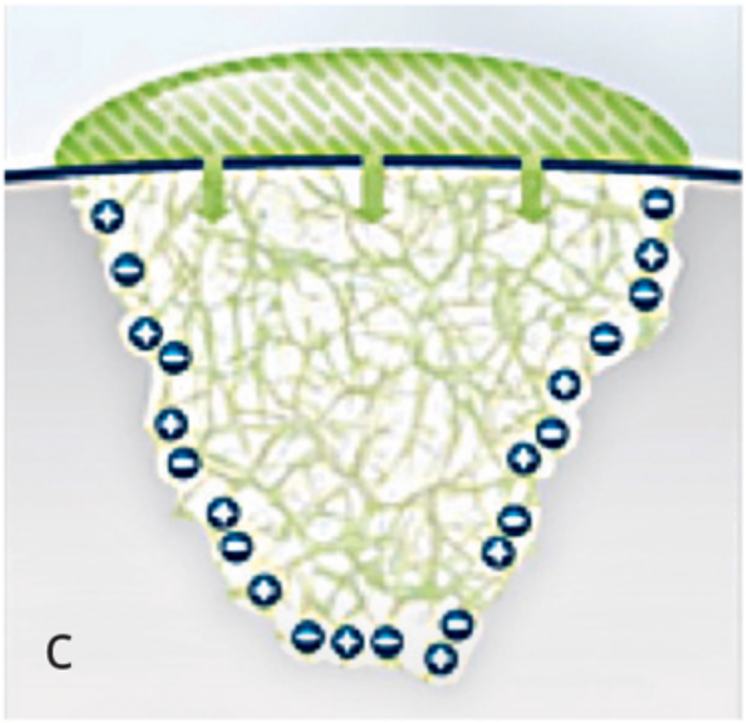
Biomimetic remineralization follows this concept in the treatment of dental caries, as it aims to remineralize initial caries lesions instead of sealing or infiltrating them with resin.

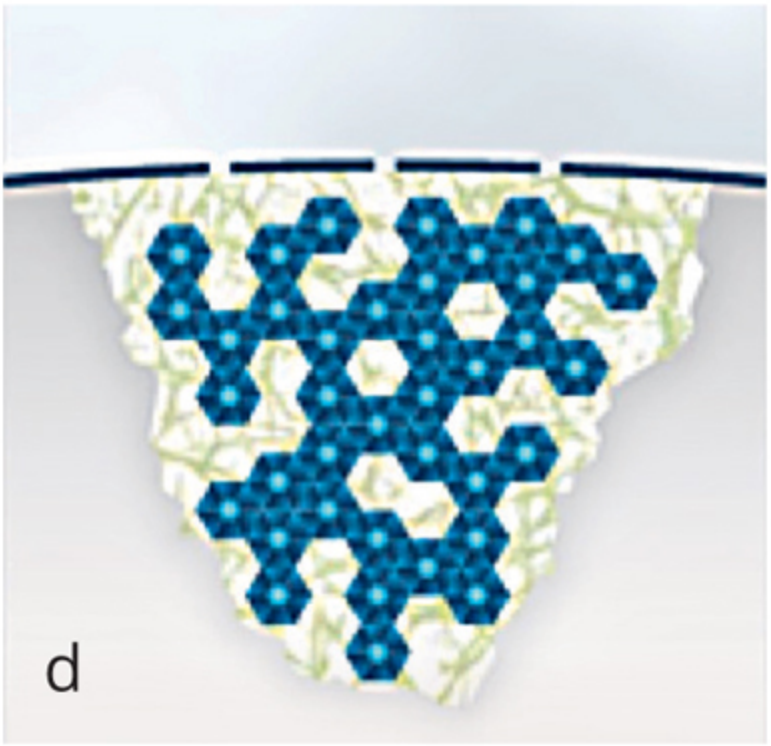
The new biomimetic approach endeavors mimicry of the enamel matrix proteins using a self-assembling peptide (SAP) system to form a three-dimensional (3D) matrix within the subsurface caries lesion.[17,18] In vitro studies showed that this matrix has a high affinity for hydroxyapatite (HA) and possesses binding sites on its surface that provide a template for HA formation.[14,19] These properties support the body's own regeneration process by saliva to remineralize larger lesions, as saliva delivers Ca^{2+} and PO_4^{3-} to the lesion body for mineralization.[20]

Biomimetic remineralization using a SAP presents a novel possibility for dental practitioners to predictively treat early caries as a disease, healing the enamel tissue. In comparison with amelogenin-based experimental therapies,[18] the advantage of SAPs is the ability to form a biomimetic scaffold within the subsurface caries lesion.[14,21] In turn, the biomimetic scaffold relies on saliva to mineralize around the matrix; the mechanism of action is displayed in Fig 13-1.









Figs 13-1a to d Illustration of the treatment of a caries lesion by the self-assembling peptide P11-4. **(a)** Initial caries lesion. **(b)** A drop of monomeric self-assembling peptide P11-4 is applied on the lesion

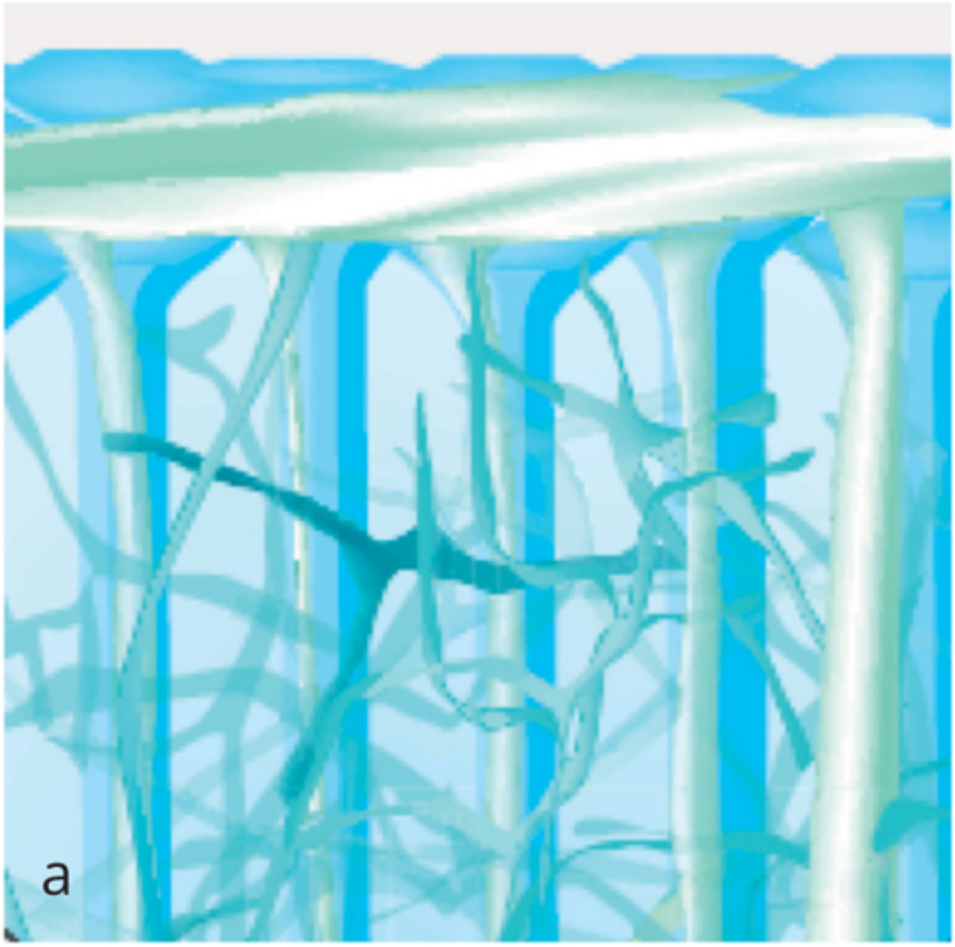
surface; the monomers diffuse into the lesion. **(c)** P11-4 assembles within the caries lesion, forming a 3D scaffold. **(d)** De novo hydroxyapatite crystals form around the self-assembling peptide scaffold. Reproduced from Alkilzy and Splieth,[22] with permission from Deutscher Ärzteverlag.

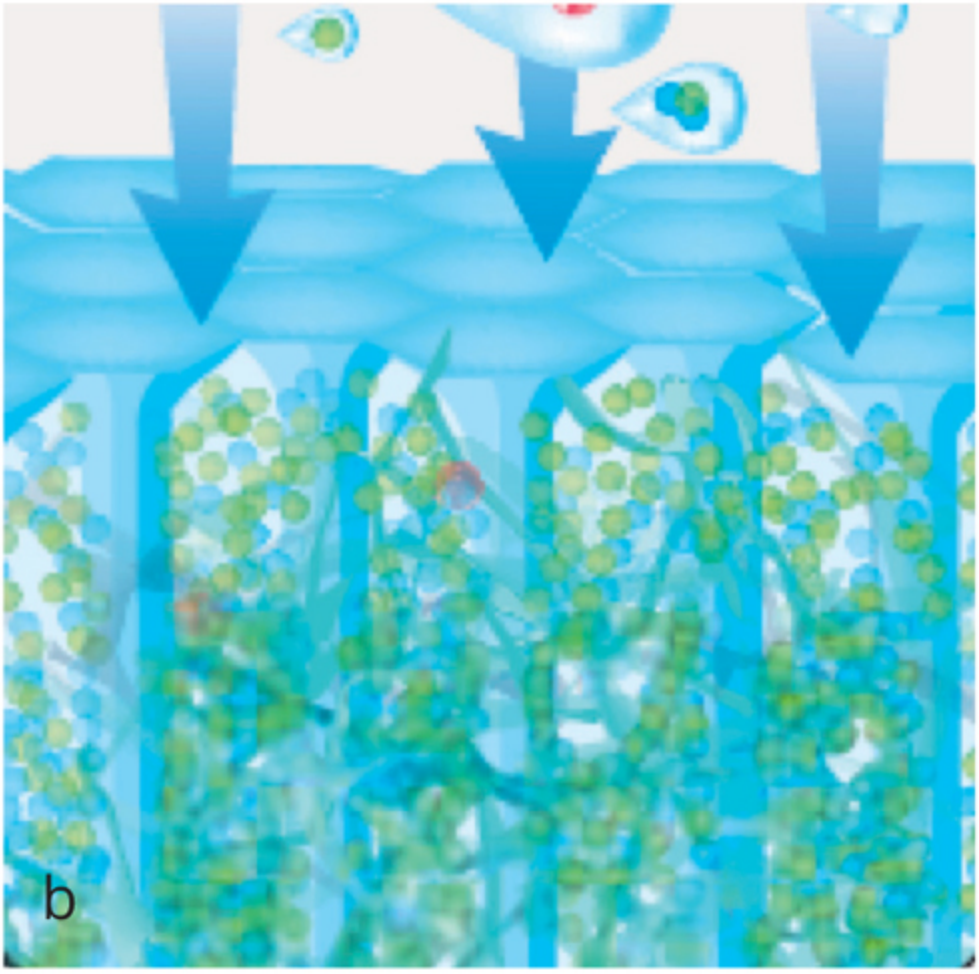
Self-assembling peptide P11-4

The SAP P11-4 is clinically available as Curodont Repair (Credentis; Fig 13-2). It has the chemical structure: Ace-Gln-Gln-Arg-Phe-Glu-Trp-Glu-Phe-Glu-Gln-Gln-NH_2. The P11-4 is formulated in a low-salt Tris-buffer preventing self-assembly to take place and contains 1% trehalose for preservation. It is fully synthetic and manufactured under current good manufacturing practices (cGMP). It contains no human- or animal-derived components.

Fig 13-2 The P11-4 Curodont Repair applicator for treatment of initial caries. Reproduced from Alkilzy and Splieth,[22] with permission from Deutscher Ärzteverlag.

P11-4 undergoes under specific physicochemical conditions, and above a critical concentration, a hierarchical self-assembly to form tapes and ribbons within seconds, and fibrils and fibers within the following 24 hours (Fig 13-3).[21-24] These resulting SAP fibers forming the 3D self-assembling peptide matrix (SAPM) can grow to a significant length. If the conditions for self-assembly are given, the assembly process cannot be stopped at the intermediates unless no more monomeric peptides are available. Physical factors such as pH and ionic strength can be used to control the assembly process.[25]





Figs 13-3a and b (a) P11-4 forms within an early caries lesion an organic 3D matrix. **(b)** The matrix has a high affinity for Ca^{2+} and PO_4^{2-} ions, thereby enabling de novo formation of dental hard tissue by biomimetic mineralization. Reproduced from Alkilzy and Splieth,[22] with permission from Deutscher Ärzteverlag.

Biocompatibility studies (according to ISO 10993 or equivalent) have shown that P11-4 did not raise any cytotoxic effects or any immunologic response.[26-28] P11-4 has been proven safe in animals and patients in vivo. No adverse device effects have been reported so far.[29]

The mechanism of action and the potential of SAPs in enhancing caries remineralization have been evaluated in a series of in vitro and in vivo studies as well as a clinical randomized controlled trial.

In vitro studies

Confocal microscopy and mass spectroscopy showed that monomeric P11-4 diffuses through the pores of demineralized enamel, where fiber formation is triggered and the 3D matrix is formed.[30] Furthermore, C-labeled P11-4 indicated that about 35% of P11-4 remained within artificial caries lesions,[30] being available for de novo HA crystal formation. Two studies[31,32] used the microtomography (microCT) analysis of remineralized specimens and found a remineralization of up to 90% of the original enamel density.

A series of in vitro studies revealed the high affinity of the P11-4 matrix for Ca^{2+} ions and its action as a nucleator for de novo HA formation.[14,21,30,33] Furthermore, the P11-4 fibers bind to the already existing Ca^{2+} ions of the HA lattice of the tooth enamel,[21] enabling stable bridge binding of the new regenerated enamel to the tooth hard tissue.

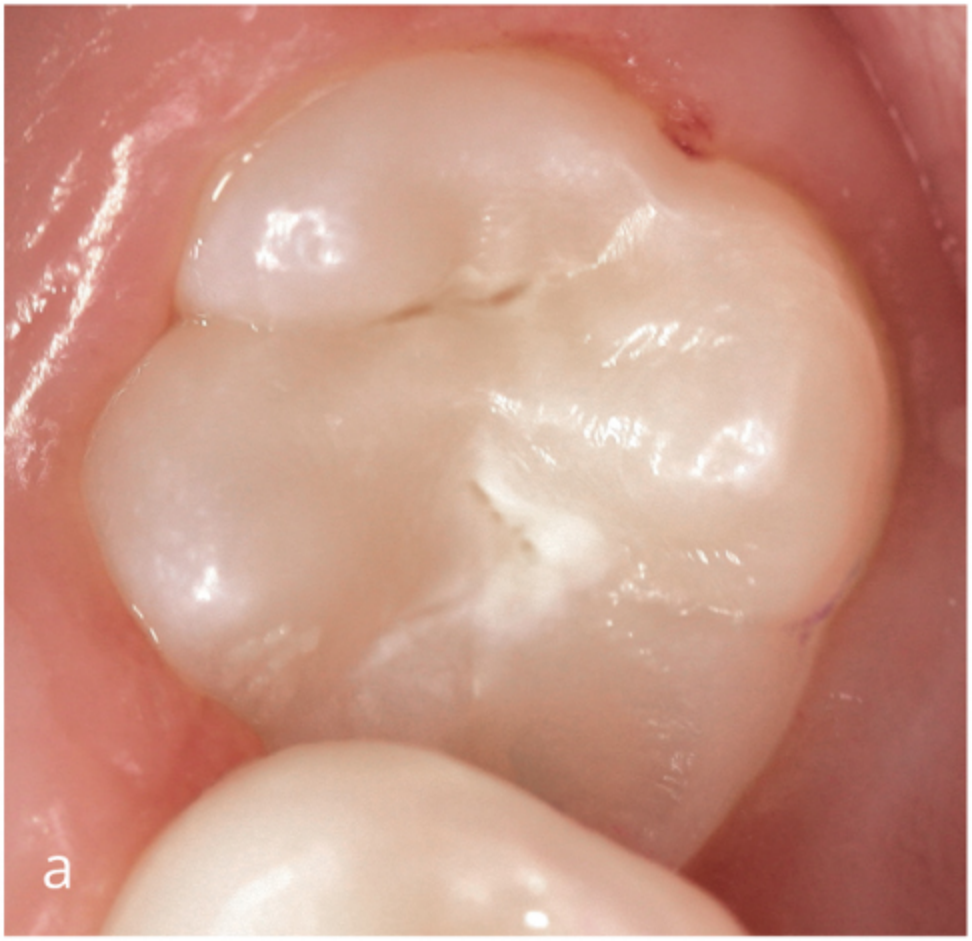
A study by Kind et al[30] investigated the diffusion of P11-4 into a caries lesion by time-resolved confocal microscopy pictures. The results showed that the P11-4 diffuses beyond the volume of the caries lesion into the enamel layer below that is defined as the caries lesion, on a microradiograph. After the formation of fibers is complete, the formed fibers seem to occupy the observed lesion.

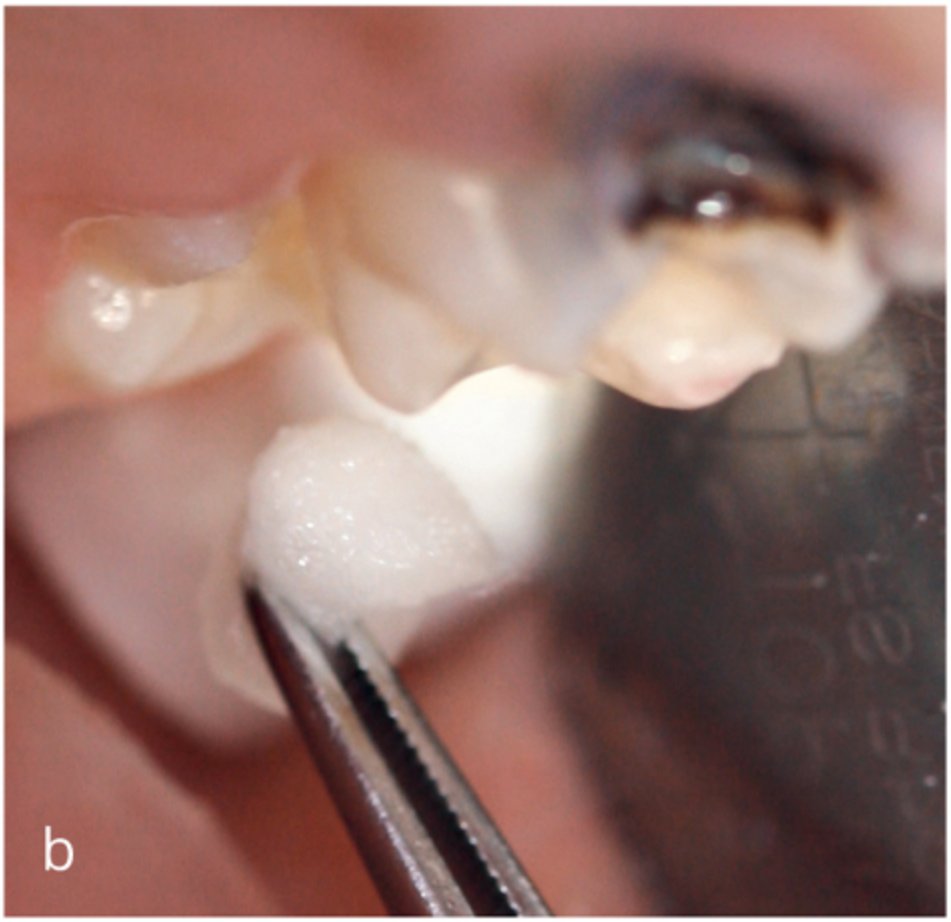
In vivo and clinical studies

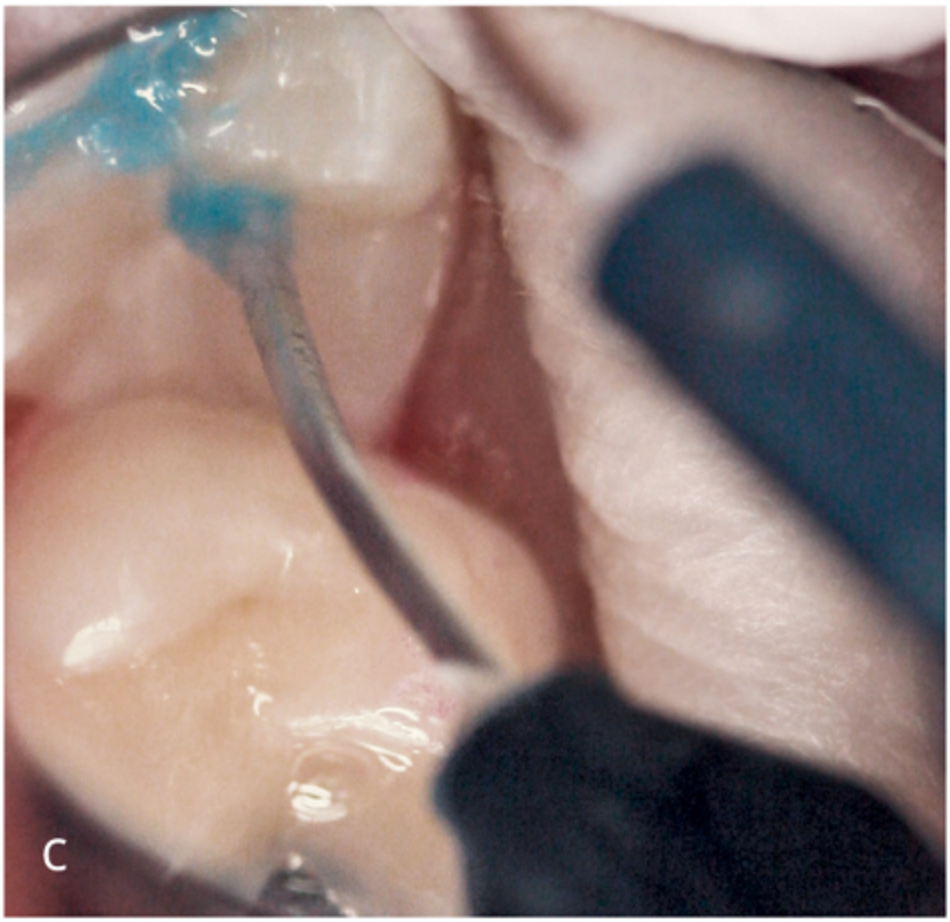
Huang et al[34] used a self-assembling bioactive matrix to investigate the ability to induce ectopic formation of enamel at chosen sites adjacent to a mouse incisor cultured in vivo under the kidney capsule. The resulting material revealed a highly organized, hierarchical structure of HA crystallites similar to native enamel.

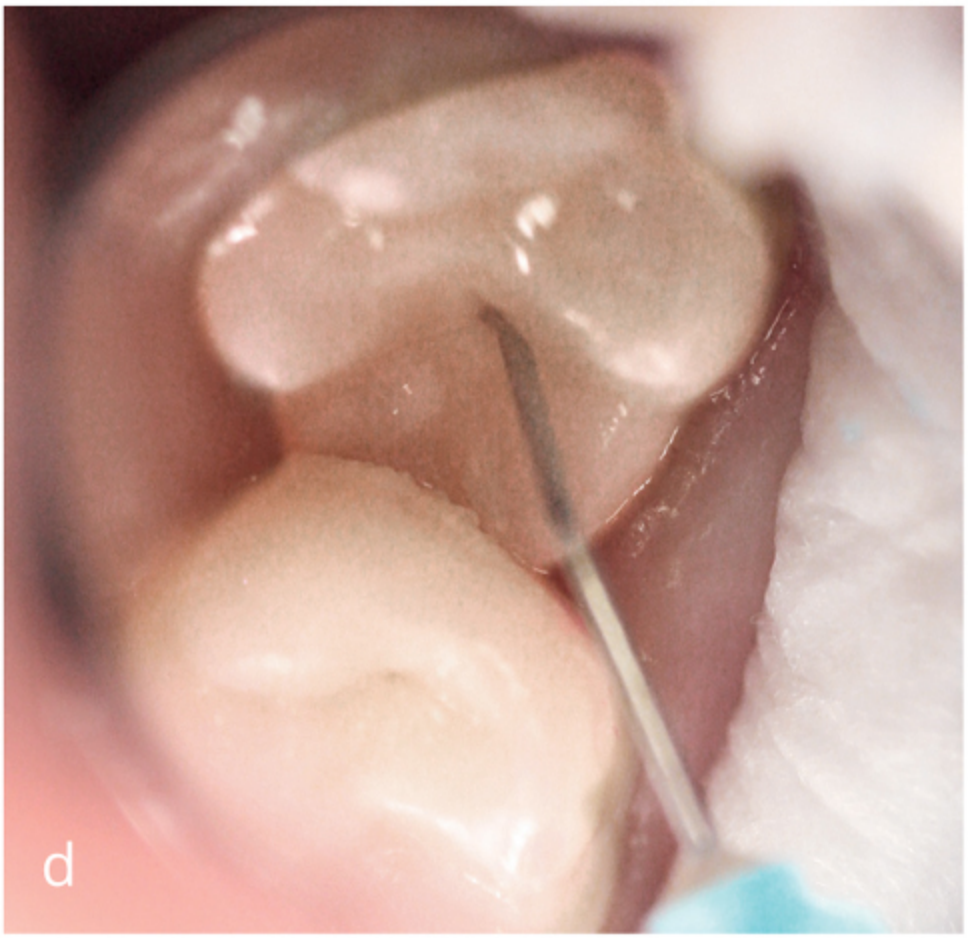
SAP for treatment of occlusal caries

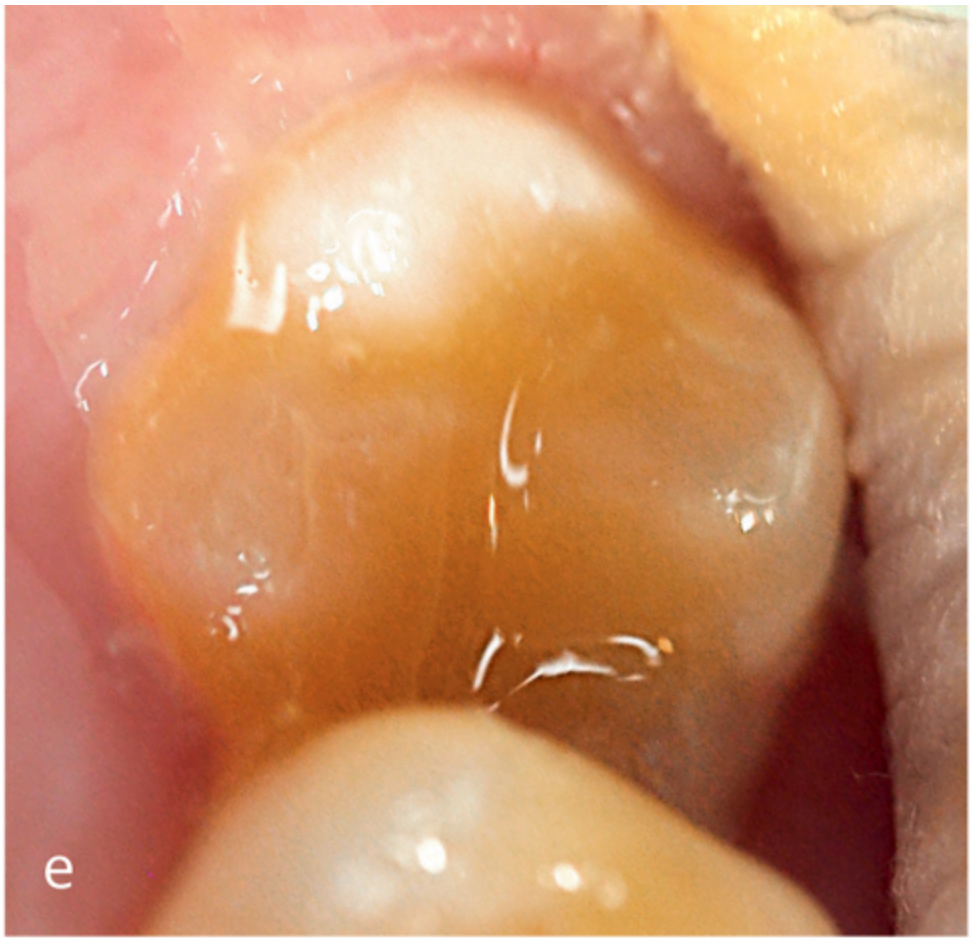
To investigate the safety and clinical efficacy of P11-4 for treatment of initial caries, a randomized controlled single-blind study was conducted by Alkilzy et al[29,35] on children aged from 5 years old with visible active early caries on erupting permanent molars. Subjects were randomized to either the test group (P11-4 + fluoride varnish) or the control group (fluoride varnish alone). Caries lesions were assessed at baseline and at 3 and 6 months posttreatment per laser fluorescence, a visual analog scale (VAS), the International Caries Detection and Assessment System (ICDAS), and Nyvad caries activity criteria. Safety and clinical feasibility of the treatment approaches were also assessed. The P11-4 (Curodont Repair) was applied according to the instructions of the manufacturer (Fig 13-4). Compared with the control group, the test group showed clinically and statistically significant improvement in all outcomes at the 3- and 6-month follow-ups. The laser fluorescence readings (odds ratio [OR] = 3.5, P = .015) and VAS scores (OR = 7.9, P < .0001) were significantly lower for the test group, and they showed regression in the ICDAS caries index (OR = 5.1, P = .018; Fig 13-5) and conversion from active to inactive lesions according to Nyvad criteria (OR = 12.2, P < .0001; Fig 13-6). No adverse events occurred. This study showed that the biomimetic mineralization facilitated by P11-4 in combination with fluoride application is a simple, safe, and effective noninvasive treatment for early caries lesions that is superior to the presently used gold standard of fluoride alone.











Figs 13-4a to e Clinical application of self-assembling peptide P11-4 (Curodont Repair). **(a)** Initial active caries lesions in a first permanent molar at eruption. **(b)** Elimination of organic debris with 3% NaOCl. **(c)** Etching with 35% phosphoric acid. **(d)** Application of P11-4 (Curodont Repair). **(d)** A 3- to 5-minute wait is required for diffusion into the lesion and matrix formation. **(e)** Application of fluoride varnish. (Reproduced from Alkilzy et al,[29] with permission from SAGE Publications.)

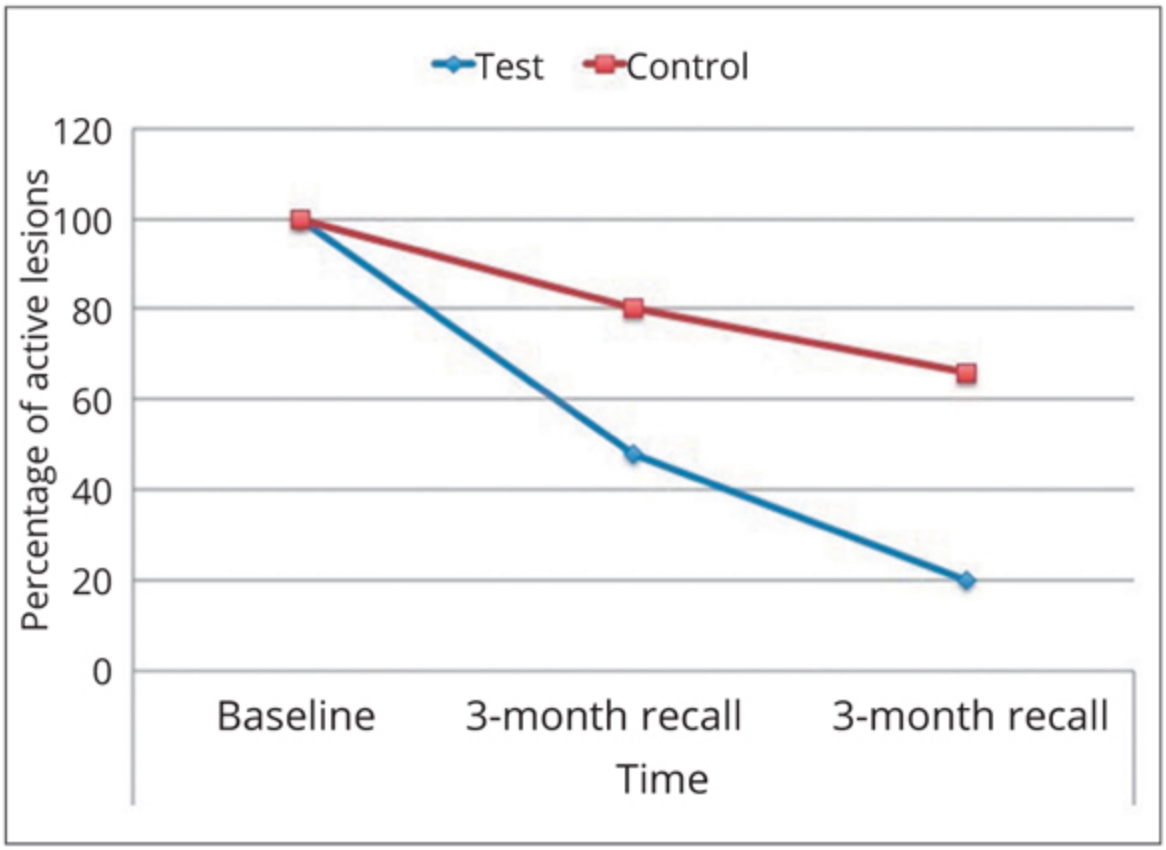


Fig 13-5 Significant reduction in caries activity of the lesions treated with self-assembling peptide in comparison to control lesions at 3- and 6-month recalls (data from Alkilzy et al[29]). (The copyright of this image remains with the author Mohammad Alkilzy.)

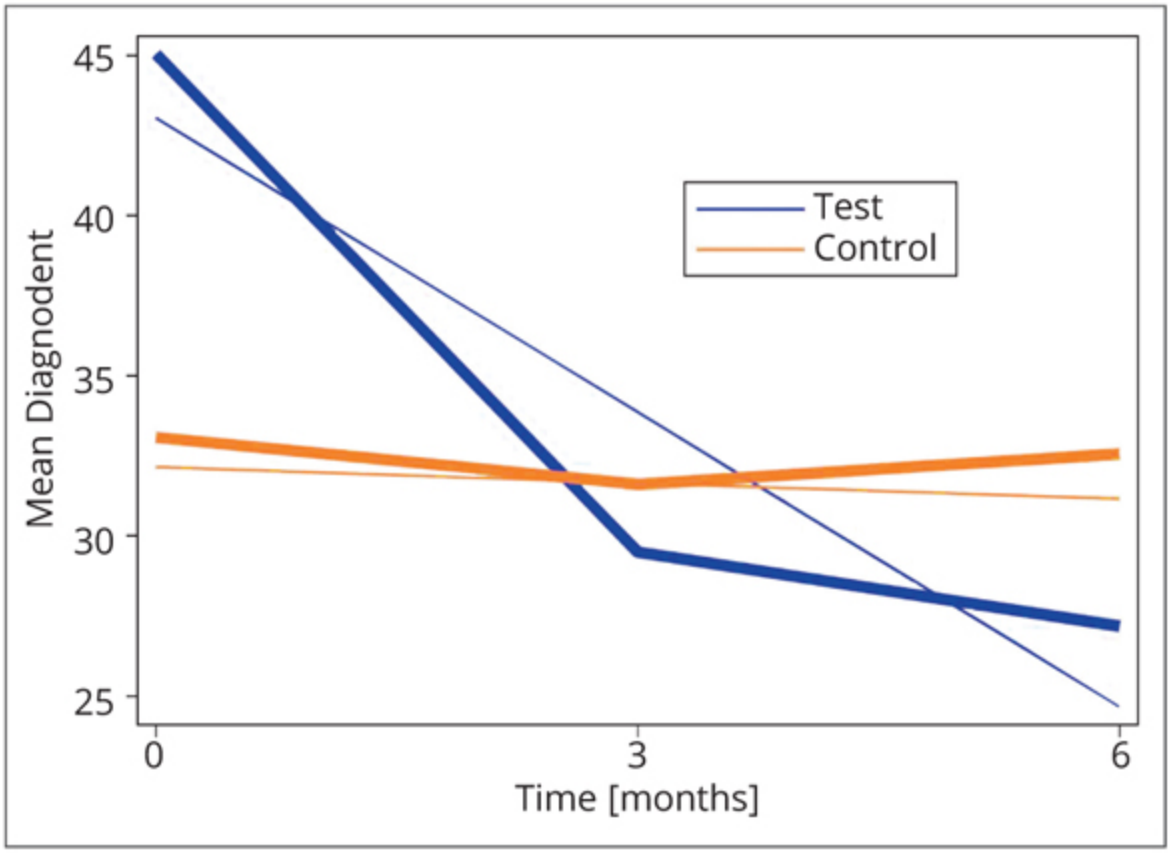


Fig 13-6 Development of mean Diagnodent values in active initial lesion treated with self-assembling peptide in comparison to controls at 3- and 6-month recalls (data from Alkilzy et al[29]) during the study (observed [bold lines] and predicted [linear mixed models, narrow lines]). (The copyright of this image remains with the author Mohammad Alkilzy.)

