# Pediatric Restorative Dentistry

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*Editors*
Soraya Coelho Leal
Department of Pediatric Dentistry
University of Brasília
Brasilia
Brazil

Eliana Mitsue Takeshita
Departamento de Odontologia
University of Brasília
Brasilia
Brazil

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# Preface

We felt very honored when about 2 years ago we were approached by Springer to write a book on Pediatric Restorative Dentistry. But it took some time for us to accept the invitation, as this is not a simple subject. There are many different restorative options for treating children; however, part of them are known and available in some countries, but not in others. Therefore, to structure a book that can be useful for practitioners globally presented a major challenge. Hence, we decided to focus on restorative approaches that are well known and have been tested by means of clinical studies.

Another aspect that needs to be clarified is that the book is not exclusively centered in presenting dental materials and restorative techniques. This might, at first glance, seem contradictory, but the idea behind this decision relies on the fact that the selection of the most suitable restorative procedure starts by identifying the child's specific needs and circumstances. Moreover, restorations tend to fail if the causes of the disease are not correctly identified and an effort to change bad and counterproductive habits is not performed. For that reason, we attempted to share a philosophy of care in which the decision to intervene in the caries process non-, micro- or minimally invasive is based on a comprehensive diagnosis: family, child and his/her oral health status. And finally that the merely placement of a restoration will not solve the problem. Consequently, oral maintenance should be mentioned, as it is a key element to long lasting restorative procedures.

Lastly, we would like to acknowledge all the colleagues who greatly contributed in writing this book. Without their expertise and collaboration, surely we would not have gotten this far.

We truly hope that practitioners in different corners of the world can benefit from the ideas that are being shared in this book.

Brasilia, Brazil — Soraya Coelho Leal
Brasilia, Brazil — Eliana Mitsue Takeshita

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# 1 Caries Diagnosis: A Comprehensive Exercise

Soraya Coelho Leal, Eliana Mitsue Takeshita,
Renata O. Guaré, and Michele B. Diniz

## 1.1 Introduction

According to the principles of Minimal Intervention Dentistry (MID), patients should be empowered through information in developing skills and be motivated to take care of their own oral health [1]. In the case of children, this task is delegated to parents/caregivers, who play an important role not only in the decision-making process but also in maintaining the oral health status of the child after treatment is concluded.

As decisions related to the health of children are usually made by parents, it is mandatory that dental professionals do their very best to understand the family beliefs and the possible impact of the socioeconomic background and the parents' level of education on the oral health of the child prior to focusing on the child's dental needs. A successful treatment is related to a broader diagnosis, which includes the context in which the child lives.

In this way, the child's first dental appointment, except in case of emergency, is focused on collecting information about the child's and his/her family profile, medical/dental history, and relevant data about oral hygiene and diet habits. This information and that collected during the clinical oral examination allows the dental professional to determine the child's needs and to develop the best dental care plan.

S. C. Leal (✉) · E. M. Takeshita
Department of Pediatric Dentistry, Faculty of Health Science, University of Brasilia, Brasilia, Brazil

R. O. Guaré · M. B. Diniz
Pediatric Dentistry, Cruzeiro do Sul University, São Paulo, Brazil



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## 1.2 Patient's Profile

Undoubtedly, dental caries is the most prevalent chronic disease during childhood, affecting hundreds of thousands of children all over the world [2]. Although a decline of caries experience in children has been observed in the last decades in a number of countries, significant variations between and within countries exist [3]. A systematic review that aimed at assessing the evidence for the association between socioeconomic position—defined by own or parental educational or occupational background, or income—and caries prevalence, experience, or incidence concluded that a low socioeconomic position was associated with a greater chance of having carious lesions or caries experience [4]. Similar findings were reported by a systematic review of caries epidemiological studies carried out in Brazil between 1999 and 2010 that showed higher percentages of dental caries among the poorest and least educated people [5].

Another important aspect in the discussion about dental caries in children is the parent's level of education. The literature shows that caregivers with a higher education level, determined by having completed high school, were directly associated with a lower number of untreated decayed teeth among their children compared to caregivers who did not complete high school [6]. However, the number of years of parents at school required for influencing children's oral health is not well established. For developing countries, there is evidence that mothers who had studied for less than 8 years are more likely to have children with higher levels of dental caries [7, 8].

Additionally, the way families are structured seems to play an important role in childhood dental caries. A study conducted in the Netherlands concluded that family organization was associated to the occurrence of dental caries, indicating that the establishment of routines; the assignment of roles, abiding to rules; and the family's ability to resolve problems are important variables to be considered when establishing a dental care plan for the child [9]. Moreover, there is indication that children from one-parent families have a higher chance to develop carious lesions than those from two-parent families [10].

## 1.3 Understanding Dental Caries

After having analyzed the child's family context, the next step in the consultation process is to perform an oral examination. The assessment of dental caries is part of it and is essential for defining the child's caries profile. But, before explaining the procedure in detail, it is important to define dental caries, as different definitions are being used in the literature.

In the past, on the basis of the knowledge that was available at that time, dental caries was described as a transmittable infectious disease, in which *Streptococcus mutans* (*S. mutans*) was the key element for the onset of the disease. However, studies using advanced molecular microbiology methods have shown that a consortium of multiple microorganisms, acting collectively, are responsible for the

**Fig. 1.1** (**a**) Primary dentition of a child of 22 months of age presenting non-cavitated (superior canines) and cavitated carious lesions (all other teeth); (**b**) observe that the second primary molar is not yet erupted

initiation and progression of dental caries [11, 12]. Even in the presence of a sugary-rich diet, a much broader spectrum of acidogenic microorganism is found in the biofilm [13]. Moreover, carious lesions have been detected in subjects without the presence of *S. mutans* but with elevated levels of *S. salivarius*, *S. parasanguinis*, and *S. sobrinus* [14].

Yet with respect to the origin of microorganisms, it is important to realize that the acquisition of the oral microflora by the baby is a natural process and what is being transmitted to the child are the microorganisms, not the disease. Therefore, in this book, dental caries is defined as an imbalance of the population of microorganisms within the biofilm to an aciduric, acidogenic, and cariogenic microbiological community, mediated by a frequent intake of fermentable dietary carbohydrates. This imbalance will influence the demineralization and remineralization processes that might lead to a net mineral loss within dental hard tissues that, depending on time, can be detected clinically [15].

The process described above is applicable to all teeth, primary or permanent, but considering the child's age, a specific denomination is used to describe dental caries—the so-called early childhood caries (ECC). ECC is defined as a rampant manifestation of dental caries that affects infants and young children.

According to the American Academy of Pediatric Dentistry [16], ECC is characterized by the presence of one or more decayed (non-cavitated or cavitated lesions), missing due to caries, or filled tooth surface in any primary tooth in a child up to 71 months of age. However, the situation can be severer, in cases that any sign of dental caries in smooth surfaces in children younger than 3 years old is observed (Fig. 1.1). In such cases, the disease is described as severe early childhood caries (sECC) and can also be observed in older children (Table 1.1).

A systematic review showed that inconsistencies in how to define ECC and the usage of a great variety of diagnostic criteria limit the understanding of the prevalence of ECC [17]. For example, although the presence of non-cavitated carious lesions should be recorded for detecting both ECC and sECC according to the American Academy of Pediatric Dentistry, the recording of only dentin carious lesions in preschool children is still observed [18, 19]. Excluding these enamel carious lesions underestimates the prevalence of dental caries.

**Table 1.1** Description of severe early childhood caries according to the child's age [16]

| Age | Description |
|---|---|
| 3 years old | One or more cavitated, missing due to caries, or filled smooth surfaces in primary maxillary anterior teeth or a decayed, missing, or filled score of ≥4 |
| 4 years old | One or more cavitated, missing due to caries, or filled smooth surfaces in primary maxillary anterior teeth or a decayed, missing, or filled score of ≥5 |
| 5 years old | One or more cavitated, missing due to caries, or filled smooth surfaces in primary maxillary anterior teeth or a decayed, missing, or filled score of ≥6 |

Nevertheless, independently of the difficulties in comparing epidemiological surveys in which different assessment methodologies are used, evidence indicates that the dental community is not being able to neither reduce caries experience nor the number of untreated cavitated dentin carious lesions in children [20]. In Brazil, for example, the last national oral health survey showed that 53.4% of the children aged 5 years old had at least one decayed, missed, or filled tooth. What is even worse is the fact that 80% of the caries experience observed in these children was related to the d-component [21].

## 1.4 Caries Detection

Diagnosing dental caries is extremely relevant, as it is the basis for caries risk assessment, management, and the treatment decision-making process [23, 24]. However, it appears to be difficult to be performed by the dental professional, making it necessary to present the current evidence-based understanding for dental caries diagnosis.

There is often confusion in the literature regarding the nomenclature used for caries detection, assessment, diagnosis, and management in everyday clinical practice. Caries detection is a process involving the recognition of changes in enamel and/or dentin and/or cementum, recognized as being caused by the caries process [25]. Carious lesion assessment is the evaluation of the characteristics of a carious lesion once it has been detected, such as severity (depth and superficial integrity), extent (enamel or dentin), and activity (active or inactive) [25]. Caries diagnosis is the art or act of identifying a disease from its signs and symptoms [26], allowing the identification of the past or present occurrence of the caries disease [25]. On the other hand, caries management focuses on surgical and nonsurgical care and prevention [23].

Knowing these concepts, let's focus on caries detection. Visual/tactile examination of all tooth surfaces is the most commonly used method for carious lesion detection in clinical practice. This evaluation is based on the use of a dental mirror and a three-in-one syringe and requires good illumination and a clean/dry tooth surface [27]. The examination is based on the tooth surface integrity, texture, translucency/opacity, location, and color [28–30].

Clinically, early carious lesion in enamel is initially seen as a white opaque spot and is characterized by being softer than the adjacent sound enamel and becomes increasingly whiter when being dried. The subsurface porosity caused by the demineralization gives the lesion a milky appearance. As these lesions are indicative of greater porosity in enamel, it is common that intrinsic or exogenous pigments penetrate into the lesion and change its color to brown or almost black [25, 31]. Depending on demineralizing factors, enamel carious lesions can develop into (micro)cavities. A micro-cavitation is a carious lesion whose surface has lost its original contour/integrity but without visually distinct cavity formation. Detecting such lesions is of paramount importance as they can be controlled by preventive measures.

A cavitated carious lesion has a surface that is not macroscopically intact, with a distinct discontinuity or break in the surface integrity. When a cavity is present, it is often difficult to control the accumulation of biofilm within the cavity through oral hygiene procedures. So, treatment options for these situations normally involve invasive intervention [25], although larger dentin cavities in primary teeth have been treated successfully through removing the biofilm from within the cavity with toothbrush and toothpaste [32].

A recent systematic review showed that visual examination has good overall performance and that the use of detailed and validated assessment systems seems to improve the accuracy of visual inspection [33]. Such systems like the ICDAS (International Caries Detection and Assessment System) [34], the CAST (Caries Assessment Spectrum and Treatment) instrument [35], and the Nyvad criteria [29] describe the characteristics of clinically relevant stages in the caries disease process, including enamel carious lesions. From these systems, ICDAS and CAST do not include the assessment of caries activity. If required, activity can be carried out separately. The Nyvad criteria encompass lesion activity, which is assessed by analyzing the superficial texture and shine of the carious lesion [29].

A point of debate refers to how to perform the examination as probing with a sharp explorer is a questionable procedure, since it may cause surface defects, enlargements, and damage to dental surfaces and may result in an enamel carious lesion [36]. Therefore, it has been recommended for long to use the WHO probe (ball-ended with a sphere presenting 0.5 mm in the extremity) for evaluating the presence of discontinuities in enamel or micro-cavitations and to evaluate the enamel surface texture [37].

Visual examination combined with radiographic examination is also a common strategy for carious lesion detection. The use of a bitewing radiography as an adjunct method to the clinical examination seems to be suitable for detecting more advanced carious lesions (extending well into dentin) and cavitated proximal lesions. However, radiography has limited validity for detecting enamel and small dentin carious lesions on occlusal surfaces [38]. This method has substantial validity on proximal surfaces, but it is technique-sensitive and unavoidably exposes the child to the hazards of ionizing radiation [37]. Therefore, the decision to take a radiograph depends on the reason why the patient is seeking dental treatment—whether it is a first visit, recall, or urgency—and the presence of clinical signs of dental caries [39].

Finally, it is important to address caries activity. The assessment of a lesion activity is essential to define the patients' treatment needs and to establish the most appropriate dental care plan. An active carious lesion is in full development and progression, with a net mineral loss over a specified period of time. An inactive carious lesion is not undergoing net mineral loss, meaning that the caries process is no longer progressing, being considered a "scar" of past disease activity [25]. Clinical conditions should be taken into consideration when assessing a tooth surface activity, such as visual appearance, tactile feeling, and potential for plaque accumulation [29, 40].

An enamel lesion is likely to be active when the surface is whitish/yellowish opaque and chalky (with loss of luster). It feels rough when the tip of the probe is moved gently across the surface and the lesion is situated in a plaque stagnation area (pits and fissures, near the gingiva and in the approximal surface below the contact point). In dentin, an active lesion is soft or leathery on gently probing. An enamel lesion is likely inactive when the surface is whitish, brownish, or black. The enamel may be shiny and feels hard and smooth when the tip of a probe is moved gently across the surface, and it is typically located at some distance from the gingival margin on smooth surfaces. In dentin, an inactive lesion may be shiny and feels hard on gently probing [25, 29, 37] (Fig. 1.2).

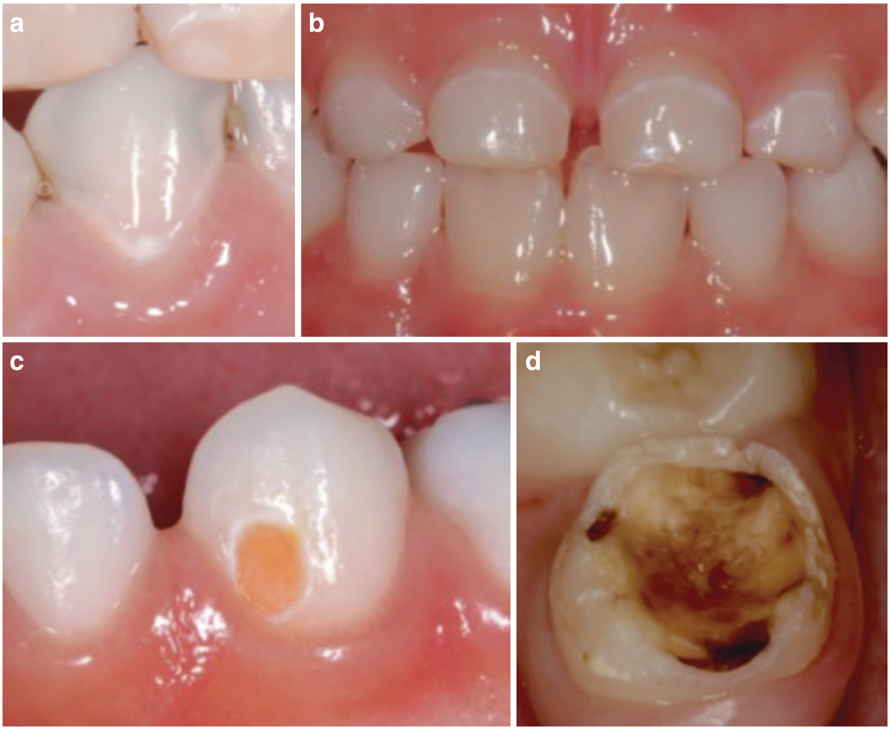


**Fig. 1.2** (**a**) Active enamel carious lesion near the gingival margin; (**b**) inactive enamel carious lesions at some distance from the gingival margin; (**c**) an active dentin carious lesion on the buccal surface of a primary canine; (**d**) inactive dentin carious lesion on occlusal and mesial surfaces of a second primary molar

By recognizing the features described above, the professional will be able to properly detect a carious lesion and determine whether it is active or not. These are decisive factors to guide the professional toward an evidence-based approach, patient centered and focused on the formulation of individualized dental care plans.

## 1.5 Caries Risk Assessment

Minimal intervention dentistry (MID) is a philosophy of care that aims to preserve tooth tissue throughout a person's life [41], focusing on the prevention and interception of the disease still in its early stages [42]. For this purpose, caries risk assessment (CRA) models have been developed and are advocated as the corner stone of a MID dental care plan, assisting the professional in determining the most appropriate interventions and individualized recall consultation strategies [43].

CRA is performed by analyzing factors that are involved in the development and progression of the disease [44], aiming at estimating the probability that a new carious lesion will develop over a certain period of time [45]. To date, many different factors have been tested as predictors for carious lesion development. When only a single factor is taken into account, past caries experience has shown to be the most powerful one for caries prediction for all age groups, presenting higher accuracy in preschool children [46].

The understanding that dental caries is a multifactorial disease led, over the last decades, to the development of different models for performing CRA (Table 1.2).

These models are based on the analysis of a set of protective and pathological factors related to the onset of dental caries. The balance between protective factors (saliva and its components: fluoride, calcium, phosphate) and pathological factors (bacteria, frequency of ingestion of fermentable carbohydrates, and reduced salivary function) is the most important aspect in the equation between demineralization and remineralization [47]. It determines whether a lesion is likely to progress or arrest [48].

As shown in Table 1.2, not all CRA models are applicable to all children, as some of them present specific forms for children of specific age groups. In contrast, as a common feature, they all include the findings retrieved from clinical assessment, but different thresholds are used. While "white spots on smooth surfaces" are assessed by CAMBRA [50], the CARIOGRAM [49] "caries experience" factor is based on the DMFS/dmfs. Another variable that is assessed by all models is the presence of visible plaque. Undoubtedly, the presence of enamel carious lesions and the presence of biofilm are factors related to caries activity [29]. If a child presents with active lesions and biofilm is not being frequently disorganized, the child, from a health perspective, is not at risk but already diseased [54]. If through preventive measures such lesions are inactivated, the child can be, then, allocated to a certain caries risk group. Moreover, it should be highlighted that patients are usually exposed to different caries risk factors during their lives [47]. A child, who is not at risk, may become at risk, for example, by the presence of an erupting permanent molar.

**Table 1.2** Caries risk assessment models, description of their main characteristics, age group, and how results are presented

| Caries risk assessment model | Main characteristics | Age group | How results are presented |
|---|---|---|---|
| *CARIOGRAM* [49] | Software program in which the following risk factors are considered: caries experience, related diseases, diet content and frequency, amount of plaque, mutans streptococci, fluoride program, saliva secretion, buffer capacity, and the clinical judgment of the dentist | All age groups | Provides the chance that an individual has to avoid new carious lesions |
| *CAMBRA*—caries management by risk assessment [50] | Form based on disease indicators, biological risk factors, and protective factors. The variables investigated vary according to the individual's age | Two forms are available according to the individual's age: (1) preschool children (0–5 years old) and (2) age 6 years old through adulthood | Classifies individuals into four caries risk categories: "low", "moderate", "high," and "extreme" |
| *CAT*—caries-risk assessment tool [51] | Form based on caries risk indicators assessed by clinical conditions, environmental characteristics, and general health conditions | Two forma are presented according to individual's age: (1) preschool children (0–5 years old) and (2) school children and adolescents (≥6 years old) | Classifies individuals in three caries risk categories: "low," "moderate," and "high" |
| *OHRA*—oral health risk assessment [52] | Form based on risk factors, protective factors, and clinical findings | Young children | Classifies individuals in two caries risk categories: "low" and "high" |
| *NUS-CRA*—National University of Singapore caries risk assessment [53] | A software program which takes into account clinical factors and sociodemographic factors | Preschool children | Provides the chance that an individual has to develop new carious lesions |

Other frequently assessed variables in CRA models are the use of fluoride and dietary habits. It is not new that sugar consumption is likely to be a powerful caries risk indicator in persons who are not regularly exposed to fluoride [55] and that the higher a person is exposed to the risk factors, the higher the intensity of protective factors must be in order to reverse the caries process [56]. With respect to fluoride, questions aim to evaluate the sources to which the child is exposed to. Considering diet, NUS-CRA [53], and the OHRA [52], besides inquiring parents about "snacks between meals," "consumption of carbohydrates," and "sugary beverages," they also assess "months of breastfeeding" [53] and "continual bottle/sippy cup use with fluid other than water" [52]. Although it is evident that the way to collect information about diet and fluoride differs among the CRA models, the fact that these two variables are assessed in all of them shows their importance in carious lesion development.

CAMBRA [50] for younger children (0–5 years old) includes the assessment of mothers' oral health, which is also evaluated by the OHRA [52], and the family's social economical status, a factor also analyzed by the NUS-CRA model [53]. The evaluation of such variables is justified by the influence of mothers' behavior and family's profile in the development of the disease [5].

The questionable aspect about CRA models refers to their validity. According to recent systematic reviews [46, 57], the scientific evidence on the validity of these models is weak and limited, especially for preschool age. Nevertheless, the application of standardized caries risk assessment models has excellent pedagogical value for family oral health education. They assist the professional in defining appropriate dental plan care and in establishing individualized return intervals.

### 1.5.1 Final Considerations

This book is about restorative procedures in children. However, it is important to highlight that the decision-making process with respect to the best restorative material to be used in a cavitated dentin lesion should be made taking in consideration a variety of factors such as child's age, behavior, parents' level of education, and family socioeconomic background. Moreover, it can only be performed after carrying out a careful caries diagnosis, as well as identifying the factors that are mostly contributing to the child's oral health condition. Finally, a restorative treatment should not be implemented apart from a preventive program, as a restoration is placed to treat the sequela of the caries process, not to control the disease. Therefore, emphasis on oral health promotion and prevention will be given in the following chapters.

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# Child Behavioral Management

# 2

Érica N. Lia and Vanessa P. P. Costa

## 2.1 Introduction

Dental treatment is commonly associated with fear, anxiety, and distress, especially in children. Although the concept of fear and anxiety are different, authors and clinicians often misuse them as synonyms. Fear is considered an adaptive response of human development and can be defined as a reaction to a real or imagined threat, while dental fear is a reaction that involves a fight-or-flight response when the patient is confronted with a threatening stimuli [1]. In turn, anxiety is characterized by the suffering related to the anticipation of facts and can be present even in the absence of a threat and consists of a complex cognitive, affective, physiological, and behavioral responses [2]. Fear and anxiety are some of the reasons responsible for uncooperative behavior during dental treatment. As a consequence, children tend to avoid dental care, what contributes to worsening their oral health condition and their quality of life [3].

A recent study showed that the prevalence of dental fear among children aged 3–14 years old was 22.6% according to the Dental Subscale of the Children's Fear Survey Schedule (CFSS-DS) and that the level of dental fear decreases as the age progresses [1]. Studies about prevalence of dental anxiety in children and adolescents using Dental Anxiety Scale (DAS) and Modified Corah Dental Anxiety Scale (MDAS) showed rates between 10 and 12.2%. A study which used the Modified Child Dental Anxiety Scale (MCDAS) showed variation rates between 13.3 and 29.3% [4]. Therefore, given the range of these problems, they cannot be ignored by those who treat children.

The etiology of dental fear and anxiety is multifactorial, and several aspects such as past pain experience, fear of invasive procedures, fear of separation from

É. N. Lia (✉) · V. P. P. Costa
Department of Pediatric Dentistry, School of Health Sciences, University of Brasília, Brasilia, Brazil
e-mail: ericalia@unb.br


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parents, contact with unknown people, and lack of control have already been pointed out as cause of dental fear/anxiety [5]. Moreover, dental fear can be influenced by family income, severity of dental caries [6], parent's expectation of children behavior during the dental examination, and the presence of toothache [5]. Children who never visited the dentist and those who frequently experienced dental pain presented higher dental fear prevalence and anxiety levels in comparison to those who went to the dentist and compared to those that had never experienced toothache [6, 7]. Pain, in turn, is a multidimensional experience and evokes physical, cognitive, emotional, and behavioral responses. Since pain and anxiety are closely linked, anxious patients tend to present increased pain perception and exaggerate their memory of pain [8].

Dental fear develops in children through learning experiences; thus, parent's negative attitudes with regard to the dental treatment have a negative impact on the anxiety and dental fear levels in their children [9]. Finally, it has been demonstrated that depression and anxiety in adolescent mothers can be associated with dental fear in their children [10].

It is, therefore, imperative that the professional who intends to provide pediatric dental care is aware of the children's common fears, to prevent and alleviate their suffering. The identification of factors that causes fear and anxiety during the dental treatment enables the use of specific behavioral management techniques and the adoption of attitudes that can help reducing the stressful character with which the child perceives the dental treatment [11].

## 2.2 Child's Behavior Classification

The motor and psychological development of children is a continuous process, from birth to adolescence, and directly influences the acceptance of dental treatment and oral health care. Their level of socialization, their ability to act independently, and their linguistic ability must be assessed by the dentist, according to their chronological age, cultural and social status, and parent's profile. In addition, the presence of any mental and/or physical disabilities should also be assessed [12]. It is important to note that both personality and temperament are not related to age; thus, children who are at the same age may present different behavior during dental care [12].