SAP for treatment of buccal caries and white spots

Bröseler et al[36] compared in a prospective, randomized, split-mouth, clinical trial the efficacy of the SAP P11-4 to that of fluoride varnish in the treatment of early buccal caries lesions. Subjects with at least two clinically affected teeth were treated at day (D) 1 and D90 with P11-4 (test) or fluoride varnish (control). At D180, fluoride varnish was applied on all study lesions. Standardized photographs were taken at D0, D30, D90, D180, and D360 and the decrease in size

between test and control groups was blindly morphometrically assessed. The results showed a significant difference between test and control groups, indicating a decrease in test lesions and stabilization of control lesions size (P = .001). The authors concluded that the size of early caries lesions treated with P11-4 was significantly reduced, and this size reduction was superior to that of fluoride varnish treat-ment.

SAP for treatment of proximal caries

A study by Schlee et al[37] investigated the clinical performance of SAP P11-4 on noncavitated initial proximal caries lesions 12 months after treatment. Twenty-six patients with 35 caries lesions were included in a practice-based case series. The radiographs of the proximal lesions at baseline and at D360 were evaluated pairwise in a randomized and blinded manner with respect to the time point. The 1-year results showed a predominant shift toward regression of the initial lesions, with 20 of 28 lesions showing total or partial regression, four unchanged, and four progressing. The authors suggested that the initial proximal caries lesions can regress after treatment with P11-4, but additional factors might influence the overall treatment outcome.

Clinically, SAP P11-4 in combination with fluoride enhanced significantly the remineralization of initial caries lesions in comparison with fluoride alone.

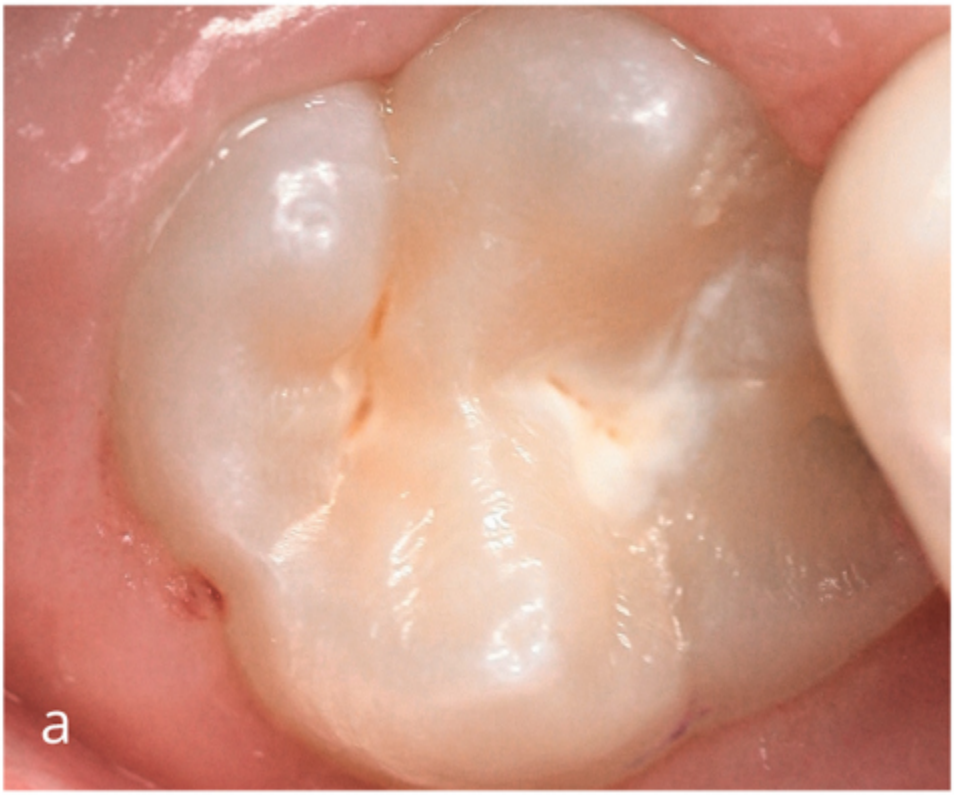
Clinical application of P11-4 for treatment of initial caries

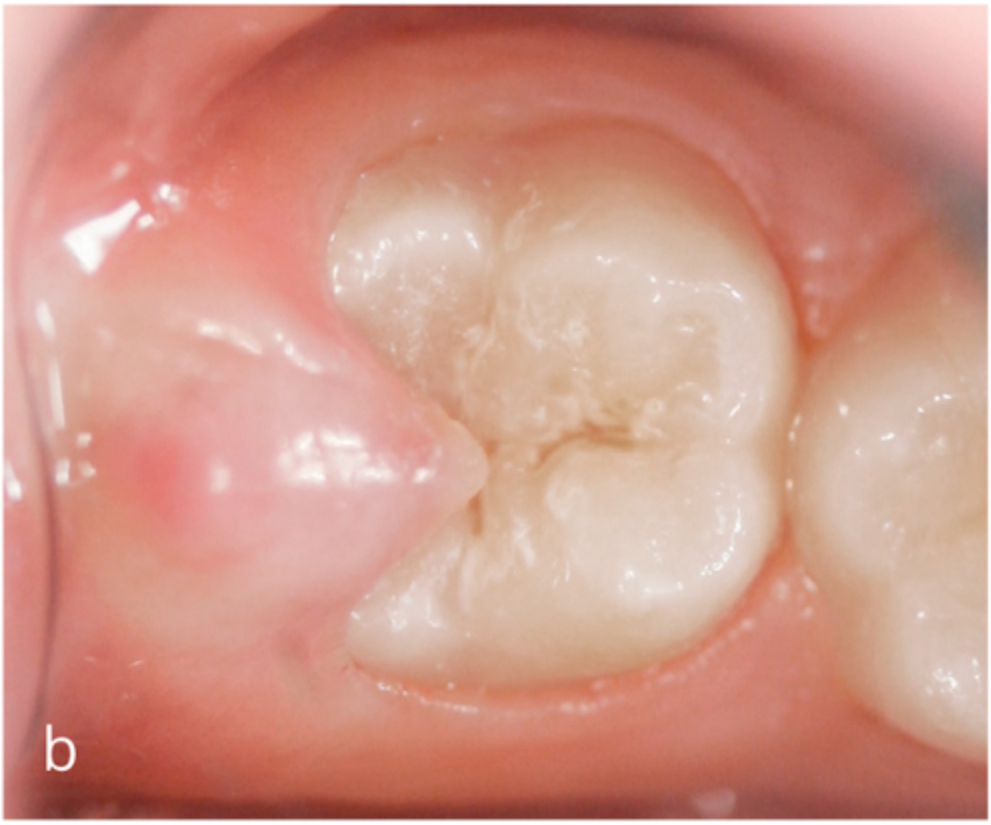
The clinical application of P11-4 for treatment of initial caries lesions is well described by the manufacturer of Curodont Repair. Figure 13-

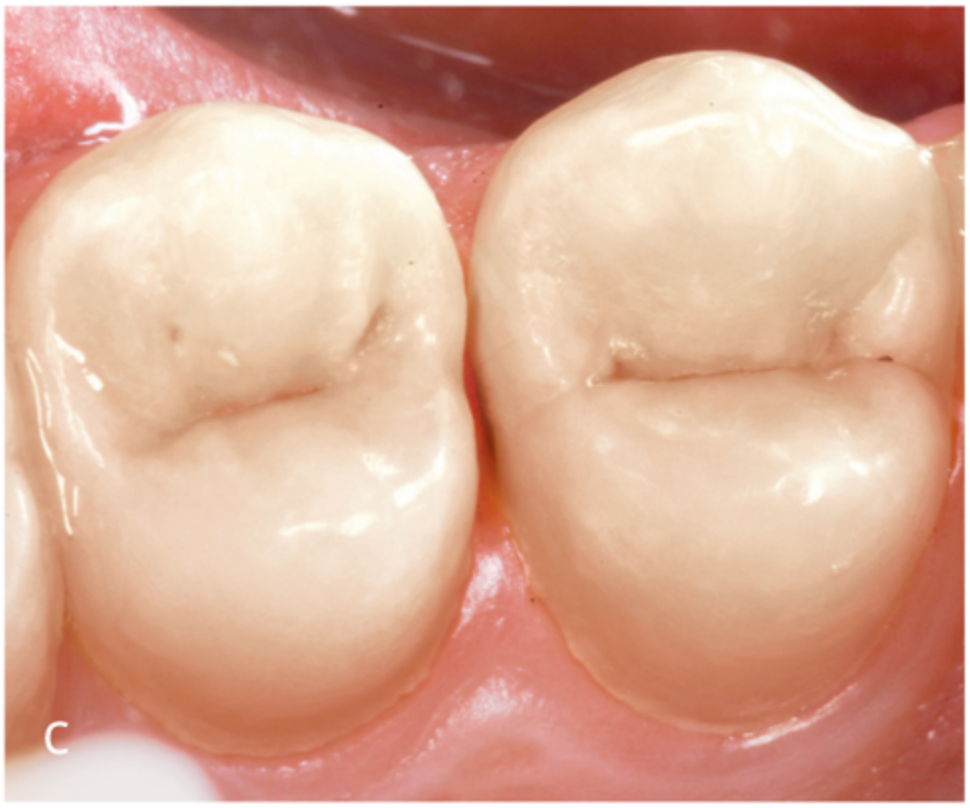
3 shows treatment of an initial caries lesion in the occlusal surface of a first permanent molar during eruption, using Curodont Repair. Table 13-1 lists some clinical indications and limitations for minimally invasive caries treatment with SAPs.

Table 13-1 Indications and limitations for minimally invasive caries treatment with self-assembling peptide (SAP)

Conditions and indications for minimally invasive caries treatment with SAP	Limitations and contraindications for minimally invasive caries treatment with SAP
Active initial lesions without cavitation (Fig 13-7)	Caries lesion with cavitation
Lack of patient compliance with tooth brushing and dental hygiene	Good patient compliance with dental hygiene
Moderate caries risk and activity	Patients with low caries risk
Age groups with elevated caries activity such as adolescents and young adults	Elderly patients with slow caries progression or already arrested lesions
Progression of the lesion in spite of preventive approaches	Patients with allergy to one or more elements of the product







Figs 13-7a to c (a and b) Active initial caries lesions in permanent molars during eruption where fissure sealing is very difficult to near-impossible. **(c)** Noncavitated initial caries lesions on premolars. In these cases, minimally invasive treatment with self-assembling peptide P11-4 is indicated. (The copyright of this image remains with the author Mohammad Alkilzy.)

Further clinical implications of SAP

Beside the main usage of SAP P11-4 in the treatment of initial caries lesions, there are other implementations of this new approach in dentistry, such as treatment of dentin hypersensitivity and tooth whitening.

SAP for treatment of dentin hypersensitivity

Dentin hypersensitivity is a diagnosis for patients exhibiting pain when their teeth are in contact with hot, cold, sweet, or sour foods and liquids.[38] Treatment of dentin hypersensitivity follows one of two approaches. The first approach is directed at lowering the potential of the nerve by giving potassium nitrate. The second approach aims to occlude the exposed dentinal tubules.[39] SAPM belongs to the class of tubule-occluding products and forms a film on the surface of the dentin.[40]

A trial at a dental practice on 70 patients suffering from dentin hypersensitivity investigated the reduction of pain sensation during dental hygiene treatment when treated with SAP or placebo before the cleaning procedure.[41] Self-reported pain via VAS and visual numeric scale was assessed before and after the dental cleaning. Patients receiving SAP before the trial experienced significantly reduced pain on thermal stimuli (81% vs 50%) and had a significantly reduced pain intensity on thermal stimuli (54% vs 34%). Furthermore, a randomized controlled trial[42] compared a 7-day twice per day regimen of SAP vs 90 days continuous use of Colgate Sensitive Pro-Relief with 8% arginine and calcium carbonate (ACC). Both products were directly applied as suggested by the manufacturers. Fifty patients were included in the trial (25 per group) and were followed up for 90 days. Both products were successful in reducing the sensitivity in the patients, but SAP led to faster sensitivity relief within 7 days, a higher number of pain-free patients, and a higher patient satisfaction after 3 and 7 days of application for the patients receiving SAP.

SAP for tooth whitening

The majority of tooth-whitening procedures are based on oxidizing agents such as peroxide to oxidize colored particles and remove the color from them. As the oxidizing reaction is aggressive in nature, the main side effect of oxidizing whitening procedures is tooth sensitivity.[43]

A novel nonoxidizing tooth-whitening approach was developed, called “paint-on” whitening. This approach relies on optical effects on the surface of the tooth by placing small particles such as HA in the size range of visible light on the surface of the tooth, so that the light is dispersed and appears “whiter” or “brighter.” However, by adding SAP P11-4 fibers to the normally used HA particles the HA become attached to the surface of the tooth. The SAP fibers act as a kind of adhesive between the enamel surface and the HA particles. In vitro measurements[44] using bovine enamel specimen and Curolox Whitening (Credentis) showed increased whitening efficacy after the first application, which can be explained by the homogenous layer of HA particles placed on the tooth surface. In a homogenous mixture of the P11-4 fibers and the HA particles, the surface presents itself uniformly. In contrast, a surface on which HA-only is applied shows an inhomogenous layer. Beside the therapeutic remineralization effect of P11-4, it may be used in the treatment of dentin hypersensitivity and tooth whitening.

In conclusion, SAPs have shown promising results in the regenerative biomimetic remineralization of initial caries lesions. In addition, this approach may help in the treatment of dental hypersensitivity and tooth whitening.

Further studies are required to confirm these effects and potentially increase the spectrum of this novel approach to the treatment of dental erosion, white spots after orthodontic treatment, molar-incisor hypomineralization (MIH), and cavitated caries lesions.

References

1. Marthaler TM. Changes in dental caries. Caries Res 2004;38:173–181.

2. Pitts NB, Zero DT, Marsh PD, et al. Dental caries. Nat Rev Dis Primers 25;3:17030.
3. Marcenes W, Kassebaum NJ, Bernabé E, et al. Global burden of oral conditions in 1990–2010: a systematic analysis. J Dent Res 2013;92:592–597.
4. Mejàre I, Stenlund H, Zelezny-Holmlund C. Caries incidence and lesion progression from adolescence to young adulthood: a prospective 15-year cohort study in Sweden. Caries Res 2004;38:130–141.
5. Ten Cate JM. Saliva a physiological medium. Ned Tijdschr Tandheelkd 1992;99:82–84.
6. Weintraub JA. Ramos-Gomez F, Jue B, et al. Fluoride varnish efficacy in preventing early childhood caries. J Dent Res 2006;85:172–176.
7. Petersson LG. Twetman S, Pakhomov GN. The efficiency of semiannual silane fluoride varnish applications: a two-year clinical study in preschool children. J Public Health Dent 1998;58:57–60.
8. Marinho VC, Worthington HV, Walsh T, Clarkson JE. Fluoride varnishes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2013;7:CD002279.
9. Oliveira BH. Salazar M, Carvalho DM, Falcão A, Campos K, Nadanovsky P. Biannual fluoride varnish applications and caries incidence in preschoolers: a 24-month follow-up randomized placebo-controlled clinical trial. Caries Res 2014;48:228–236.
10. Divaris K, Preisser JS, Slade GD. Surface-specific efficacy of fluoride varnish in caries prevention in the primary dentition: results of a community randomized clinical trial. Caries Res 2013;47:78-87.
11. Ahovuo-Saloranta, A. Forss H, Walsh T, et al. Sealants for preventing dental decay in the permanent teeth. Cochrane Database Syst Rev 2013;3:CD001830.
12. Heyduck C, Meller C, Schwahn C, Splieth, CH. Effectiveness of sealants in adolescents with high and low caries experience.

Caries Res 2006;40:375–381.

13. Editorial, Advancing regenerative medicine. Nat Med 2014;20,795..
14. Kirkham J, Firth A, Vernals D, et al. Self-assembling peptide scaffolds promote enamel remineralization. J Dent Res 2007;86:426–430.
15. Nyman S, Gottlow J, Lindhe J, Karring T, Wennstrom J. New attachment formation by guided tissue regeneration. J Periodontal Res 1987;22:252–254.
16. Gottlow J, Nyman S, Lindhe J, Karring T, Wennström J. New attachment formation in the human periodontium by guided tissue regeneration. Case reports. J Clin Periodontol 1986;13:604–616.
17. Kirkham J, Zhang J, Brookes SJ, et al. Evidence for charge domains on developing enamel crystal surfaces. J Dent Res 2000;79:1943–1947.
18. Kirkham J, Brookes SJ, Shore RC, Wood SR. Physico-chemical properties of crystal surfaces in matrix–mineral interactions during mammalian biomineralisation. Curr Opin Colloid Interface Sci 2002;7:124–132.
19. Thomson BM, Hardaker L, Davies RPW, et al. P11-15 (NNRFEWEFENN): A second generation biocompatible, self-assembling peptide with potential to promote enamel remineralisation. Caries Res 2014;48:384–450(Abstract 47).
20. de Almeida Pdel V, Grégio AM, Machado MA, de Lima AA, Azevedo LR. Saliva composition and functions: a comprehensive review. J Contemp Dent Pract 2008;9:72–80.
21. Brunton PA, Davies RP, Burke JL, et al. Treatment of early caries lesions using biomimetic self-assembling peptides: a clinical safety trial. Br Dent J 2013;215:E6.
22. Alkilzy M, Splieth Ch. Self-assembling peptides for caries prevention and treatment of initial carious lesions, a review. DZZ Int 2020;1:21–25.

23. Aggeli A, Fytas G, Vlassopoulos D, McLeish TC, Mawer PJ, Boden N. Structure and dynamics of self-assembling beta-sheet peptide tapes by dynamic light scattering. Biomacromolecules 2001;2:378–388.
24. Davies RP, Aggeli A, Beevers AJ, et al. Self-assembling β-sheet tape forming peptides. Supramol Chem 2006;18:435–443.
25. Aggeli AM. Bell LM. Carrick C, et al. pH as a trigger of peptide beta-sheet self-assembly and reversible switching between nematic and isotropic phases. J Am Chem Soc 2003;125:9619–9628.
26. Burke JL. In situ engineering of skeletal tissues using self-assembled biomimetic scaffolds. Leeds: Leeds Dental Institute, The University of Leeds, 2011:1–277.
27. Felton S. Self assembling b-sheet peptide networks as smart scaffolds for tissue engineering, in chemistry. Leeds: University of Leeds, 2005:184.
28. Kyle SA. Aggeli A, Ingham E, McPherson MJ. Recombinant self-assembling peptides as biomaterials for tissue engineering. Biomaterials 2010;31:9395–9405.
29. Alkilzy M. Tarabaih A, Santamaria RM, Splieth CH. Self-assembling peptide P11-4 and fluoride for regenerating enamel. J Dent Res 2018;97:148–154.
30. Kind L, Stevanovic S, Wuttig S, et al. Biomimetic remineralization of carious lesions by self-assembling peptide. J Dent Res 2017;96:790–797.
31. Deyhle H, Dziadowiec I, Kind L, Thalmann P, Schulz G, Müller B. Mineralization of early stage carious lesions in vitro—a quantitative approach. Dent J 2015;3:111–122.
32. Kang J, Davies RP, Brookes SJ, Kirkham J. Multi-level modelling to further understanding of micro-CT data. In: Proceedings, Enamel 9 Conference in Harrogate, University of Leeds, 2016:Abstract 68.
33. Sousa J, Carvalho RG, Barbosa-Martins LF, Tersariol IL, Nascimento FD, Puppin-Rontani RM. Peptide P11-4 acts as a

nucleator of hydroxyapatite crystals formation. J Dent Res 2017;96:A3297.

34. Huang Z, Newcomb CJ, Bringas P Jr, Stupp SI, Snead ML. Biological synthesis of tooth enamel instructed by an artificial matrix. Biomaterials 2010;31:9202–9211.
35. Alkilzy M, Santamaria RM, Schmoeckel J, Splieth CH. Treatment of carious lesions using self-assembling peptides. Adv Dent Res 2018;29:42–47.
36. Bröseler F, Tietmann C, Bommer C, Drechsel T, Heinzel-Gutenbrunner M, Jepsen S. Randomised clinical trial investigating self-assembling peptide P_{11}-4 in the treatment of early caries. Clin Oral Investig 2020;24:123–132.
37. Schlee M, Schad T, Koch JH, Cattin PC, Rathe F. Clinical performance of self-assembling peptide P_{11}-4 in the treatment of initial proximal carious lesions: a practice-based case series. J Investig Clin Dent 2018;9:e12286.
38. Kielbassa AM. Dentine hypersensitivity: Simple steps for everyday diagnosis and management. Int Dent J 2002;52:394–396.
39. Gillam DG, Ramseier CA. Advances in the management of the patient with dentine hypersensitivity: motivation and prevention. In: Gillam DG (ed). Dentine Hypersensitivity: advances in diagnosis, management, and treatment. Cham: Springer International Publishing, 2015:143–156.
40. Chen X, Gillam DG, Mustafa HA, Lysek DA, Hill RG. Dentine tubule occlusion of a novel self-assembling peptide containing gel. J Dent Res 2014;93B:1347.
41. Saxer UP, Widera V, Bischof C. Efficacy of CURODONT™ D'SENZ to reduce tooth sensitivity when applied before professional dental cleaning. Dental material report. ZMK 2017;33:901–902.
42. Schlee M, Rathe F, Bommer C, Bröseler F, Kind L. Self-assembling peptide matrix for treatment of dentin

hypersensitivity: a randomized controlled clinical trial. J Periodontol 2018;89:653–660.

43. Rezende M, Loguercio AD, Kossatz S, Reis A. Predictive factors on the efficacy and risk/intensity of tooth sensitivity of dental bleaching: a multi regression and logistic analysis. J Dent 2015;45:1–6.
44. Bommer C, Flessa HP, Xu X, Kunzelmann KH. Hydroxyapatite and self-ssembling peptide matrix for non-oxidizing tooth whitening. J Clin Dent 2018;29:57–63.

14

Nonrestorative cavity control: Can nonoperative “preventive” treatment replace restorations?

Ruth M. Santamaría, Nicola Innes

Until recently, caries lesions were managed by the conventional “drill and fill” philosophy, meaning complete carious tissue removal and the replacement of missing tooth tissue with a restoration. This operative or surgical approach to dental care, where all carious tooth tissue is removed as a standard part of the procedure to manage the carious tooth, is no longer advocated.[1,2]

More modern and evidence-based approaches to managing lesions involve selectively removing carious tissue from a cavity and sometimes not removing any of the carious tooth tissue at all, before making a decision about how to restore the missing tooth substance. These approaches promote the preservation of tooth structure and the health of the dental pulp, and minimize intervention. However, they must be applied alongside activities aimed at preventing further disease. These activities focus on efforts to modify behaviors that led to the disease in the first place or supported factors leading to the

disease (ie, inadequate biofilm removal, remineralization, or high sugar consumption). Methods like this to prevent the establishment of caries lesions can also be used to prevent progression of the disease and, therefore, stop its consequences. This can be especially useful in primary teeth, which are shed.

It is possible to use preventive methods to stop the progression of dental caries rather than removing any of the diseased tissue, but it is not always possible, or desirable, to restore the remaining tooth. This approach is known as nonrestorative cavity control (NRCC).

What is nonrestorative cavity control?

NRCC is a single term used to describe a philosophy of treatment that comprises multiple stages and approaches. The choice of these depends on the lesion extension, location, and activity, and requires understanding the patient and their family rather than being a single procedure with prescribed linear steps. An active decision is made to arrest a single lesion, or multiple lesions in a child's mouth, rather than to restore. This is done by making the lesion into a cleansable shape by the clinician, regular biofilm removal by the patient and/or carer, and remineralization usually through fluoride-based products applied by the clinician or in toothpaste.[3]

Natural history of dental caries

The natural history of a disease describes how it progresses in an individual over time, without intervention. The common model of disease progression suggests that it will either result in: (1) full resolution with recovery; (2) resolution but leaving some disability or, in the case of dental caries, tooth destruction; or (3) continue to

progress, in the case of dental caries, until loss of the affected tooth/teeth. Although there is some variability between patients with regards to the rate of progression, a proceeding caries lesion will start with a subclinical presentation then become detectable with visual and/or tactile investigation. Next there will be tissue destruction leading to cavitation, potentially reversible then irreversible inflammation and infection of the dental pulp with eventual bone infection, and ultimately loss of the tooth. However, it is not inevitable that the disease will always continue to progress through these stages. Nor is it inevitable that there will ultimately be loss of the tooth. This is because the factors leading to the initiation and progression of the disease change as the disease progresses.

In young permanent teeth, lesions that are confined to enamel only progress at a rate of around 3.9 years (per 100 surfaces at risk) to reach at least the inner half of enamel,[4] and the annual rate is 5.4 years from the inner half of the enamel to the outer half of the dentin. However, in primary teeth enamel lesions progress to dentin more quickly, at a rate of around 2.5 years.[5] Dental practitioners are motivated to interfere in this process to stop the lesion progressing and improve outcomes for the patient. However, we do not often consider what would happen if we did not interfere in the disease process. Sometimes, the disease can stop because the circumstances that caused it or the environment the tooth is in has changed. Also, in the case of primary teeth, the teeth may be shed before they give the patient any problems. It is therefore not always necessary (or possible) to manage the lesion by restoring it. Less invasive treatment approaches like NRCC can be used.

Prevention as a desirable approach to managing dental caries

Prevention has traditionally been thought of as having three categories or layers:

- primary prevention – the actions taken to ensure that a disease does not occur
- secondary prevention – actions that reduce the impact of a disease or injury after it has already occurred
- tertiary prevention – actions to reduce the impact of an ongoing illness or injury that has lasting effects.

However, more recently there have been moves to include a fourth layer: quaternary prevention, essentially a concept that aims primarily to ensure patients are not overmedicalized or exposed to unnecessary risk associated with medical activities.[6,7] This approach can be related to the disease dental caries and improving its management (Table 14-1).[8]

Table 14-1 Levels of preventive care and examples related to dental caries

Category of prevention	Definition	Examples related to caries	
Primary	Actions taken to ensure that a disease does not occur.	Prevention at a community level such as introducing fluoridated water, or at an individual level by supporting use of fluoride toothpaste or placement of fissure sealants.	
Secondary	Actions that reduce the impact of a disease or injury after it has already occurred.	Improving early detection of caries lesions and increasing prevention at early stages to halt or slow progress, ie enhanced prevention or fissure sealing over noncavitated lesions.	
Tertiary	Actions to reduce the impact of an ongoing illness or injury that has lasting effects.	Restoring or placing crowns over cavitated lesions, replacing missing teeth with fixed/removable dental prostheses.	
Quaternary	Actions to avoid overmedicalization and reduce exposure to unnecessary risk associated with medical activities (ie, reduce potential for harm).	Choosing the least invasive treatment option:	Managing noncavitated lesions with tooth brushing/topical fluoride/fissure sealants.
			Promoting cleaning of a cavitated lesion that is cleansable to avoid restorative intervention and the associated risk of iatrogenic damage to adjacent teeth and treatment-induced anxiety.

Historical management of caries lesions

Since the beginning of dental surgery, and until recently, when a caries lesion (even when confined to enamel) or dentinal cavity was seen, dental practitioners would completely remove the carious tooth

tissue to the extent that only hard dentin was left in all parts of the cavity (cavity walls and pulpally). They would then place a filling. This used to be known as complete caries removal but now tends to be called “non-selective caries removal.”

The benefits of removing all carious tissue across the cavity have been called into doubt because of concerns about the possible adverse effects (mainly pulp damage but also unnecessary weakening of tooth structure) of removing all soft carious dentin from the lesions. Thus, nowadays, nonselective caries removal is considered overtreatment and is no longer recommended.[1,9]

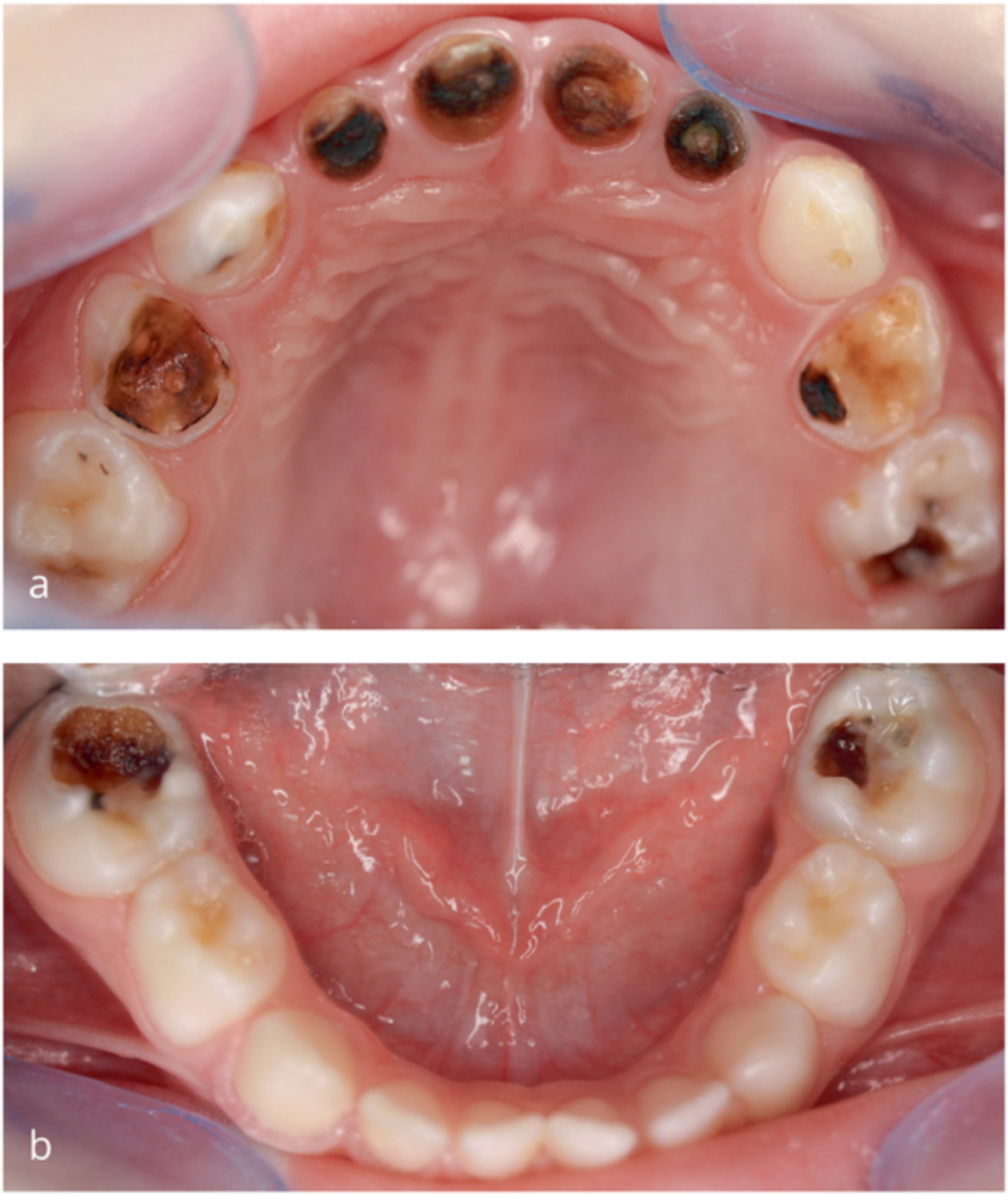
Caries used to be considered an infectious disease caused by microorganisms that needed to be fully eliminated from the lesion. In contrast to this, the current concept of the pathophysiology of dental caries defines it as a process, which occurs in the biofilm, leading to an imbalance in the equilibrium between tooth mineral and biofilm fluids. The biofilm is always metabolically active, with constant fluctuations in pH. The result may be a net loss of mineral, leading to the symptom of the disease, the manifest caries lesion. However, when re-deposition of mineral dominates and lesion environmental conditions change, the result can be that the lesion’s progression halts.[10,11] Over the last four decades, diverse studies including ones placing fissure sealants over carious dentin,[12] some involving selective (one-step) and stepwise excavation and restoration,[13] and others involving no caries removal,[13,14] suggest that caries lesions can be arrested provided that clinically biofilm-free/biofilm disturbance conditions are maintained.[15] Thus, the contemporary aim of treating caries lesions focuses on controlling the lesions’ activity, while preserving tooth tissue and pulp vitality. Even those lesions into dentin can be managed by changing the biologic conditions causing the imbalance (mainly by manipulating the biofilm) or simply

sealing over them with materials whether this is on the occlusal or the proximal surface.[13,14,16,17]

Is restorative management always necessary or possible?

The main reason for placing a restoration is to aid biofilm control, protect the pulp, and restore the function, form, and esthetics of the affected tooth.[18] Cavitated dentinal caries lesions have been traditionally restored with filling materials. However, in those lesions, biofilm control and remineralization can be enough to control the disease process. Cavitated lesions that are accessible to visual-tactile examination are potentially cleansable lesions or can often be converted into cleansable lesions by widening the lesion opening. The lesion can then be arrested by continual plaque disruption/cleaning. In those cases, the need for restorative treatment is questioned.[19,20]

In addition, it is not always possible to restore some lesions/teeth. There can be too much tooth tissue loss to place or retain a restoration, or the lesion may have extended subgingivally and moisture control cannot be achieved. Despite such extensive lesions, there are often no signs of infection such as periradicular pathology on radiographs or soft tissue signs of infection, and the patient has no pain (Fig 14-1). The pulp responds to the advancing lesion by laying down reactionary dentin, and the coronal pulp becomes much smaller than it was originally. Although the lesion looks as though it should have encroached upon the pulp from a clinical perspective, often it has still not directly reached it. Of course, some of the proteolytic enzymes, acids, and bacteria may still have entered the dentinal tubules and the pulp may be inflamed in reaction to this. However, the pulp may not be irreversibly damaged, and with removal of the factors causing inflammation, through brushing the biofilm away, and by causing no further inflammation through treatment, the pulpal inflammation can reduce.

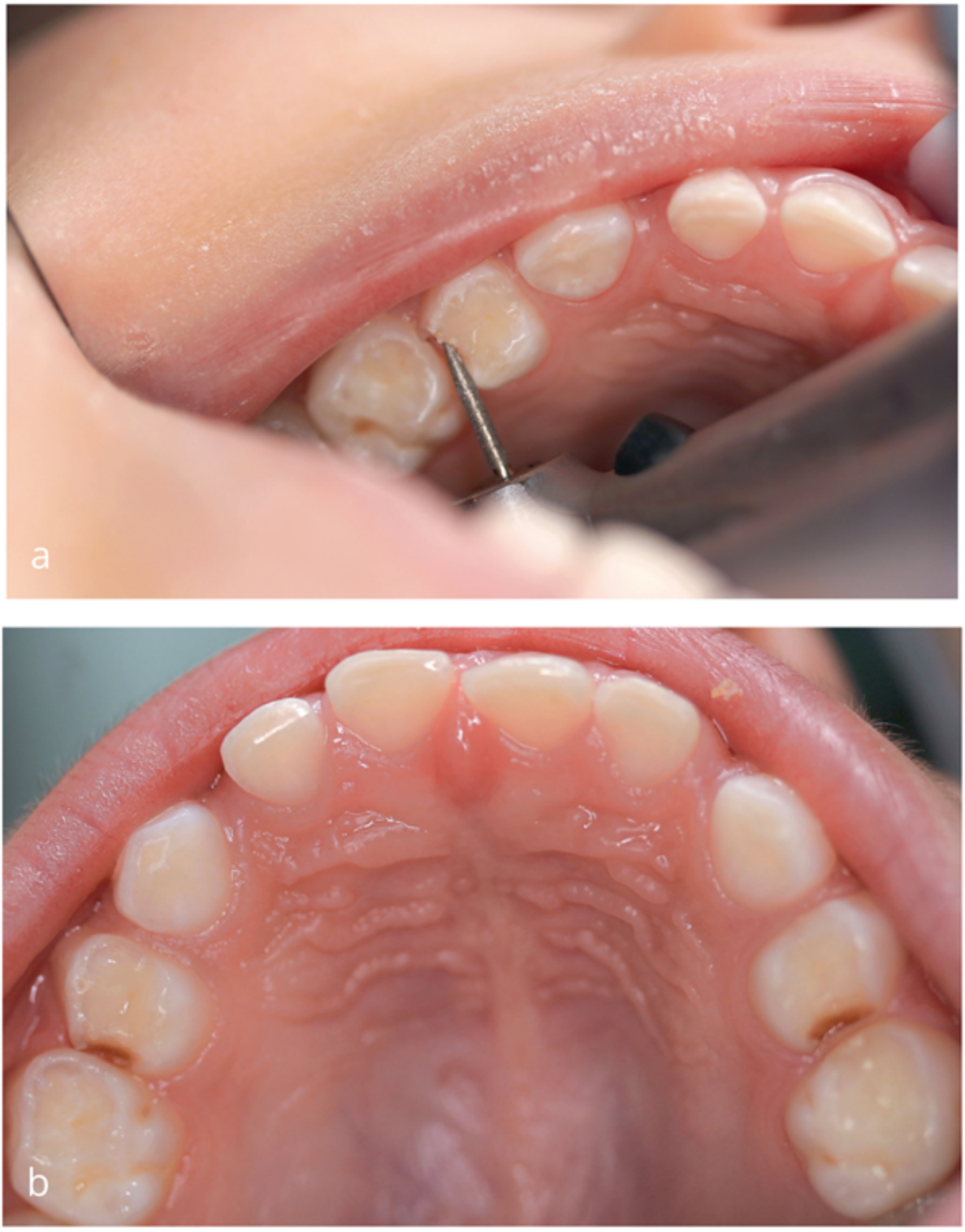


Figs 14-1a and b Nonrestorative cavity control of the maxillary **(a)** and mandibular **(b)** primary teeth in a 3-year-old child with early childhood caries: The large carious symptomless cavities in the primary maxillary first molars make it difficult to achieve a good seal using an adhesive restorative material, and the lack of sufficient sound tissue reduces the retention of a preformed metal crown.

In these cases, it is difficult to justify extracting the tooth as the patient gains no benefit. In fact, it can be detrimental to do so as this can lead to treatment-induced anxiety and may also result in loss of space as the remaining teeth can move into the space.

How to carry out NRCC

When the active decision has been made to arrest a single lesion, or multiple lesions, in a child's mouth by constant biofilm removal (by the patient/carer) and remineralization, rather than to restore the lesion, it is very important that a baseline record of the status of the tooth/lesion is taken at that point. This can be written, photographs, or using an index such as the International Caries Detection and Assessment System (ICDAS),[21] and should include the size and depth of the lesion and whether it is active or arrested (partially or completely). The caries lesion(s) is(are) made accessible to a toothbrush or additional cleansing device. This can be done by rotary instrumentation or hand removal (chiseling) of overhanging enamel (Fig 14-2). Arresting the lesion must be supported by applying sodium fluoride varnish or silver diammine fluoride (SDF) solutions. Lesions are repeatedly monitored over time for progression and a record made of the success or failure of the NRCC approach, with the clinician always considering changing the treatment plan if it looks like this approach is not working.



Figs 14-2a and b Symptomless primary maxillary first molars (54 and 64 according to FDI notation) with disto-occlusal cavities. To

make the cavity cleansable, the overhanging enamel is removed using a high-speed handpiece to open the cavities on these teeth.

The potential of SDF in caries prevention and arrest of dentin caries lesions in the primary dentition has already been demonstrated in various randomized clinical trials and presented in reviews.[22-24] This topic is discussed in detail in Chapter 12.

What is the aim of NRCC?

NRCC aims to manage the carious process until a primary tooth exfoliates by using techniques at both a tooth and a person level to preserve the dental hard tissue and avoid initiation of the restorative cycle. Specifically, the aims are to:

- avoid pain and infection from the tooth before exfoliation
- inactivate or control the disease process in caries lesions by promoting tooth brushing and fluoride use at a person level
- preserve the dental hard tissues
- avoid initiating the cycle of restoration
- preserve the tooth for as long as possible
- prevent new caries lesions
- support the child in the dental setting by building their capacity and confidence in accepting dental care
- support the family in adopting long-term oral hygiene habits that promote lifelong dental health.

For which patients is NRCC indicated?

NRCC is particularly indicated for children who have active dentinal caries lesions in the primary dentition. In addition, it can be used to control the disease process, in order to control cavitated lesions that

are considered inactive but due to their location or morphology have the risk of becoming active. Furthermore, NRCC is especially suitable for managing caries lesions in anxious children, and very useful as a treatment option for cooperation improvement and building a child's confidence with the treatment. Detailed indications, contraindications, advantages, and disadvantages of NRCC are presented in Table 14-2.

Table 14-2 Detailed indications, contraindications, advantages, and disadvantages of NRCC for primary teeth by tooth and person level factors

	Tooth/person level	Description
Indications	Tooth	Asymptomatic cavitated dentin caries lesions in primary teeth
		Lesions that are or can be made cleansable
		Nonrestorable
	Person	Already has a high standard of brushing or is likely to be responsive to measures to change behavior to carry out frequent, high quality tooth brushing or other methods to clean caries lesion
		High standards of tooth brushing

	Tooth/person level	Description
Contraindications	Tooth	Clinical signs or symptoms of irreversible pulpitis, or dental abscess/fistula
		Radiographic signs of pulpal involvement, or periradicular pathology
		Infection or pain from pulp or food packing (unless shape of tooth can be changed to become cleansable
		Ongoing active lesions that are not arresting (only detectable over time)
	Person	Not able or willing to brush and likely that patients (or parents) unable or unwilling to take responsibility
Advantages	Tooth	Can help to maintain space
	Person	As a potential treatment for building child's confidence and improving cooperation

	Tooth/person level	Description
Disadvantages	Tooth	Can be difficult to monitor success before pulp becomes irreversibly damaged or infected
	Person	Esthetics

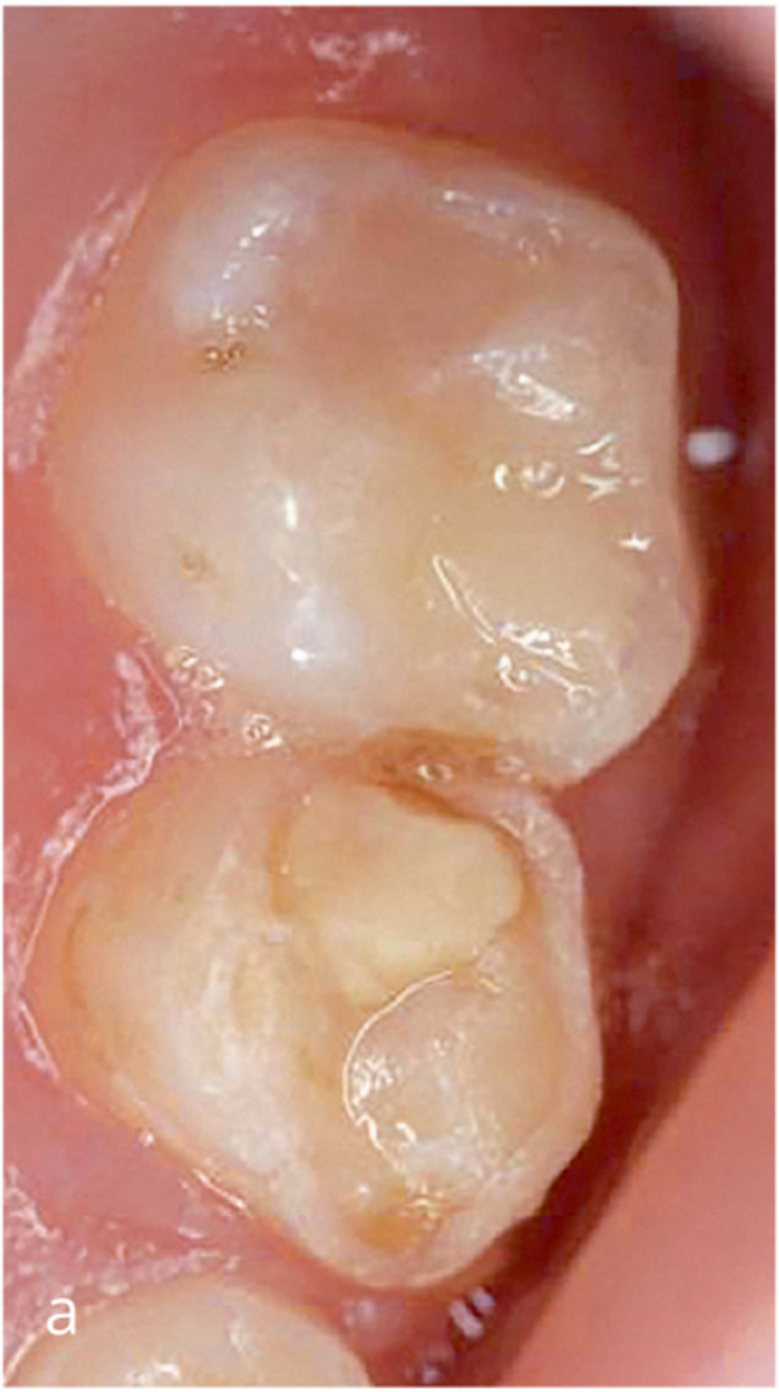
NRCC technique

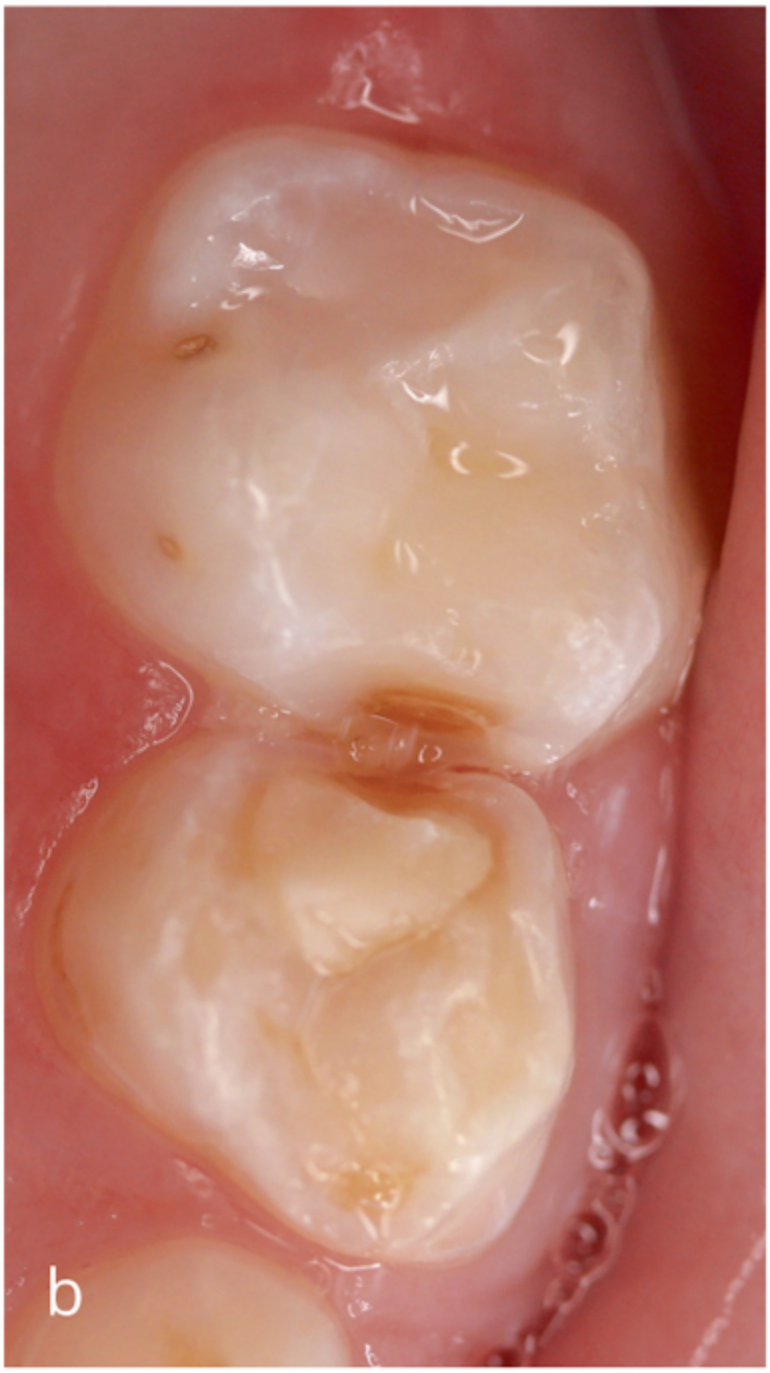
NRCC is a form of quaternary prevention. It is essential that the parent/carer is in agreement with the approach as they have a crucial role. The treatment option should be discussed in depth with the parent/carer. If agreed upon, it is essential that they, and the child, understand that they are entering into a contract to play their part in stopping the progression of the lesion. This first role is critical to the success of the method. This partnership approach and the important role of the parent contrasts with conventional restorative treatment where the responsibility for success is considered to lie mainly with the dental practitioner. In the NRCC treatment, success depends mostly on parental cooperation, as parents are responsible for brushing the caries lesions.

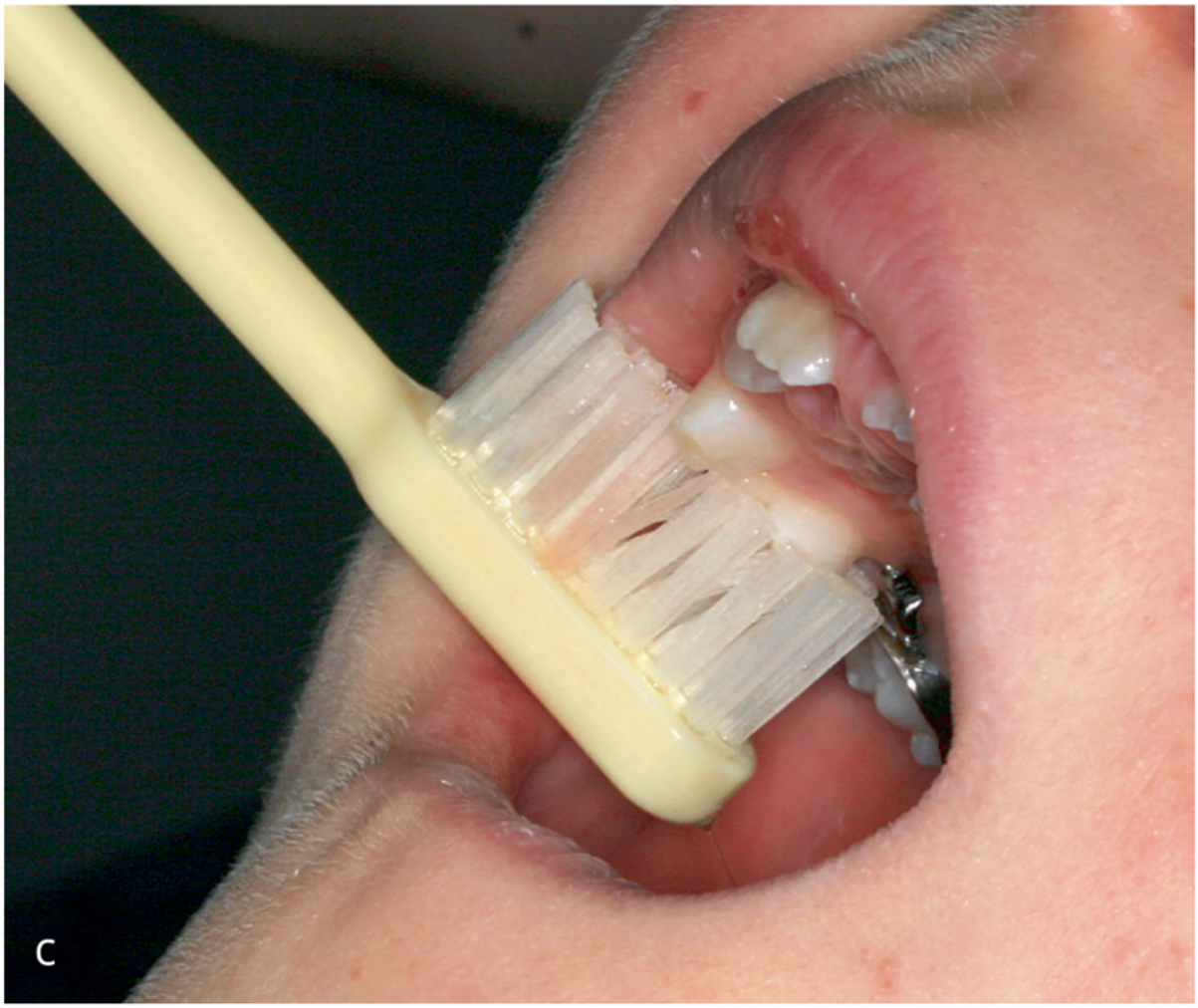
NRCC demands specific measures to manage the caries lesions:

- obtaining informed consent and agreement to cooperate in their role, from parent/carer
- taking photographs at baseline and follow-up appointments to record and assess the status of the lesion; if this is not possible, there should be a written record of the status of the lesion (eg, using ICDAS)
- making the caries lesions at the cavity level cleansable and accessible for biofilm removal (Figs 14-3a and b)

- applying anticariogenic agents such as fluoride varnish or SDF to optimize success of lesion arrest and prevention of lesion progression
- involving the parent in a comprehensive caries control program involving: behavior change, training in biofilm control, diet instructions, fluoride use, daily brushing of the opened teeth, ie perpendicular to the dental arch (Fig 14-3c) twice daily using fluoride-containing toothpaste (≥ 1,000 ppm F)
- setting regular recall visits allowing lesion activity to be monitored: assessment of the lesion extension (enamel/dentin) and caries activity assessment (active/inactive).







Figs 14-3a to c (a) These primary maxillary first and second molars have approximal cavities on the contact area of the teeth. **(b)** To make the cavity cleansable, the overhanging enamel was removed. **(c)** The opened teeth should be brushed perpendicular to the dental arch.

The main characteristics of active and inactive lesions are presented in Table 14-3. In addition, it is essential to reinforce and maintain motivation in the parent/carer to brush the lesion(s). The requirements for success when using NRCC are presented in Table 14-4.

Table 14-3 Characteristics of lesion activity (active/inactive) based on ICDAS-II classifications[25,26]

	Active lesion		Inactive/arrested lesion	
	Enamel	Dentin	Enamel	Dentin
Visual appearance	Dull, matte area although likely to be covered in biofilm	Often lighter in appearance but this is not definitive. Likely to be covered in biofilm	Shiny	Often darker in appearance but this is not definitive. Likely to be free of biofilm
Tactile features (by gently probing across the surface)	Rough	Soft	Smooth	Hard

Table 14-4 The requirements for success when using NRCC for tooth/cavity, parent, and clinician level factors

Tooth/cavity		The cavity should be shaped to avoid food packing and allow easy cleansing
		Regular and careful monitoring (with accurate recording)
Parent	**Knowledge**	Understand the treatment success depends on their adherence to tooth brushing
	Skills	Have the parenting skills to manage the child, instill a positive attitude, and gain cooperation with the plan
		Have the skill to brush open dentinal lesions (in a small mouth in a young child, this should not be underestimated)
	Attitude	Willing to brush the lesions

Child	**Knowledge**	Understand as well as possible what is planned
	Skills	Tolerate having the lesion opened and fluoride varnish applied
		Tolerate having the parents shown by the clinician how to brush the lesion successfully
	Attitude	Willing to allow the parent/carer to brush their teeth frequently and in the way required

Clinician	**Knowledge**	Understand the limitations
	Skills	Able to synthesize all the information from the parent/child/mouth/lesion to determine whether NRCC is an appropriate treatment to offer
		Able to assess the best way to open the lesion without causing dentinal pain and the ultimately desired shape of the cleansable cavity
		Able to apply silver diammine fluoride safely and assess treatment outcome
	Attitude	Willing to change treatment if not successful. This means assessing the lesion, child, and parent at each review appointment to determine whether, in the long-term, the result will be successful exfoliation of the tooth without pain and infection
		Are the parent and child's needs being met regarding their expectations, eg esthetics?

What are the main advantages of NRCC?

The advantage of this cause-related caries management approach is that success or failure can be observed by the activity of the lesion over time and discussed with the child and/or parents/caregiver, perhaps using photographs. The effect of the cause-directed

treatment can be clinically evaluated by assessing hardness and shiny appearance of the demineralized tooth surface. The main advantages of this therapy are listed below:

- NRCC has the genuine potential to biologically manage the caries process, preserving dental hard tissue, and avoiding initiation of the restorative cycle.
- NRCC is well accepted by children, parent/carer, and dental practitioner.[27,28]
- NRCC can “buy” time for a child to develop the cognition to understand and cope with a more invasive treatment should it be necessary. It also allows time for them to become acclimatized to the dental environment.
- Local anesthesia is not needed and rotary instruments are minimally used; these are two of the most anxiety-provoking stimuli in the dental environment.[29,30]

What are the main disadvantages of NRCC?

The main disadvantages of NRCC are the following:

- The pulp may already be irreversibly too damaged to recover.
- Patients (children) cannot carry out the required oral hygiene measures by themselves, so they rely on their parent’s willingness to accept and cope with the treatment.
- There need to be particular circumstances that allow this approach to work – parent/carer (or older children) who are able to accept responsibility for the disease and commit to remedial action including diet modification and regular, frequent tooth brushing with a fluoride toothpaste. It should not be used where an assessment is made that there is no readiness to change behaviors that have led to development of the disease in the first place.

- NRCC might be interpreted as “watchful neglect” by other dental practitioners who might not recognize this as a treatment, so records must be high quality and the parent/carer must be fully informed and “on board.”
- It is very difficult to monitor for success – so photographs might be needed.
- With NRCC the esthetics of teeth will not be restored and it often does not “look nice.”
- NRCC does not always feel satisfying to the clinician or even the parent.
- NRCC involves increased dental visit frequency for lesion(s) follow-up.
- NRCC is not yet considered as a treatment option itself, thus payment will be mostly private or mixed public-private.

Is taking an NRCC approach cost-effective?

The cost-effectiveness of the NRCC approach has been recently compared to other treatment options such as conventional restorations and the Hall Technique for treating asymptomatic carious primary teeth.[31] Costs were calculated on an existing randomized controlled trial for 2.5 years, and according to the German health care system fees. The NRCC approach was the least cost-effective option, with costs of 296€ compared to 83€ for conventional fillings and 66€ for the Hall Technique. However, the NRCC participants were invited to attend 3-monthly recalls, while participants in the other two groups were seen only twice per year, and the cumulative impact of these visits’ costs was considerable. Further studies should aim to evaluate this in more detail.

Is taking an NRCC approach clinically effective?

Although empirically there is much to support NRCC from a physiologic and pathologic perspective, there is very little evidence from clinical trials of NRCC in comparison to other treatments. This is important because the biologic evidence can tell us much, but without understanding the role that human (patient and clinician) factors play in NRCC, its actual success when applied in the "real world" environment cannot be accurately determined, ie effectiveness vs efficacy.

To date, there is only one randomized controlled trial that has looked at NRCC approaches in a controlled environment, and one longitudinal clinical study of a group of children managed in this way. The first took a patient level approach in a specialist dental hospital environment in Germany.[32] The 169 children (3 to 8 years) in the trial were all high caries risk and had asymptomatic proximal cavities in primary molars. Three treatment protocols to manage the cavities were investigated:

- conventional restoration (compomer)
- the Hall Technique
- NRCC.

For NRCC, the dental practitioners improved accessibility of proximal cavities in primary teeth and applied a fluoride varnish (5% NaF). The children's caregivers were taught how to brush the lesion perpendicular to the dental arch. Fluoride varnish and the instructions were repeated every 3 months. After 2.5 years, 142 children were assessed.[33] Compared to conventional treatment no significant difference was observed in percentage of failures including abscesses, pulpal complaints, or necessity for an endodontic treatment for NRCC, with the rate being 9% for both treatments, although only 2.5% for the Hall Technique. Within the NRCC group, most failures occurred in children not adhering to the 3-month recall interval, indicating that there may have been a lack of

commitment or ability to follow the requirements on the parent/carer's side. Children treated according to the conventional treatment showed less cooperative dental behavior compared to children treated according to the Hall Technique or NRCC.[27]

A small, uncontrolled study evaluated 30 cavities in the proximal surfaces of primary molars treated with daily site-specific tooth brushing with fluoridated toothpaste and supplemented with professional topical fluoride treatment and dietary advice.[34] The treatment was considered unsuccessful if – for a major failure – the child experienced pain and/or the tooth developed pulpal or periapical pathology, or – for a minor failure – the tooth had a filling or sensitivity or lesion progression preventing further adjustment of the lesion margins without promoting biofilm stagnation and food retention. Fifteen of the children were considered to have had successful treatment and 15 were unsuccessful, ie 50% of the children experienced failed treatments with 10 having pain, pulp/periradicular pathology (six were extracted and four untreated) after an average period of 26 months (9 to 44 months). Lesion failure was associated with poor compliance or lesions that were not suitable for the method. However, children and parents were highly satisfied with the treatment, despite the high number of failures in a third (10/30) of the children and pain/infection. In total, 82% of the children pointed to the smiling faces on the visual analog scale, and 95% of parents. The children explained their choice of score with words like: "fun" and "no pain." The authors concluded that this NRCC treatment can be a helpful method to control caries lesion progression in primary teeth and may familiarize the child with dental treatment.

Thus, although there are reports of success in certain situations, when assessed in dental clinic situations, in the hands of dental practitioners who support this technique, NRCC seems to have a very low clinical success although high parent/child acceptability, and this may limit its applicability to general situations. Overall, the factors need to be understood that promote or inhibit the success of NRCC, and some of these would seem to be closely related to our ability, as clinicians, to change patient behavior.

The use of a NRCC approach has been promoted as a treatment option for caries control, particularly in primary teeth, extending the classic preventive approach to carious defects. Although reported first more than a century ago, the effectiveness of NRCC treatment needs further research. Current available research outcomes seem to point towards treatment being effective if cavity cleaning is performed under supervision. However, a number of questions remain, including for primary teeth:

- At what age can NRCC be applied?
- What is the effect of motivational behavior change techniques?
- What is the effect of NRCC on the overall level of cleanliness of the dentition?

In addition, there are currently no clinical studies in which lesion control is supported by applying silver diammine fluoride solutions as compared to conventional treatments. The use of silver products may be advantageous for caries arrest.

In light of the current evidence, the use of NRCC cannot be unanimously recommended for management of all types of dentin caries lesions in primary teeth. The decision to use NRCC should be made with all tooth, patient, and family considerations in mind, taking into account when lesion inactivation without caries removal will be feasible and favorable for the patient. Because treatment success is almost completely dependent on excellent parental cooperation to brush their children's teeth, careful case/family selection is essential for treatment success.

References

1. Schwendicke F, Frencken JE, Bjørndal L, et al. Managing carious lesions: consensus recommendations on carious tissue removal. Adv Dent Res 2016;28:58–67.

2. Innes NPT, Frencken JE, Bjørndal L, et al. Managing carious lesions: consensus recommendations on terminology. Adv Dent Res 2016;28:49–57.
3. Gruythuysen RJ, van Strijp AJ, van Palestein Helderman WH, Frankenmolen FW. Niet-restauratieve behandeling van cariës in het melkgebit: doelmatig en kindvriendelijk [Non-restorative treatment of cavities in temporary dentition: effective and child-friendly]. Ned Tijdschr Geneeskd 2011;155(42):A3489.
4. Mejare I, Kallest lC, Stenlund H. Incidence and progression of approximal caries from 11 to 22 years of age in Sweden: a prospective radiographic study. Caries Res 1999;33:93–100.
5. Mejare I, Stenlund H. Caries rates for the mesial surface of the first permanent molar and the distal surface of the second primary molar from 6 to 12 years of age in Sweden. Caries Res 2000;34:454–461.
6. Martins C, Godycki-Cwirko M, Heleno B, Brodersen J. Quaternary prevention: reviewing the concept. Eur J Gen Pract 2018;24:106–111.
7. Norman AH, Tesser CD. Quaternary prevention: a balanced approach to demedicalisation. Br J Gen Pract 2019;69:28–29.
8. Domejean S, Grosgogeat B. Evidence-based deep carious lesion management: from concept to application in everyday clinical practice. Monogr Oral Sci 2018;27:137–145.
9. Kidd E. The implications of the new paradigm of dental caries. J Dent 2011;39(Suppl 2):S3–S8.
10. Kidd E, Fejerskov O. Changing concepts in cariology: forty years on. Dent Update 2013;40:277–278,280–282,285–286.
11. Schwendicke F. Contemporary concepts in carious tissue removal: A review. J Esthet Restor Dent 2017;29:403–408.
12. Mertz-Fairhurst EJ, Schuster GS, Fairhurst CW. Arresting caries by sealants: results of a clinical study. J Am Dent Assoc 1986;112:194–197.
13. Ricketts D, Lamont T, Innes NPT, Kidd E, Clarkson JE. Operative caries management in adults and children. Cochrane

Database Syst Rev 2013;3:CD003808.

14. Innes NPT, Ricketts D, Chong LY, Keightley AJ, Lamont T, Santamaria RM. Preformed crowns for decayed primary molar teeth. Cochrane Database Syst Rev 2015;12:CD005512.
15. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 1999;33:252–260.
16. Pitts NB, Zero DT, Marsh PD, et al. Dental caries. Nat Rev Dis Primers 2017;3:17030.
17. Dorri M, Dunne SM, Walsh T, Schwendicke F. Micro-invasive interventions for managing proximal dental decay in primary and permanent teeth. Cochrane Database Syst Rev 2015;11:CD010431.
18. Kidd EAM. How ‘clean’ must a cavity be before restoration? Caries Res 2004;38:305–313.
19. Banerjee A, Watson TF, Kidd EA. Dentine caries: take it or leave it? Dent Update 2000;27:272–276.
20. Kidd E. Should deciduous teeth be restored? Reflections of a cariologist. Dent Update 2012;39:159–162,165–166.
21. Pitts N. ‘ICDAS’: an international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriate clinical management. Community Dent Health 2004;21:193–198.
22. Urquhart O, Tampi MP, Pilcher L, et al. Nonrestorative treatments for caries: systematic review and network meta-analysis. J Dent Res 2019;98:14–26.
23. Duangthip D, Jiang M, Chu CH, Lo ECM. Non-surgical treatment of dentin caries in preschool children: systematic review. BMC Oral Health 2015;15:44.
24. Milgrom P, Horst JA, Ludwig S, et al. Topical silver diamine fluoride for dental caries arrest in preschool children: a randomized controlled trial and microbiological analysis of caries associated microbes and resistance gene expression. J Dent 2018;68:72–78.

25. Pitts NB, Ekstrand KR. International Caries Detection and Assessment System (ICDAS) and its International Caries Classification and Management System (ICCMS) - methods for staging of the caries process and enabling dentists to manage caries. Community Dent Oral Epidemiol 2013;41:e41–e52.
26. Ekstrand KR, Gimenez T, Ferreira FR, Mendes FM, Braga MM. The International Caries Detection and Assessment System - ICDAS: A systematic review. Caries Res 2018;52:406–419.
27. Santamaria RM, Innes NP, Machiulskiene V, Evans DJ, Alkilzy M, Splieth CH. Acceptability of different caries management methods for primary molars in a RCT. Int J Paediatr Dent 2015;25:9–17.
28. Innes NP, Evans DJ, Stirrups DR. The Hall Technique; a randomized controlled clinical trial of a novel method of managing carious primary molars in general dental practice: acceptability of the technique and outcomes at 23 months. BMC Oral Health 2007;7:18.
29. van Bochove JA, van Amerongen WE. The influence of restorative treatment approaches and the use of local analgesia, on the children's discomfort. Eur Arch Paediatr Dent 2006;7:11–16.
30. Goumans C, Veerkamp JS, Aartman IH. Dental anxiety and behavioural problems: what is their influence on the treatment plan? Eur J Paediatr Dent 2004;5:15–18.
31. Schwendicke F, Krois J, Splieth CH, et al. Cost-effectiveness of managing cavitated primary molar caries lesions: A randomized trial in Germany. J Dent 2018;78:40–45.
32. Santamaria RM, Innes NP, Machiulskiene V, Evans DJ, Splieth CH. Caries management strategies for primary molars: 1-yr randomized control trial results. J Dent Res 2014;93:1062–1069.
33. Santamaría RM, Innes NPT, Machiulskiene V, Schmoeckel J, Alkilzy M, Splieth CH. Alternative caries management options

for primary molars: 2.5-year outcomes of a randomised clinical trial. Caries Res 2018;51:605–614.

34. Hansen NV, Nyvad B. Non-operative control of cavitated approximal caries lesions in primary molars: a prospective evaluation of cases. J Oral Rehabil 2017;44:537–544.

15

Prevention and prophylaxis in orthodontics: Neglected opportunities for successful prevention

Karl-Friedrich Krey, Anja Ratzmann, Nadezhda Stancheva

Prevention, derived from the Latin word *praevenire*, includes measures, programs, and projects to prevent undesirable events or developments. In general, the term can be translated as “anticipatory problem avoidance.” Prophylaxis is derived from the Greek word προφύλαξις (*prophýlaxis*) and can be understood as guard, outpost, or protection, stressing the aspect of primary prevention. In medicine, dentistry, and, therefore, also orthodontics, prophylaxis mostly means concrete actions that are supposed to prevent the onset of a disease, eg vaccination or oral hygiene. Prevention is broader and describes a concept within which prophylaxis can be an integral part.

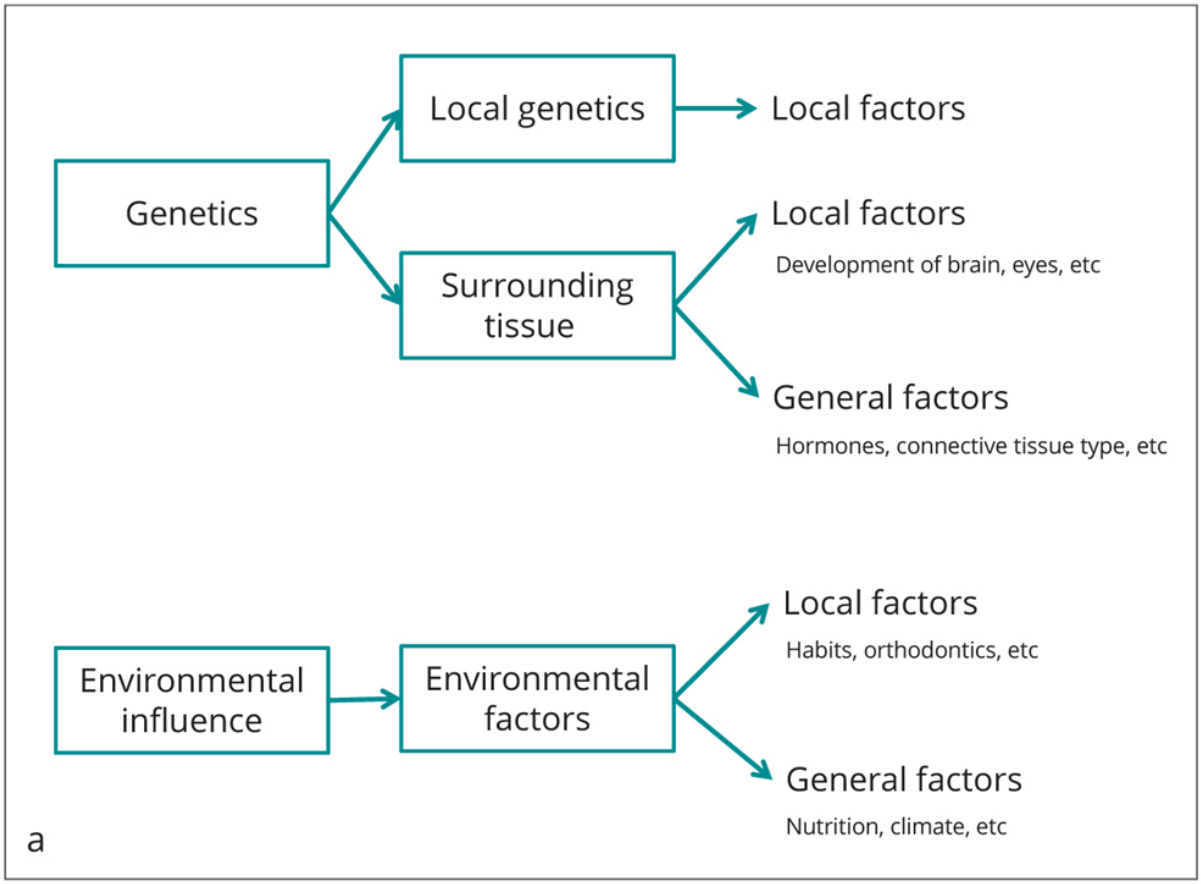
The majority of books and publications in the orthodontic literature deal with the diagnosis and often sophisticated treatment of malocclusions in order achieve harmonious static and dynamic

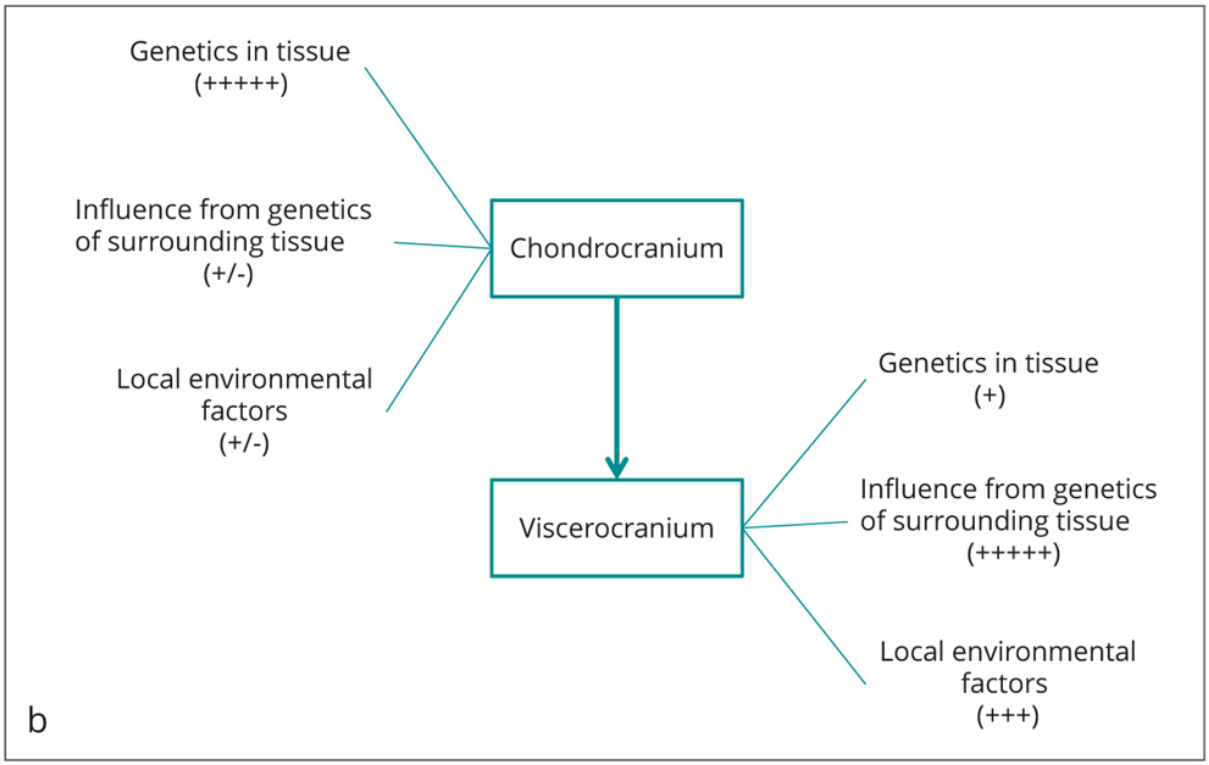
occlusion. However, the prevention of malocclusion may be a more rational approach if possible. For this, an understanding of the etiology of malocclusions and malfunctions is crucial.