In a simplified way, the child behavior can be classified into three stages [13]: pre-cooperative, cooperative, and uncooperative, as summarized in the Table 2.1. Infants and young children commonly belong to the pre-cooperative stage, which does not mean that they can develop a cooperative behavior in the future, despite not being collaborative at present. Children who are in the pre-cooperative stage can move into cooperative stage as well, as they develop communication capacity and are able to follow directions [12].

Sometimes, children can modify their behavior according the complexity and the duration of the dental treatment [14]. So, the same child can show cooperative behavior during preventive procedures, e.g., dental prophylaxis or fluoride application, and he/she can show uncooperative behavior during invasive procedures, like

**Table 2.1** The characteristics of the most frequent child behavior stages during dental treatment

| Behavior stage | Main characteristics |
|---|---|
| Pre-cooperative | Young children (0–3 years)<br>Strong connection between the child and her/his mother/parents<br>Lack of comprehension of the dental treatment<br>Lack of cooperative ability at actual moment<br>Parent-child separation not recommended (anxiety of separation) |
| Cooperative | Children who demonstrate socialization and communication skills (generally more than 4 years old)<br>Establishment of conversation between the dentist and the child<br>The child can follow directions |
| Uncooperative | Personality/temperament or negative previous experience<br>Mental disabilities |

Adapted from: Wright GZ, Alpern GD. [13]

local anesthesia, restorations, dental extractions, or endodontic treatment. In some situations, parents can project their own anxiety and fear to the child, contributing to the genesis of the uncooperative behavior [12].

Still about behavior, special attention should be given to uncooperative children, and the origin of their negative behavior should be investigated. The causes can be related to personality or temperament, negative past experiences (e.g., feel pain during dental treatment), lack of trust between patient-professional, and mental disabilities [12].

The clinician must consider the child's status of oral health and the complexity of the dental treatment required, besides the mental and physical development of the patient and parental characteristics before choosing a behavioral management technique [12]. The pain control is fundamental to the behavior management of children of all ages.

The techniques of behavior management can be divided into non-pharmacological and advanced techniques (protective stabilization and pharmacological techniques) as described in flow diagram below (Fig. 2.1).

## 2.3 Non-pharmacological Techniques

### 2.3.1 Tell-Show-Do

This technique is very effective and involves verbal explanations of the dental procedures using language according to the cognitive and emotional developmental level of the child (tell). After this initial step, the instruments and materials are presented by exploring visual, auditory, olfactory, and tactile aspects and successive approximation (show). Finally, completion of the procedure is done (do) (Fig. 2.2). Communication skills (verbal and nonverbal) and positive reinforcement are used too. The main objective is familiarizing the child with the dental setting and acceptance of the dental procedures [12, 15, 16].

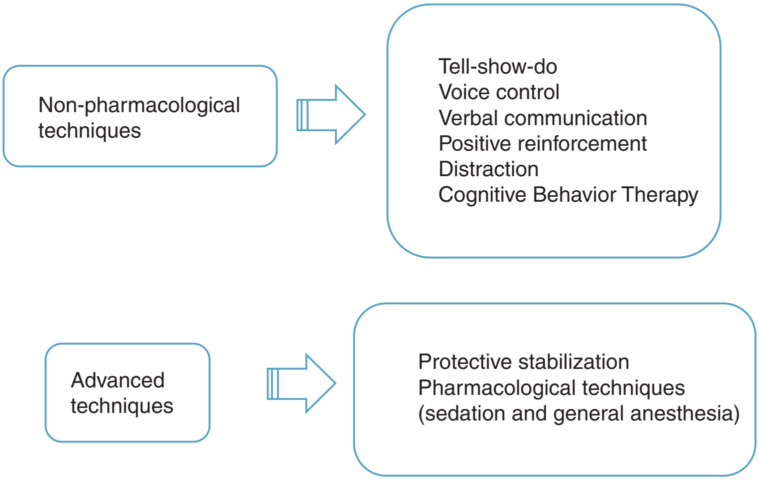


**Fig. 2.1** Techniques of behavior management


**Fig. 2.2** Tell-show-do technique in three stages: (**a**) The dentist is explaining the dental procedures to the child using words and expressions according to her age (tell). (**b**) Demonstration of dental prophylaxis in the child's finger (show). (**c**) Performing dental prophylaxis (do). Note the use of distraction elements, like tolls and colorful clothes

### 2.3.2 Voice Control

This technique can be useful with children who are not cooperative. The dentist alters the voice volume, tone, or pace purposely, intending to influence and direct the patient's behavior. The objectives of voice control are to gain the patient's attention and compliance, besides avoiding negative behavior. The use of an assertive voice may be considered aversive to some parents unfamiliar with this technique. Therefore, it is advisable an explanation prior to its use, in order to prevent misunderstanding [12, 15].

### 2.3.3 Nonverbal Communication

This technique is called multisensory communication and advocates the use of body language, posture, and facial expression. For example, the child can be greeted with a smile and a handshake. The objectives of nonverbal communication are to enhance the effectiveness of other communicative management techniques and gain or maintain the patient's attention and compliance [12, 15].

### 2.3.4 Positive Reinforcement

This technique aims to reinforce desired behaviors in order to be repeated. It can include positive voice modulation, facial expression, and verbal praise. Cooperative behaviors should be praised and encouraged; and toys and small rewards can be used too [14, 16].

### 2.3.5 Distraction

Distraction diverts the patient's attention from the unpleasant and invasive procedures. The focus attention can be directed to specific alternative visual and/or auditory stimuli [16]. In this technique, complementary comments, music, imaginative plays, video eyewear [17], and various subjects like, e.g., favorite sports, super heroes, and cartoon characters can be used [15].

### 2.3.6 Cognitive Behavior Therapy (CBT)

The cognitive behavior therapy (CBT) focuses on the patient's life situation, altered thinking, altered behavior, altered emotions, and altered physical symptoms associated with his/her anxiety. It offers an accessible model for the assessment and management of dental anxiety that can be applied in the clinical setting [18]. CBT is a therapy, which aims to help people in the management of their problems by changing how they think and behave in relation to these problems through the incorporation of a variety of different cognitive and behavioral strategies [19]. It can be used to teach patients (and often their parents/careers) skills for the self-management of their anxiety.

## 2.4 Advanced Techniques

Advanced techniques comprise protective stabilization and pharmacological techniques (sedation and general anesthesia).

### 2.4.1 Protective Stabilization

Protective stabilization is considered an advanced technique and is characterized by the restriction of the patient's movement during dental treatment (Fig. 2.3). The aims of this technique are to decrease the risk of injury or accident and to reduce the time for completion of the dental treatment, optimizing and enhancing the quality of the procedures. This technique is indicated to very young children (0–3 years) and patients with special health care needs, who don't have ability to collaborate. It is extremely important to explain the technique to the parents and obtain their authorization by an informed consent [15].

### 2.4.2 Pharmacological Techniques

Pharmacological techniques comprise the use of sedation and general anesthesia and should be employed when extensive treatments need to be performed in patients who often cannot cooperate due to the lack of psychological or emotional maturity and/or mental, physical, or medical disability [15, 20].

**Fig. 2.3** Protective stabilization. The child is wrapped in a tissue sheet and supported by the mother

#### 2.4.2.1 Sedation

Sedation is defined as the use of a drug or combination of drugs to depress the patient's central nervous system (CNS), reducing, thereby, his/her alertness. The responsiveness to verbal, tactile, or painful stimuli, besides spontaneous ventilation and cardiovascular function, is usually maintained, except in deep sedation. Even though, local anesthesia is required because the drugs used to sedate the patient do not eliminate completely the pain [20]. However, the reduction of pain and anxiety and the muscular relaxation provided by sedation gives more comfort to the patient during the dental treatment. Anterograde amnesia can occur depending on the drug used, e.g., midazolam [21]. The use of oral midazolam in combination or not with ketamine during pediatric dental treatment allows children to respond more positively during follow-up sessions than those patients who did not receive sedation [22].

According to the American Society of Anesthesiologists (ASA), only patients who are classified as healthy (ASA I) or with mild systemic disease without functional limitation (ASA II) are eligible for receiving sedation. Depending on the degree of the CNS depression, the sedation may be mild, moderate, or deep, in a dose-response manner [20]. Higher drug doses and a variety of individual factors like medication type, delivery route, and patient's characteristics can alter the depth of sedation, in such a manner that the patient becomes unresponsive and incapable of maintaining his/her protective reflexes and own breathing or cardiovascular function [23]. Thus, it is important to emphasize the need of monitoring patient's cardiac and respiratory frequency, blood pressure, and blood oxygen saturation, in addition to training the professional team and the presence of an anesthesiologist [15].

During mild (conscious or minimum) sedation, patients respond normally to verbal commands, and their airway reflexes are maintained; besides ventilator and cardiovascular functions are unaffected. This level of sedation is achieved with either oral drugs alone (e.g., midazolam) or $N_2O/O_2$ (nitrous oxide and oxygen) inhalation [20]. Conscious sedation with nitrous oxide and oxygen is a safe and effective method to obtain cooperation of patients with dental fear and mental disabilities, even in young children. The prevalence of adverse effects in this type of procedure is low, and the common symptoms are nausea and vomiting (1.2%) [24]. The advantages of nitrous oxide sedation are its quick start of action and the patient's rapid recuperation, besides titration dosage. Moreover, the oral sedation has a great variability of patient's responses, and children can refuse the medication due to bitter taste. Once the drug is administered, it is not advisable to offer increment doses due to the risk of over sedation [23].

In a moderate sedation, patients respond to verbal commands, either by themselves or accompanied by light tactile stimulation. No interventions are required to maintain the patent's airway. Ventilation is spontaneous, and cardiovascular function is usually maintained [20]. To achieve moderate sedation, oral drugs are used alone or in combination with nitrous oxide and oxygen inhalation.

Deep sedation can be achieved with intravenous administration of sedative drugs (usually drugs combination). In this level of sedation, patients cannot be easily aroused, but respond purposefully following repeated or painful stimulation.

Patients may require assistance in maintaining a patent airway, and spontaneous ventilation may be inadequate. Cardiovascular function is not altered [20].

#### 2.4.2.2 General Anesthesia

General anesthesia is a controlled state of unconsciousness accompanied by a loss of protective reflexes, including the ability to maintain a patent airway. Patients do not respond purposefully to physical stimulation or verbal command [15], and ventilator support is required in most cases. This technique is indicated for patients for whom local anesthesia is ineffective due to acute infection, allergy, and patients requiring major surgical procedures or in case of special care needs like syndromes, dementia, and cognitive decline [15]. General anesthesia requires hospitalization and medical support, which increase the complexity and the cost of the dental treatment.

## 2.5 Final Considerations

The child behavioral management during dental treatment is of paramount importance since it improves the quality of dental care, reducing the duration of dental session and the psychological stress of patients, dental surgeon, and parents. Thus, the child behavioral management including reduction of pain and distress contributes to the dental treatment success.

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# Primary and Permanent Dentitions: Characteristics and Differences

# 3

Vanessa P. P. Costa, Ingrid Q. D. de Queiroz, and Érica N. Lia

## 3.1 Introduction

Primary and permanent teeth present many different morphological characteristics that have been studied by multiple areas of knowledge (biology, anthropology, dentistry, paleopathology, archeology, forensic science). This interest relies on the fact that teeth can be used, for example, in the estimation of biological relationships between populations [1] and in the determination of human identity [2].

In dentistry, the understanding of the dental anatomy characteristics, besides being essential in determining individual teeth morphology, has a clinical implication in several fields: pathology, radiology, orthodontics, prosthesis, oral surgery, and restorative dentistry [3].

Particularly in pediatric dentistry, the differentiation between primary and permanent dentitions is of paramount importance, as for a certain period of the child's life, a mixed dentition is present. In that way, it is mandatory not only that the professional is able to identify individual teeth characteristics but also be aware of the influence of such characteristics in treating a primary or a permanent tooth and their impact on restorative techniques.

## 3.2 Anatomical Characteristics and Differences Between Primary and Permanent Dentitions

The primary dentition is composed of twenty (20) teeth divided into three groups: incisors, canines, and molars (Table 3.1), while the permanent dentition is formed by thirty-two (32) teeth divided into four groups: incisors, canines, premolars, and molars.