Etiology of malocclusion and malfunction as the basis of prevention

A number of explanatory models have been devised for the development of teeth and jaw malpositions and malfunctions.[1] The best known are the theory of the functional matrix and the servo system theory.[2,3] A combination of different theories, also considering the therapeutic consequences, was proposed by van Limborgh.[4] Overall, an interaction of genetic, epigenetic, and environmental factors can be assumed.

This gives starting points for prevention, and also knowledge on processes such as craniosynostosis that can hardly be influenced and are, therefore, not susceptible to prevention. In contrast to this, deviations due to local or general environmental factors are to be treated with good prognoses and possibly even prevented. Also, tissues of the viscerocranium are more susceptible to interventions than those of the neurocranium (Fig 15-1).





Figs 15-1a and b Etiology of malocclusions and malfunctions according to van Limborgh.[4] Differentiation of influencing factors and localizations leads to identification of preventive strategies.

Form follows function

The connection between form and function has been well known for a long time.[5,6] Especially during growth and development, these interactions are significant. An imbalance in the muscles of the tongue and cheek or lip, combined with respiratory function, chewing, and swallowing form the dentoalveolar complex in the development of the teeth and influence the position of the jaw.

So far, only a few specific forms of malocclusion have been genetically localized by genome-wide association studies (primary failure of eruption, Class III).[7] A careful family history is essential, but the modeling influence of environmental factors (local and general) seems to predominate. The maxilla is more receptive to influences, and the primary goal of therapeutic or preventive interventions.[8] Further investigations will be able to better describe the relationship between phenotype and genotype with regard to malocclusions.[9]

The beginning of orthodontic prevention

Some early publications in the orthodontic literature focused explicitly on the prevention of dental malocclusions. Salzmann[10] coined the term “public health orthodontics.” In the 1950s, Schwarz recommended inter alia the following valid points for prevention to the general dental practitioner[11]:

- (early) orthodontic examination of each child
- informing the parents
- stop habits and secure free nasal breathing

- register premature primary tooth loss or retention in time (better to avoid it)
- do not extract canines
- do not extract first molars.

After the significant decline in caries in recent years, secondary crowding caused by premature decay of the primary tooth is decreasing. On the other hand, Perkins[12] already saw the essential role of orthodontic prevention in the control of harmful habits: In a study of 8,864 German kindergarten and school-age children, in 57% of all children dental anomalies were found.[13] From the primary dentition to the mixed dentition, this percentage increased from 42% to 60%. Only the open bite showed a tendency for improvement due to a decrease of muscular dysfunction.

A selection of possible approaches for prevention-oriented orthodontics is presented and relevant topics will be briefly explained in this context. The currently most important aspect regarding prevention and prophylaxis is putting existing knowledge into practice and avoiding the “tragedy of unused medical knowledge.”[14]

Breastfeeding, swallowing, and chewing

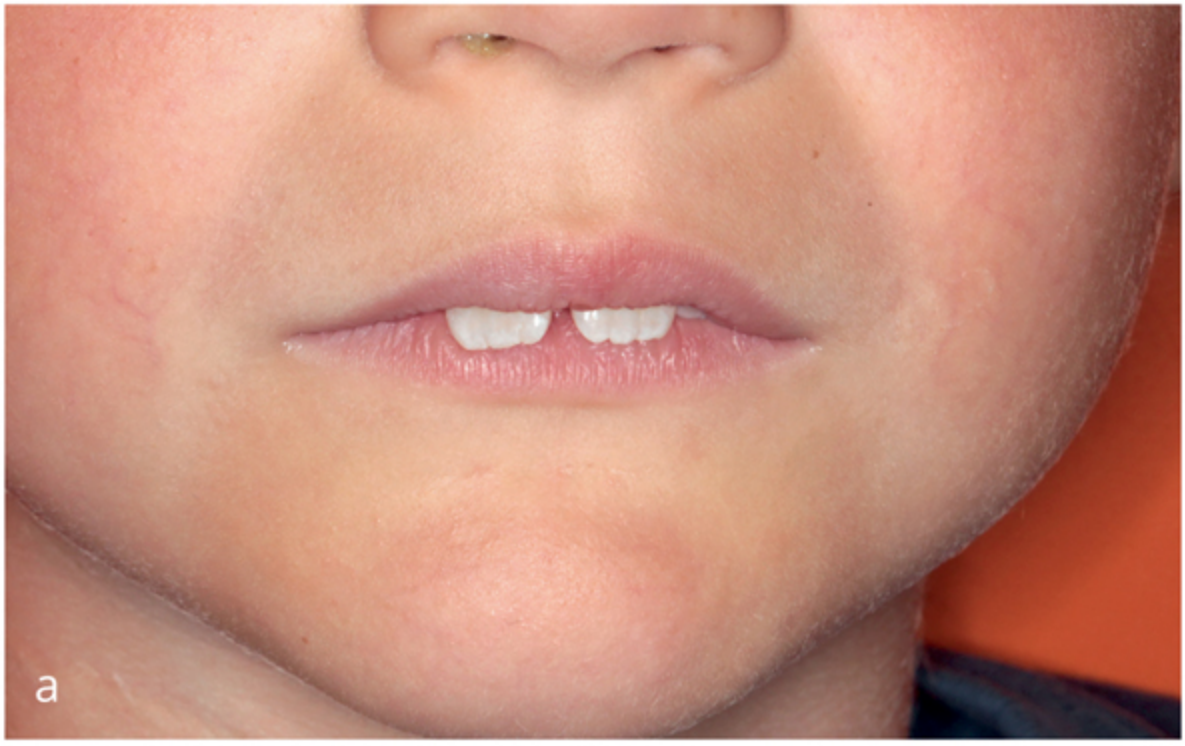
The influence of infant diet on orofacial development has been discussed for a long time. A comprehensive review by Sabuncuoglu[15] outlines the evidence base: a cross-sectional study of 2,060 subjects found associations between breastfeeding less than 6 months and Class II development and, therefore, concluded that short or no breastfeeding time can be a cofactor in the formation of oral parafunctions.[16] Narbutyte et al[17] see a protective effect of breastfeeding on craniofacial development, such as posterior reverse articulation (cross bite) and open bite. Similarly, the frequency of occurrence of parafunctional habits appears to be reduced.[18] After evaluating a birth cohort of 1,303 children, Peres et al[19] concluded that 6 months of breastfeeding are an effective prevention strategy. Last but not least, a number of general

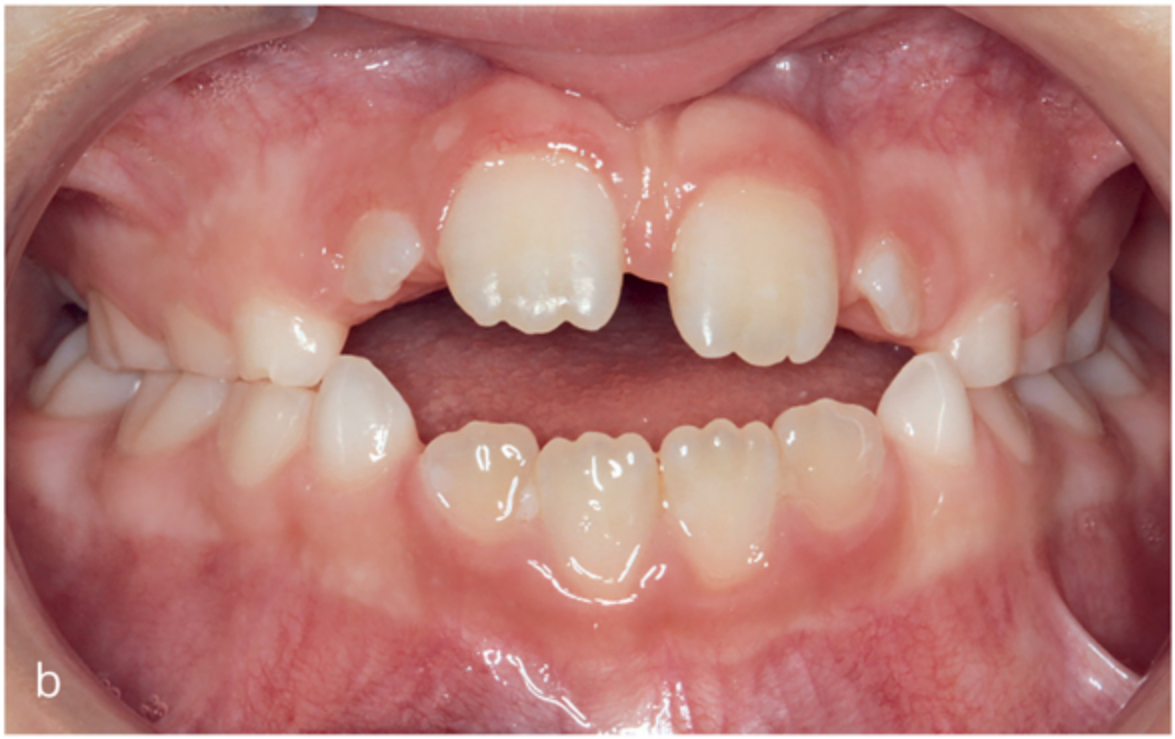
medically relevant positive effects are attributed to breastfeeding, eg improved cognitive development and less diabetes and cardiovascular disease.[20] Due to the heterogenous study situation, research is still needed in this field.[21] When the first primary teeth erupt at about an age of 6 months, additional feeding should be started aiming to transfer the sucking reflex into a proper chewing pattern. Chewing is considered to be an important modulating factor in the development of the dentition.[22,23] For instance, changes in craniofacial morphology were found in animal experiments depending on the chewing pattern.[24] To what extent this can be transferred to the development of human teeth is uncertain.

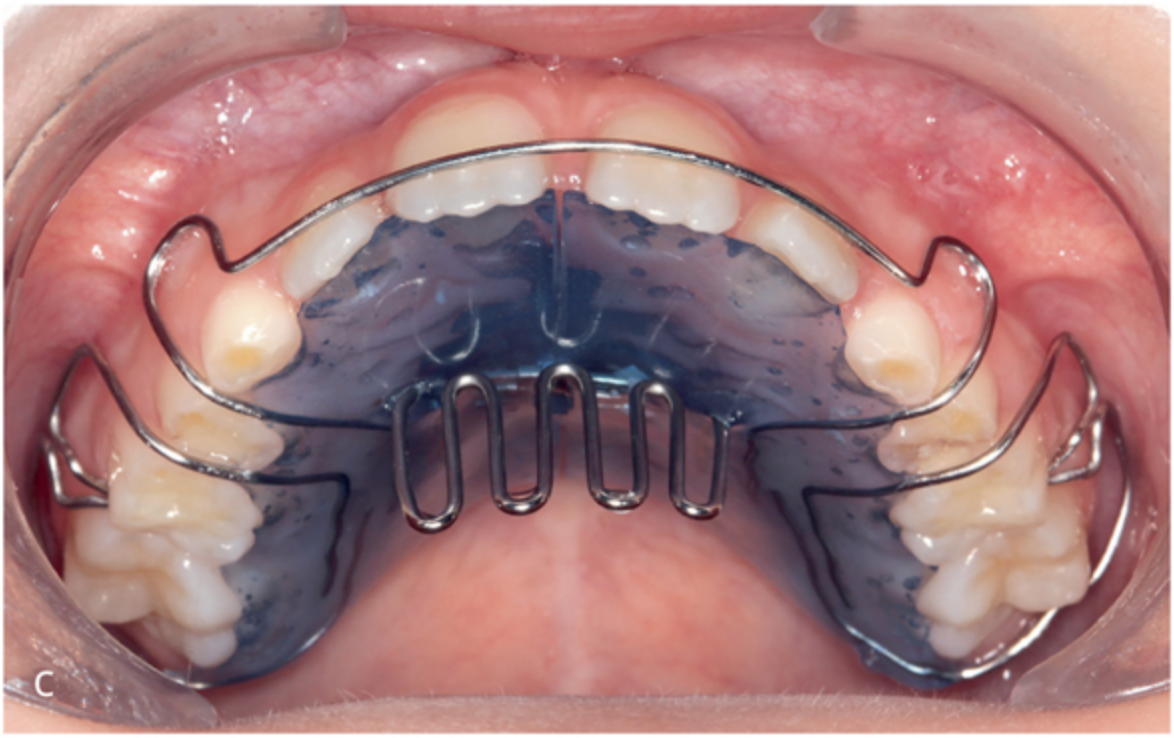
Breastfeeding of at least 6 months is very likely to have a positive effect on craniofacial development.

Habits and malfunctions

Hands and mouth are represented with large areas in the neocortex to enable differentiated perception and movement. This is why thumb sucking in embryonic development and early childhood is important for neural facilitation.[25] Even at these early stages, habits such as the handedness are preformed in this interplay.[26] For this reason, thumb sucking is still physiologic in the first year of life, whereas later on, deformation of the alveolar processes and changes in the position of the teeth may occur (Fig 15-2).[27] The close connection between form and function is the basis of the recommendation of early treatment of harmful habits. For example, Ramesh et al[28] found malocclusions in almost 60% of children with a persisting sucking habit at the age of 3 to 6 years.

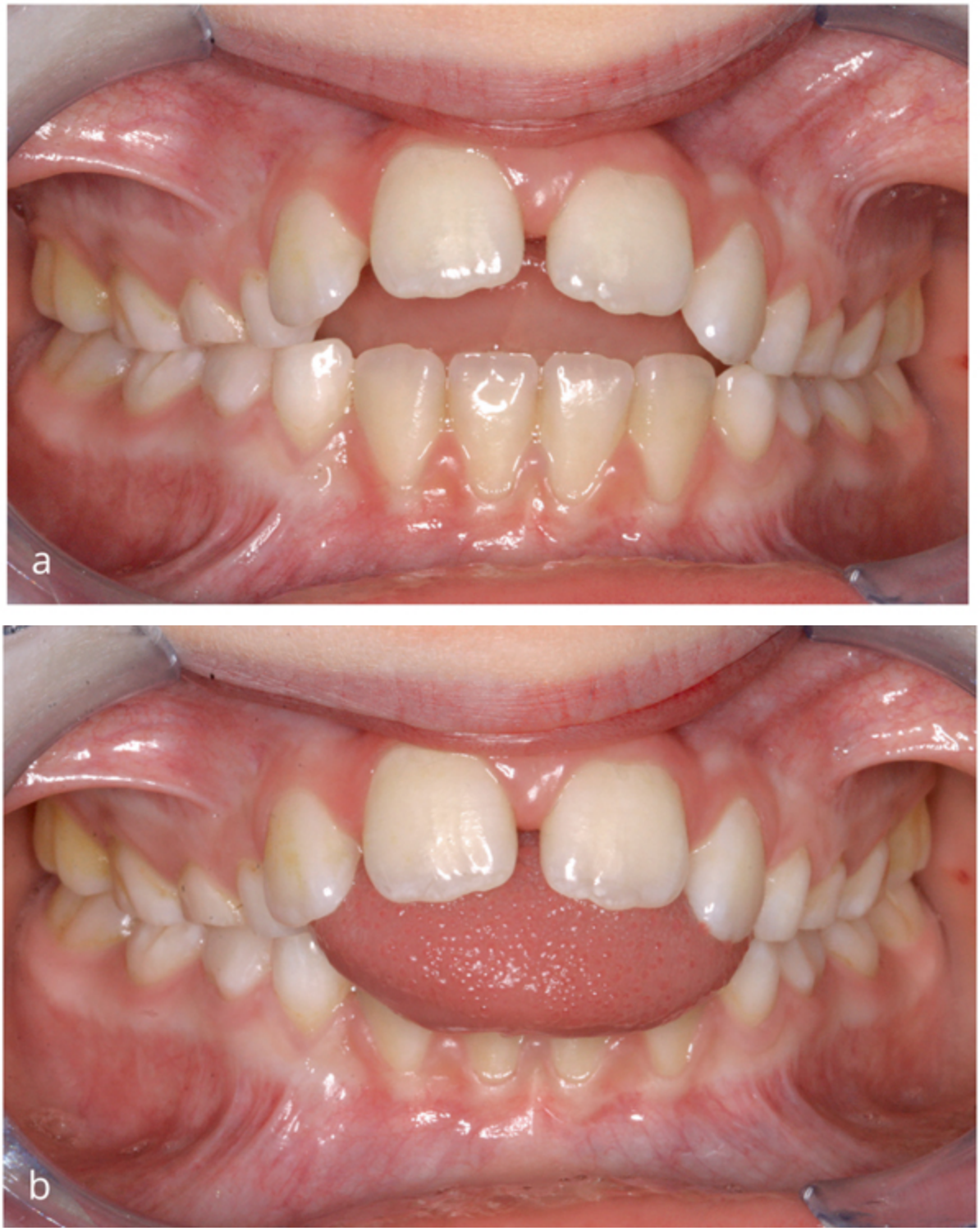




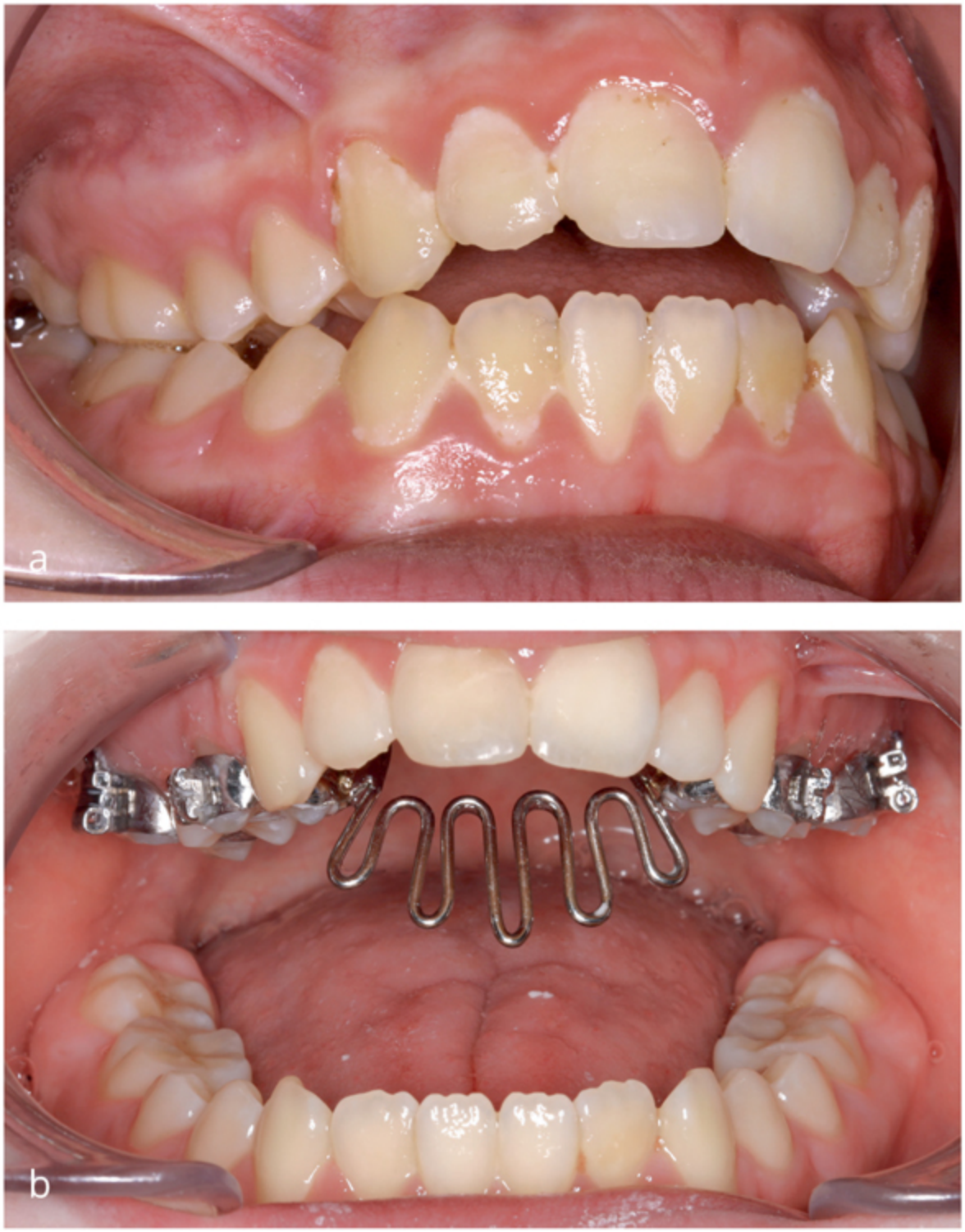


Figs 15-2a to c Examples of functional disturbances and accompanied malocclusions. **(a)** Insertion of the lower lip in Class II, division 1 patient with large horizontal overlap. **(b)** Anterior open bite with thumb sucking. **(c)** Removable appliance with tongue crib.

The weaning of harmful habits can be done on different levels,[29] including nonapparative approaches such as sucking calendars, a therapeutic counseling by the dental practitioner, or myofunctional therapy. Apparently, removable appliances have proven most useful, eg plates with tongue crib against persistent sucking or oral screen plates against the insertion of the lower lip between the teeth. A cross-sectional study (489 children) found a negative influence of persistent sucking on the dentition even when using a pacifier.[30] Tongue dysfunctions, tongue pressing (Fig 15-3), cheek sucking, sigmatism, and other functional deviations are also closely linked with the development of the tooth position and should be treated myofunctionally early on, before the onset of structural changes. Later in teenagers, fixed appliances may be the therapy of choice (Fig 15-4).



Figs 15-3a and b Secondary dysfunction of the tongue with infantile swallowing pattern. The result is a habitual frontal open bite. When breaking the habits, there is a tendency to self-healing.



Figs 15-4a and b (a) Persisting habits leads to bending of the alveolar processes and open bite in the permanent dentition, mostly associated with a dysfunction of the tongue. **(b)** A fixed “anti-sucking

device” can be useful during orthodontic therapy. In the case of existing habits, no active fixed orthodontics should be started.

The aim is to stop harmful habits by the 36th month of life.

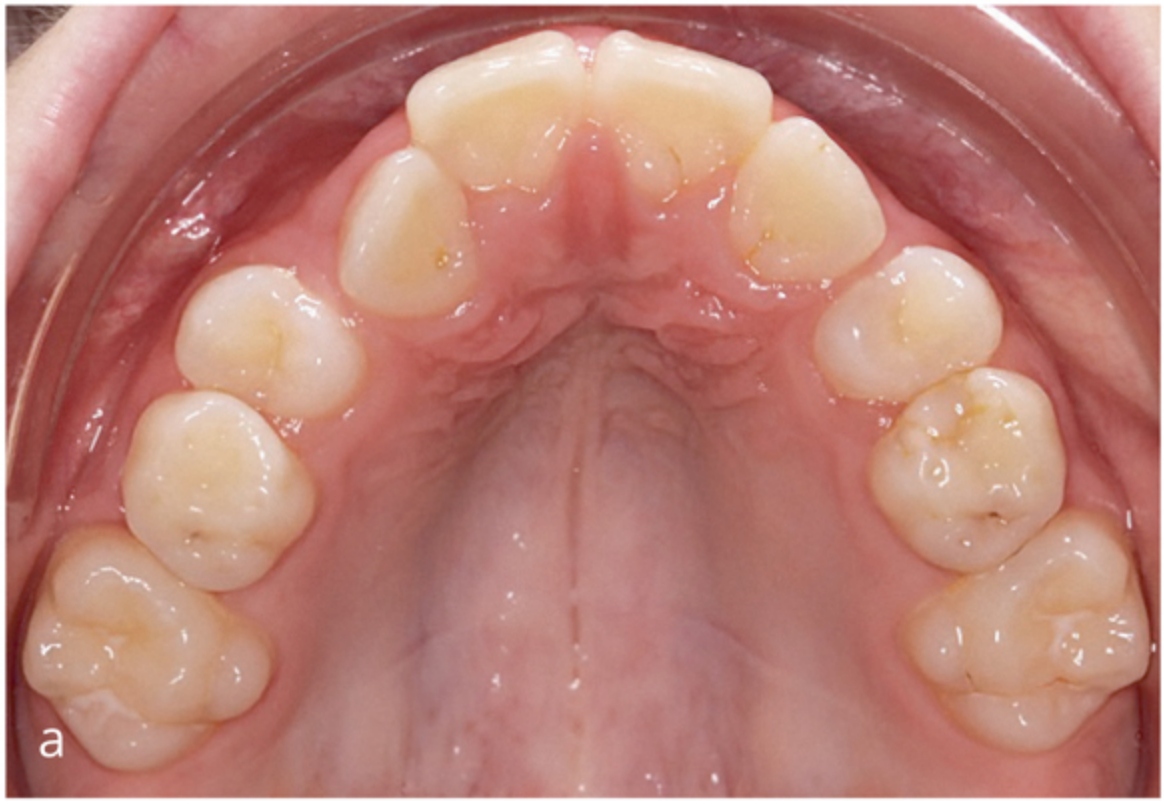
Playing musical instruments

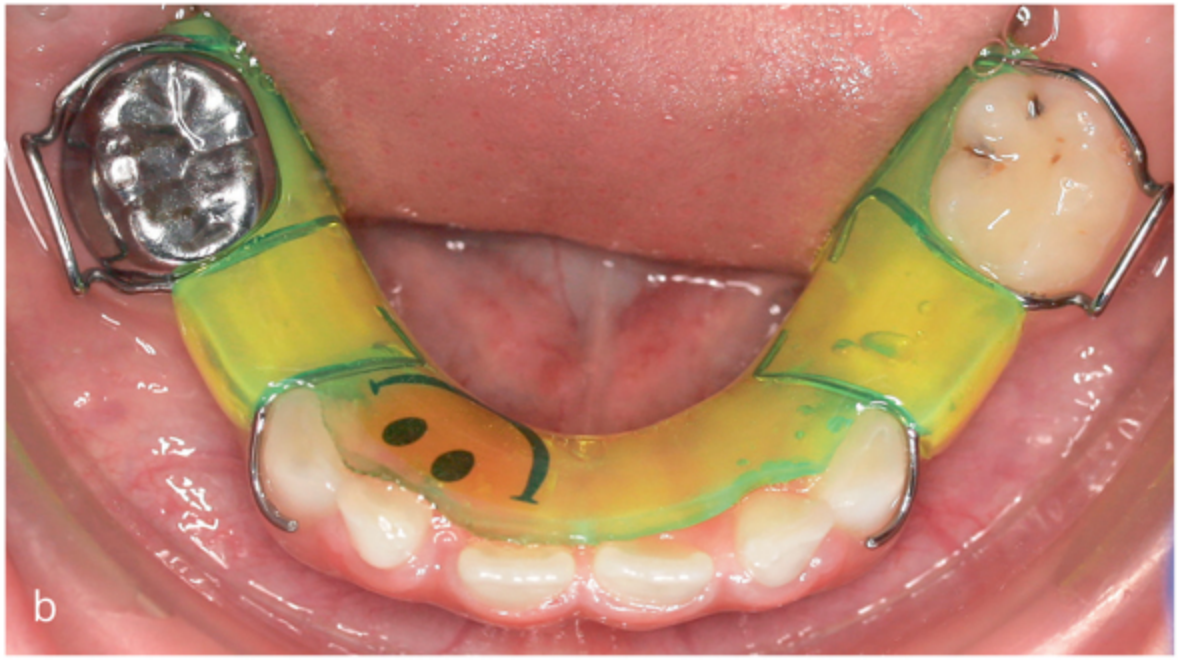
According to Strayer’s classification[31] of wind instruments, Grammatopoulos et al[32] studied occlusal parameters in 170 professional musicians. It could be shown that even intense playing of a wind instrument has no significant influence on the position of the anterior teeth in adults. However, in the developing dentition the intense playing of brass instruments involves the danger of developing lingual reverse articulation. With intensive playing of string instruments the risk of temporomandibular disorder increases, and this should be counteracted by physiotherapy and possibly bite ramps.[33] The playing of wind instruments can train the orofacial musculature and with the correct playing technique instruments such as horn or trumpet can be recommended as an adjunct therapy in cases with class III tendencies.[31]

Depending on the pattern of growth, wind instruments can positively affect the muscles; careful observation when playing string instruments intensively is recommended.

Premature loss of primary molars and space maintainers

The maintenance of the leeway and molar space is *conditio sine qua non* for an undisturbed development of the dentition,[34] and evidence-based caries-preventive programs can almost completely avoid premature decay of the primary tooth.[35] In case of a premature loss of primary molars, the positive effects of space maintainers have been described and implemented in different appliances for a long time.[36] Still, the evidence base for the implementation of space maintainers is unsatisfactory, especially for first primary molars.[37] However, it is undisputed that migration due to premature primary tooth loss and subsequent secondary crowding can lead to a lengthy and expensive orthodontic treatment, sometimes with the extraction of permanent teeth (Fig 15-5).[38]





Figs 15-5a and b (a) Example of a lack of space in the canine area due to migration of teeth after premature primary tooth loss. For correction, a complex orthodontic therapy, possibly with extraction of

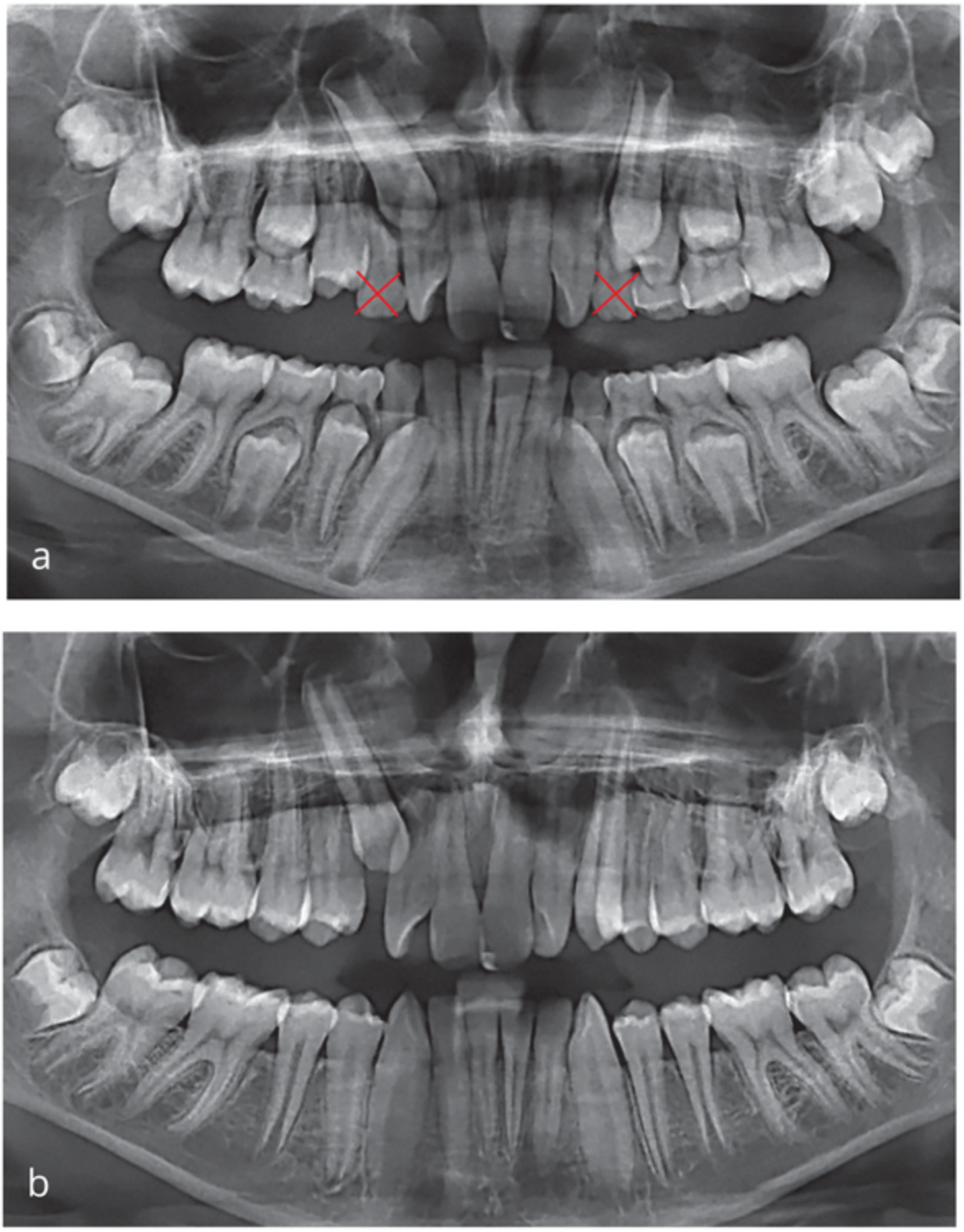
premolars, is necessary. **(b)** A space maintainer can prevent secondary crowding (case by Ch Splieth).

Caries prevention is also prevention of malocclusion.

Canine retention

Canines are the most frequently retained teeth, with a frequency of 1% to 2%, after the third molars.[39] Retention results in extensive and lengthy orthodontic and surgical therapy.[40]

Ideally, a first examination for the maxillary canines should take place at the age of 8 to 9 years. This includes visual inspection, palpation, and x-ray diagnostics.[41] In the case of apparent retention in situations where there is no crowding and Class I molar relation, the situation can be improved by extraction of the primary canines (Fig 15-6) at the age of 10 to 13 years.[42] According to Power and Short,[43] in 62% of cases canine retentions can be averted. In the presence of transversal space deficiency, the combination of rapid maxillary expansion (RME) with extraction of the primary canine teeth can significantly improve the situation.[44]

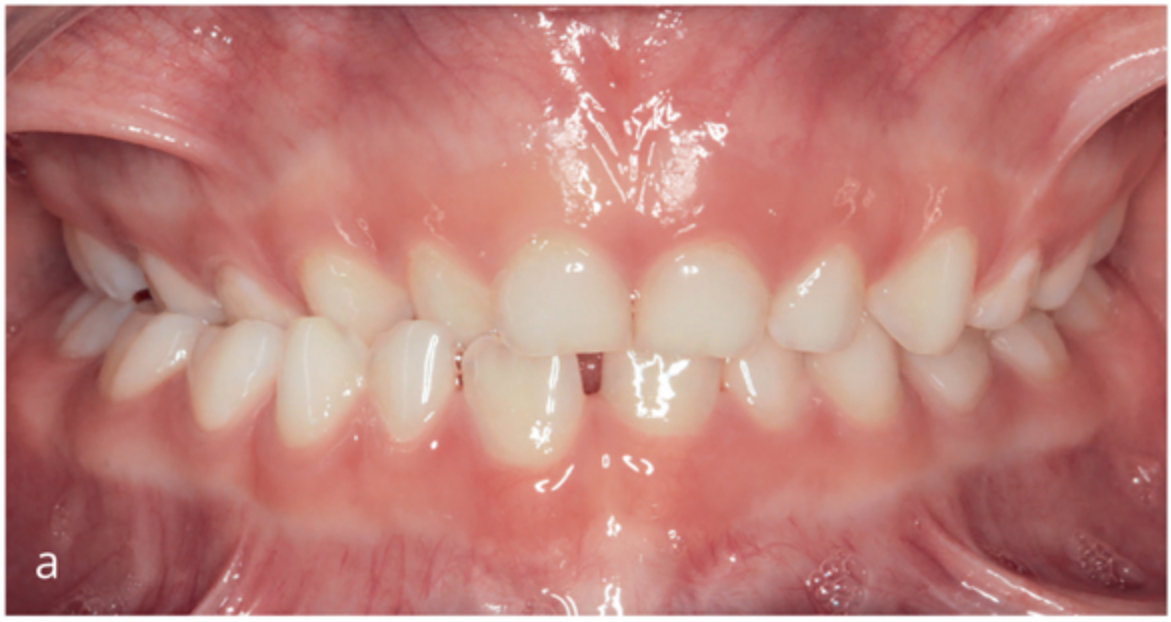


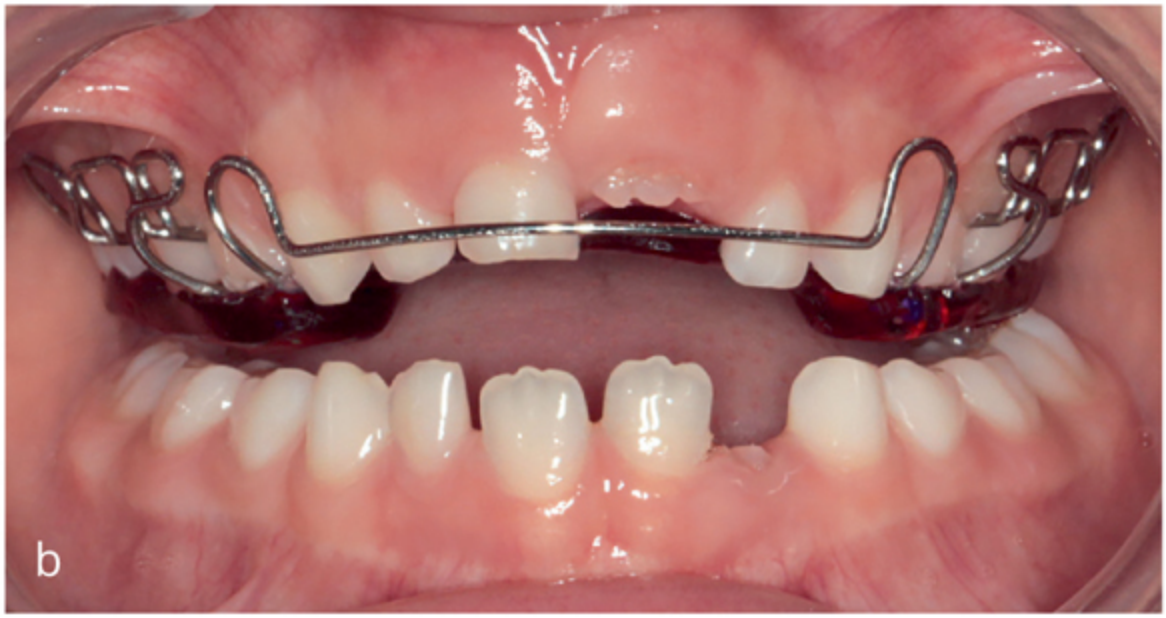
Figs 15-6a and b Development of canine position after extraction of maxillary primary canines. Retained positions **(a)** and normal position **(b)**.

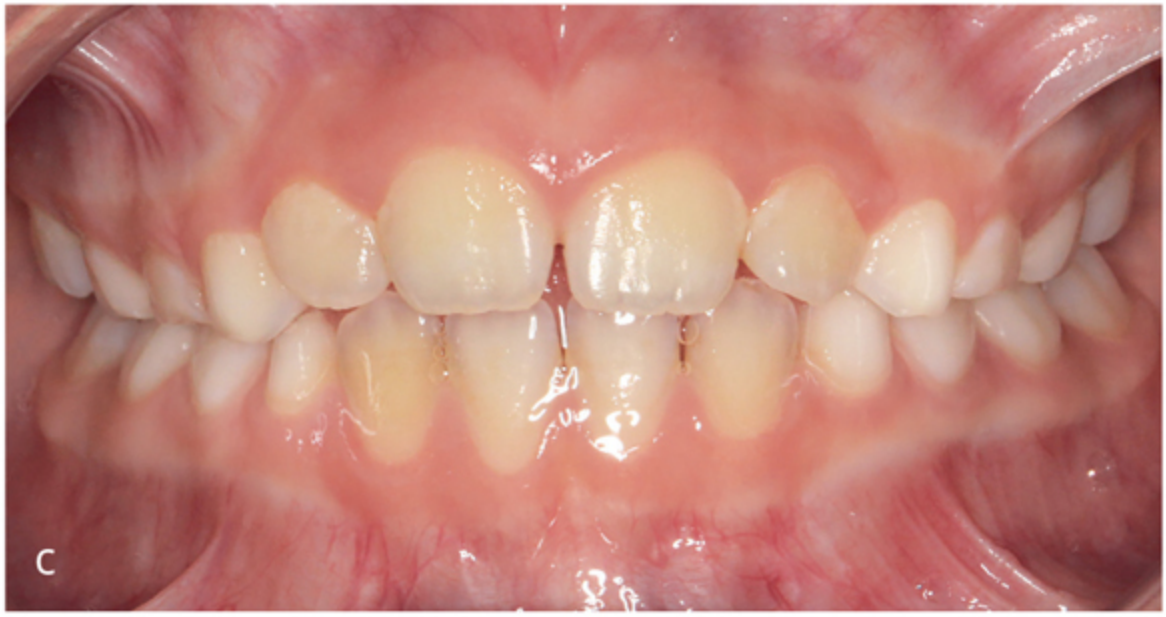
In the case of imminent canine retention, early extraction of the primary canines, possibly combined with RME, can significantly reduce the risk of retention.

Unilateral reverse articulation

According to Tonni et al,[45] unilateral reverse articulation is effectively treatable in the mixed dentition. There are indications arising from possible consequences of an untreated unilateral reverse articulation on musculoskeletal functions and adjacent organ systems. For example, unilateral reverse articulation may be associated with diminished ocular motility,[46] and a connection between posture and malocclusion has been discussed.[47] The evidence base is contradictory: März et al[48] found no influence on the mandibular position due to posture, while other authors found correlations between malocclusions and reduced static body posture and an influence of occlusal changes on posture and spine.[49,50] Therefore, a less invasive, risk-free interceptive treatment for reverse articulation is recommended (Fig 15-7).





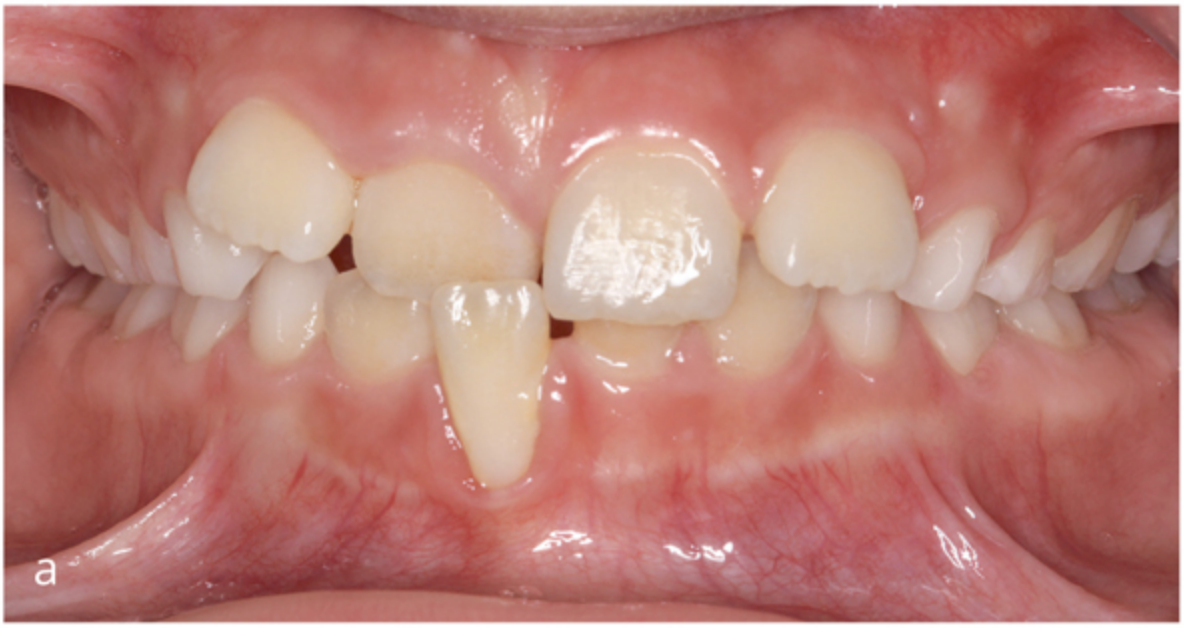


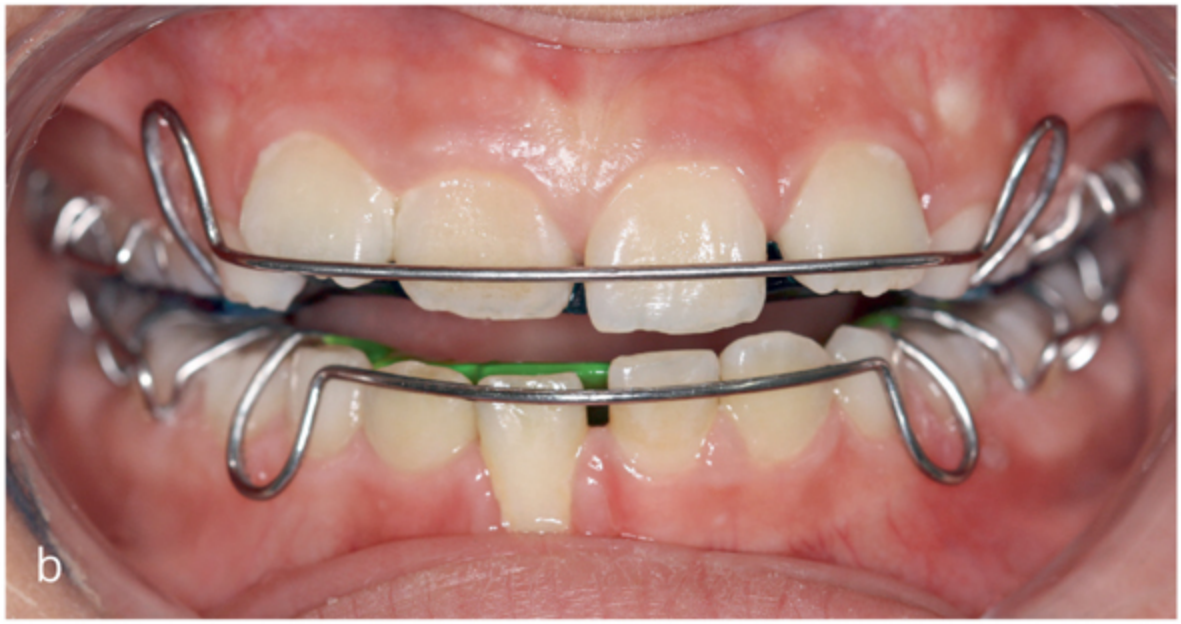
Figs 15-7a to c Interceptive correction of unilateral reverse articulation with midline shift by a removable Schwarz appliance. Early interceptive treatment for correcting a unilateral reverse articulation is recommended.

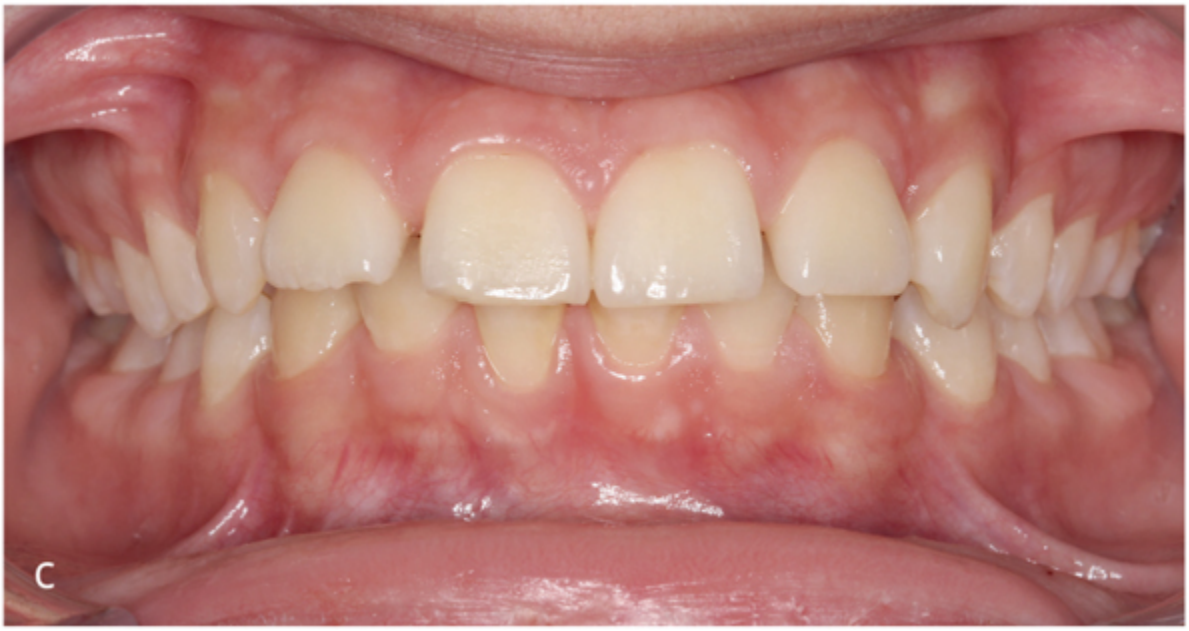
Early interceptive treatment for correcting a unilateral reverse articulation is recommended.

Anterior reverse articulation and periodontal health

In the mixed dentition, a reverse articulation of individual anterior teeth may cause periodontal damage, especially in the mandible. Tooth mobility also increases with traumatic contact leading to a thin labial bone and subsequent gingival recessions.[51-53] Simple orthodontic removable appliances or partial multi-bracket devices (2 by 4) can correct this and achieve an almost complete regeneration of the damaged tissue (Fig 15-8).[54]







Figs 15-8a to c Interceptive treatment of an anterior reverse articulation with severe attachment loss and nearly *restitutio ad integrum* within 3 years.

Treatment of isolated anterior reverse articulation is prophylaxis for periodontal attachment loss.

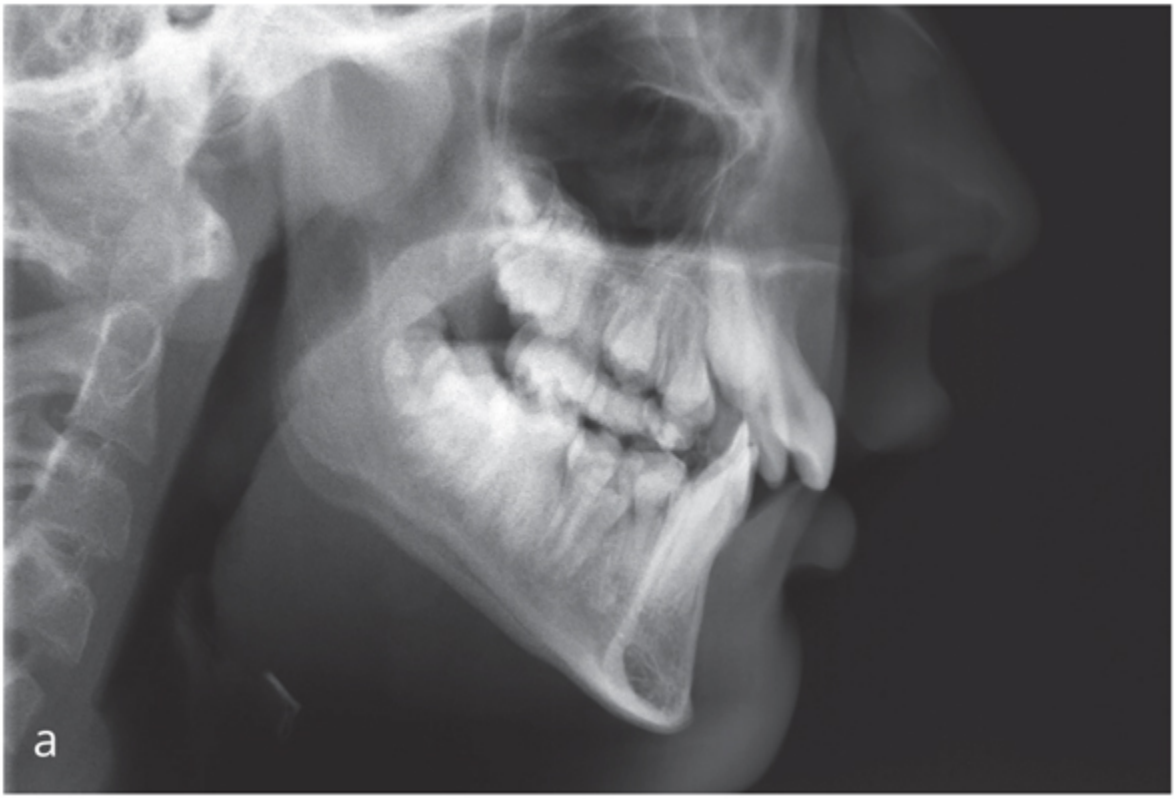
Caries

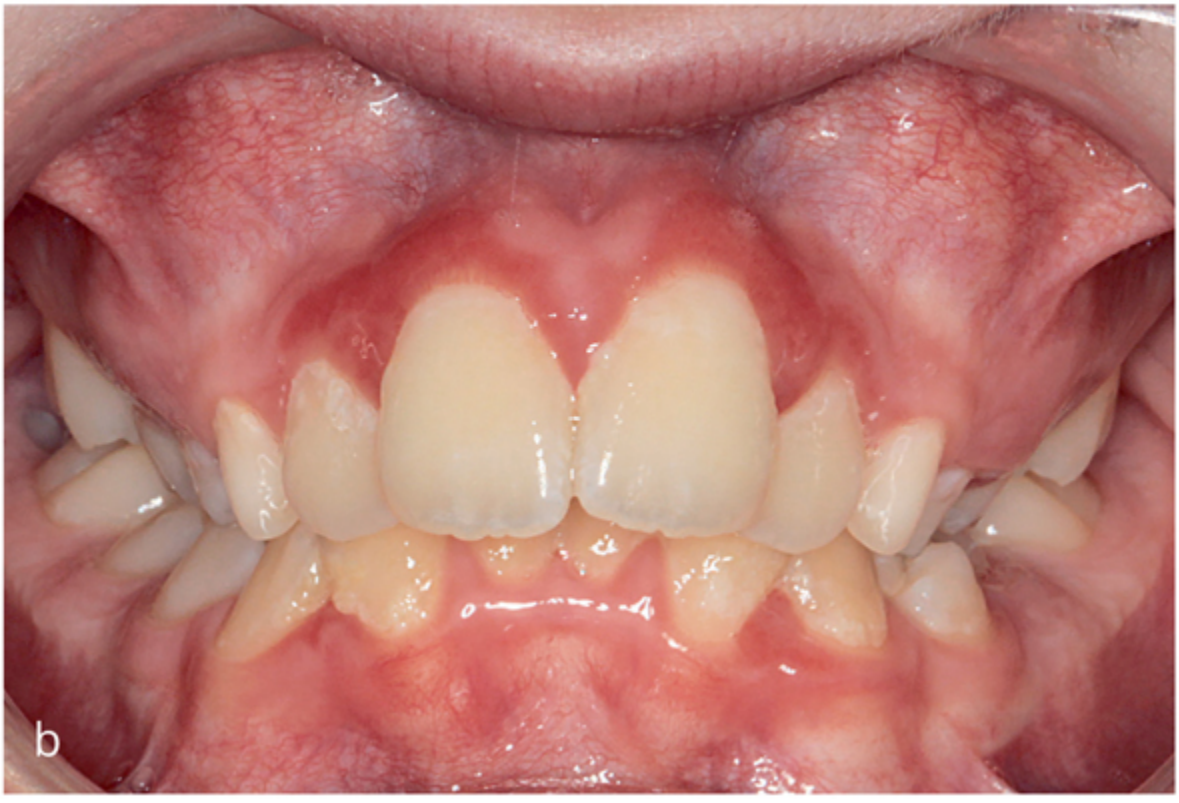
The influence of malocclusion on caries development has long been controversial, especially as cohort studies carry a significant risk of bias. Feldens et al[55] showed such a relationship in a cross-sectional study of 509 11- to 14-year-olds. Crowding of the maxillary incisors and deviating molar position seem to correlate with caries frequency and severity.[56] A final statement seems difficult, and it is likely the association strongly depends on the underlying caries activity.

The connection between caries and malocclusion is uncertain and under current research.

Sleep disorders and upper airway management

In a recent review, Macari and Haddad[57] emphasized the importance of unobstructed nasal breathing for the development of the craniofacial complex. Oral breathing leads to altered bone morphology such as “long” or “adenoid faces” and poses numerous health risks including asthma, learning difficulties, and postural changes (Fig 15-9).[59-61] Mouth-breathing-related malocclusions are associated with a higher prevalence of allergy and medication use.[62] Switching from mouth to nasal breathing has a high priority as a prophylactic measure.





Figs 15-9a and b Typical features of a patient with transverse deficiency, mouth breathing, gingival inflammation, and dolichofacial growth type.[58]

Regarding diagnosis, a history of snoring to obstructive sleep apnea syndrome (OSAS) is always indispensable. A recent systematic review showed that orthodontic treatment of existing risk factors such as a narrow jaw or short mandible can have a beneficial effect on the upper airways.[63]

In particular, the therapeutic development of the naso-maxillary complex by RME is an important interceptive measure.[64] An early start of treatment at the onset of first symptoms is recommended (Fig 15-10); some authors propose this at 3 to 6 years of age with bimaxillary elastomeric devices.[65] On the other hand, a retrognathic mandible seems to influence the airways negatively. Thus, early Class II therapy, probably independent of the device used, results in an increased pharyngeal airspace,[66-68] leading to improvements of OSAS.[69] An interdisciplinary therapy, together with ear, nose, and throat (ENT) specialists, is indispensable.[70]

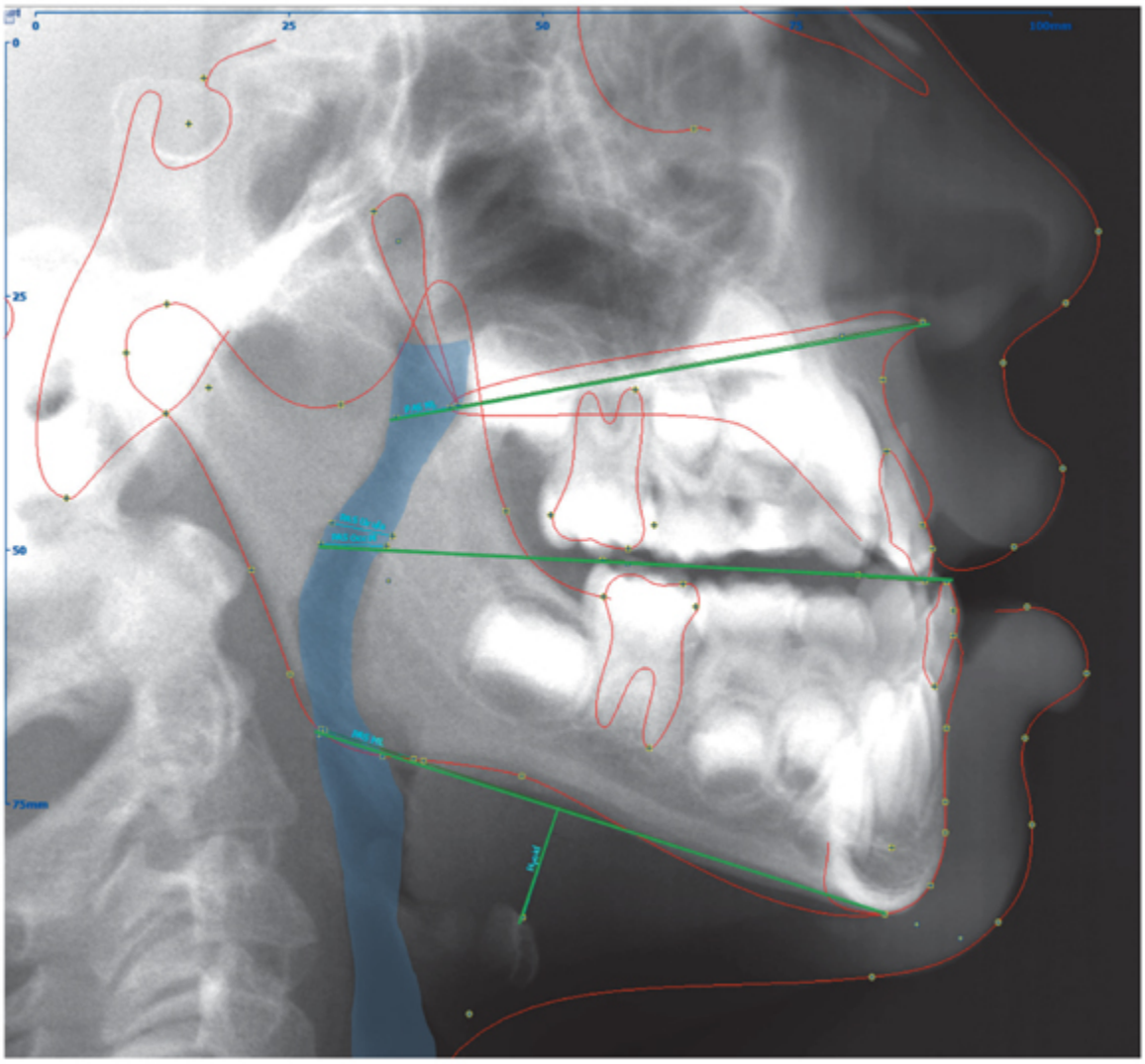


Fig 15-10 Small posterior airway space in a 6-year-old boy with Class III malocclusion with a medical history of severe snoring and sleep apnea. Maxillary protraction with rapid maxillary expansion and Delaire face mask can significantly improve airway ventilation.

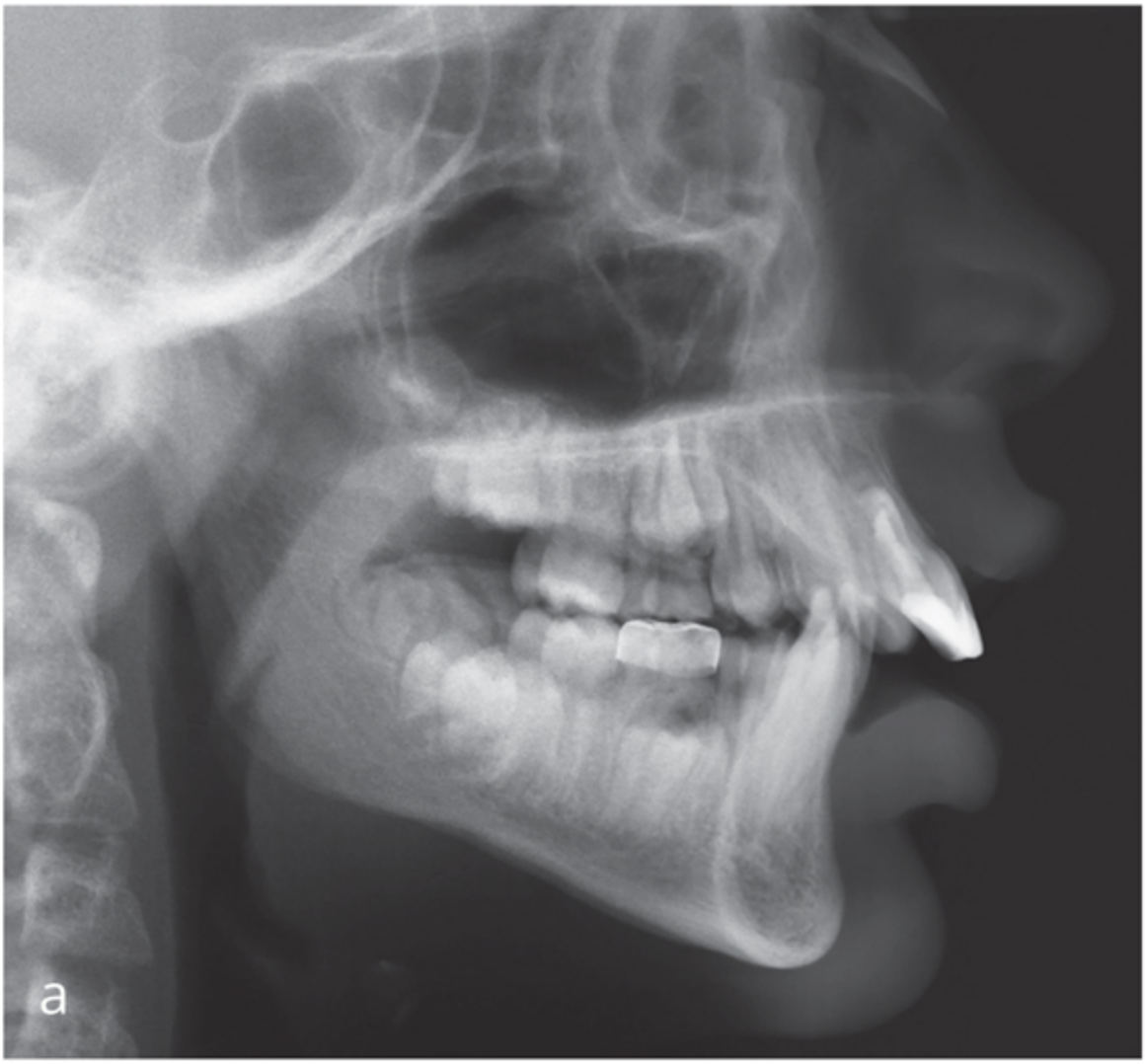
Early interdisciplinary approach for maintaining airway space and physiologic breathing is recommended.

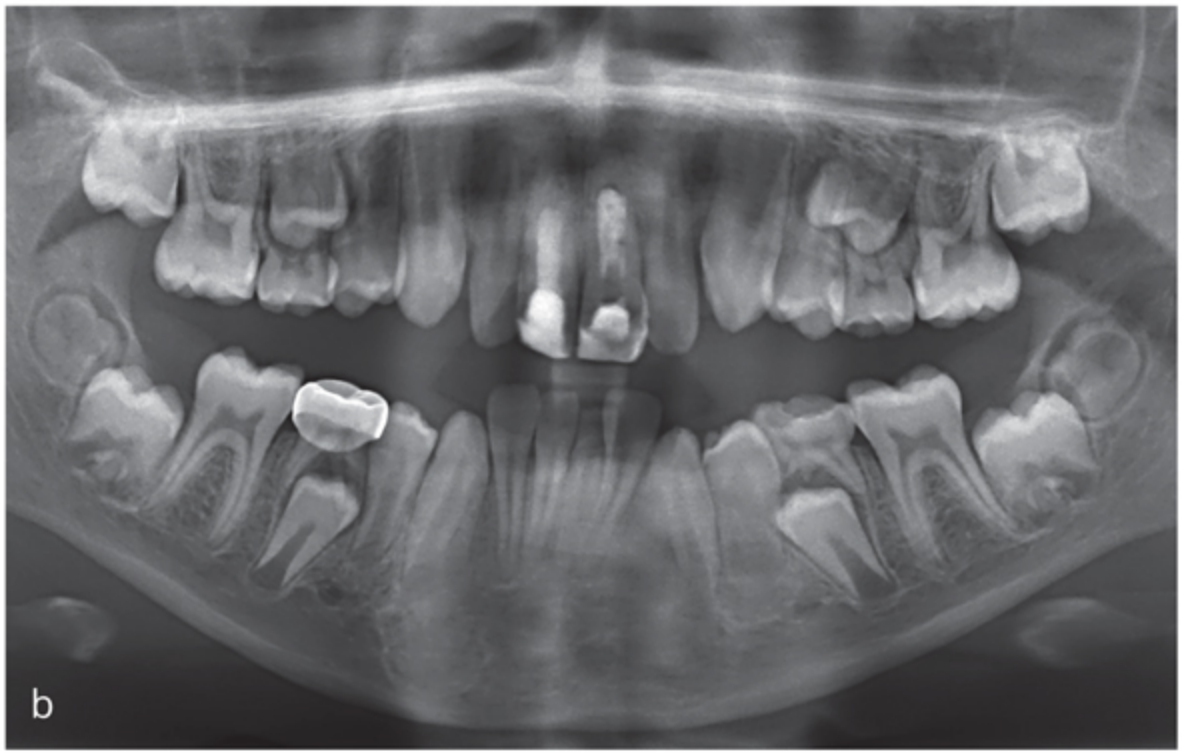
Trauma prevention

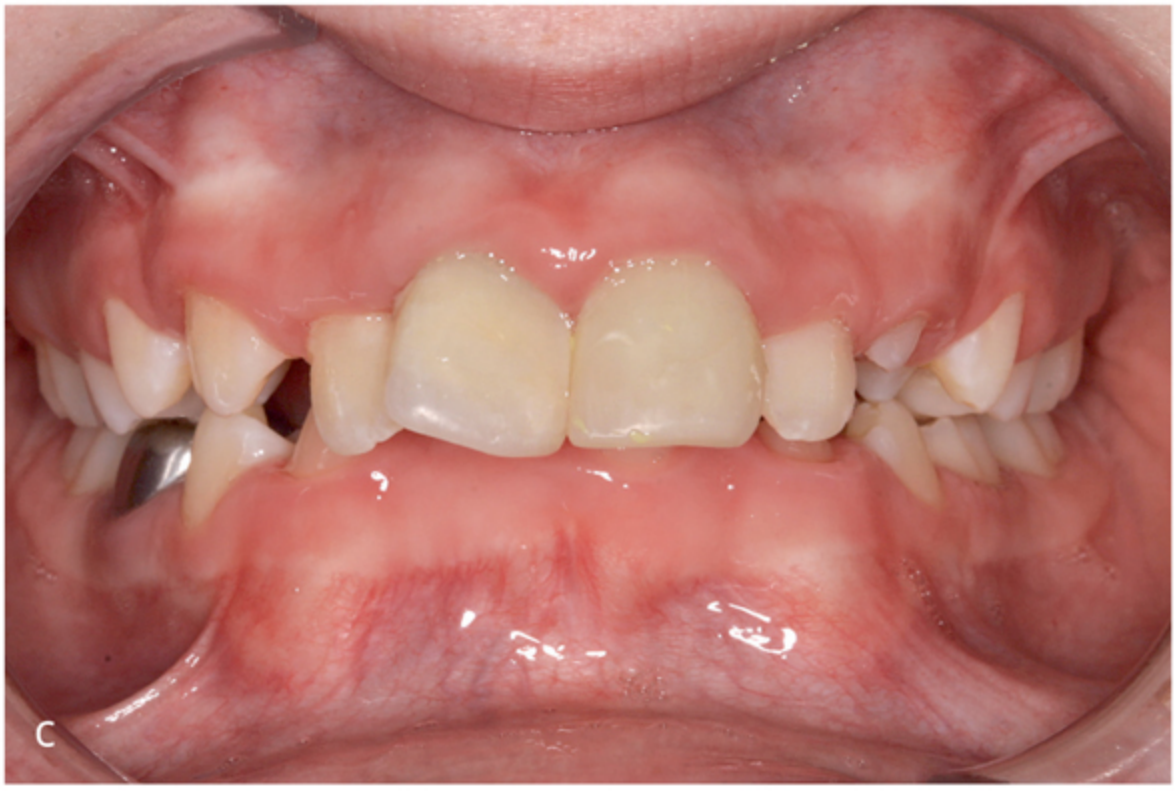
A mouth guard made by an orthodontist or general dental practitioner can significantly reduce the risk of injuries to the teeth and neck.[71] According to American Dental Association estimates, head and mouth guards help prevent approximately 200,000 injuries in US high school and college football.[72] These positive effects have been known for a long time,[73] but they need to be put into practice for everyone at risk.[74] Boil and bite mouth guards offer the best cost-benefit ratio for nonprofessionals in noncombat sports, while professionals should opt for a custom-made mouth guard (Fig 15-11).

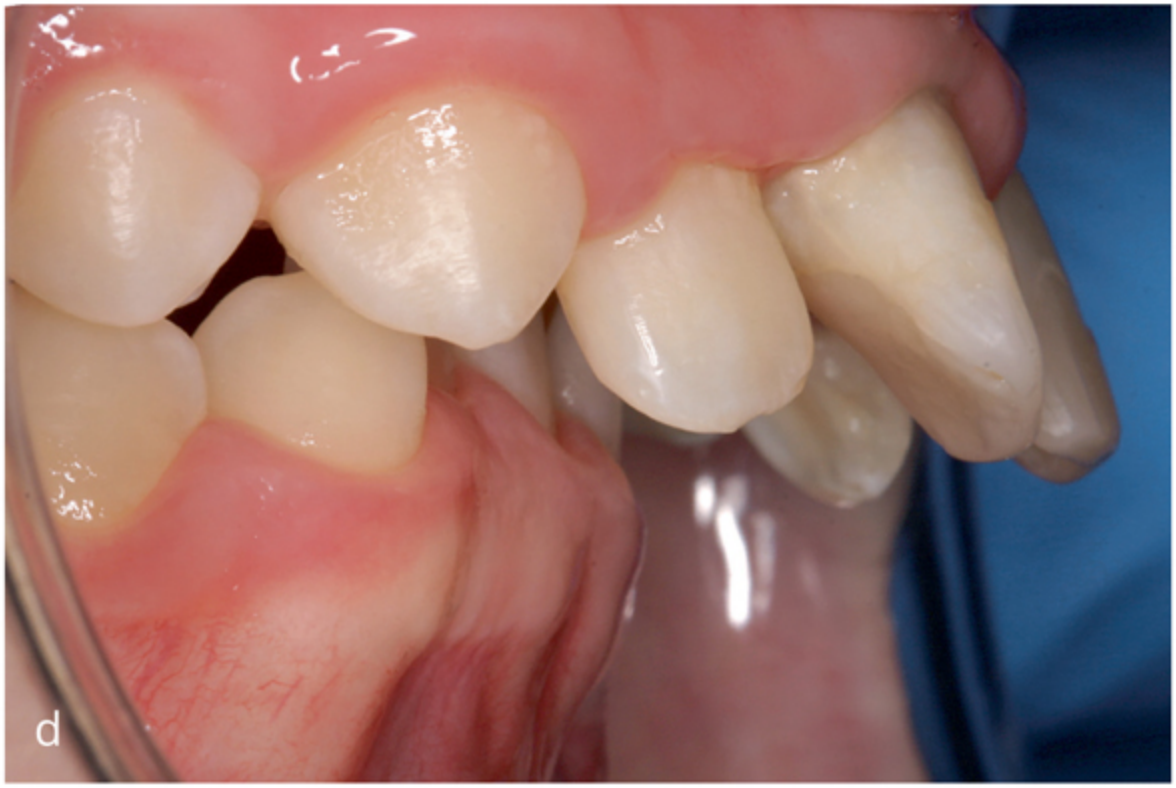
Fig 15-11 An example of a custom-made mouthguard.