V. P. P. Costa (✉) · É. N. Lia
Department of Pediatric Dentistry, Faculty of Health Science, University of Brasília, Brasília, Brazil

I. Q. D. de Queiroz
Post-Graduate Program in Dentistry, University of Brasília, Brasília, Brazil


S. C. Leal, E. M. Takeshita (eds.), *Pediatric Restorative Dentistry*,
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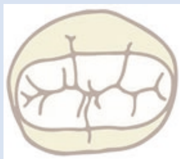
**Table 3.1** Main morphological characteristics of primary teeth

| | | |
|---|---|---|
| Upper incisors | From the vestibular, the crown has a square format, as the mesiodistal distance is almost equal to the cervical-incisal one. The mesial face is higher than the distal, making the incisal edge to be slightly tilted to distal. The root is conical with a slight vestibulolingual flattening |  |
| Lower incisors | The contour is similar to that of the permanent lower central incisor. However, as in the other primary teeth, the mesiodistal distance overlaps the cervico-occlusal distance. The root is very flat in the mesiodistal direction with slight curvature for distal and vestibular |  |
| Canines | The crown is sharper than the permanent crown because the inclinations of the occlusal slopes are greater. The tooth dimensions are similar in height and width |  |
| First upper molar | Its form has no correspondent in the permanent dentition. It is the smallest of all primary molars. The crown is irregularly cubic, with cervical constriction. The occlusal face has three cusps, two vestibular and one palatal. The three roots, two vestibular and one palatine, are long, flat, and divergent |  |
| Second upper molar | The occlusal surface presents four cusps, two vestibular and two palatines. Three grooves separate these cusps. The three roots, two vestibular and one palatine, are longer than those of the first primary molar |  |
| First lower molar | As the first upper molar, its form is different from any permanent tooth. The occlusal face, elongated in the mesiodistal direction, presents four cusps, two vestibular and two lingual. The two roots, mesial and distal, are long, divergent, and flattened in the mesiodistal direction |  |
| Second lower molar | Similar to the first permanent molar. The occlusal face has five cusps, three buccal and two lingual, separated by several grooves. The two roots, one mesial and a distal, are long, divergent, and flattened in the mesiodistal direction |  |

Adapted from: Toledo AO, Leal SC. [6]

It is unquestionable that the characteristics of primary dentition substantially differ from that of the permanent dentition with respect to the arch form [4, 5], inclinations of the teeth [6, 7], number of teeth [3], and others.

The length of the dental arch is smaller in the deciduous dentition when compared to the permanent dentition. The size of the molar series also differs comparing the two dentitions. While in the permanent dentition the molar size decreases (the first molar is larger than the second molar that is larger than the third molar), in the primary dentition the second molar is larger than the first molar [3].

Dentin in permanent and primary teeth has similar morphology, composition, and histological structure. However, while the dentin of permanent teeth shows dentinal tubules following an “s”-shaped curve, in primary teeth, dentin tubules exhibit a straight course. In addition, the number and caliber of the tubules are different in both dentitions [8].

Another relevant difference between primary and permanent dentitions is related to the fact that the primary teeth are less mineralized than the permanent teeth. As a consequence, their color is blue-white in comparison to a more yellowish color observed in permanent teeth. Moreover, the volume of the primary teeth is smaller than that of their permanent counterparts [3].

In respect to enamel structure, the enamel of primary teeth is less mineralized than the enamel of permanent teeth, and the diffusion coefficient is higher in primary than in permanent teeth enamel [9]. It has been shown that the demineralization of the enamel of primary and permanent teeth in acidic media presents significant differences, with the enamel of primary teeth having a greater susceptibility to demineralization than the enamel of permanent teeth [10]. The comparison of both dentitions is summarized in Table 3.2.

Moreover, the crowns of primary teeth are wider in the mesiodistal direction in relation to its cervico-occlusal dimension.

Primary teeth present a more pronounced cervical constriction than the permanent teeth, and the roots of primary teeth are more prolonged and sharp in relation to the dimensions of the crown [6]. Overall, primary teeth are smaller in size with the pulp chamber wider and the pulp horns more prominent than in the permanent teeth and the roots are more divergent (Fig. 3.1).

**Table 3.2** Main differences between primary and permanent teeth

| Primary teeth | Permanent teeth |
|---|---|
| 20 teeth | 32 teeth |
| Three groups of teeth: incisors, canines, and molars | Four groups of teeth: incisors, canines, premolars, and molars |
| Molar size increase | Molar size decrease |
| Dentinal tubules straight course | Dentinal tubules an s-shaped curve |
| Blue-white color | Yellowish color |

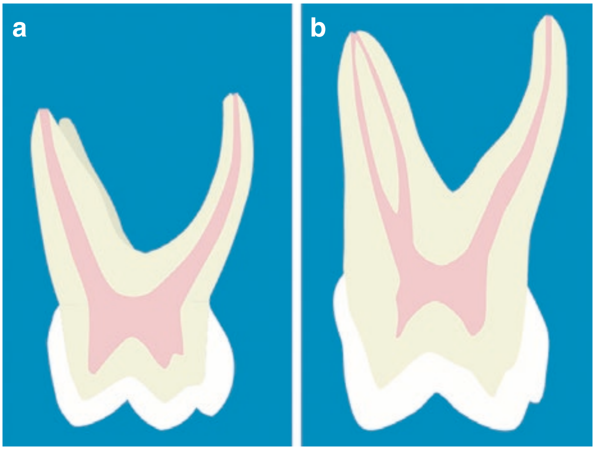



**Fig. 3.1** Macromorphological comparison between a primary molar (**a**) and permanent molar (**b**)

## 3.3 Dental Anatomy Implications on Restorative Procedures

### 3.3.1 Difficulties of Isolation with Rubber Dam

It is known that the use of rubber dam isolation (RDI) shortens the treatment time and provides optimal moisture control during restorative procedure [11]. However, its use may compromise the level of the child acceptance/satisfaction with the treatment due to the use of local anesthetics and the pressure generated by the clamp [12].

In addition, anatomical characteristics of some primary teeth (constricted cervix and crown size with similar distances between mesiodistal and cervical-incisal dimensions) make the placement of RDI, from a technical perspective, a more complicated matter in primary teeth compared to permanent teeth.

A survey carried out with American and Canadian pediatric dentists with respect to the indications and contraindications of RDI on the use of direct restorative materials in posterior molars (primary and permanent) showed that the main reason for using it was moisture control, while the reasons given for not using the RDI included decreased trauma to the patient, being able to prevent soft tissue from interfering with the procedure without using rubber dam, and decreased time for appointment [12].

Whether the use of RDI has a positive effect on direct treatments in dental patients is a point of debate. A systematic review that aimed to answer this question could only include two studies performed in primary molars in which the use of rubber dam was compared to the use of cotton rolls isolation. None of the studies assessed the use of RDI in terms of costs or patients' satisfaction/acceptance. Therefore, it was concluded that more studies of high quality are still needed in order to establish in which situation the RDI is really needed [13].

### 3.3.2 Adhesion of Dental Materials

Operative dentistry has evolved from the “amalgam era” to the “adhesion era” in which adhesive restorative materials are mostly used for direct restorations. However, the adhesion process is a critical phase of any restorative procedure, particularly, in primary teeth, due to its technique sensitivity that might be compromised by a reduced working time to perform the procedure resulted by the lack of cooperation of some pediatric patients [14].

Moreover, structural differences between permanent and primary teeth might explain, in part, the reason why adhesives seem to be more effective in permanent teeth than in primary teeth. The dental substrates (enamel and dentin) of primary teeth present lower thickness and less mineral content in comparison with the dental substrates of permanent teeth. In addition, the outer aprismatic enamel layer, observed in both primary and permanent teeth, is more pronounced in primary enamel. Finally, dentin tubule density is higher in primary dentin when compared to permanent dentin, and consequently, intertubular dentin area available for bonding is reduced in primary teeth [15]. These differences explained the lower bond strengths and increased gingival microleakage observed in class II resin composite restorations of primary teeth in comparison to permanent teeth in a controlled in vitro study [16].

### 3.3.3 Risk of Cervical Wall Loss During Cavity Preparation

Anatomically, the crowns of primary molars have a mesiodistal dimension greater than the cervico-occlusal dimension. The preservation or recovery of these dimensions is essential for the normal development of the occlusion, ensuring that there is no extrusion of the opposing teeth [17].

The proximal contacts of deciduous teeth are broad and flattened, known as “contact areas” opposite to what is observed for permanent teeth, which have small contact points [17]. This anatomical characteristic increases the risk of cervical wall loss during cavity preparation/cleaning in primary teeth, which in turn increases the risk of contamination and hampers the adaptation of the restorative material. Therefore, the professional should opt for conservative approaches during carious tissue removal in order to preserve as much sound tissue as possible, decreasing the chances of inadvertently causing cervical wall loss.

### 3.3.4 Longevity of Restorations

The current literature shows relatively lack of data available on the longevity of restorations in the primary teeth. Aspects such as type of restorative material, cavity size, and caries experience have shown to influence the longevity of direct restorations in permanent teeth [18], but in primary teeth, this issue is still inconclusive [19]. However, when comparing the survival rates, specially of class II restorations, performed in primary and permanent teeth, lower survival rates are observed for primary teeth [20] than those reported for permanent teeth [21, 22]. These results may be explained, in part, by anatomical differences between primary and permanent dentitions, which make the restorative procedure more challenging in the primary teeth.

### 3.3.5 Risk of Pulp Exposure

The pulp of the primary teeth presents some peculiarities: the pulp horns are higher in the primary molars compared with permanent molars, and the pulp chambers are proportionally broader than the ones from permanent teeth [6]. In other words, the pulp of a primary tooth is relatively large with respect to its crown. This feature increases the risk of pulp exposure during carious tissue removal.

The literature shows that the use of more conservative approaches for managing cavitated dentin carious lesions is able to reduce the number of direct pulp capping, pulpotomy and pulpectomy in primary teeth [23, 24] and, therefore, should be the first option for managing dentin cavitated carious lesions.

## 3.4 Final Considerations

The characteristics of the primary dentition should be taken into account in pediatric restorative dentistry, since their particularities influence not only in the success of the procedures but also in how the professional will manage a carious lesion. As the risk of pulp exposure and cervical loss in primary teeth is higher during cavity preparation/cleaning, more conservative approaches should be selected.

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# The Role of Diet and Oral Hygiene in Dental Caries

4

Carlos Alberto Feldens, Paulo F. Kramer, and Fabiana Vargas-Ferreira

## 4.1 Introduction

The current definition of oral health involves the ability to speak, smile, smell, taste, touch, chew, swallow and convey a range of emotions through facial expressions with confidence and without pain and discomfort [1]. Health conditions that threaten the functional and emotional balance of individuals should be the object of investigation, with an emphasis on the recognition of risk factors and the evaluation of the effectiveness of interventions on both the individual and collective levels. In this context, dental caries stands out as a highly prevalent oral condition that affects oral health-related quality of life in different age groups and socioeconomic strata [2–4]. In this chapter, we intend to contribute to the understanding of the aetiology of dental caries as well as the drafting and implementation of strategies for the prevention and control of this condition.

Dietary practices, especially the consumption of free sugars, are recognised as a common risk factor for the occurrence of non-communicable diseases [5]. There is increasing concern that intake of free sugars—particularly in the form of sugar-sweetened beverages—increases overall energy intake and may reduce the intake of foods containing more nutritionally adequate calories, leading to an unhealthy diet, weight gain and increased risk of various diseases and conditions, such as cardiovascular disease, diabetes, obesity and dental caries [5, 6]. The World Health Organization considers the promotion of healthy food practices to be one of the most important challenges required to ensure the health of children throughout the world. This chapter addresses various aspects involved in the relationship between

C. A. Feldens (✉) · P. F. Kramer
Department of Pediatric Dentistry, Universidade Luterana do Brasil, Canoas, Brazil

F. Vargas-Ferreira
Department of Community and Preventive Dentistry, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil


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dietary practices and dental caries, such as the early introduction of sucrose as well as the frequency and quantity of free sugars consumed.

Biofilm (bacterial plaque) on tooth surfaces is fundamental to the development of dental caries. Therefore, its removal through adequate oral hygiene theoretically has the potential to contribute to the prevention and control of carious lesions [7]. However, there is no clear evidence that guidance with regard to oral hygiene contributes to a reduction in caries experience among children and adolescents. In this context, the role of oral hygiene in biofilm control according to the current evidence will also be addressed in this chapter.

## 4.2 Diet and Dental Caries

### 4.2.1 The Role of Diet in the Occurrence of Dental Caries

The answer to the question "what causes dental caries?" has intrigued researchers throughout the world. Like other chronic diseases, dental caries has a widely recognised multifactor dimension that has been demonstrated in studies that identify demographic, socioeconomic, behavioural and biological risk factors [8, 9].