Especially open bite and enlarged sagittal horizontal overlap (overjet) present an increased risk of anterior dental trauma (Fig 15-12).[75-77]









Figs 15-12a to d Case of a young patient with horizontal overlap > 10 mm and dental trauma on both maxillary incisors.

Mouth guards significantly reduce the risk of injury in sports. Open bite and enlarged horizontal overlap are of higher risk for dental trauma.

Temporomandibular disorders

The current evidence base does not really see links between specific dental and jaw malformations and the development of temporomandibular disorders (TMD),[79,80] especially when performed early before the full formation of the temporomandibular joint. This is also supported by the American Academy of Orofacial Pain.[81]

Orthodontic treatments during growth and development are highly likely to be jaw-joint neutral.

Third molar removal as prevention of crowding

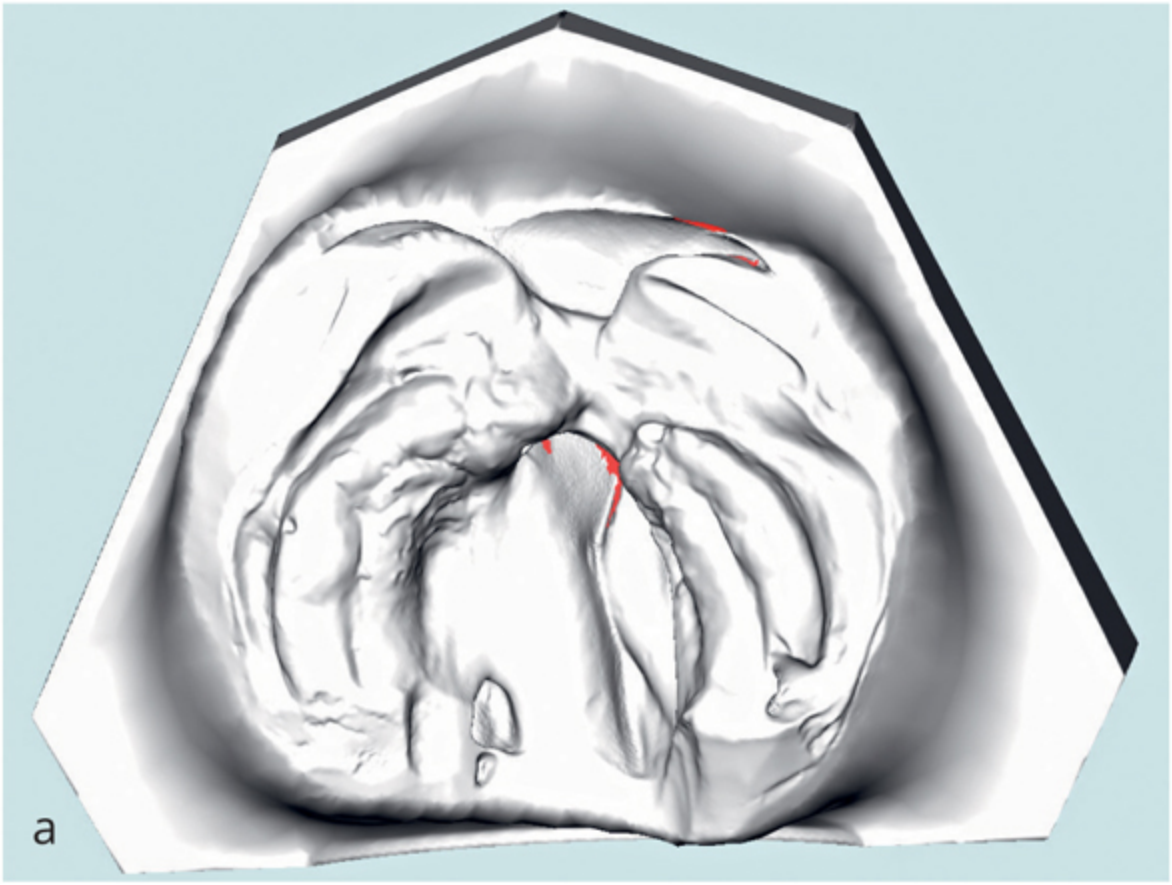
Tertiary crowding in the mandible has been associated with third molars for a long time,[82] but the majority of studies do not see any association between the presence or absence of third molars and tertiary crowding in mandibular incisors.[83,84] Even mesial forces in the dentition are not influenced by the third molars,[85] but the extraction of the third molars can improve the average space in 70% of the patients, without certain predictive value in the whole dental arch.[86] A general indication for the prophylactic removal of the third molars is, therefore, not necessarily justified.[87]

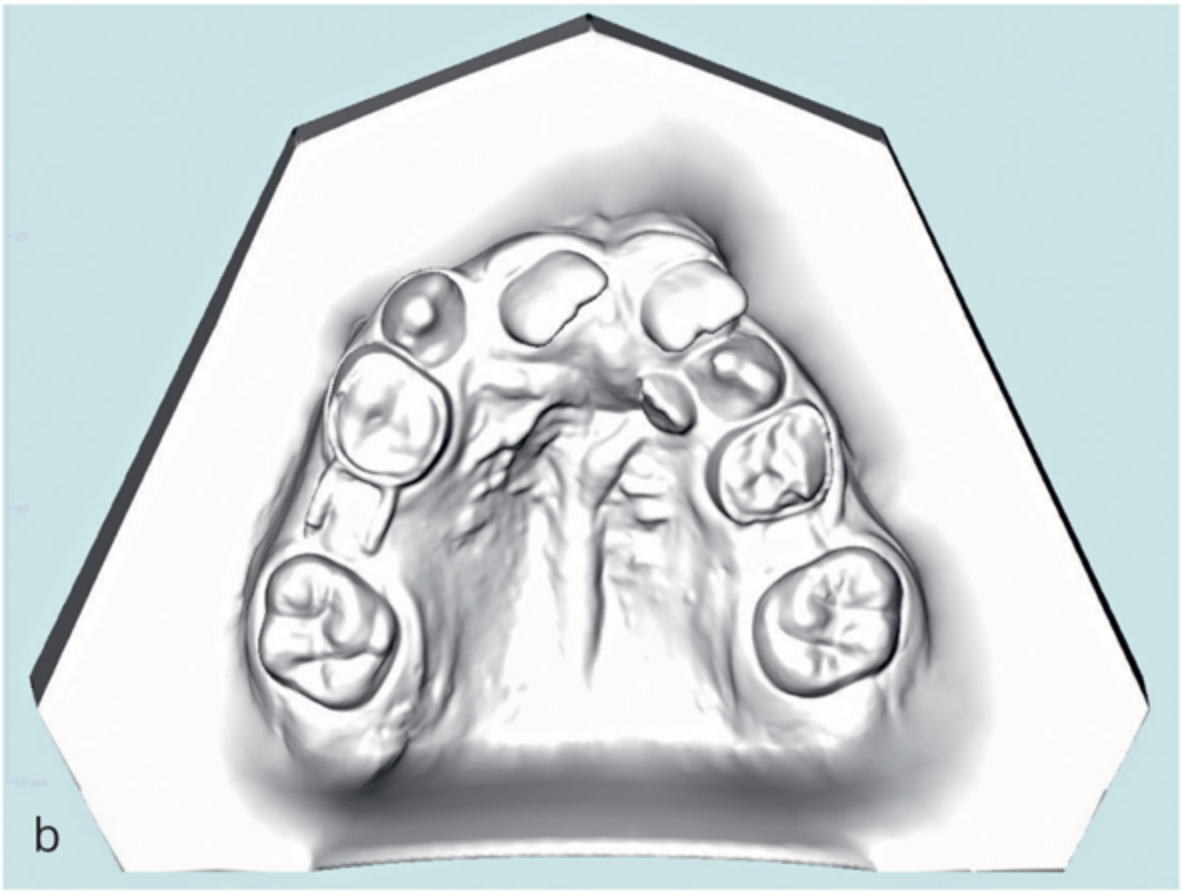
Prophylactic removal of third molars is not protective for tertiary crowding.

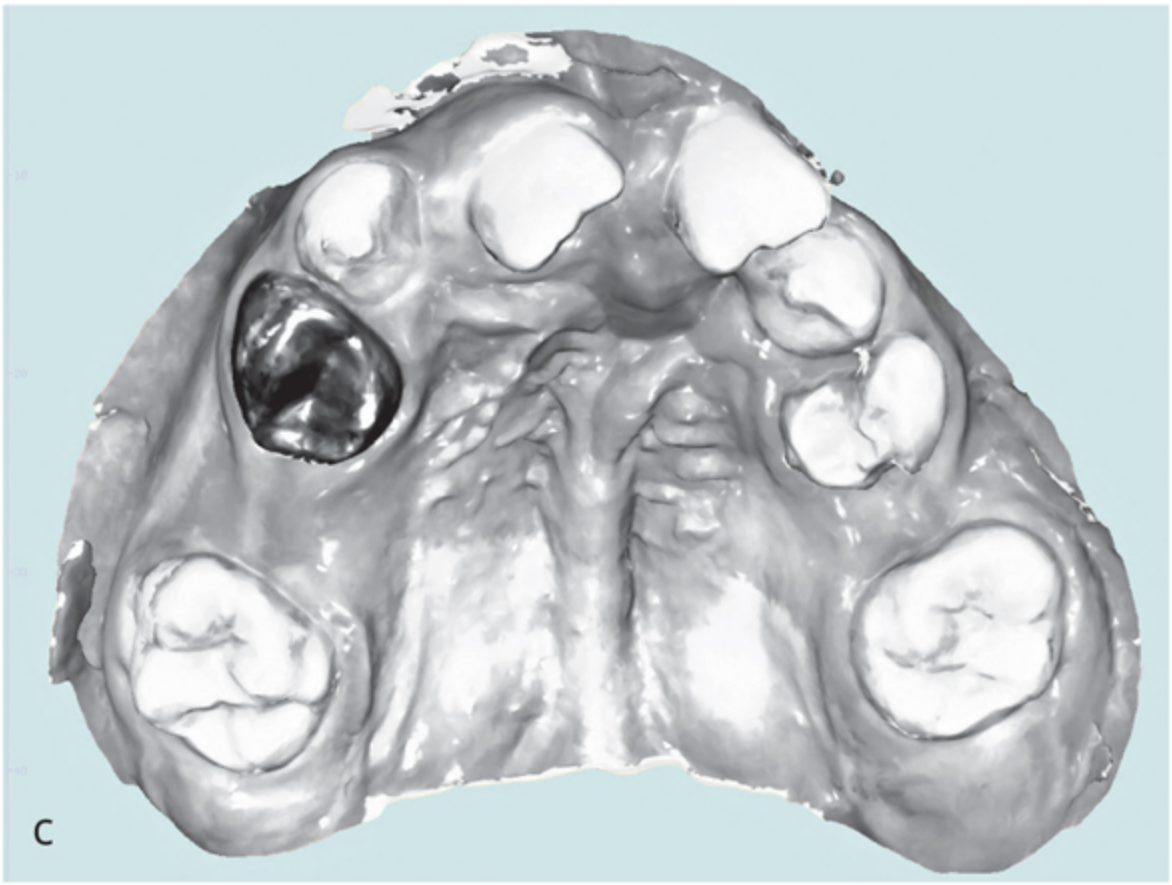
Orofacial clefts

With a frequency of 1:600 to 1:1,000, orofacial clefts are one of the most common congenital defects. Some 70% of the clefts are nonsyndromic and arise with a complex, multifactorial etiology with threshold effects. For the patients, this means a high burden of care, and lengthy orthodontic and surgical therapies (Fig 15-13). Prevention is based on two pillars: education about risk factors and vitamin administration. In addition, human genetic counseling for risk parents is possible. In the case of genetic clefts, prevention by vitamin administration is probably not successful.[88] In nonsyndromic

clefts, folic acid supplementation (> 400 µg/day) during pregnancy can reduce the risk of isolated cleft lip by about one third.[89]







Figs 15-13a to c Development of the maxilla of a patient with unilateral cleft lip and palate with severe malocclusions in the mixed dentition.

According to current systematic reviews,[90,91] the following indications for the prevention of orofacial clefts can be summarized:

- education of women of childbearing potential via a multivitamin substitution with a folic acid content of 0.4 mg pre- and post-conceptually[92,93]
- nutritional guidance of the mothers
- avoiding medications during pregnancy
- avoid alcohol and tobacco consumption, avoidance of passive smoking
- genetic testing in predisposed women who want to have children

- conscious awareness of socioeconomic risk factors.

All possibilities for the prevention of orofacial clefts should be considered.

In conclusion, orthodontics offers a great variety of approaches for prevention and prophylaxis. These should be put into practice and a prevention-oriented perspective could lead to a fundamental change in clinical routines.[94] A considerable amount of research is still needed to improve the evidence base for these procedures.[95] From a clinical point of view, early screening of the dentition and orofacial function for abnormalities and the initiation of interceptive measures is highly recommended.[96]

References

1. Carlson DS. Theories of craniofacial growth in the postgenomic era. Semin Orthod 2005;11:172–183.
2. Moss ML, Salentijn L. The primary role of functional matrices in facial growth. Am J Orthod 1969;55:566–576.
3. Petrovic A. Control of postnatal growth of secondary cartilages of the mandible by mechanisms regulating occlusion. Cybernetic model. Trans Eur Orthod Soc 1974;69–75.
4. van Limborgh J. The role of genetic and local environmental factors in the control of postnatal craniofacial morphogenesis. Acta Morphol Neerl Scand 1972;10:37–47.
5. Roux W. Der Kampf der Theile im Organismus. Ein Beitrag zur Vervollständigung der mechanischen Zweckmäßigkeitslehre. Leipzig: W Engelmann,1881.
6. Wolff J. The law of bone remodelling. Berlin – Heidelberg: Springer, 1986.
7. Hanisch M, Hanisch L, Kleinherz J, Jung S. Primary failure of eruption (PFE): a systematic review. Head Face Med

2018;14:5.

8. Ionescu E, Teodorescu E, Badarau A, Grigore R, Popa M. Prevention perspectives in orthodontics and dento-facial orthopedics. J Med Life 2008;1:397–402.
9. Uribe LMM, Miller SF. Genetics of the dentofacial variation in human malocclusion. Orthod Craniofac Res 2015;18:91–99.
10. Salzmann JA. Dento-maxillo-facial orthopedics: Etiology and prevention. Am J Orthod 1957;43:242–264.
11. Schwarz AM. Die 10 Gebote der Kieferorthopädie für Zahnärzte. Dtsch Zahnärztl Zahnheilk 1955;12:917–920.
12. Perkins FM. Pedodontics: a perspective on prevention. J Pediatrics 1971;78:199–206.
13. Stahl F, Grabowski R. Orthodontic findings in the deciduous and early mixed dentition – inferences for a preventive strategy. J Orofac Orthop 2003;64:401–416.
14. Baumgartner L. Orthodontics as a public health service. Am J Orthod 1961;47:809–813.
15. Sabuncuoglu O. Understanding the relationships between breastfeeding, malocclusion, ADHD, sleep-disordered breathing and traumatic dental injuries. Med Hyp 2013;80:315–320.
16. Thomaz EBAF, Cangussu MCT, Assis AMO. Maternal breastfeeding, parafunctional oral habits and malocclusion in adolescents: A multivariate analysis. Int J Ped Otorhinolaryngol 2012;76:500–506.
17. Narbutyte I, Narbutyte A, Linkeviciene L. Relationship between breastfeeding, bottle-feeding and development of malocclusion. Baltic Dent Maxillofac J 2013;15:67–72.
18. del Valle LML, Dave-Singh G, Feliciano N, Machuca MDC. Association between a history of breast feeding, malocclusion and parafunctional habits in Puerto Rican children. Puerto Rico Health Sci J 2006;25:31–34.
19. Peres KG, Barros AJ, Peres MA, Victora CG. Effects of breastfeeding and sucking habits on malocclusion in a birth cohort study. Rev Saude Publica 2007;41:343–350.

20. Binns C, Lee M, Low WY. The long-term public health benefits of breastfeeding. Asia Pac J Public Health 2016;28:7–14.
21. Abreu LG, Paiva SM, Pordeus IA, Martins CC. Breastfeeding, bottle feeding and risk of malocclusion in mixed and permanent dentition: a systematic review. Bras Oral Res 2016;30:e22.
22. Engström C, Kiliaridis S, Thilander B. The relationship between masticatory function and craniofacial morphology. II. A histological study in the growing rat fed a soft diet. Eur J Orthod 1986;8:271–279.
23. Limme M. The need of efficient chewing function in young children as prevention of dental malposition and malocclusion. Arch Ped 2010;17:213–219.
24. Böhmer C, Böhmer E. Shape variation in the craniomandibular system and prevalence of dental problems in domestic rabbits: a case study in evolutionary veterinary science. Vet Sci 2017;24;E5.
25. Kolb B, Whishaw I, Teskey CG. An introduction to brain and behaviour. 6th edn. Duffield: Worth, 2019.
26. Hepper PG, Wells DL, Lynch C. Prenatal thumb sucking is related to postnatal handedness. Neuropsychologia 2005;43:313–315.
27. Littlefield WH. Thumb-sucking and its relationship to malocclusion in children. Am J Orthod 1952;38:293–300.
28. Ramesh N, Guruanthan D, Karthikeyan SA. Association of nonnutritive sucking habits and malocclusion: a crosssectional study. Int J Pedod Rehabil 2016;1:15–18.
29. Majorana A, Bardellini E, Amadori F, Conti G, Polimeni A. Timetable for oral prevention in childhood—developing dentition and oral habits: a current opinion. Progr Orthod 2015;16:39–41.
30. Costa CTD, Shqair AQ, Azevedo MS, Goettems ML, Bonow MLM, Romano AR. Pacifier use modifies the association between breastfeeding and malocclusion: a cross-sectional study. Braz Oral Res 2018;32:e101.

31. Strayer ER. Musical instruments as an aid in the treatment of muscle defects and perversions. Angle Orthod 1939;9:18-27.
32. Grammatopoulos E, White AP, Dhopatkar A. Effects of playing a wind instrument on the occlusion. Am J Orthod Denotfac Orthop 2012;141:138–145.
33. Glowacka A, Matthews-Kozanecka M, Kawala M, Kawala B. The impact of the long term playing of musical instruments on the stomatognathis system – review. Adv Clin Exp Med 2014;23:143–146.
34. Lundström A. The significance of early loss of deciduous teeth in the etiology of malocclusion. Am J Orthod 1955;41:819–826.
35. Fleming P. Timetable for oral prevention in childhood – a current opinion. Progr Orthod 2015;16:27.
36. Offer-spitz A. Prophylactic appliances in early childhood. Am J Orthod Oral Surg 1944;30:378–387.
37. Canadian Agency for Drugs and Technologies in Health. Dental space maintainers for the management of premature loss of deciduous molars: a review of the clinical effectiveness, cost-effectiveness and guidelines. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2016. https://www.ncbi.nlm.nih.gov/books/NBK401552/. Accessed 25 January 2020.
38. Krey KF. Vorzeitiger Milchzahnverlust und seine Folgen für die Gebissentwicklung aus kieferorthopädischer Sicht. Quintessenz 2019;70:612–621.
39. Bass TB. Observations on the misplaced upper canine tooth. Dent Pract Dent Rec 1967;18:25–33.
40. Williams BH. Diagnosis and prevention of maxillary cuspid impaction. Angle Orthod 1981;51:30–40.
41. Shapira Y, Kuftinec MN. Early diagnosis and interception of potential maxillary canine impaction. J Am Dent Assoc 1998;129:1450–1454.
42. Richardson G, Russel KA. A review of impacted permanent maxillary cuspids – diagnosis and prevention. J Can Dent

Assoc 2000;66:497–501.

43. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. Br J Orthod 1993;20:217–223.
44. Baccetti T, Sigler LM, McNamara JA. An RCT on treatment of palatally displaced canines with RME and/or a transpalatal arch. Eur J Orthod 2010;33:601–607.
45. Tonni I, Iannazzi A, Piancino MG, Costantinides F, Dalessandri D, Paganelli C. Asymmetric molars' mesial rotation and mesialization in unilateral functional posterior crossbite and implications for interceptive treatment in the mixed dentition. Eur J Orthod 2017;39:433–439.
46. Bollero P, Ricchiuti MR, Lagana G, di Fusco G, Lione R, Cozza P. Correlations between dental malocclusions, ocular motility, and convergence disorders: a cross-sectional study in growing subjects. Oral Implantol 2017;10:289–294.
47. Marini I, Bonetti GA, Bortoletti F, Bartolucci ML, Gatto MR, Michelotti A. Effects of experimental insoles on body posture, mandibular kinematics and masticatory muscles activity. A pilot study in healthy volunteers. J Electromyogr Kinesio 2015;25:531–539.
48. März K, Adler W, Matta RE, Wolf L, Wichmann M, Bergauer B. Can different occlusal positions instantaneously impact spine and body posture? A pilot study using rasterstereography for a three-dimensional evaluation. J Orofac Orthop 2017;78:221–232.
49. Arumugam P, Padmanabhan S, Chitharanjan AB. The relationship of postural body stability and severity of malocclusion. APOS Trends Orthod 2016;6:205–210.
50. Parrini S, Comba B, Rossini G, Ravera S, Cugliari G. Postural changes in orthodontic patients treated with clear aligners: a rasterstereographic study. J Electromyogr Kinesiol 2018;38:44–48.

51. Bollen AM. Effects of malocclusions and orthodontics on periodontal health: evidence from a systematic review. J Dent Educ 2008;72:912–918.
52. Vithanaarachchi SN, Nawarathna LS. Prevalence of anterior cross bite in preadolescent orthodontic patients attending an orthodontic clinic. Ceylon Med J 2017;62:189–192.
53. Sockalingam SNMP, Khan KZM, Kuppusamy E. interceptive correction of anterior crossbite using short-span wire-fixed orthodontics appliance: A report of three cases. Case Rep Dent 2018;4323945.
54. Nagarajan S, Sockalingam MP, Khan KAM, Kuppusamy E. Interceptive correction of anterior crossbite using short-span wire-fixed orthodontic appliance: a report of three cases. Case Rep Dent 2018:4323945.
55. Feldens CA, dos Santos Dullius AI, Kramer PF, Scapini A, Busato ALS, Vargas-Ferreira F. Impact of malocclusion and dentofacial anomalies on the prevalence and severity of dental caries among adolescents. Angle Orthod 2015;85:1027–1034.
56. Sa-Pinto AC, Rego TM, Marques LS, Martins CC, Ramos-Jorge ML, Ramos-Jorge J. Association between malocclusion and dental caries in adolescents: a systematic review and meta-analysis. Eur Arch Paed Dent 2018;19:73–82.
57. Macari AT, Haddad RV. The case for environmental etiology of malocclusion in modern civilizations: Airway morphology and facial growth. Sem Orthod 2016;22:223–233.
58. Albertini FR, dos Santos Diaz CT, Rizzati-Barbosa C, Reimao RNAA. Lateral tele radiography for diagnosis of obstructive sleep disorder in children with attention deficit hyperactivity disorder. J Adv Med Dent Sci Res 2016;4:1–4.
59. Grippaudo C, Paolantonio EG, Antonini G, Saulle R, La Torre G, Deli R. Association between oral habits, mouth breathing and malocclusion. Acta Odontorhinolaryngol Ital 2016;36:386–394.
60. Luzzi V, Di Carlo G, Saccucci M, et al. Craniofacial morphology and airflow in children with primary snoring. Eur Rev Med

Pharmacol Sci 2016;20:3965–3971.

61. Mottl W, Pfister R. Adenoide – ein kausaler Faktor beim vertikalen Wachstumsmuster. J Orofac Orthop 1982;43:19–28.
62. Yamaguchi H, Tada S, Nakanishi Y, et al. Association between mouth breathing and atopic dermatitis in Japanese children 2-6 years old: a population-based cross-sectional study. PLoS One 2015;10:e0125916.
63. Huynh NT, Desplats E, Almeida FR. Orthodontics treatments for managing obstructive sleep apnea syndrome in children: a systematic review and meta-analysis. Sleep Med Rev 2016;25:84–94.
64. Villa MP, Rizzoli A, Miano S, Malagola C. Efficacy of rapid maxillary expansion in children with obstructive sleep apnea syndrome: 36 months of follow-up. Sleep Breath 2011;15:179–184.
65. Balian A, Malerba A, Strohmenger L. Obstructive sleep apnea syndrome (OSAS) treated with orthodontic appliances in children: a new feasible approach. Ann Dentist Oral Disord 2018;1:105.
66. Drosen C, Bock NC, von Bremen J, Pancherz H, Ruf S. Long-term effects of Class II Herbst treatment on the pharyngeal airway width. Eur J Orthod 2018;40:82–89.
67. Fabiani G, Galván Galván J, Raucci G, et al. Pharyngeal airway changes in pre-pubertal children with Class II malocclusion after Fränkel-2 treatment. Eur J Paediatr Dent 2017;18:291–295.
68. Xiang M, Hu B, Liu Y, et al. Changes in airway dimensions following functional appliances in growing patients with skeletal class II malocclusion: A systematic review and metaanalysis. Int J Pediatr Otorhinolaryngol 2017;97:170–180.
69. Pavoni C, Lombardo EC, Lione R, Bollero P, Ottaviani F, Cozza P. Orthopaedic treatment effects of functional therapy on the sagittal pharyngeal dimensions in subjects with sleep-

disordered breathing and Class II malocclusion. Acta Otolaryncol Ital 2017;37:479–485.

70. Ruoff CM, Guilleminaulst C. Orthodontics and sleep-disordered breathing. Sleep Breath 2012;16:271–273.
71. Mantri SS, Mantri SP, Deogade S, Bhasin AS. Intra-oral mouth-guard in sport related oro-facial injuries: prevention is better than cure! J Clin Diagn Res 2014;8:299–302.
72. Jerolimov V. Temporomandibular injuries and disorders in sport. RAD Med Sci 2010;34:149–165.
73. Stenger JM, Lawson EA, Wright JM, Ricketts J. Mouthguards: protection against shock to head, neck and teeth. J Am Dent Assoc 1964;69:273–281.
74. Newsome PR, Tran DC, Cooke MS. The role of the mouthguard in the prevention of sports-related dental injuries: a review. Int J Paediatr Dent 2001;11:396–404.
75. Primo-Miranda EF, Ramos-Jorge ML, Homem MA, et al. Association between occlusal characteristics and the occurrence of dental trauma in preschool children: a case-control study. Dent Traumatol 2019;35:95–100.
76. Dosdogru YE, Gorken FN, Erdem AP, et al. Maxillary incisor trauma in patients with Class II division 1 dental malocclusion: associated factors. J Istanb Univ Fac Dent 2017;51:34–41.
77. Petti S. Over two hundred million injuries to anterior teeth attributable to large overjet: a meta-analysis. Dent Traumatol 2015;31:1–8.
78. Kramer PF, Pereira LM, Ilha MC, Borges TS, Freitas MPM, Feldens CA. Exploring the impact of malocclusion and dentofacial anomalies on the occurrence of traumatic dental injuries in adolescents. Angle Orthod 2017;87:816–823.
79. Mohlin B, Axelsson S, Paulin G, et al. TMD in relation to malocclusion and orthodontic treatment. Angle Orthod 2007;77:542–548.
80. Manfredini D, Stellini E, Gracco A, Lombardo L, Nardini LG, Siciliani G. Orthodontics is temporomandibular disorder–

neutral. Angle Orthod 2016;86:649–654.

81. De Leeuw R, Klasser GD. Orofacial Pain (American Academy for Orofacial Pain). Guidelines for Assessment, Diagnosis, and Management, 6th edn. Chicago: Quintessence Publishing, 2018.
82. Godfrey K, Kean HK. Prophylactic removal of asymptomatic third molars: a review. Aust Dent J 1999;44:233–237.
83. Kaplan RG. Mandibular third molars and postretention crowding. Am J Orthod 1974;66:411–430.
84. Karasawa LH, Rossi AC, Groppo FC, Prado FB, Caria PHF. Cross-sectional study of correlation between mandibular incisor crowding and third molars in young Brazilians. Med Oral Patol Oral Bucal 2013;1:e505–e509.
85. Southard TE, Southard KA, Weeda LW. Mesial forces from unerupted third molars. Am J Orthod Dentofac Orthop 1991;99:220–225.
86. Lindquist B, Thilander B. Extraction of third molars in cases of anticipated crowding in the lower jaw. Am J Orthod 1982;81:130–139.
87. Kandasamy S. Evaluation and management of asymptomatic third molars: watchful monitoring is a low-risk alternative to extraction. Am J Orthod Dentofac Orthop 2011;140:11–17.
88. Scheller K, Quitzke V, Kappler M. New molecular aspects in the mechanism of oromaxillofacial cleft prevention by B-vitamins. J Craniomaxillofac Surg 2018;46:2058–2062.
89. Wilcox AJ, Lie RT, Solvoll K, et al. Folic acid supplements and risk of facial clefts: national population based case-control study. BMJ 2007;334:464e.
90. Stancheva N. Ist Prävention von nichtsyndromalen Lippen-Kiefer-Gaumen-Spalten heute möglich? – eine Literaturübersicht [Masters thesis]. Krems an der Donau: Danube University, 2017.
91. Millacura N, Pardo R, Cifuentes L, Suazo J. Effects of folic acid fortification on orofacial clefts prevalence: a meta-analysis.

Public Health Nutr 2017;12:2260–2268.

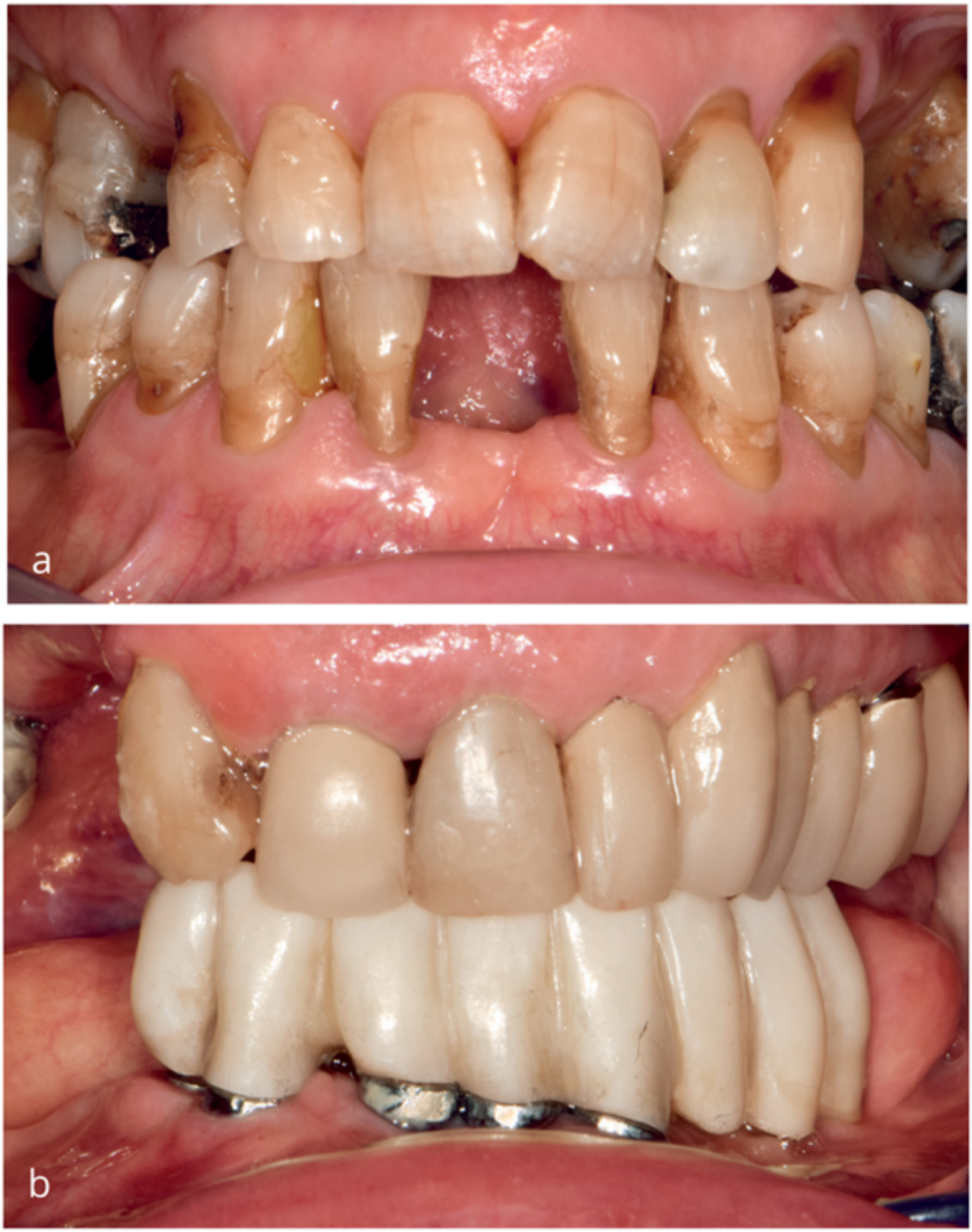
92. Wehby GL, Félix TM, Goco N, et al. High dosage folic acid supplementation, oral cleft recurrence and fetal growth. Int J Environ Res Public Health 2013;10:590–605.
93. Wehby GL, Goco N, Moretti-Ferreira D, et al. Oral cleft prevention program (OCPP). BMC Pediatrics 2012;12:184.
94. Varrela J, Alanen P. Prevention and early treatment in orthodontics: a perspective. J Dent Res 1995;74:1436–1438.
95. Ackerman JA, Proffit WR. Preventive and interceptive orthodontics: a strong theory proves weak in practice. Angle Orthod 1980;50:75–86.
96. Wilson WL. Some considerations of preventive and interceptive orthodontics. Am J Orthod 1967;53:525–532.

16

Prevention in elderly and medically compromised patients

Murali Srinivasan

Dental treatment concepts for elderly and medically compromised individuals focus on restoring mastication in order to reestablish nutrition and thereby improve the oral health-related quality of life (OHRQoL).[1-5] This goal should be achieved with treatment concepts that are minimally invasive and reduce the treatment burden (Fig 16-1). This can be accomplished by adopting procedures that promote preventive measures, simplify restorative procedures, and avoid surgeries.[6-14] However, the need for minimally/optimally invasive rehabilitation in age-advanced and/or medically compromised patients can be questioned. Would it be better if tooth loss in such individuals could be prevented, in order to avoid rehabilitation?



Figs 16-1a and b Restorative care in elderly and medically compromised individuals is possible, but it is strenuous for patients,

caretakers and the dental team. Thus, prevention should be intensified to reduce other interventions to a minimum.

Aging is inevitable; the associated sequelae to this phenomenon are hence unavoidable, but may be preventable. Dental treatments, either for maintaining the natural teeth or for restoring the lost dentition, are an expensive and complicated affair in dependent and medically compromised individuals.

Maintaining oral health and adopting preventive strategies are cardinal measures that must be considered as prerequisites when planning oral health care for medically compromised or elderly individuals.

Demographics of aging: related effects and retention of natural teeth

Population demographics for the year 2017 reveal that there are approximately 962 million people aged 60 years or over worldwide, and this is expected to double by 2050.[15] There are an estimated 137 million people aged 80 years and over, and this is likely to rise to approximately 425 million by 2050 (Fig 16-2).[15,17] By then, 35% of Europe's population will be aged 60 years or over. Switzerland alone is currently estimated to have 18.4% of its population who are 65 years or over, of which 5.1% are above 80 years; it is expected to increase to 28.7% and 11.7% by 2050, respectively.[15,18]

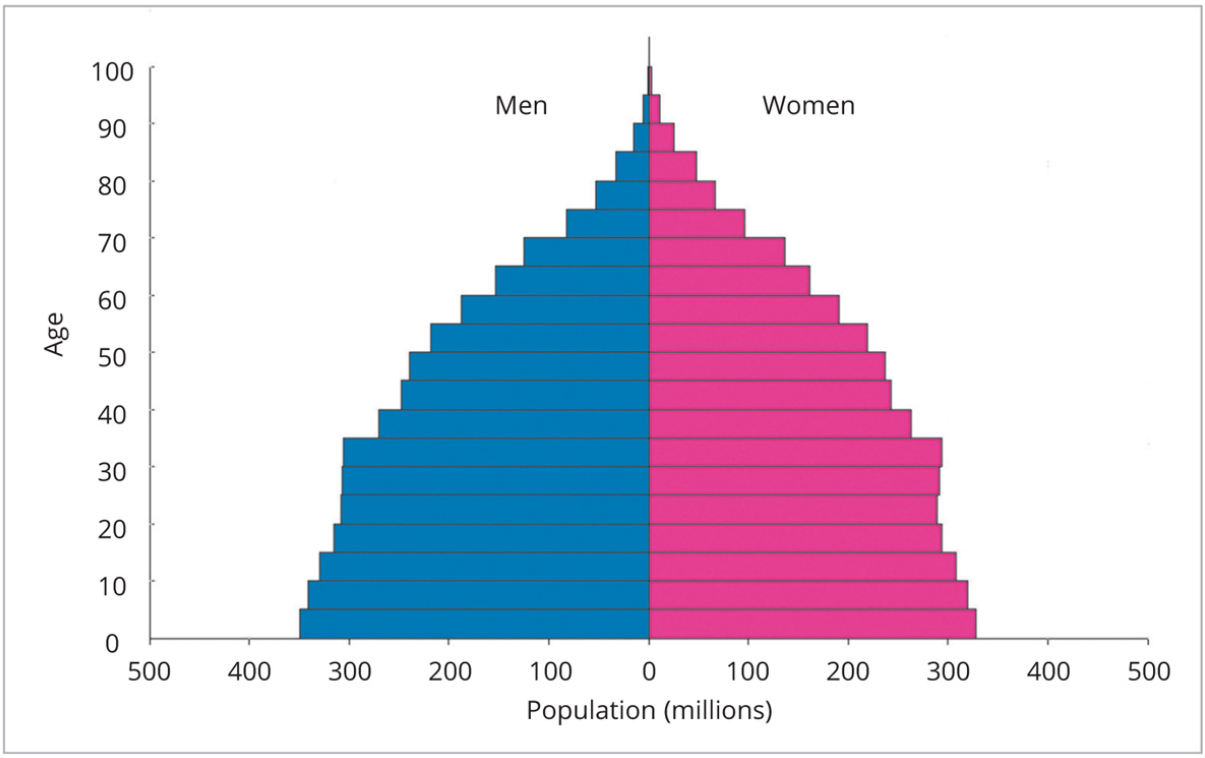


Fig 16-2 Distribution of global population by age and sex (Modified from United Nations, DESA, Population Division.[17] Licensed under Creative Commons license CC BY 3.0 IGO.)