The relationship between dietary practices and dental caries has been suggested and reinforced since classic studies conducted in the 1950s [10–12]. In the last 10 years, evidence has demonstrated that dietary practices, particularly the consumption of free sugars,* are of critical importance to the development of dental caries, constituting the necessary cause of its occurrence, and modulate other factors, such as dental biofilm [5, 13, 14].

> *"Free sugars include monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates" [5].

The effect of diet on dental caries essentially refers to the *local effect* of carbohydrates on dental tissue or metabolised by cariogenic microorganisms in the oral cavity. Carbohydrates involve a broad group of foods and those that are more easily fermented by bacterial species are monosaccharides (glucose and fructose) and disaccharides (sucrose, lactose and maltose), which have a low molecular mass and are designated sugars. Starch is a polysaccharide with a complex, voluminous molecule that hinders its diffusion in dental biofilm and its use in bacterial metabolism [15].

The consumption of sucrose enables cariogenic microorganisms to use sugar as a primary energy source and promotes biochemical events through extracellular and intracellular mechanisms [16], as summarised in Table 4.1.

The variation in dietary practices, especially the consumption of free sugars, is largely responsible for the variation among individuals and communities with regard to caries experience. There is evidence that two key characteristics (risk

**Table 4.1** Mechanisms of use of sucrose by cariogenic microorganisms

| Intracellular | Extracellular |
|---|---|
| • After the ingestion of sugar, microorganisms produce organic acids as metabolic by-products, which lower the pH to 5.0 or lower, favouring the demineralisation process<br>• Cariogenic microorganisms are able to produce and store intracellular polysaccharides, which serve as a substrate reservoir to be used for the production of energy between meals in which carbohydrate sources are not available<br>• The production of acid promotes a shift in the balance or resident plaque microflora favouring bacteria that preferentially grow under acidic conditions, which leads to the selection of more cariogenic microflora if the pH remains repeatedly low | • Sucrose is especially cariogenic because it serves as substrate through the polymerisation of glucose and fructose for the synthesis of extracellular polysaccharides in dental plaque<br>• Extracellular polysaccharides promote bacterial adherence to dental surfaces and contribute to the integrity of biofilm by increasing its porosity, thereby enabling sugars to diffuse from the outer layers to deeper areas of the biofilm<br>• Biofilm formed in the presence of sucrose has low concentrations of calcium and fluoride, which are critical ions in the demineralisation-remineralisation process |

Source: Bowen et al. 1966 [17]; Zero et al. 1986 [18]; Rölla 1989 [19]; Marsh 1994 [20]; Cury et al. 1997 [21]; Paes Leme et al. 2006 [22]

factors) potentiate the role of dietary practices in dental caries and should be the focus of interventions: the age at which sugar is introduced and the frequency of its consumption [23, 24]. The recognition of sugar as a common risk factor for non-communicable diseases, including dental caries, suggests that the amount of free sugar intake should also be the object of interventions [5]. These aspects will be explored next.

#### 4.2.1.1 Early Introduction of Free Sugars

Prospective longitudinal studies have demonstrated associations between sugar consumption during the first year of life and colonisation by cariogenic microbiota as well as the occurrence of dental caries in subsequent years [23, 25]. The fact that sucrose serves as substrate for the production of extracellular deposits and an insoluble matrix of polysaccharides seems to favour colonisation by oral microorganisms and increases the viscosity of biofilm [26]. When introduced early in the life of an infant, sucrose promotes conditions for the implantation and successive colonisation of new dental surfaces by a cariogenic microbiota, especially the mutans group *Streptococci*. Thus, dietary practices have repercussions on the presence and proportion of cariogenic microorganisms in the oral cavity of infants, which recognisably influences future caries experience [25].

The age and way by which sucrose is introduced in the diet of children vary in accordance with socioeconomic and cultural characteristics. However, it is recognised that most children in different communities have access to foods with free sugars before completing their first year of life. Table 4.2 displays the prevalence of the use of different foods and beverages with sugar at 6 and 12 months of age in the city of Porto Alegre, Brazil. Analysing the products consumed, the intake of foods and beverages with sugar is extremely high in this community (higher than 80% at 6 months of age and higher than 95% at 12 months of age) [23].

**Table 4.2** Prevalence of consumption of different foods and beverages with sugar at 6 and 12 months of age; Porto Alegre, Brazil ($n$ = 458)

| 6 months | | 12 months | |
|---|---|---|---|
| Item | % | Item | % |
| Added sugar | 71.5 | Sweet biscuits | 90.4 |
| Sweet biscuits | 60.8 | Added sugar in drink | 84.9 |
| Gelatine | 59.6 | Cookies | 79.7 |
| Petit-suisse cheese | 58.6 | Petit-suisse cheese | 79.1 |
| Soft drinks | 31.1 | Soft drinks | 77.0 |
| Candy | 28.7 | Candy | 75.1 |
| Chocolate | 18.7 | Gelatine | 67.4 |
| Fruit-flavoured drink | 15.2 | Chocolate | 58.3 |
| Ice cream | 13.0 | Fruit-flavoured drink | 58.0 |
| Chips | 9.9 | Chocolate milk | 46.2 |

Source: Chaffee et al. 2015 [23]

**Table 4.3** Relative incidence of severe early childhood caries and relative number of decayed, missing or filled teeth at 38 months according to dietary patterns in first year of life

| 12-month sweet index | Outcome: severe ECC | | | | Outcome: dmft | | | |
|---|---|---|---|---|---|---|---|---|
| | Unadjusted | | Adjusted[a] | | Unadjusted | | Adjusted[a] | |
| | RR | 95% CI | RR | 95% CI | Ratio[b] | 95% CI | Ratio[b] | 95% CI |
| 1st tertile | 1 | | 1 | | 1 | | 1 | |
| 2nd tertile | 1.08 | 0.80, 1.70 | 1.01 | 0.75, 1.60 | 1.13 | 0.76, 1.84 | 1.10 | 0.69, 1.90 |
| 3rd tertile | 1.64 | 1.24, 2.36 | 1.55 | 1.17, 2.23 | 1.79 | 1.23, 2.77 | 1.78 | 1.20, 2.90 |
| Continuous | 1.09 | 1.05, 1.15 | 1.08 | 1.04, 1.14 | 1.13 | 1.07, 1.21 | 1.14 | 1.08, 1.22 |

*ECC* early childhood caries, *dmft* decayed (cavitated), missing due to caries, restored primary tooth index, *RR* cumulative incidence ratio (relative risk)

Source: Chaffee et al. 2015 [23]

[a]Adjusted for socioeconomic and demographic variables, breastfeeding duration and use of nursing bottle

[b]Ratio of dmft count compared to reference

In this birth cohort study, the researchers investigated whether early exposure to sugar (before 12 months of age) was a predictor of caries incidence in subsequent years [23]. At the 6- and 12-month assessments, mothers were asked about all sugary items consumed, which were totalled to form an index corresponding to the number of sweet foods or drinks introduced to the infant before 6 and 12 months of age. The children were then followed up until 3 years of age and examined. The prevalence of severe early childhood caries (ECC) and the decayed, missing and filled teeth (dmft) index were analysed in the lowest tertile (children who ate fewer sugary items), intermediate tertile and the highest tertile of sugar consumption. Children with the highest number of sugary items consumed at 6 and 12 months of age had the highest incidence of severe ECC and dmft at 3 years of age (Table 4.3).

Interestingly, a sensitivity analysis showed that the results were maintained when adding or removing specific items. Thus, it was not a matter of one or two specific sweet items but rather a pattern of the early introduction to sweet foods. The authors concluded that dietary patterns in infancy, characterised by a greater number of highly sweetened foods and drinks, were strongly associated with the incidence of severe ECC in subsequent years [23]. The following are possible explanations for these findings:

(a) Early dietary patterns may influence bacterial ecology, such as the establishment of mutans group *Streptococci*, which is a strong predictor of future caries incidence in young children. Sugar exposure in infancy was positively associated with the initial acquisition of *Streptococcus mutans* in an Australian birth cohort [25], and the adhesion properties of *S. mutans* may be sensitive to the sucrose concentration of the oral environment [27].
(b) Moreover, early exposure to sugar can exert an influence on the future preference for sweets, resulting in the increasing addition of sugar to foods and beverages [28], which may have contributed to caries experience in the subsequent years.

In general, dietary preferences are associated with foods with high energy densities, which are rich in sugar, fat and sodium, and the early exposure increases the acceptance and consumption of these foods in detriment to the consumption of healthier foods [29, 30]. In a Swedish cohort, habits established at 1 year of age, such as the intake of soft drinks and sweet snacks, predicted the continuation of such behaviours 1–2 years later [31]. As dietary patterns acquired in early childhood form the basis for future dietary practices in schoolchildren, the early introduction of sucrose can have a negative effect on future dietary preferences.

With regard to the early introduction of sugar, one can state the following:

- The early provision of free sugars may have significant dental consequences, potentially by setting the foundation for future cariogenic dietary patterns or through shaping bacterial populations in the oral cavity.
- The relationship between caries incidence and the sweet index scores demonstrates the benefit of *reducing* or *delaying* exposure to sweet items, even if consumption cannot be eliminated entirely.
- Therefore, parents and caregivers should be advised to delay the introduction of sucrose to after the first year of life and, preferably, to not before the child completes 2 years of age. It is possible that introducing adequate dietary behaviour is more effective than modifying long-established cariogenic dietary practices.

#### 4.2.1.2 High Frequency of Sugar Intake

Investigations with different study designs, at different times and in different populations have demonstrated the role of high food intake frequency in the occurrence of dental caries [12, 24, 32–34]. The process by which this relationship is established is based on the repeated production of acid and the maintenance of very low pH in the bacterial biofilm to which children who frequently consume carbohydrate between meals are exposed, impeding the physiological replacement of minerals in demineralisation-remineralisation cycles. Under such conditions, demineralisation prevails over remineralisation, and the conditions are established for the onset and progression of carious lesions (Fig. 4.1).

This practice seems to be particularly frequent and therefore harmful to preschool children and those in the early school phase. This occurs due to a number of factors, such as the belief that a child should be constantly fed to be well nourished or to compensate for the fact that the child did not eat in the way the parents/caregivers judged necessary, thereby generating a repetitive cycle of snacking between meals and a lack of appetite. Moreover, it is of fundamental importance to understand the non-biological dimension of diet, which makes foods be offered with other meanings, such as guilt or reward [35].

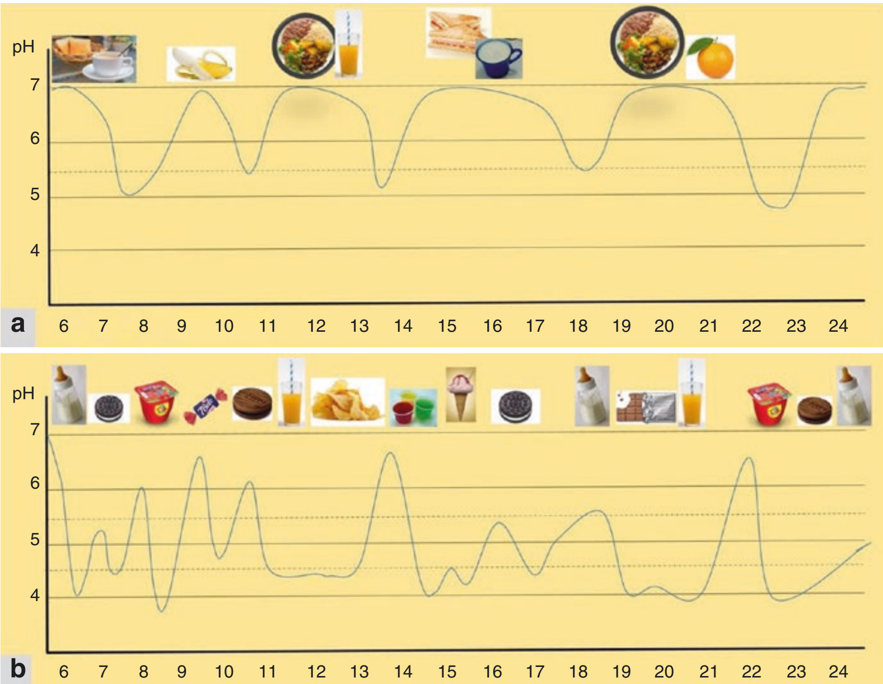


**Fig. 4.1** Drops in biofilm pH according to dietary pattern: (**a**) child with habit of eating five meals a day with low or no sugar intake and (**b**) child with habit of eating frequently, including consumption of various products with sugar throughout day

Snacking between meals can occur in solid form, such as cookies and sweets, or liquid form, such as tea, juice, soft drinks and milk, with or without the addition of other carbohydrates. Cross-sectional and longitudinal studies report that the high intake frequency of carbohydrates, particularly those rich in sucrose, is considered an important predictor for the development of caries in childhood [36–38].

Besides sucrose, the monosaccharides glucose and fructose, which are naturally found in fruit, vegetables and honey, and the polysaccharide starch should also be considered with regard to cariogenicity. The refinement or industrialisation process generally makes carbohydrates more susceptible to fermentation by cariogenic microorganisms. Thus, processed foods containing starch, such as bread and cookies, are potentially more cariogenic than non-refined carbohydrates. On par with its reputation among laypersons, honey is also contraindicated in the first year of life from the standpoint of oral health. With a highly sticky physical form and composed mainly of fructose and glucose, honey is metabolised by cariogenic bacteria [39] and, when offered frequently, can be an important factor in the aetiology of dental caries in childhood.

A birth cohort study in the city of São Leopoldo, Brazil, demonstrated that children who received foods and beverages more than eight times a day at 12 months of age had 42% more severe early childhood caries than children who consumed foods and beverages with less frequency [40]. Dietary practices were collected using a 24-h recall, and the results occurred independently of the concomitance of other cariogenic practices, such as bottle-feeding, high density sugar intake or high breastfeeding frequency.

A birth cohort of children in the city of Porto Alegre, Brazil, investigated associations between feeding frequency at 12 months of age and the prevalence of caries at 3 years of age [24]. All foods and drinks consumed at 12 months, including bottle-feeding and breastfeeding, were recorded using two 24-h infant dietary recalls with mothers. After adjusting for socioeconomic status and carbohydrate intake, the findings demonstrated a strong dose-response relationship between intake frequency and the incidence of early childhood caries, severe early childhood caries and the dmft index (Table 4.4). The authors concluded that high-frequency feeding in infancy, including both bottle use and breastfeeding, was positively associated with dental caries in early childhood, suggesting possible early-life targets for caries prevention.

Studies have investigated the effect of two specific dietary practices in childhood: bottle-feeding and breastfeeding. The fact that these practices are related to other dietary behaviours and inversely related to each other (children who bottle-feed with a greater frequency breastfeed with less frequency or not at all and vice versa) hinders the identification of the role of each feeding practice in the occurrence of dental caries [24]. This indicates the need for results to be statistically adjusted to discard the possibility that the effect is due to confounding factors, particularly socioeconomic status and other parallel dietary practices.

With regard to the association between breastfeeding and dental caries, most studies have important limitations, such as a cross-sectional design, data collection problems, breastfeeding cut-off points, the examination of children after 6 years of

**Table 4.4** Child dental status at 3 years of age according to quintiles of total daily feeding episodes at 12 months

| Total feeding frequency | *N* | ECC<br>*n* (%) | Adjusted[a]<br>RR (95% CI) |
|---|---|---|---|
| 1st quintile | 55 | 22 (40.0) | 1.00 |
| 2nd quintile | 90 | 39 (43.3) | 1.09 (0.73, 1.62) |
| 3rd quintile | 62 | 39 (62.9) | 1.62 (1.11, 2.35) |
| 4th quintile | 72 | 43 (59.7) | 1.50 (1.03, 2.18) |
| 5th quintile | 66 | 46 (69.7) | 1.75 (1.21, 2.52) |
| Total feeding frequency | *N* | Severe ECC | Adjusted[a] |
| | | *n* (%) | RR (95% CI) |
| 1st quintile | 55 | 7 (12.7) | 1.00 |
| 2nd quintile | 90 | 26 (28.9) | 2.44 (1.13, 5.27) |
| 3rd quintile | 62 | 18 (29.0) | 2.62 (1.19, 5.77) |
| 4th quintile | 72 | 31 (43.1) | 3.79 (1.80, 7.97) |
| 5th quintile | 66 | 30 (45.5) | 3.94 (1.84, 8.44) |
| Total feeding frequency | *N* | Mean dmft (SD) | RR (95% CI) |
| 1st quintile | 55 | 0.84 (1.3) | 1.00 |
| 2nd quintile | 90 | 1.61 (2.5) | 1.96 (1.13, 3.40) |
| 3rd quintile | 62 | 1.77 (2.1) | 2.30 (1.35, 3.91) |
| 4th quintile | 72 | 2.94 (3.9) | 3.57 (2.09, 6.10) |
| 5th quintile | 66 | 3.02 (3.6) | 3.52 (2.07, 6.00) |

Source: Feldens et al. 2018 [24]

[a]Adjusted for child's age, child's sex, mother's age, mother's schooling, social class, allocation status in nesting trial and total carbohydrate intake

age (when the most affected teeth are no longer present) and failure to take sugar intake into consideration. The most recent systematic review on this topic excluded the majority of studies with such problems and pointed to a protective effect of breastfeeding up to 12 months as well as a harmful effect when breastfeeding is prolonged beyond 12 months [41]. However, there was no adjustment for confounding factors in some studies, which hampers the determination of whether the protective effect or risk stemmed from breastfeeding or some parallel dietary practice.

The most valid response to this question requires the selection of the best available evidence based on the following criteria: (a) longitudinal studies that follow children from birth, enabling a more accurate collection of dietary practices and not depending on memory; (b) breastfeeding cut-off points beginning at 12 months rather than 6 months, which no harmful effect of breastfeeding is plausible; (c) the collection of outcomes until 6 years of age; and (d) adjustments for socioeconomic status and other dietary practices in order to isolate the effect of specific breastfeeding patterns. Taken together, these criteria would enable investigating the relationship of causality.

The articles listed in Table 4.5 consistently point to a greater risk (approximately twofold greater) of childhood caries with prolonged and/or highly frequent breastfeeding. Cut-off points of >12, ≥18 and ≥24 months were used for prolonged breastfeeding. All studies in the table made adjustments for socioeconomic status and other dietary practices, including sugar intake, in order to "isolate" the effect of breastfeeding [42].

Likewise, studies have demonstrated that bottle use, mainly with non-milk contents and at night, is associated with dental caries [40, 47]. The increased risk

**Table 4.5** Birth cohort studies investigating association between breastfeeding practices beginning at 12 months and childhood caries, taking into account other feeding behaviours and socio-economic status

| Author | *N*, sample | Exposure | Outcome | Adjusted effect measures[a] |
|---|---|---|---|---|
| Feldens et al. 2010 [40] | 340, São Leopoldo, Brazil | BF frequency at 12 months | Severe ECC (a) at 4 years | BF frequency 3–6 times/day, RR 2.04 (1.22–3.39), and ≥ 7×/day, RR 1.97 (1.45–2.68) |
| Tanaka et al. 2013 [43] | 315, Neyagawa City, Japan | BF ≥ 18 months | ECC (b), severe ECC at 3–4 years | BF ≥ 18 m: OR 2.47 (0.94–6.51) (ECC) quadratic trend for association $p < 0.05$ |
| Chaffee et al. 2014 [44] | 458, Porto Alegre, Brazil | BF ≥ 24 months | Severe ECC at 3 years | BF ≥ 24 mo: PR 2.1 (1.5–3.25) compared to <6 mo |
| Nirunsittirat et al. 2016 [45] | 554, Thailand | BF ≥ 18 months | dmft at 3–4 years | BF ≥ 18 mo: RR 2.94 (0.86–10.1) |
| Peres et al. 2017 [46] | 1303, Pelotas, Brazil | BF ≥ 24 months | dmft, severe ECC at 5 years | BF ≥ 24 mo: higher dmft (mean ratio 1.9; 95% CI 1.5, 2.4) and 2.4 times greater risk of having severe ECC (risk ratio 2.4; 95% CI 1.7, 3.3) |

*BF* breastfeeding, *ECC* early childhood caries, *RR* relative risk, *OR* odds ratio
Source: Adapted from Peres et al. 2018 [42]
[a]Adjusted for socioeconomic level and other feeding practices

derives from the content (usually liquids with sugar or with a very low pH) and the fact that liquids from bottles tend to be deposited on maxillary incisors (the most affected teeth in young children). Thus, bottles delivering sugary drinks and frequently used during day or night expose the tooth surface to acidic conditions for long periods of time.

It should be stressed that the cariogenicity of both practices depends on the frequency of use: bottle- or breastfeeding is commonly used as a pacifier, especially at night, when there is a low saliva flow rate in the mouth.

With regard to the frequency of sugar intake, the following can be stated:

- There is a dose-response relationship between the intake frequency of carbohydrates and dental caries in children and adolescents; a greater frequency of carbohydrate intake, especially sucrose, leads to a greater risk of dental caries.
- Although there is no cut-off point that defines a “safe” intake frequency, it is not plausible that intake five to six times a day represents a greater risk of caries, as there is a balance between demineralisation and remineralisation processes under these conditions.
- The strong association between high frequency of sugar intake and dental caries is the basis for the maintenance of intervals between meals and restricting sugar intake to dessert time.

#### 4.2.1.3 Amount of Sugar

According to the World Health Organization, high free sugar intake is a concern due to its association with poor dietary quality, obesity and the risk of non-communicable diseases. A systematic review of studies was conducted to gather evidence on the association between the amount of sugar intake and dental caries and the effect of restricting sugar intake to <10 and <5% energy (E) on caries to update sugar consumption guidelines [5]. Studies conducted with children and adults reported a positive association between the amount of sugar intake and caries. There was evidence of moderate quality showing that caries is lower when free sugar intake is <10% E. With the <5% E cut-off, a significant relationship was found, but the evidence was judged to be of very low quality. The findings are relevant to minimising the risk of caries throughout the course of one's lifetime [5].

A longitudinal study involving adults who participated in at least two of three surveys in Finland explored the dose-response association between sugar intake and caries in adults [48]. The findings in adults suggest a linear relationship between the two variables, with the amount being more important than the frequency of intake. It should be stressed, however, that the data were collected using a food frequency questionnaire, which may be limited with regard to measuring dietary practices [49]. Nonetheless, frequency and amount are generally strongly correlated, as children and adolescents who consume a large amount of sugar do so often.

A birth cohort study conducted in Pelotas, Brazil, performed the first investigation of the effects of sugar-related feeding practices on changes in dental caries from early childhood to young adulthood [14]. Feeding practices were assessed at 4, 15 and 18 years of age. The results showed that high and upward sugar consumers had a higher prevalence rate of dental caries and mean DMFT index in all cohort waves when compared to low sugar consumers. The adjusted analysis showed that the increase in dental caries between ages 6 and 18 years was 20 and 66% higher in upward and high sugar consumer groups when compared to low consumers. Thus, higher sugar consumption throughout the course of one's life translates to a greater increase in the occurrence of dental caries.

The choice for healthy products should also take into consideration the fact that various foods can contain hidden sugar or at least not clearly described on the label. Thus, special attention should be given to processed foods that actually contain sugar, which varies depending on the commercial brand, such as bread, yogurt, breakfast cereals, crackers, granola bars, dried fruit, non-dairy milk and bottled tea, juices and sport drinks.

The association suggested by some studies between the consumption of medications/syrups and caries in the first years of life is related to the sugar content, as caries can occur when such products are used for long periods and with high frequency [50]. However, this association is not consistent, as it has not been found in other studies [51, 52]. It is possible that differences between countries regarding the products used to sweeten medications, such as xylitol and sorbitol in Finland, may partially explain the divergent findings.

Sugar intake should be understood as the result of a pattern that has occurred in practically all countries and characterises nutritional transition, which has had disastrous consequences with regard to the burden of morbidity and mortality throughout the world. Rather than being a mere individual choice on the part of a child, sugar intake is a pattern influenced by advertising and established at the beginning of life by parents and caregivers [53, 54].

With regard to the amount of sugar and considering different health outcomes, including dental caries, the World Health Organization recommends the following based on current evidence:

- Reduced intake of free sugars throughout the life course (strong recommendation)
- In both adults and children, reducing the intake of free sugars to less than 10% of total energy intake (strong recommendation)
- A further reduction in the intake of free sugars to below 5% of total energy intake (conditional recommendation)

In practical terms:

- For a 3-year-old child with a mean daily intake of 1300 kcal, a can of soda pop (350 mL) represents more than 130 kcal and therefore already extrapolates the maximum limit of 10% of sugar of the total energy intake.
- For an adolescent with a mean daily intake of 2000 kcal, two pieces of cake (60 g each) contain approximately 50 g of sugar and equal approximately 200 kcal, which is the maximum limit of 10% of sugar of the total energy intake of 10%.