An aging society has an impact on a socioeconomic as well as on a biologic front. Age-related changes cause functional and structural changes in the body and affect all systems.[19] The systems degenerate,[20,21] along with a diminution of the oral and perioral structures.[22-27] Irreversible degenerative changes are evident in the skin and the musculoskeletal system.[28-31] These musculoskeletal changes are pertinent when treating elderly adults as it potentially limits the overall mobility of the individual. Metabolic capacities and responses to drug treatments are also affected,[32] making the therapeutic doses of the drugs administered fairly complicated.

In elderly and medically compromised pa-tients, multimorbidity is often a common presentation.[33,34] Due to this, polypharmacy is an associated feature and, as a consequence, xerostomia and drug-induced hyposalivation are frequently a common finding in these

individuals.[35] Moreover, these individuals usually present with a loss of functional autonomy with/without cognitive decline, with dementia being very common in age-advanced institutionalized dependent elders.[36,37]

Cognitive decline is one of the biggest health risks in elderly people, with Alzheimer disease (AD) occurring in almost 50% of those 85 years and over.[38] Furthermore, functional and nutritional status is poor in institutionalized elders.[39]

Poor oral hygiene is a very common finding in such institutionalized dependent elders,[40] and this is further deteriorated in those with cognitive impairments and dementia.[41] Poor oral health and untreated oral infections can be precursors for developing cognitive impairment and clinical manifestations of AD.[41,42]

Physiologic age-related changes and complications have a direct clinical impact on oral health and the dental team. The treatment rationale, therefore, migrates towards a more preventive approach, with the focus on an attempt to delay some of the age-related changes.[18]

Along with advancing age, another demographic trend that has been witnessed in developing nations is the retention of natural teeth to an advanced age.[43,44] This trend can be attributed to the advancements in dental treatments, success of the preventive treatment programs, and provision of, as well as access to quality dental care. The “domino effect” predicted a decline in edentulism almost two decades ago.[45-47] Current demographic trends show this prediction to be true.[43,48] A factor to consider is that the retention of teeth to an older stratum might be beneficial, but the risk of caries and periodontal infections is augmented.[49-53] Problems with dental health start occurring in this advanced age due to age-associated chronic disease and/or disability. Tooth loss eventually presents itself in a

much older and, more frequently, in a frail dependent older population segment.

Periodontal disease and root caries

Periodontal disease is one of the most prevalent diseases known to man that affects both the young and elderly adult population.[48,54] Recent reports indicate that this condition has undergone a demographic shift, in the direction of the advanced age strata.[48] This shift is more evident in high-income countries. Possible explanations are that the younger adult population lead a healthy lifestyle, are better educated, and hence more aware of preventive measures, as well as the increasing affordability of dental treatments along with relatively good access to quality dental care.[55] While these factors may be considered common denominators for the older population, it is difficult to draw and predict the same inferences for this older age group. The age-advanced individual is relatively more at risk for periodontal disease. Hence periodontal treatment needs will become more age-specific, isolated to the advanced age groups.[48]

A similar trend observed is in the incidence of caries, and in particular, root caries. Root caries prevalence has steadily increased in elderly adults, and increases even more as age advances.[48] Root caries is a growing problem in medically compromised subjects because of the comorbidities, such as drug-induced hyposalivation, cognitive decline, and loss of physical and functional autonomy.

Prevention of root caries and its management with minimally invasive techniques are essential in this vulnerable patient cohort.

Prevention of periodontal disease

Certain adults are more prone to periodontal disease than others because of genetic and/or microbial influences. It is important to understand that the progression of periodontal disease is not a continuous entity but occurs over periods of recurrent acute episodes.[56,57] In older adults, the general health status plays a crucial role in the disease progression. This does not imply that periodontal disease occurs because of the underlying health condition, but rather that the underlying condition makes the medically compromised elder more susceptible to it.[57] The actual disease onset may have occurred at an earlier age and before the elder became dependent and/or medically compromised. The progression, however, becomes more pronounced in elders who require more care.[57,58] These institutionalized dependent elders have usually poor oral health in comparison with elders living independently. Elevated levels of dental biofilms/plaque in the oral cavity lead to an increase in the oral bacterial load that could make the institutionalized dependent elder more susceptible to various systemic diseases, and augment the risk of death due to aspiration pneumonia.[40,50,51,53,59]

An important aspect to consider is the disease propensity. In a study with a mixed age cohort (age range 28 to 75 years) that induced experimental gingivitis and experimental peri-implant mucositis, the authors concluded that the inflammatory responses could be reversed at the biomarker level, soon after resuming plaque control.[60] Clinically, however, the restoration of gingival and peri-implant health to pre-experimental levels took longer than the stipulated time period. Furthermore, it was observed that the inflammatory responses were stronger around the implants.[60] Another study that had included only an elderly cohort (mean age 77.0 years) demonstrated similar findings in elders. In this study, the inflammatory response around the implants was again stronger than around the natural teeth.[61] Although a distinction between the peri-implant mucosal and gingival responses existed, the bacterial profiles in the submucosal/subgingival sulci were similar.[62] A longer healing period was required clinically to reverse the induced effects.[60-62] This demonstrates that periodontal disease must be contained or arrested before the effects of aging set in.

Although old age is not a contraindication to periodontal therapy in medically compromised institutionalized dependent elders, it is a general consensus that treatments that prevent disease progression are recommended.[63,64] Preventive strategies to minimize periodontal diseases in young or middle-aged adults are cardinal. This will limit the progression of the disease to an advanced age, thereby reducing the potential susceptibility as well as preserving the natural teeth. It has been documented that institutionalized dependent elders receiving regular oral care will retain more teeth when compared to elders not receiving regular care. However, routine care received by dependent elders does not have the same outcome as in younger adults.[65] Therefore, the preventive care should focus more on improving and maintaining oral hygiene. Factors such as manual dexterity, access to care, the knowledge and skills of the care providers, reluctance in providing care by the providers, and/or the reluctance of the elders themselves to accept or perform the required care all play an important role in preventing the disease progression.

The strategy for oral prevention in elderly or medically compromised patients should be individualized based on patient needs, and tailor-made (Fig 16-3). Provision of appropriate tools for oral care (manual or electric toothbrushes, flosses, floss-handles, interdental brushes, tongue scrapers), and modifying them based on the elders' disabilities or for the ease of use may dramatically help to improve oral hygiene.[66]

Fig 16-3 An elder brushing with a toothbrush with a modified handle. The handle can be modified by various techniques. In this picture, the handle is fitted with a bicycle handgrip to increase the size of the handle to improve grip on the toothbrush.

Primary prevention strategies such as routine biofilm removal and professional mechanical plaque removal reduce gingivitis and help decrease the prevalence of mild/moderate periodontitis.[67-69] Routine professional mechanical plaque debridement as supportive therapy restricts the progressive attachment loss and prevents further tooth loss.[70] Additionally, careful monitoring of risk factors, such as diabetes mellitus, can further prevent disease progression. Periodic recalls to assess the progress of the therapy are important. If during recall, the treatment benefits are not evident then a referral to the periodontist would be mandatory. Professional elimination of both supragingival and subgingival plaque deposits either by surgical or nonsurgical interventions is key to achieving success.[71] A successful therapy would result in the following[70]:

- reducing the sites of bleeding on probing and restricting them to below 15%
- restricting probing pocket depths to less than 5 mm
- eliminating active infections (absence of suppuration/pus).

It is empirical that there is complete compliance with home care, from both the patient and the caregiver, involving efficient plaque removal, and that scheduled recall visits are maintained.

Prevention of root caries

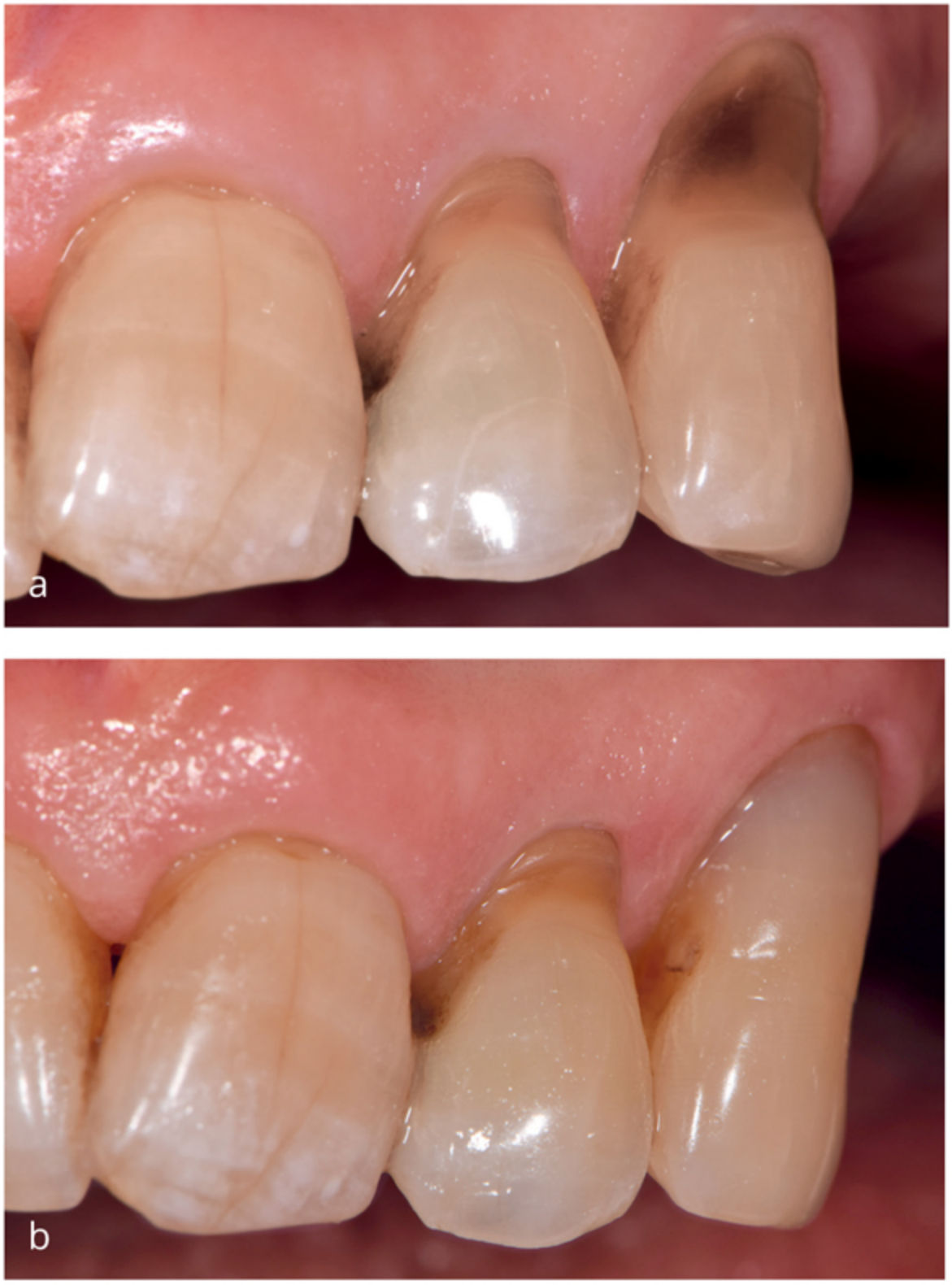
Preventive strategies for coronal caries are well documented in children and young adults, and these srategies are relatively similar for elderly patients. This section focuses on the preventive strategies for root caries in particular for elderly/medically compromised patients because of its increasingly high prevalence in this cohort.

The incidence of root caries is especially high in older individuals because of the inherent risk factors present[72-77]:

- periodontal disease and associated recessions
- xerostomia, hyposalivation
- impaired manual dexterity
- cognitive decline
- poor oral hygiene, a high Plaque Index
- high carbohydrate diet
- mobility issues with a lack of access to quality dental care.

Although root caries can be treated with traditional restorative procedures, this is not always possible, due to procedural difficulties or logistic reasons. Therefore, therapeutic strategies for root caries predominantly focus on prevention. Prevention of root caries can be primary, secondary, or tertiary. Primary prevention aims to prevent the initiation of root caries, whereas secondary and tertiary methods take place after the caries has occurred.

Tertiary prevention of root caries comprises invasive restorative procedures that constitute the conventional “drill and fill” and atraumatic restorative therapy (ART) (Fig 16-4) techniques.



Figs 16-4a and b Simple no drill technique for restoring arrested root caries using atraumatic restorative therapy (ART).

There is evidence in the literature suggesting that root caries can be prevented by the following methods:

- dietary control
- oral hygiene improvement
- regular recalls
- antimicrobial agents
- chewing gums
- topical fluorides (dentifrices, gels, varnishes, silver diammine fluoride [SDF])
- arginine-based dentifrices
- casein phosphopeptide (CPP) formulations with amorphous calcium phosphate (CPP-ACP), or amorphous calcium fluoride phosphate (CPP-ACFP)
- ozone applications.

Evidence is very strong for the use of topical fluorides in preventing/arresting root caries in elderly/medically compromised subjects.[78]

Fluorides in the prevention of root caries

The use of fluorides has always been beneficial in the prevention of coronal caries in children and young adults. Fluorides may be administered either systemically or topically. These may be administered at a community level by adding fluorides to water, milk, or salt. However, the systemic fluorides have a “pre-eruptive effect” and usually play only a minor role in their preventive action.[79] The most frequently used and popular method of fluoride administration is topical fluorides.[78] Topical fluorides may be applied either professionally or at home. However, the preparations and the fluoride concentrations for these applications are different. Professionally administered topical fluorides are available as varnishes or gels. Topical fluorides for self-application are available as dentifrices, rinses, and gels, as over-the-counter products.

Role of fluoride content in the prevention of root caries

The efficacy of topical fluorides depends on mainly two factors:

- the chemotherapeutic agent
- the concentration of the agent.

Based on the agent used, the concentrations vary and can be categorized as either low- or high-fluoride preparations. Fluorides have been commercially marketed since the 1950s in the United States. The concentration used at that time was fairly low (< 1,000 ppm F). For a significant caries reduction to occur the minimum concentration required is 1,000 ppm F. This was demonstrated in children with stannous fluoride (SnF). Currently, most regular fluoride dentifrices contain 1,000 to 1,500 ppm F. Concentrations above this would be considered as high-fluoride preparations. High-fluoride dentifrices are available with a fluoride content that ranges from 2,000 to 2,500 ppm, or even 5,000 ppm. The fluoride concentrations in professionally applied high-fluoride solutions/gels/varnishes are even higher.

Fluorides interfere with the caries process by decreasing the demineralization of the enamel and promoting its remineralization, and also play a role in limiting bacterial metabolism. The efficacy of regular fluoride-containing products is well documented in children and young adults. These dentifrices, varnishes, or gels have contributed significantly to reduce caries incidence in developed countries. The amount of CaF formed is directly proportional to the concentration of fluoride present in the saliva/biofilm. This concentration is an important aspect for its effectiveness in prevention. Studies have demonstrated that an increase of the F content by 500 ppm F within the range of 1,100 to 2,500 ppm F brings about an increase of 6% caries reduction. However, regular fluoride preparations are not very effective in high-risk individuals because the content of fluoride present in the saliva/biofilm is not sufficient. High-fluoride dentifrices demonstrate a clear superiority with their preventive effect against caries in high-risk individuals.

They demonstrate a reduction in the risk of root caries by 50%,[78] mainly because[78,80]:

- the F content is high in the saliva and plaque
- the CaF deposition is promoted
- there is a reduction in plaque accumulation
- there may be a reduction in the counts of certain cariogenic bacteria.

Recommendations for preventing root caries

Several recommendations exist for the prevention of root caries.[81] Reductions in plaque accumulation, bleeding, and inflammatory response have been noted even with low-concentration fluoride mouth rinses.[82] However, this was in a cohort of young adults (aged 19 to 48 years).[82]

The addition of an adjunct (1.5% arginine) with a regular fluoride (1,450 ppm F) toothpaste has been proven to be effective when compared with a standard regular fluoride toothpaste.[81,83,84] There is a small positive trend for the use of NaF mouth rinses in concentrations of even 225 to 900 ppm F.[81,85-88] A moderate effect has been observed for SDF against placebos when professionally applied either quarterly or annually.[81,89,90] Chlorhexidine mouth rinse demonstrates a moderate effect against placebos in controlling root caries lesions.[81,89,90] It is generally agreed that high-fluoride dentifrices work well in elderly and vulnerable adults. The type, concentration, and mode of application are dependent on the individual receiving the intervention.

It has been demonstrated that the application of high-fluoride-containing dentifrice (5,000 ppm F) (Fig 16-5) twice daily is effective in preventing and arresting root caries in adults when compared to regular fluoride-containing dentifrices.[10,79,81]

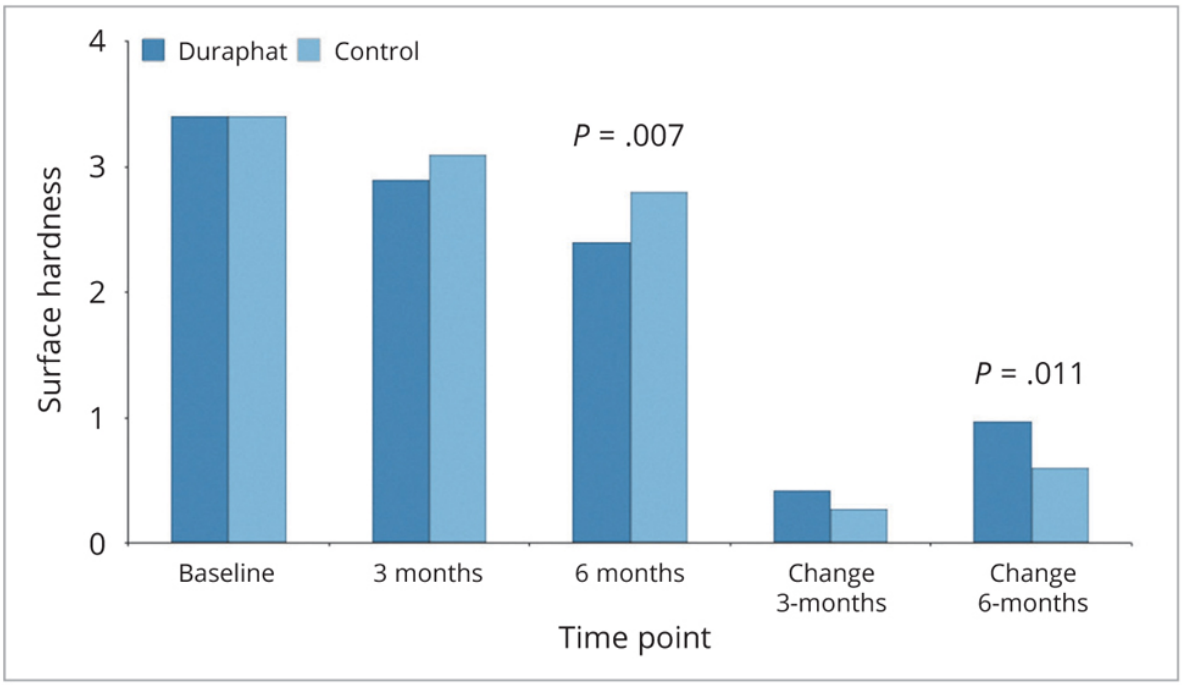


Fig 16-5 Results of a multicenter randomized controlled trial in adults (Srinivasan et al[10]) showing the significance (P < .05) of twice daily application of high-fluoride (5,000 ppm F) toothpaste (Duraphat) (surface hardness: 1, hard; 2, hard to leathery; 3, leathery; 4, leathery with local softening; 5, soft).

Although a general consensus does not exist, Gluzman et al[91] in 2013 put forward a widely accepted recommendation to prevent root caries lesions in elderly patients, with the use of chemotherapeutic agents. The most highly effective primary preventive agent suggested is the professional application of SDF solution annually (72% reduction in root caries lesions in comparison with placebo). The next best choice that is most effective is the use of 22,500 ppm F varnish applied every 1 to 3 months. This has demonstrated a 54% to 92% reduction in root caries lesions. The recommendations for self-application are the daily use of ACP toothpaste in conjunction with a NaF (250 ppm F) rinse, and the use of high-fluoride (5,000 ppm F) toothpaste, as the first and second choices, respectively.

The global population is increasing at an alarming rate and, along with it, the number of elderly individuals. Teeth are being retained to an advanced age, and problems with dentition will arise later in life. The general patient pool will be elderly adults, with/without a compromised medical status, requiring all facets of dental care. It is recommended that the treatment burden is kept to a minimum while treating this cohort of patients. Preservation of natural teeth becomes cardinal so that complex restorative and rehabilitative procedures can be avoided at this advanced age.

Preventive treatment concepts become the first line of therapy to avoid tooth loss, and the potentials of these concepts are particularly beneficial in improving oral health and reducing the susceptibility of elderly and medically compromised adults to oral diseases.

References

1. Ervin RB, Dye BA. Number of natural and prosthetic teeth impact nutrient intakes of older adults in the United States. Gerodontology 2012;29:e693–e702.
2. Gil-Montoya JA, Ponce G, Sanchez Lara I, et al. Association of the oral health impact profile with malnutrition risk in Spanish elders. Arch Gerontol Geriatr 2013;57:398–402.
3. Gil-Montoya JA, Subira C, Ramon JM, Gonzalez-Moles MA. Oral health-related quality of life and nutritional status. J Public Health Dent 2008;68:88–93.
4. Stenman U, Ahlqwist M, Bjorkelund C, Hakeberg M. Oral health-related quality of life: associations with oral health and conditions in Swedish 70-year-old individuals. Gerodontology 2012;29:e440–e446.

5. Müller F, Barter S. ITI Treatment Guide Vol. 9: Implant therapy in the geriatric patient. 1st edn. Berlin: Quintessence Publishing, 2016.
6. MacEntee M, Müller F, Wyatt CC. Oral healthcare and the frail elder: a clinical perspective. Iowa: Wiley-Blackwell, 2010.
7. da Mata C, Cronin M, O'Mahony D, et al. Subjective impact of minimally invasive dentistry in the oral health of older patients. Clin Oral Investig 2015;19:681–687.
8. McKenna G, Allen PF, O'Mahony D, et al. The impact of rehabilitation using removable partial dentures and functionally orientated treatment on oral health-related quality of life: a randomised controlled clinical trial. J Dent 2015;43: 66–71.
9. McKenna G, Allen PF, O'Mahony D, et al. Comparison of functionally orientated tooth replacement and removable partial dentures on the nutritional status of partially dentate older patients: a randomised controlled clinical trial. J Dent 2014;42:653–659.
10. Srinivasan M, Schimmel M, Riesen M, et al. High-fluoride toothpaste: a multicenter randomized controlled trial in adults. Community Dent Oral Epidemiol 2014;42:333–340.
11. Srinivasan M, Vazquez L, Rieder P, et al. Survival rates of short (6 mm) micro-rough surface implants: a review of literature and meta-analysis. Clin Oral Implants Res 2014;25:539–545.
12. ten Bruggenkate CM, Asikainen P, Foitzik C, Krekeler G, Sutter F. Short (6-mm) nonsubmerged dental implants: results of a multicenter clinical trial of 1 to 7 years. Int J Oral Maxillofac Implants 1998;13:791–798.
13. Friberg B, Grondahl K, Lekholm U, Branemark PI. Long-term follow-up of severely atrophic edentulous mandibles reconstructed with short Branemark implants. Clin Implant Dent Relat Res 2000;2:184–189.
14. Schimmel M, Müller F, Suter V, Buser D. Implants for elderly patients. Periodontol 2000 2017;73:228–240.

15. United Nations, Department of Economic and Social Affairs (UNDESA). World Population Ageing 2017 Highlights. New York: United Nations, Department of Economic and Social Affairs, 2017.
16. United Nations, DESA, Population Division. World Population Prospects 2019. https://population.un.org.wpp. Accessed 7 October 2020.
17. United Nations, Department of Economic and Social Affairs (UNDESA), Population Division. World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP/248. New York: United Nations, Department of Economic and Social Affairs, 2017.
18. Swiss Federal Statistical Office (FSO). Statistical Data on Switzerland (2016). Neuchâtel: Swiss Federal Statistical Office, 2016.
19. Boss GR, Seegmiller JE. Age-related physiological changes and their clinical significance. West J Med 1981;135:434–440.
20. Janssens JP, Pache JC, Nicod LP. Physiological changes in respiratory function associated with ageing. Eur Respir J 1999;13:197–205.
21. Weinstein JR, Anderson S. The aging kidney: physiological changes. Adv Chronic Kidney Dis 2010;17:302–307.
21. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. J Prosthet Dent 1972;27: 120–132.
22. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. 1972. J Prosthet Dent 2003;89: 427–435.
23. Tzakis MG, Osterberg T, Carlsson GE. A study of some masticatory functions in 90-year old subjects. Gerodontology 1994;11:25–29.
24. Newton J, Yemm R, Abel R, Menhinick S. Changes in human jaw muscles with age and dental state. Gerodontology 1993;10: 16–22.

26. Newton JP, Abel EW, Robertson EM, Yemm R. Changes in human masseter and medial pterygoid muscles with age: a study by computed tomography. Gerodontics 1987;3: 151–154.
27. Newton JP, McManus FC, Menhenick S. Jaw muscles in older overdenture patients. Gerodontology 2004;21:37–42.
28. Cerimele D, Celleno L, Serri F. Physiological changes in ageing skin. Br J Dermatol 1990;122(Suppl 35):13–20.
29. Campbell MJ, McComas AJ, Petito F. Physiological changes in ageing muscles. J Neurol Neurosurg Psychiatry 1973;36: 174–182.
30. Roberts S, Colombier P, Sowman A, et al. Ageing in the musculoskeletal system. Acta Orthop 2016;87(Suppl 363):15–25.
31. Newton JP, Yemm R. Changes in the contractile properties of the human first dorsal interosseous muscle with age. Gerontology 1986;32:98–104.
32. Mangoni AA, Jackson SH. Age-related changes in pharmacokinetics and pharmacodynamics: basic principles and practical applications. Br J Clin Pharmacol 2004;57:6–14.
33. Wallace E, Salisbury C, Guthrie B, et al. Managing patients with multimorbidity in primary care. BMJ 2015;350:h176.
34. Fortin M, Bravo G, Hudon C, Vanasse A, Lapointe L. Prevalence of multimorbidity among adults seen in family practice. Ann Fam Med 2005;3:223–228.
35. Cockburn N, Pradhan A, Taing MW, Kisely S, Ford PJ. Oral health impacts of medications used to treat mental illness. J Affect Disord 2017;223:184–193.
36. Ferri CP, Prince M, Brayne C, et al. Global prevalence of dementia: a Delphi consensus study. Lancet 2005;366(9503):2112–2117.
37. Prince M, Bryce R, Albanese E, et al. The global prevalence of dementia: a systematic review and metaanalysis. Alzheimers Dement 2013;9:63–75.e2.

38. Bishop NA, Lu T, Yankner BA. Neural mechanisms of ageing and cognitive decline. Nature 2010;464(7288):529–535.
39. Zekry D, Herrmann FR, Grandjean R, et al. Demented versus non-demented very old inpatients: the same comorbidities but poorer functional and nutritional status. Age Ageing 2008;37:83–89.
40. Andersson P, Renvert S, Sjogren P, Zimmerman M. Dental status in nursing home residents with domiciliary dental care in Sweden. Community Dent Health 2017;34:203–207.
41. Pritchard AB, Crean S, Olsen I, Singhrao SK. Periodontitis, microbiomes and their role in Alzheimer's disease. Front Aging Neurosci 2017;9:336.
42. Daly B, Thompsell A, Sharpling J, et al. Evidence summary: the relationship between oral health and dementia. Br Dent J 2018;223:846–853.
43. Schneider C, Zemp E, Zitzmann NU. Oral health improvements in Switzerland over 20 years. Eur J Oral Sci 2017;125:55–62.
44. Zitzmann NU, Staehelin K, Walls AWG, et al. Changes in oral health over a 10-yr period in Switzerland. Eur J Oral Sci 2008;116:52–59.
45. Mojon P, Thomason JM, Walls AW. The impact of falling rates of edentulism. Int J Prosthodont 2004;17:434–440.
46. Slade GD, Akinkugbe AA, Sanders AE. Projections of U.S. edentulism prevalence following 5 decades of decline. J Dent Res 2014;93:959–965.
47. Walls AW, Steele JG. Geriatric oral health issues in the United Kingdom. Int Dent J 2001;51(3 Suppl):183–187.
48. Schwendicke F, Krois J, Kocher T, et al. More teeth in more elderly: Periodontal treatment needs in Germany 1997–2030. J Clin Periodontol 2018;45:1400–1407.
49. Holmen A, Stromberg E, Hagman-Gustafsson ML, Wardh I, Gabre P. Oral status in home-dwelling elderly dependent on moderate or substantial supportive care for daily living:

prevalence of edentulous subjects, caries and periodontal disease. Gerodontology 2012;29:e503–e511.

50. Imsand M, Janssens JP, Auckenthaler R, Mojon P, Budtz-Jorgensen E. Bronchopneumonia and oral health in hospitalized older patients. A pilot study. Gerodontology 2002;19:66–72.
51. Quagliarello V, Ginter S, Han L, et al. Modifiable risk factors for nursing home-acquired pneumonia. Clin Infect Dis 2005;40:1–6.
52. Stromberg E, Hagman-Gustafsson ML, Holmen A, Wardh I, Gabre P. Oral status, oral hygiene habits and caries risk factors in home-dwelling elderly dependent on moderate or substantial supportive care for daily living. Community Dent Oral Epidemiol 2012;40:221–229.
53. Zuluaga DJ, Ferreira J, Montoya JA, Willumsen T. Oral health in institutionalised elderly people in Oslo, Norway and its relationship with dependence and cognitive impairment. Gerodontology 2012;29:e420–e426.
54. Kassebaum NJ, Smith AGC, Bernabe E, et al. Global, regional, and national prevalence, incidence, and disability-adjusted life years for oral conditions for 195 countries, 1990–2015: A systematic analysis for the global burden of diseases, injuries, and risk factors. J Dent Res 2017;96: 380–387.
55. Frencken JE, Sharma P, Stenhouse L, et al. Global epidemiology of dental caries and severe periodontitis: a comprehensive review. J Clin Periodontol 2017;44(Suppl 18): S94–S105.
56. Socransky SS, Haffajee AD, Goodson JM, Lindhe J. New concepts of destructive periodontal disease. J Clin Periodontol 1984;11:21–32.
57. Scannapieco FA, Cantos A. Oral inflammation and infection, and chronic medical diseases: implications for the elderly. Periodontol 2000 2016;72:153–175.

58. Loesche WJ, Lopatin DE. Interactions between periodontal disease, medical diseases and immunity in the older individual. Periodontol 2000 1998;16:80–105.
59. Heo SM, Haase EM, Lesse AJ, Gill SR, Scannapieco FA. Genetic relationships between respiratory pathogens isolated from dental plaque and bronchoalveolar lavage fluid from patients in the intensive care unit undergoing mechanical ventilation. Clin Infect Dis 2008;47:1562–1570.
60. Salvi GE, Aglietta M, Eick S, et al. Reversibility of experimental peri-implant mucositis compared with experimental gingivitis in humans. Clin Oral Implants Res 2012;23:182–190.
61. Meyer S, Giannopoulou C, Courvoisier D, et al. Experimental mucositis and experimental gingivitis in persons aged 70 or over. Clinical and biological responses. Clin Oral Implants Res 2017;28:1005–1012.
62. Meyer S, Giannopoulou C, Cancela J, et al. Experimental mucositis/gingivitis in persons aged 70 or over: microbiological findings and prediction of clinical outcome. Clin Oral Investig 2019;23:3855–3863.
63. Renvert S, Persson GR. Treatment of periodontal disease in older adults. Periodontol 2000 2016;72:108–119.
64. Boehm TK, Scannapieco FA. The epidemiology, consequences and management of periodontal disease in older adults. J Am Dent Assoc 2007;138(Suppl):26S–33S.
65. Nordstrom G, Bergman B, Borg K, et al. A 9-year longitudinal study of reported oral problems and dental and periodontal status in 70- and 79-year-old city cohorts in northern Sweden. Acta Odontol Scand 1998;56:76–84.
66. Gonsalves WC, Wrightson AS, Henry RG. Common oral conditions in older persons. Am Fam Physician 2008;78: 845–852.
67. Tonetti MS, Bottenberg P, Conrads G, et al. Dental caries and periodontal diseases in the ageing population: call to action to protect and enhance oral health and well-being as an essential

component of healthy ageing: Consensus report of group 4 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases. J Clin Periodontol 2017;44(Suppl 18):S135–S144.

68. Eke PI, Dye BA, Wei L, et al. Prevalence of periodontitis in adults in the United States: 2009 and 2010. J Dent Res 2012;91:914–920.
69. Tonetti MS, Eickholz P, Loos BG, et al. Principles in prevention of periodontal diseases: Consensus report of group 1 of the 11th European Workshop on Periodontology on effective prevention of periodontal and peri-implant diseases. J Clin Periodontol 2015;42(Suppl 16):S5–S11.
70. Sanz M, Baumer A, Buduneli N, et al. Effect of professional mechanical plaque removal on secondary prevention of periodontitis and the complications of gingival and periodontal preventive measures: consensus report of group 4 of the 11th European Workshop on Periodontology on effective prevention of periodontal and peri-implant diseases. J Clin Periodontol 2015;42(Suppl 16):S214–S220.
71. Heitz-Mayfield LJ, Trombelli L, Heitz F, Needleman I, Moles D. A systematic review of the effect of surgical debridement vs non-surgical debridement for the treatment of chronic periodontitis. J Clin Periodontol 2002;29(Suppl 3):92–102.
72. Hayes M, Da Mata C, Cole M, et al. Risk indicators associated with root caries in independently living older adults. J Dent 2016;51:8–14.
73. Zhang J, Leung KCM, Sardana D, Wong MCM, Lo ECM. Risk predictors of dental root caries: a systematic review. J Dent 2019;89:103166.
74. Bignozzi I, Crea A, Capri D, et al. Root caries: a periodontal perspective. J Periodontal Res 2014;49:143–163.
75. Christensen LB, Bardow A, Ekstrand K, et al. Root caries, root surface restorations and lifestyle factors in adult Danes. Acta Odontol Scand 2015;73:467–473.

76. Ritter AV, Shugars DA, Bader JD. Root caries risk indicators: a systematic review of risk models. Community Dent Oral Epidemiol 2010;38:383–397.
77. Tan HP, Lo EC. Risk indicators for root caries in institutionalized elders. Community Dent Oral Epidemiol 2014;42:435–440.
78. Ekstrand KR. High fluoride dentifrices for elderly and vulnerable adults: does it work and if so, then why? Caries Res 2016;50 (Suppl 1):15–21.
79. Ekstrand KR, Poulsen JE, Hede B, et al. A randomized clinical trial of the anti-caries efficacy of 5,000 compared to 1,450 ppm fluoridated toothpaste on root caries lesions in elderly disabled nursing home residents. Caries Res 2013;47:391–398.
80. Exterkate RA, Crielaard W, Ten Cate JM. Different response to amine fluoride by *Streptococcus mutans* and polymicrobial biofilms in a novel high-throughput active attachment model. Caries Res 2010;44:372–379.
81. Wierichs RJ, Meyer-Lueckel H. Systematic review on noninvasive treatment of root caries lesions. J Dent Res 2015;94:261–271.
82. Hagedorn B, Willershausen B, Ernst CP, Wehse T, Schimmel M. A comparative study of 2 fluoride-based mouthrinses. Quintessence Int 2000;31:125–128.
83. Hu DY, Yin W, Li X, et al. A clinical investigation of the efficacy of a dentifrice containing 1.5% arginine and 1450 ppm fluoride, as sodium monofluorophosphate in a calcium base, on primary root caries. J Clin Dent 2013;24(Spec no A):A23–A31.
84. Souza ML, Cury JA, Tenuta LM, et al. Comparing the efficacy of a dentifrice containing 1.5% arginine and 1450 ppm fluoride to a dentifrice containing 1450 ppm fluoride alone in the management of primary root caries. J Dent 2013; 41(Suppl 2):S35–S41.
85. Fure S, Lingstrom P. Evaluation of different fluoride treatments of initial root carious lesions in vivo. Oral Health Prev Dent 2009;7:147–154.