### 4.2.2 Interventions on Dietary Practices

There are different intervention options on dietary practices from the individual to the collective level or downstream to upstream interventions. The aim of dietary counselling and food education is to change behaviours, but the two processes have distinct characteristics. Dietary counselling emphasises the immediate change in dietary practices from a professional prescription, as well as an evaluation of the short-term results. It regards routine recommendations given in clinics and in the offices of nutritionists or physicians. Food education is a continuous process with the aim of educating individuals regarding the importance of healthy eating habits and is normally performed through formal educational programs at schools or other institutions and in the media. Meeting the desired goals ideally involves joint and parallel actions involving these two processes.

#### 4.2.2.1 Dietary Counselling: The Individual Level

The role of health professionals in the prevention and control of different conditions, including dental caries, presupposes counselling with regard to risk factors. Thus, before any specific advice, the health professional should learn about the family's situation, such as socioeconomic status, behaviours, motivations, etc. The collection of data must be performed with consolidated technical criteria as well as considerable insightfulness in the interpretation of the responses provided. The choice of the type of inquiry depends on the child's age, the issue being evaluated, socioeconomic characteristics and the availability of time. Although it is recognised that the collection of data on food intake normally involves measurement errors, such information is very important to the nutritional diagnosis.

For the diagnosis of dietary practices among preschool children, a 24-h recall, in which the mother reports everything the child ate in the previous day, or a 1-day habitual eating inquiry is recommended. If the intake annotations are very regular and adequate intervals are found between one meal and another, it is important for the health professional to confirm with the mother whether the child did not consume sweetened juices, soft drinks, candy, cookies and chocolate milk between meals. With this type of inquiry, the problem of under-reported unhealthy snacks between meals is not uncommon, as the health professional "guides" the data collection process by emphasising what was consumed between meals. On eating frequency questionnaires, with which the health professional inquires about the number of times the child eats particular foods on a monthly, weekly or daily basis, the caregiver tends to note only the foods consumed at scheduled meals and overlook those consumed between meals, which could lead to a false diagnosis that the child's diet is not a risk factor for dental caries or other health problem.

In the school phase, the child should participate in the dietary inquiry, contributing to the information provided. The health professional should pay particular attention to foods and beverages consumed between meals, such as candy, cookies, sweetened juices and soft drinks, which are consumed during the child's times of recreation and often without the knowledge of the parents or caregivers.

Figure 4.2 illustrates two quite different eating patterns for 3-year-old children taken from patient's history records.

From an analysis of the child's or adolescent's routine, the health professional should detect positive and negative aspects of the dietary practices and then counsel the parents/caregivers and/or patients. Based on previously described risk factors, counselling for dietary practices should focus on the following:

**a**

| Time | Meal |
|---|---|
| 7:30 am | 1 glass of milk + 1 roll with butter |
| 10:00 am | 1 fruit |
| 12:30 pm | Lunch: rice, beans, meat, potato and 1 or 2 vegetables |
| 4:00 pm | School snack: sandwich or baked cheese roll and orange juice |
| 20:30 pm | Dinner: generally same as lunch |
| | Dessert: gelatin or chocolate |

**b**

| Time | Meal |
|---|---|
| 6:00 am | Milk (bottle fed in bed, sleeping) |
| 8:30 am | Wakes up: bottle fed chocolate milk |
| 9:00 am to 12:00 pm | No set time to eat; period spent snacking on cookies, chips, sweetened juice, candy, yogurt… |
| 12:00 pm | Lunch: not hungry – does not want to eat |
| 12:30 pm | Bottle fed chocolate milk (Sleeps) |
| 3:00 pm | Bottle fed chocolate milk |
| 3:30 to evening | No set time to eat; period spent snacking on cookies, chips, sweetened juice, candy, yogurt… |
| 8:00 pm | Eats little: rice and small amount of bean soup |
| 10:00 pm | Bottle fed chocolate milk to sleep |
| During night | Wakes up 2 or 3 times asking for bottle |

**Fig. 4.2** Daily food intake records: (**a**) 3-year-old child with five meals per day. (**b**) 3-year-old child with high intake meals frequency

- Breastfeeding: encouragement of exclusive breastfeeding until 6 months of age, followed by the introduction of solid foods such that the feeding of the child at about 12 months of age is similar to that of the rest of the family. Breastfeeding after 1 year of age and highly frequent breastfeeding: reduce the frequency to a maximum of two times a day; do not replace with formulated milk.
- Sugar: introduction of sucrose at the latest possible time, preferentially only after 2 years of age, so that the child recognises the natural flavour of foods; when the use of sugar becomes “unavoidable”, considering the influences of the family and social environment rationalises its consumption, offering it only in the form of dessert.
- Bottle-feeding: preferentially advise to replace with a glass or cup; it is fundamental to avoid using a bottle with sweetened juices, soft drinks and other sugary beverages between meals, prior to sleep or during sleep.
- Frequency of food intake: maintain regular intervals between meals to enable the pH to return to a neutral value, and ensure the balance between natural processes of demineralisation and remineralisation. Demonstrate to parents/caregivers that the best meals are associated with larger intervals.

#### 4.2.2.2 Food Education: The Collective Level

Different strategies can be used for the promotion of healthy dietary practices:

(a) Strategies that seek to promote healthy dietary practices
(b) Strategies that seek to reduce availability or access to sugar

There is still no evidence on the effectiveness of these two strategies. Strategies designed to promote healthy dietary practices are based on the “convincing method”, such as counselling to introduce healthy foods beginning in the first year of life or focused on the reduction of dietary practices identified as risks for the occurrence of negative health outcomes.

Mothers in an intervention group in a randomised controlled trial conducted in the city of São Leopoldo, Brazil, were advised based on a program entitled “Ten Steps for Healthy Feeding” during eight visits in the child’s first year of life. The ten steps included breastfeeding promotion and avoiding the introduction of sugar in the first year of life. Mothers from the control group did not receive any advice, and their routine was followed up at health centres. The intervention increased the occurrence of exclusive breastfeeding up to 6 months, reduced the consumption of sweets and led to reductions in the occurrence of diarrhoea and respiratory disease [55].

Regarding oral health outcomes, counselling on feeding practices led to the reduction of pacifier use as well as a reduction in the incidence of ECC by nearly 50% [56]. When the children were 4 years of age, the prevalence of a poor diet was 70% lower in the intervention group, the incidence of ECC was reduced by 22% and

**Table 4.6** Reduction in childhood caries and number of affected teeth at 4 years of age with nutritional counselling of mothers in their homes

| Outcome | Intervention ($n$ = 141) | Control ($n$ = 199) | $p$ value |
|---|---|---|---|
| *Primary outcome* | | | |
| Children with early childhood caries[a] | | | |
| *N* (%) | 76 (53.9) | 138 (69.3) | 0.004 |
| RR (95% CI) | 0.78 (0.65–0.93) | 1.00 | |
| NNT (95% CI) | 7 (4–20) | | |
| *Secondary outcomes* | | | |
| Children with severe early childhood caries[b] | | | |
| *N* (%) | 41 (29.1) | 85 (42.7) | 0.010 |
| RR (95% CI) | 0.68 (0.50–0.92) | 1.00 | |
| NNT (95% CI) | 8 (5–30) | | |
| Affected teeth ($d_{1+}$mft) | | | |
| Mean (SD) | 3.25 (4.25) | 4.15 (4.57) | 0.023 |

*RR* relative risk, *NNT* number needed to treat
Source: Feldens et al. [57]
[a]Early childhood caries defined as $d_{1+}$mft ≥ 1
[b]Severe early childhood caries defined as one or more cavitated, missing or filled smooth surfaces in primary maxillary anterior teeth or $d_{1+}$mfs ≥ 5

the incidence of severe ECC was reduced by 32% [56] (Table 4.6). Therefore, dietary counselling worked, at least in part. However, the number of families necessary to treat for the main outcome was seven, indicating that seven families need to be advised in order to prevent one case of ECC.

It is noteworthy that the intervention was successful with regard to establishing some healthy behaviours, but not others. Delaying the introduction of sugar; avoiding sweets, honey and cookies; and having larger intervals between meals are simpler measures and were effective in the families that received counselling. On the other hand, no differences in the consumption of thicker foods, fruit and vegetables or a reduction in bottle-feeding occurred between groups, possibly because such behaviours are more complex and include an emotional component.

Another possibility to promote healthy dietary practices is the training of personnel at healthcare services to counsel families, which is a low-cost approach. A cluster randomised trial conducted at health centres investigated the effect of providing training to the staff at primary care centres using the “ten steps”, which is a less intensive, more affordable intervention [58]. The findings showed a delay in the introduction of added sugar, cookies and gelatine as well as reductions in the consumption of sugary products, such as soft drinks and chocolate. However, no reduction in dental caries was found. This is a more indirect, less intensive intervention that is therefore less likely to offer positive results with regard to clinically relevant outcomes. However, a significant reduction in dental caries occurred among children of mothers who exclusively used the same health centre. On the one hand, these findings underscore the importance of ties between families and healthcare services. On the other hand, it is possible that strategies based solely on a change in behaviour increase inequality, since the “best mothers” benefit more from it.

In recent years, the adoption of "upstream" strategies focused on reducing availability or access to sugar and not depending exclusively on behavioural changes have been suggested. Such strategies are promising, but few studies have evaluated their effects, especially on clinically relevant outcomes. A recent systematic review investigated the effectiveness of different intervention models for promoting healthy eating [59]. The focus of the compared interventions was *price* (fiscal measures, such as taxes and subsidies), *place* (environmental measures in specific settings, such as schools, workplaces, etc.), *product* (modification of food products to make them healthier, such as additives, the elimination of a specific nutrient, etc.), *prescriptive* (restrictions on advertising), *promotion* (mass media public information campaigns) and *person* (individual-based education: counselling or nutrition education).

The results showed that most of the *price* and *place* interventions reduced inequalities by preferentially improving healthy eating outcomes among individuals with a lower socioeconomic status. However, an important proportion of the *person* interventions widened inequality, as such interventions had a greater impact on individuals with a higher socioeconomic status. The authors concluded that upstream interventions appear to decrease inequality. However, these results are based on intermediate outcomes (better dietary practices) rather than clinically relevant outcomes.

Another systematic review investigated the effect of implementing taxes on sweet beverages. The results showed a reduced dietary intake of added sugars, which could potentially reduce the incidence of obesity and diabetes [60]. In dentistry, a single simulation study investigated the effect of implementing a 20% sugar-sweetened beverage sales tax on the population of Germany [61]. The authors estimated that this tax would reduce sugar intake, especially in younger individuals and among those with a low income. Although positive, the findings of these studies were also based on intermediate outcomes and do not ensure a reduction in the incidence of dental caries.

Although evidence is scarce, the literature describes guiding principles that can be applied [62]:

- *Empowerment*—Interventions should enable individuals to exert more control over the factors that affect their oral health.
- *Participatory*—Key stakeholders should be encouraged to be involved in planning and implementing interventions.
- *Multi-strategy and multi-professional*—A combination of complementary actions should be encouraged, from indoor actions to upstream interventions, such as promoting water fluoridation and taxing unhealthy products. Oral health professionals alone cannot improve oral health in children without partners.

There are additional experiences of interventions targeting the reduction in sugar consumption, such as reducing the availability of sugary products in schools and retail environments, raising awareness of sugar in products or increasing the acceptability of water. Testing the effectiveness of such strategies on clinically relevant outcomes is a challenge for researchers but has a potentially considerable benefit to populations.

Regardless of the focus of each strategy, there seems to be a consensus on the notion that interventions should adopt a broad approach focusing on *common risk factors* [6]. Thus, delaying the introduction of sugar in the life of a child and promoting consumption compatible with general and oral health should be the constant goals of every health professional.

## 4.3 Oral Hygiene and Dental Caries

### 4.3.1 The Role of Oral Hygiene in the Occurrence of Dental Caries

The fundamental aim of any oral hygiene measure is the removal of bacterial biofilm, the metabolic activity of which can result in mineral loss. From the standpoint of the physiopathological mechanism, it is therefore plausible that toothbrushing is a protective behaviour with regard to dental caries. In situ and in vivo studies support the hypothesis that the mechanical control of biofilm is important to the control of mineral loss and the progression of dental caries [63, 64].

However, the relationship between the degree of oral hygiene and the severity of dental caries is not clear, which hinders the quantification of the benefits of this strategy. Divergent results are found from population-based studies that have evaluated the effect of brushing on the prevention of dental caries. While some studies describe an association between oral hygiene measures and dental caries [52, 65], others have not found a protective effect [37, 66–68].

The degree of oral hygiene is not merely the result of an individual choice. There are different variables that influence the effectiveness of the mechanical control of biofilm. Psychosocial issues can make patients neglect oral hygiene such that the resulting build-up of plaque is detrimental to oral health [69]. Likewise, there is evidence of social determination, since oral hygiene is poorer among groups with a low socioeconomic status [70].