86. Ripa LW, Leske GS, Forte F, Varma A. Effect of a 0.05% neutral NaF mouthrinse on coronal and root caries of adults. Gerodontology 1987;6:131–136.
87. Wallace MC, Retief DH, Bradley EL. The 48-month increment of root caries in an urban population of older adults participating in a preventive dental program. J Public Health Dent 1993;53:133–137.
88. Wyatt CC, MacEntee MI. Caries management for institutionalized elders using fluoride and chlorhexidine mouthrinses. Community Dent Oral Epidemiol 2004;32:322–328.
89. Tan HP, Lo EC, Dyson JE, Luo Y, Corbet EF. A randomized trial on root caries prevention in elders. J Dent Res 2010; 89:1086–1090.
90. Zhang W, McGrath C, Lo EC, Li JY. Silver diamine fluoride and education to prevent and arrest root caries among community-dwelling elders. Caries Res 2013;47:284–290.
91. Gluzman R, Katz RV, Frey BJ, McGowan R. Prevention of root caries: a literature review of primary and secondary preventive agents. Spec Care Dent 2013;33:133–140.

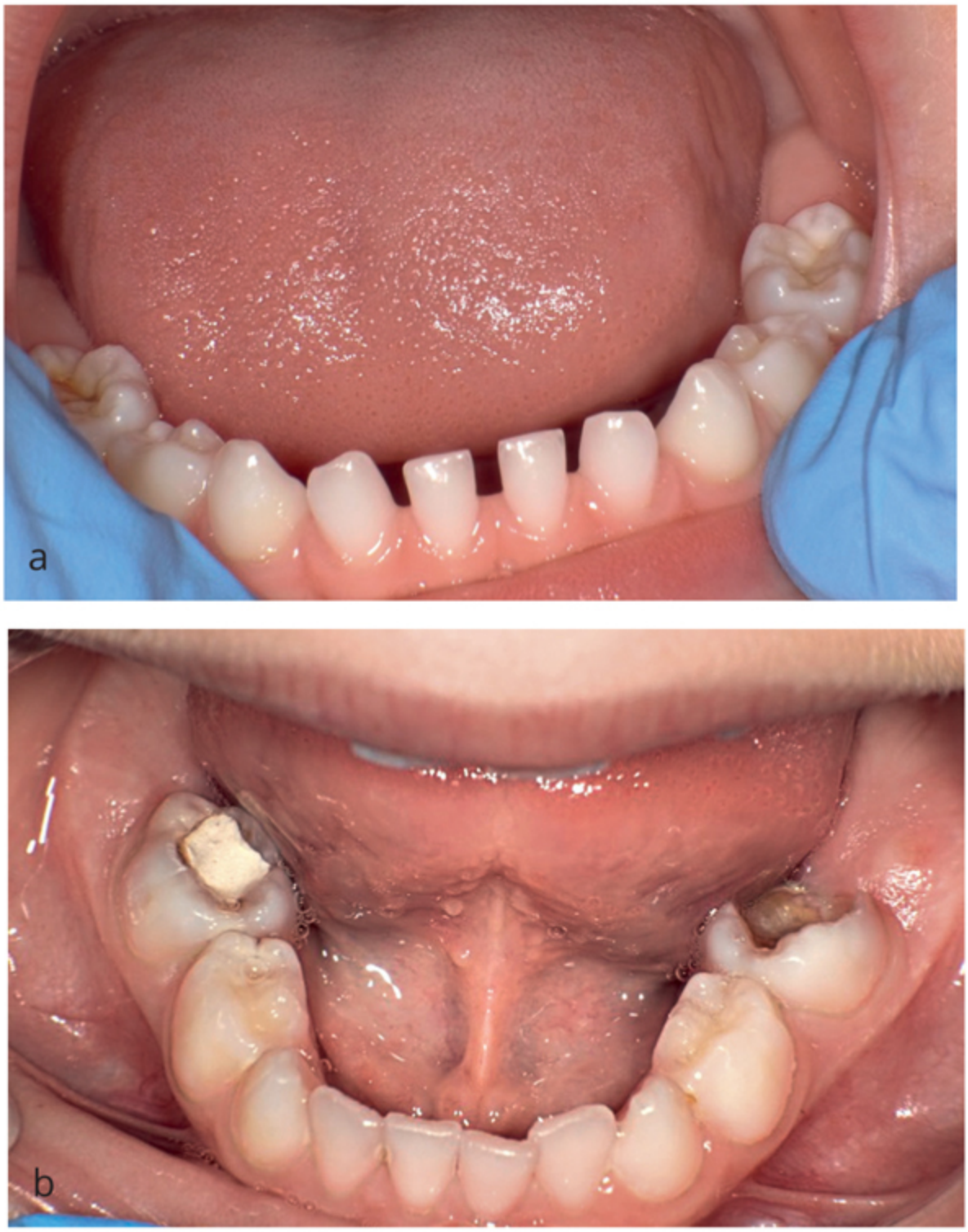
17

Caries risk or activity: Which should we assess?

Margherita Fontana, Ruth M. Santamaría

Effective management of dental caries throughout the lifespan of an individual depends on an ongoing process that involves not only detection and diagnosis of existing caries lesions, with a focus on understating lesion activity, but also an assessment of caries risk, both at the tooth and patient level (Fig 17-1). This information helps to determine the activity of the caries disease process at the tooth level, which unfortunately is still the strongest indicator of future caries activity or risk at the individual level. However, the assessment of risk factors further aids in understanding why there is disease activity and what factors drive the progression of this disease activity, as well as which factors aid in lesion arrest. Thus, information from both an assessment of lesion activity and caries risk factors is necessary, together with an understanding of the patient's needs and desires, available evidence supporting treatment alternatives, and the dental practitioner's clinical expertise should be used to reach a clinical decision on how to effectively control existing lesions and prevent occurrence of new caries lesions in a personalized manner for each individual. In the future, as caries risk tools become informed by richer and newer evidence sources, and

validated across patient groups in different countries, they may become increasingly more accurate in their ability to predict the caries disease process before it develops, and help target preventive interventions in a more cost-effective manner.

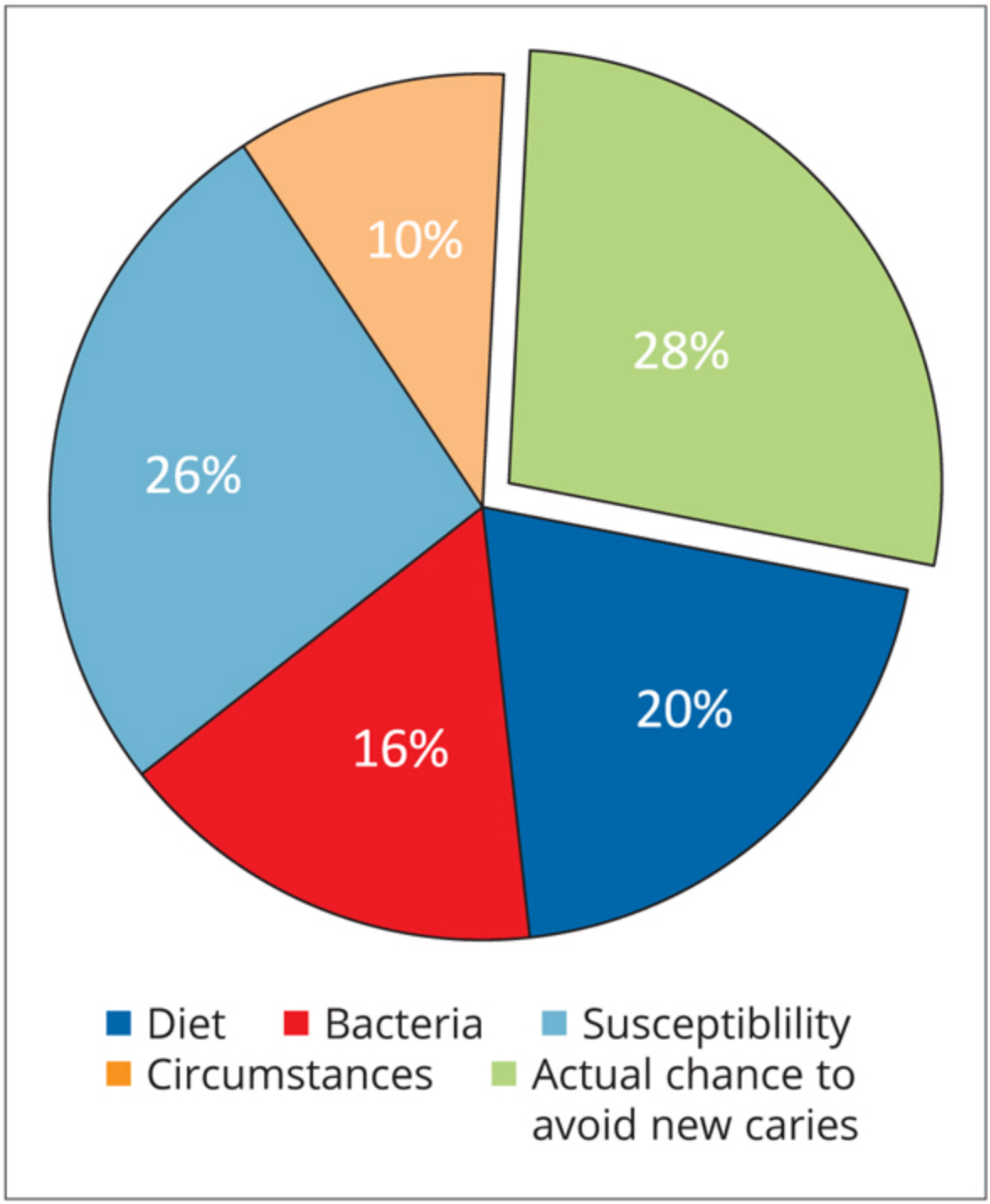


Figs 17-1a and b Individuals carry different caries risk and the outcome can be seen in patients with varying caries activity and

damage due to caries. **(a)** Lower risk, activity, and experience. **(b)** Higher risk, activity, and experience.

Caries risk assessment

Risk assessment is an essential component of targeted health care delivery. Dentistry has entered an era of “personalized care,” in which targeting care to individuals or groups based on their risk has been advocated as a means to make use of limited existing resources, especially when the disease process is unequally distributed among the population. Caries risk assessment is defined as the process of establishing the probability of an individual to develop new caries lesions over a certain time period, and/or the probability that there will be a change in severity and/or activity of currently present lesions.[1,2] But a risk assessment involves much more than just caries prediction. It also involves identification of factors that cause or increase/decrease risk of disease, to then target cost-effective interventions to manage the caries disease process and determine the periodicity of these services.[3] In fact, caries risk assessment has been considered an essential component of cariology curricula in dental education,[4] and caries management systems (eg, International Caries Classification and Management System) (Fig 17-2).



Figs 17-2a Caries risk can be assessed by various tools or systems: Cariogram tool, as it appears after entering the data for a patient. The pie chart shows the actual chance to avoid new caries (green sector, 27% in this example). Reprinted from Al Mulla et al[5] with permission.

CARIES PROTECTIVE AND RISK FACTORS

Caries protective factors

Fluoride toothpaste

- Twice daily brushing with fluoridated toothpaste (at least 1,000 ppm)

Dental care

- Regular preventive-oriented dental care, including for example application of topical fluoride

Systemic fluoride

- Access to fluoridated drinking water or other community fluoride vehicles (where available)

Caries risk factors

Risk factors, social/medical/behavioral

- Hyposalivation, either drug-, disease-, head/neck-radiation or/and induced
- High intake (amount/frequency) of free sugars from drinks (including fruit juice/smoothies), snacks and meals
- Low socioeconomic level, low health literacy, health access barriers
- Inability to comply, low motivation and engagement
- Special health care needs, physical disabilities
- Symptomatic-driven dental attendance

Risk factors, clinical

- Recent caries experience and presence of active caries lesion(s)
- PRS/prs*
- Poor oral hygiene with thick plaque accumulation
- Plaque stagnation areas (higher biofilm retention)
- Low salivary flow rate

Additional risk factors for children

- Mother/caregiver with active caries lesions
- Bottle/non-spill cup/pacifier containing natural or added sugar used frequently or at night (this includes milk and fruit juices/smoothies)
- Non-daily use of at least 1,000 ppm fluoridated toothpaste
- Eruption of molar teeth

Particular risk factors for elderly patients

- Exposed root surfaces (dentin)
- Reduced ability to deliver oral hygiene

At lower risk

- Protective factors are present
- None of the risk factors marked in red are present
- Any other risk factors are within "safe" ranges (eg sugary snacks, oral hygiene practice, fluoride exposure)

At higher risk

- One or more of the risk factors marked in red are present
- The level or combination of other risk factors suggests a higher risk status
- With protective factors absent

* Pulpal involvement-Roots-Sepsis Index (modified from PUFA/pufa): clinical consequences of untreated caries. P/p caries process reached pulp chamber; Roots (R/r): caries process destroyed tooth structures (non-restorable); S/s: pus-releasing tract/tooth-related pus containing swelling

Note: Risk factors in red will always classifiy an individual as high caries risk.

Figs 17-2b Caries risk can be assessed by various tools or systems: The ICCMS Caries Care system. Reprinted from Martignon et al,[6] with permission.

What does validation of a caries risk form entail?

Validation of a caries prediction tool involves longitudinal follow-up of caries-related changes over time, with the outcome expressed as continuous values, eg sensitivity, specificity, and area under receiver operating characteristic curves (AUC).[3] Because of the multifactorial and chronic nature of the dental caries disease process, studies on risk assessment tend to be complex, with multiple factors influencing risk at the individual, family, and community level, and challenging the prediction throughout the lifetime.[7] However, caries experience/activity is still considered one of the greatest indicators of future risk.[8] Usually, demographic, social, behavioral, and biologic variables, along with the clinical/radiographic examination and supplementary tests, are used to develop a caries risk profile or category (for example low, moderate, or high caries risk),[9] which needs to be reassessed periodically over time. For a clinician, the concepts of assessment of risk and prognosis are important parts of clinical decision-making. In fact, the dental practitioner's overall subjective impression of the patient has good predictive power for caries risk,[2,10] although this is not always factored in existing caries risk forms.[9]

Existing evidence suggests that it is difficult to accurately identify "at risk" patients, and the evidence on targeting preventive measures for high-risk individuals is still limited. Most studies on risk assessment have been conducted in children, and there is very little evidence from adults.[11] However, most experts and dentistry organizations contend that when the wellbeing of the patient is considered, it is more important to carry out a risk assessment incorporating the best available evidence than just doing nothing due to lack of strong evidence. Yet a survey of clinical practices within the US Practice-Based Research Networks suggests that a significant

proportion of dental practitioners had not adopted caries treatments based on assessment of caries risk.[12]

Risk tools available for use in practice

Caries risk tools must be inexpensive and have a high level of accuracy to be cost-effective,[13] and they must be quick and require limited armamentarium to be acceptable.[14] There are numerous strategies and tools available for caries risk assessment in daily practice, including an informal assessment, use of structured paper forms, and use of computer-based programs (eg, Cariogram; Fig 17-2a). While the Cariogram is probably the most studied caries risk tool across the world, the majority of other caries risk tools are expert-based with limited validation.[15]

Today, the majority of structured paper caries risk forms available for use have not been validated, except for some forms in selected patient populations.[3,16,17]

How is low, moderate, and high caries risk defined in most forms?

In general, in most risk forms a low caries risk assessment is based on a combination of the following factors: no caries lesion development or progression for a recent period of time; low amount of plaque; low frequency of sugar intake; no presence of salivary problems; and adequate exposure to protective factors. In addition, the following factors, whether appearing singly or in combination, would yield a moderate to high risk assessment of caries[6,18]:

- development of new caries lesions
- presence of active lesions

- placement of restorations due to active disease since the patient's last examination
- detrimental change in amount of plaque
- incremental frequency of carbohydrate consumption
- decrease in saliva flow
- decrease in exposure to caries-protective factors.

What is the roll of caries risk assessment in interprofessional settings?

As imprecise as most risk tools are, they can be particularly helpful when used by individuals not trained to examine the oral cavity and assess caries lesion activity. For example, expanded partnership with the medical community is a promising strategy for reducing disparities in dental caries among young children. A validated caries risk instrument for use in primary health care settings would aid with triaging children at higher risk for preventive and referral strategies. The validity of caries risk tools for use in medical settings in the US is currently being investigated.[18]

Caries activity

Detecting dental caries is important to plan treatment; however, it merely represents part of the caries diagnostic process. The assessment of lesion activity, whether a lesion is active or inactive, and lesion severity (depth, and presence or absence of cavitation) are essential for appropriate control and management of the caries process.

The ability of a dental practitioner to accurately assess the lesion activity will be reflected in the management strategy to be implemented, whether noninvasive, minimally invasive, or an

operative treatment. Not considering lesion activity could lead to superfluous treatment on inactive lesions, or even operative treatment involving unnecessary tissue removal. If the concept of caries lesion activity is understood, clinicians can use it routinely as part of the daily caries diagnostic process in favor of their patients.

What is caries activity?

Dental caries is a dynamic process determined primarily on the availability of the fermentable dietary sugars, bacteria, biofilm, and host factors. Metabolic activity takes place continually within the bacterial plaque resulting in several fluctuations in pH. If the pH drops, loss of calcium and phosphate ions from the tooth surface will occur, and if the pH increases, gain of mineral may compensate for the mineral loss. The cumulative result may be a net loss of mineral causing dental hard tissue dissolution and possibly a caries lesion. If a lesion is manifested it can be classified according to activity (active or inactive). In active lesions the demineralization process is in progress and loss of minerals occurs, whereas for inactive lesions the demineralization process is interrupted.[19,20]

In general, the activity of the lesion mirrors the existing de- and remineralization processes in the caries lesion. In light of this, caries activity has been defined as “a concept that reflects the mineral balance, in terms of net mineral loss, net mineral gain, or stasis over time.”[21]

Criteria for caries activity assessment

Mostly clinical indicators, including lesion visual appearance, tactile feeling, potential for biofilm accumulation – mainly in stagnation

areas, and gingival status have been used to assess the activity of caries lesions (Fig 17-3).[22-25] Although no single indicator determines whether a lesion is active or arrested, lesion tactile feeling and visual appearance have been used in clinical practice as the most consistent indicators for activity assessment.[25] In Table 17-1, the main characteristics of active and inactive caries lesions based on tactile feeling and visual appearance are presented.[22,26]

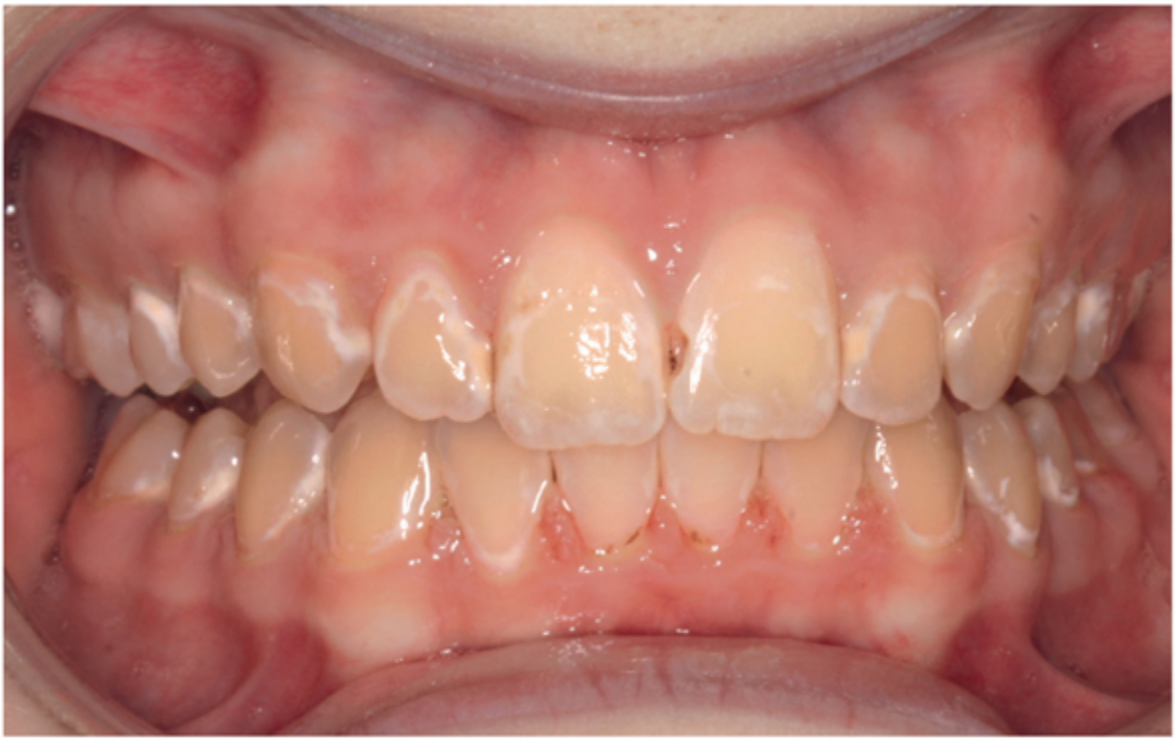


Fig 17-3 The signs and symptoms of caries activity can be assessed according to the nature of the caries process: plaque accumulation and gingivitis indicate inadequate oral hygiene and an opaque, non-shiny initial lesions suggest overall active (ongoing) demineralization.

Table 17-1 Characteristics of active and inactive caries lesions on coronal caries based on tactile feeling

Characteristics of active lesions	Characteristics of inactive lesions
Surface of lesion is whitish/yellowish	Surface of enamel is whitish, brownish, or black
Lesion looks opaque with loss of luste. Lesion feels rough (enamel lesion) or feels soft/leathery on gentle probing (dentin lesion).	Surface is shiny and feels hard on gentle probing
Lesion is located in a plaque stagnation area*	Lesion may be located at some distance from the gingival margin (smooth surfaces)
Lesion may be covered by thick plaque before cleaning	Lesion may not be covered by thick plaque before cleaning

*Pits and fissures of occlusal surfaces, near the gingival margin, proximal surfaces, etc.

Methods for assessment of caries activity

A variety of systems (Nyvad criteria, Maltz criteria, Ekstrand criteria, International Caries Detection and Assessment System [ICDAS]-II, etc), materials (ClinPro, 3M), and tools (quantitative light-induced fluorescence [QLF]; DIAGNOdent, Kavo; SoproLife, Acteon; Calcivis) (Fig 17-4) have been used for assessing caries lesion activity. All of them have benefits and drawbacks in terms of clinical applicability, ease of use, validity of the method, costs for clinician and patient, etc. The most commonly used caries activity concepts are those involving visual-tactile parameters, describing the activity according to appearance and tactile feeling.[27] A description of the most used concepts to assess caries activity is presented in Table 17-2.

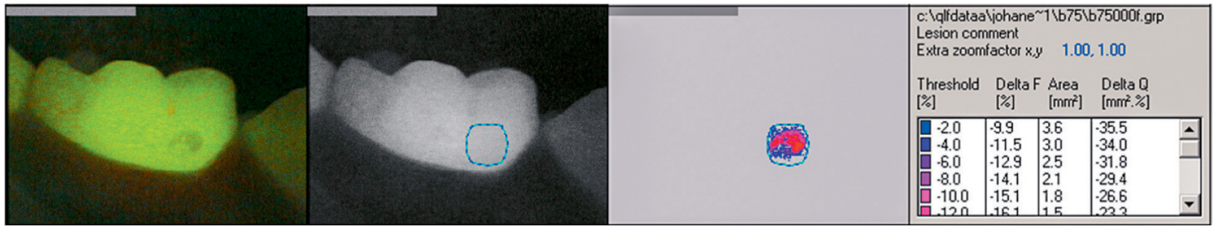


Fig 17-4 Additional tools, systems, or materials, such as quantitative light-induced fluorescence (QLF) and DIAGNOdent, are used for assessing the level mineralization and caries activity of a caries lesion, and allow control of the success of primary or secondary prevention over time.

Table 17-2 Description of different concepts used for caries lesion activity assessment

Concept		Criteria	Description
Index	Nyvad criteria (1999)[28]	Score 0: Sound	Normal enamel translucency and texture.
		Score 1: Active caries – intact surface	Surface of enamel is whitish/yellowish opaque with loss of luster; feels rough when the tip of the probe is moved gently across the surface; generally covered with plaque. No clinically detectable loss of substance.
			Smooth surface: caries lesion typically located close to gingival margin.
			Fissure/pit: intact fissure morphology; lesion extending along the walls of the fissure.
		Score 2: Active caries – surface discontinuity	Same criteria as score 1. Localized surface defect (microcavity) in enamel only. No undermined enamel or softened floor detectable with the explorer.
		Score 3: Active caries – cavity	Enamel/dentin cavity easily visible with the naked eye; surface of cavity feels soft or leathery on gentle probing. There may or may not be pulpal involvement.
		Score 4: Inactive caries – intact surface	Surface of enamel is whitish, brownish, or black. Enamel may be shiny and feels hard and smooth with gentle probing. No clinically detectable loss of substance.
			Smooth surface: caries lesion typically located at some distance from gingival margin.
			Fissure/pit: intact fissure morphology; lesion extending along the walls of the fissure.
		Score 5: Inactive caries – surface discontinuity	Same criteria as score 4. Localized surface defect (microcavity) in enamel only. No undermined enamel or softened floor detectable with the explorer.
		Score 6: Inactive caries – cavity	Enamel/dentin cavity easily visible with the naked eye; surface of cavity may be shiny and feels hard on probing with gentle pressure. No pulpal involvement.
	ICDAS-CAA[23,24]	ICDAS 1–3	Active lesion: Surface of enamel is whitish/yellowish opaque with loss of luster; feels rough when the tip of the probe is moved gently across the surface. Lesion is in a plaque stagnation area, ie pits and fissures, near the gingival and approximal surface below the contact point.
			Inactive lesion: Surface of enamel is whitish, brownish, or black. Enamel may be shiny and feels hard and smooth on gently probing. For smooth surfaces, the caries lesion is typically located at some distance from the gingival margin.
		ICDAS 4	Dentin lesions, no evident cavitation, probably active
		ICDAS 5, 6	Active lesion: Cavity feels soft or leathery on gently probing the dentin.
			Inactive lesion: Cavity may be shiny and feels hard on gently probing the dentin.

Material/ tool	ClinPro (2007) (no longer commercially available)	Detect variations on pH	Active lesions: pH ≤ 5, blue color change of the impression material, due to lactic acid production.
			Inactive lesion: plaque pH > 5, no color change of the impression material.
	DIAGNOdent (2010)[29]	Based on fluorescence: The device measures changes in tooth structure due to caries and reports variations on the fluorescence index according to the lesion activity	Higher fluorescence readings: active lesion
			Lower fluorescence readings: inactive lesion
	Soprolife (2013)[30,31]	Based on fluorescence: A diagnostic camera detects caries lesions and shows color variations to differentiate between active and inactive lesions.	Active lesion: Bright red
			Inactive lesion: Red
	QLF (2016)[32]	Based on fluorescence: The device detects caries lesions and lesion activity. It shows color variations to differentiate between active and inactive lesions.	Active lesion: Orange/red
			Inactive lesion: Green
	Calcivis (2018)[33]	Based on bioluminescence: An integrated camera visualizes the amount of calcium ions on the lesion as a light signal and assesses caries lesion activity.	Active lesion: Bright blue signal: active lesion
			Inactive lesion: No signal

CAA: Caries Activity Assessment; QLF, quantitative light-induced fluorescence.

How valid are the methods to assess caries activity?

The use of validated methods/tools is crucial when assessing caries lesion activity. Ideally, a method should have a high sensitivity in order to minimize false-negative results. The most studied methods to assess caries activity are based on visual-tactile parameters, described by specific scoring criteria, mainly using the Nyvad criteria and ICDAS. Those studies report their findings mainly based on the intra-examiner and inter-examiner reproducibility. On the other hand, the sensitivity and specificity of the methods are rarely reported.

Nyvad et al[28] showed a good reliability of the index (inter-examiner 0.78 and 0.80; intra-examiner 0.74 and 0.85) when repeated

examinations of 50 children (9- to 14-year-olds) by two examiners over a period of 3 years were performed. Braga et al[34] compared the clinical performance of the Nyvad criteria and ICDAS-II to assess caries lesion activity: 139 three- to 12-year-olds (763 primary molars) were examined by two calibrated examiners. Visual criteria showed excellent reproducibility regarding lesion activity (Nyvad 0.90; ICCDAS-II 0.91). In addition, a good association in caries activity assessment between both indexes (r = 0.88; *P* < .001) was observed.

Recently, a systematic review[27] assessed different methods/tools available for activity assessment of coronal caries lesions. The techniques were classified as:

- systems based on combinations of visual-tactile criteria (mainly the Nyvad criteria and ICDAS)
- devices based on:
  - pH assessment (ClinPro)
  - fluorescence (DIAGNOdent, Soprolife, and QLF)
  - bioluminescence (Calcivis).

The results of the review showed good intrinsic validity of the Nyvad criteria (sensitivity 0.71; specificity 0.73 to 0.75; intra-examiner 0.68 to 0.80; inter-examiner reproducibility 0.74 to 0.90) and ICDAS-II (sensitivity 0.87 [enamel] and 0.60 [dentin]; specificity 0.50 [enamel] and 0.95 [dentin]; intra-examiner 0.11 to 0.96; inter-examiner reproducibility 0.20 to 0.95). In addition, the authors reported that further research is needed to evaluate the in vivo validity of fluorescence and bioluminescence methods in both permanent and primary teeth.

Assigning lesion activity

Even using a reliable method for lesion activity assessment, it can be challenging to decide whether a lesion is active or inactive, since the lesion may contain characteristics of both active and inactive lesions,

or the lesion may be in an in-between phase between active and inactive caries lesion.[28] Therefore, from a treatment perspective, it is important to carry out repeated assessment of the lesion activity, which will confirm the diagnosis or lead to a change in management modality if the lesion is seen to progress. Active lesions always require management, which can be either nonoperative or operative, depending on the disease severity (depth, and presence or absence of cavitation), while inactive caries lesions require control, according to individual patient caries risk.

In summary, the assessment of caries lesion activity, whether a lesion is active or inactive, is an essential component of the caries diagnosis for adequate control and management of the caries process. An active caries lesion is considered to have a higher probability of change (whether progression, arrest, or regression), compared to an inactive lesion. In contrast, an inactive caries lesion (arrested) is considered to have a lower likelihood of change, since there is less movement of minerals and the lesion stays at the same severity phase. There are different methods/techniques for lesion activity assessment, though the most studied methods are those based on visual-tactile parameters mainly using the Nyvad criteria and ICDAS. Those methods have been shown to be reliable in terms of method validity (sensitivity/specificity), and reproducibility (inter- and intra-examiner). Before considering the use of a method/tool the clinical validity of the method should be considered.

Multiple caries risk assessment tools have been developed, yet the evidence supporting their use is either limited, or it suggests that the activity of the caries disease process at the tooth level is still, unfortunately, the strongest indicator of future caries activity or risk at the individual level. However, the assessment of risk factors further aids in understanding why there is disease activity and what the factors are driving the progression of this disease activity, as well as factors that aid in

lesion arrest. Thus, information from both an assessment of lesion activity and caries risk factors is necessary to reach a clinical decision on how to effectively control existing lesions and prevent occurrence of new caries lesions in a personalized manner for each individual.

References

1. Fontana M, Zero DT. Assessing patients' caries risk. J Am Dent Assoc 2006;137:1231–1239.
2. Fontana M. The clinical, environmental, and behavioral factors that foster early childhood caries: evidence for caries risk assessment. Pediatr Dent 2015;37:217–225.
3. Brons-Piche E, Eckert GJ, Fontana M. Predictive validity of a caries risk assessment model at a dental school. J Dent Educ 2019;83:144–150.
4. Fontana M, Guzmán-Armstrong S, Schenkel AB, et al. Development of a core curriculum framework in cariology for U.S. dental schools. J Dent Educ 2016;80:705–720.
5. Al Mulla AH, Al Kharsa S, Kjellberg H, Birkhed D. The use of Cariogram to evaluate caries-risk profiles in orthodontic patients. World J Orthod 2010;11:160–167.
6. Martignon S, Pitts NB, Goffin G, et al. CariesCare practice guide: consensus on evidence into practice. Br Dent J 2019;227:353–362.
7. Mejàre I, Axelsson S, Dahlén G, et al. Caries risk assessment. A systematic review. Acta Odontol Scand 2014;72:81–91.
8. Twetman S, Fontana M, Featherstone JDB. Risk assessment - can we achieve consensus? Community Dent Oral Epidemiol 2013;41:e64–e70.
9. Twetman S, Fontana M. Patient caries risk assessment. Monogr Oral Sci 2009;21:91–101.

10. Disney JA, Graves RC, Stamm JW, Bohannan HM, Abernathy JR, Zack DD. The University of North Carolina Caries Risk Assessment study: further developments in caries risk prediction. Community Dent Oral Epidemiol 1992;20:64–75.
11. Fontana M, Gonzalez-Cabezas C. Minimal intervention dentistry: part 2. Caries risk assessment in adults. Br Dent J 2012;213:447–451.
12. Riley JL 3rd, Gordan VV, Rindal DB, et al. Preferences for caries prevention agents in adult patients: findings from the dental practice-based research network. Community Dent Oral Epidemiol 2010;38:360–370.
13. Quinonez R, Crall J. Caries risk. In: Berg J, Slayton R (eds). Early childhood oral health. Oxford: Wiley-Blackwell, 2009:170–197.
14. Stamm JW, Disney JA, Graves RC, Bohannan HM, Abernathy JR. The University of North Carolina Caries Risk Assessment Study. I: Rationale and content. J Public Health Dent 1988;48:225–232.
15. Tellez M, Gomez J, Pretty I, Ellwood R, Ismail AI. Evidence on existing caries risk assessment systems: are they predictive of future caries? Community Dent Oral Epidemiol 2013;41:67–78.
16. Featherstone JDB, Chaffee BW. The evidence for caries management by risk assessment (CAMBRA). Adv Dent Res 2018;29:9–14.
17. Domejean S, White JM, Featherstone JDB. Validation of the CDA CAMBRA caries risk assessment: a six-year retrospective study. J Calif Dent Assoc 2011;39:709–715.
18. Fontana M, Gonzalez-Cabezas C. Evidence-based dentistry caries risk assessment and disease management. Dent Clin North Am 2019;63:119–128.
19. Nyvad B, Fejerskov O. Assessing the stage of caries lesion activity on the basis of clinical and microbiological examination. Community Dent Oral Epidemiol 1997;25:69–75.

20. Ekstrand KR, Zero DT, Martignon S, Pitts NB. Lesion activity assessment. Monogr Oral Sci 2009;21:63–90.
21. Machiulskiene V, Campus G, Carvalho JC, et al. Terminology of Dental Caries and Dental Caries Management: Consensus Report of a Workshop Organized by ORCA and Cariology Research Group of IADR. Caries Res 2020;54:7–14.
22. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 1999;33:252–260.
23. Nyvad B, Machiulskiene V, Baelum V. Construct and predictive validity of clinical caries diagnostic criteria assessing lesion activity. J Dent Res 2003;82:117–122.
24. Ekstrand KR, Ricketts DNJ, Longbottom C, Pitts NB. Visual and tactile assessment of arrested initial enamel carious lesions: an in vivo pilot study. Caries Res 2005;39:173–177.
25. Ekstrand KR, Martignon S, Ricketts DJN, Qvist V. Detection and activity assessment of primary coronal caries lesions: a methodologic study. Oper Dent 2007;32:225–235.
26. Pitts NB, Ekstrand KR. International Caries Detection and Assessment System (ICDAS) and its International Caries Classification and Management System (ICCMS) - methods for staging of the caries process and enabling dentists to manage caries. Community Dent Oral Epidemiol 2013;41:e41–e52.
27. Drancourt N, Roger-Leroi V, Martignon S, Jablonski-Momeni A, Pitts N, Doméjean S. Carious lesion activity assessment in clinical practice: a systematic review. Clin Oral Investig 2019;23:1513–1524.
28. Nyvad B, Baelum V. Nyvad criteria for caries lesion activity and severity assessment: a validated approach for clinical management and research. Caries Res 2018;52:397–405.
29. Braga MM, de Benedetto MS, Imparato JCP, Mendes FM. New methodology to assess activity status of occlusal caries in primary teeth using laser fluorescence device. J Biomed Opt 2010;15:47005.

30. Tassery H, Levallois B, Terrer E, et al. Use of new minimum intervention dentistry technologies in caries management. Aust Dent J 2013;58(Suppl 1):40–59.
31. Domejean S, Rongier J, Muller-Bolla M. Detection of occlusal carious lesion using the SoproLife camera: a systematic review. J Contemp Dent Pract 2016;17:774–779.
32. Novaes TF, Reyes A, Matos R, et al. Association between quantitative measures obtained using fluorescence-based methods and activity status of occlusal caries lesions in primary molars. Int J Paediatr Dent 2017;27:154–162.
33. Jablonski-Momeni A, Moos J, Sakhaei Manesh V, Stoll R. Diagnostic accuracy of a bioluminescence system for the assessment of caries activity on occlusal surfaces. Caries Res 2018;52:279–287.
34. Braga MM, Ekstrand KR, Martignon S, Imparato JC, Ricketts DN, Mendes FM. Clinical performance of two visual scoring systems in detecting and assessing activity status of occlusal caries in primary teeth. Caries Res 2010;44:300–308.