The effect of different interventions, including counselling with regard to brushing, can only be truly known through the results of randomised clinical trials or systematic reviews of clinical trials. Considering the benefits demonstrated regarding the use of toothpastes for the prevention and control of dental caries, it is impossible to isolate the effect of the mechanic removal of biofilm from the beneficial effect of fluoride, since it is ethically inappropriate to allocate children to a group instructed to control biofilm without fluoride toothpaste. In practice, poorer hygiene also indicates less exposure to fluoride in toothpaste [71].

In general, studies have demonstrated that oral hygiene counselling may contribute to improvements in intermediate outcomes, such as an increase in the number of times children brush their teeth, better supervision on the part of parents and caregivers and a reduction in biofilm, but not clinically relevant outcomes, such as dental caries [72, 73].

A recent systematic review with meta-analysis evaluated the effectiveness of oral health educational actions in the school context at improving oral hygiene and reducing dental caries in schoolchildren [74]. Considerable methodological variation was found among the studies selected with regard to the type of intervention, such as lectures, albums, slides, leaflets, counselling, games, drawings and theatre. Likewise, the duration of the interventions varied from 1 month to 4 years. The results revealed a positive effect of some interventions on the plaque index, but no effect on gingivitis or dental caries. Thus, there is no evidence that traditional oral health education on oral hygiene in schoolchildren prevents dental caries.

The lack of effectiveness of oral hygiene counselling on the occurrence of dental caries does not mean that brushing does not contribute to reducing the risk of new carious lesions. These results may, at least in part, be related to the difficulty in obtaining patient adherence and maintaining patients motivated in the medium and long terms. Thus, highly frequent professional cleaning strategies were suggested and tested in the past on children and adults [75, 76]. With intervals ranging from 15 days to 3 months, a professional cleaning program leads to a significant reduction in the number of new carious lesions. However, the results of similar studies that investigated this type of program in other populations were not consistent [77, 78]. Moreover, the strategy is expensive.

Although such circumstances demonstrate the limitation of establishing evidence-based guidelines on oral hygiene, other aspects should be considered [79–81]:

- Toothbrushing is a simple, inexpensive manner to deliver constant fluoride to the oral cavity.
- Poor oral hygiene may be associated with periodontal disease and even other health conditions, such as pneumonia.
- Behaviours acquired in childhood tend to be maintained in adolescence and perpetuated throughout adulthood.
- Thus, although the isolated benefit of the mechanical control of biofilm is limited, it is rational for counselling with regard to the control of biofilm to be part of oral health promotion strategies.

### 4.3.2 Oral Hygiene Counselling

Oral hygiene counselling should not be standardised for all children. Factors such as age, erupted teeth, motivation and the skill of both the parent/caregiver and child should be considered. Moreover, the health professional should record the presence and location of biofilm throughout the arches during the physical examination. Taken together, this information can contribute to a more effective oral hygiene counselling strategy.

In general, parents/caregivers should be instructed to initiate oral hygiene as soon as the first incisors erupt. For the adequate removal of biofilm and to accustom the child at an early age to a routine that will accompany him/her in the future, it is better for cleaning to be done with a toothbrush from the beginning. There are a huge variety of toothbrushes on the market that differ in terms of bristle type, colour or associated cartoon character. Parents/caregivers should be advised to prioritise brushes soft bristles that provide adequate grip and are appropriate for the child's age.

In the early years of life, brushing the teeth with the child lying down may be easier and more effective. It is fundamental to explain to the parents/caregivers of younger children that the behaviour of different children or even the same child at different ages varies considerably and that complaining or crying is natural. Some parents become extremely sensitive when facing this situation and even demonstrate fear that the child will become "traumatised". It is the dentist's role to demonstrate that, as occurs with regard to eating habits, the child's reaction to oral hygiene may be a way of manipulating the parents. Negative reactions to oral hygiene should be understood and faced in the same way as other routing practices, such as a haircut, cutting fingernails or taking a bath.

With regard to the recommended frequency, one should bear in mind that the benefit of brushing is mainly associated with the fluoride toothpaste used. It therefore seems rational to recommend brushing at least twice a day. Since salivary flow and the spontaneous elimination of carbohydrates are diminished during sleep, emphasis should be placed on controlling biofilm at night before the child goes to bed.

There is no evidence regarding the best oral hygiene technique. The quality of biofilm removal seems to be related to the skill of the person performing the action. Therefore, it is fundamental for a parent/caregiver to be the person who brushes a preschool child's teeth and not the child alone. Surfaces and teeth that accumulate more biofilm—depending on the child's age and stage of teeth eruption—merit special attention [82, 83]:

- Up to 2 years of age: upper incisors
- Three to five years of age: occlusal surfaces of primary molars
- Six to eight years of age: occlusal surfaces of first permanent molars

Thus, parents should be instructed with regard to the hygiene of the permanent first molars, especially during their eruption, which is a period in which more biofilm accumulates and the teeth are more prone to develop active carious lesions [82]. It is possible, however, that the benefit of oral hygiene counselling is greater in high-risk populations [68].

The mechanical control of biofilm includes the use of dental floss as a way to disorganise and remove interproximal plaque, potentially contributing to the prevention and control of caries on these surfaces. However, systematic reviews have not demonstrated evidence of the effectiveness of the individual use of dental floss in adults and children [84, 85]. In practice, flossing requires greater dexterity, and the majority of parents find it difficult to adhere to this behaviour. The same is true with regard to self-care performed by children or even adults. It therefore does not seem adequate to recommend its use on all teeth in all children. Maxillary incisors, molars without spacing and incipient lesions on proximal surfaces should be the major focus of counselling regarding the use of dental floss.

The dentist's role is to motivate and advise parents, children and adolescents regarding the adequate control of biofilm to reduce it to levels that are compatible with health, prioritising surfaces at greater risk of caries. Beyond merely theoretical counselling, it is fundamental to demonstrate all the steps involved: application of the toothpaste, positioning of the child to enable the best possible view of the teeth and a technique that is simple and possible for parents/caregivers or the children themselves to execute. Therefore, this is no single piece of advice for all families. During the clinical examination, characteristics of the patient that could interfere with the effectiveness of the mechanical control of biofilm, such as age, type of arch (with or without spacing), teeth present and those in the process of eruption, physical or motor impairment and the use of an orthodontic appliance, should be recorded. Likewise, there are parents who are more or less motivated, who are more or less present in the daily routine of their children and who are willing to dedicate more or less time to this task. All these variables should be taken into consideration to ensure greater effectiveness in the control of biofilm.

In practice, oral health professionals should consider that:

- Outlining methods and clear, palpable goals for the control of biofilm in each situation and transmitting to both parents and patients the reasoning behind these measures may be the best way to achieve their cooperation.

## 4.4 Final Considerations

The high prevalence and severity of caries in children, adolescents and adults requires the adoption of prevention and control strategies. Such actions can be on the collective level (public policies that promote health and health education), both the collective and individual levels (dietary counselling) and specific actions on the part of the dentist, such as individual counselling with regard to oral hygiene with a fluoride toothpaste. However, this is not an easy task. To promote healthy dietary practices and adequate oral hygiene beginning in the first year of life, it is necessary to understand the biological and psychosocial aspects involved.

As it is a common risk factor for different non-communicable diseases and plays a fundamental role in the occurrence of dental caries, sugar should be the main focus of strategies aimed at the adoption of healthy behaviours. However, to ensure the delayed introduction of sugar in the lives of children and reductions in its consumption in different phases of life, it is fundamental to adopt strategies that have a broad scope, such as reducing the availability of sugar in schools and raising taxes on sugar, which would increase the potential for improving both oral and general health outcomes.

Among specific caries prevention and control measures, the mechanical control of biofilm alone has the lowest level of scientific evidence. Nonetheless, brushing is the best way to provide a constant source of fluoride to the teeth and is a way for a parent and child to interact in a way that educates and prepares the child with regard to the importance of self-care.

Dentists should be prepared to counsel parents, caregivers and patients on how to achieve the maximum benefits from both behaviours in accordance with the characteristics of each family. It is therefore fundamental for dentists to go beyond a merely technical function and be willing to address the inherent difficulties and limitations. It is essential to know how to listen, inquire, recommend and compliment. At the same time, dentists should understand that evidence-based practice includes not only the best available scientific evidence but also the preferences of patients. Therefore, the autonomy of the patient and family should be respected.

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# Fluoride Agents and Dental Caries

# 5

Alberto C. B. Delbem and Juliano P. Pessan

## 5.1 Introduction

Fluoride was introduced into the dental practice over eight decades ago. The discovery of its therapeutic effects occurred by means of observational studies demonstrating that the same agent that caused "mottled enamel" (later known as dental fluorosis) was responsible for the low levels of dental caries in several cities of the United States, in a dose-dependent relationship [1]. These initial epidemiological findings subsequently led to the experimental fluoridation of public water supply in several regions of the World, which later became one of the greatest public health measures of the twentieth century, considering its safety and cost-effectiveness. At present, sodium fluoride is part of World Health Organization's model list of essential medicines, and access to fluorides has been recognized as a part of the basic human right to health [2].

The initial understanding was that fluoride should be ingested during the phase of tooth formation, in order to be absorbed by the apatite crystals of the developing enamel, thus exerting its preventive action by a pre-eruptive (i.e., systemic) effect. It was, therefore, mandatory that fluoride had to be ingested, so that the occurrence of dental fluorosis was an inherent risk for achieving the caries-protective benefits of fluoride [3]. Considering the early epidemiological findings on the relationship between fluoride levels in the drinking water and the resulting effect on dental caries and dental fluorosis, it has been established that an optimum level of exposure to fluoride should be determined to provide the maximum caries-protective effect with minimum dental fluorosis [4]. This concept lasted for several decades and was mainly based on data of the lower prevalence of dental caries in individuals from areas supplied with naturally fluoridated water, compared to residents of non-fluoridated regions.

A. C. B. Delbem (✉) · J. P. Pessan
School of Dentistry, Araçatuba, São Paulo State University (UNESP), Araçatuba, Brazil
e-mail: adelbem@foa.unesp.br



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Following the artificial fluoridation of the drinking water, other methods of fluoride delivery were gradually introduced, intended to "compensate" the lack of systemic exposure to naturally fluoridated water. Epidemiological and laboratory findings, however, led researchers to question the exactness of an exclusively preeruptive effect. Shortly after the introduction of fluoride supplements, it was shown that the use of lozenges (which were dissolved in saliva) by children led to lower caries increment (~ 40%) in comparison with those swallowing pills, suggesting that the caries reduction produced by lozenges resulted from the effect of fluoride on the external surfaces of the teeth [5]. Decades later, clinical and laboratory studies provided the basis for a better understanding of enamel de- and remineralization processes, as well as the mechanisms by which fluoride interferes in this dynamics. Simultaneously, the increasing knowledge of fluoride metabolism and toxicity allowed a better comprehension of appropriate doses of exposure and safety measures, in order to achieve optimum caries-preventive effects with minimum unwanted chronic or systemic side effects.

## 5.2 Overview of the Mechanisms of Action of Fluoride on Dental Caries

Several laboratory studies and literature reviews have addressed the mechanisms by which fluoride exerts its effects on the dynamics of enamel de- and remineralization (for detailed review, please see Monogr Oral Sci 2011; 22:97–114). Due to the scope of the present chapter, it will only provide a brief overview on how fluoride interferes in this dynamics, providing the essential concepts for a better understanding of the various forms of fluoride delivery covered in the present chapter.

In the late 1980s and early 1990s, studies conducted in Scandinavia assessed the effects of fluoride incorporated into the enamel crystals on the development of caries lesions in an in situ model, comparing specimens of human and shark enamel (which consists mainly of fluorapatite) [6, 7]. While fluoride structurally bound to enamel was indeed effective in reducing subsurface mineral loss at some extent, the use of a daily rinse with a 0.2% fluoridated solution significantly reduced mineral loss of human enamel when compared with shark enamel. These data supported the concept that fluoride available in the oral environment is more effective in inhibiting demineralization than the fluoride incorporated into the dental enamel. Several other important studies were conducted and helped to elucidate the etiology of dental caries and how fluoride acts in this process. In short, fluoride can interfere with caries dynamics by acting on the processes of de-remineralization of tooth structure, as well as on bacterial metabolism [3], as summarized below.

### 5.2.1 Effects on Enamel Demineralization and Remineralization

Figure 5.1 provides a brief overview on how fluoride interferes with the de- and remineralization of tooth enamel. In short, fluoride can be present in various "pools"

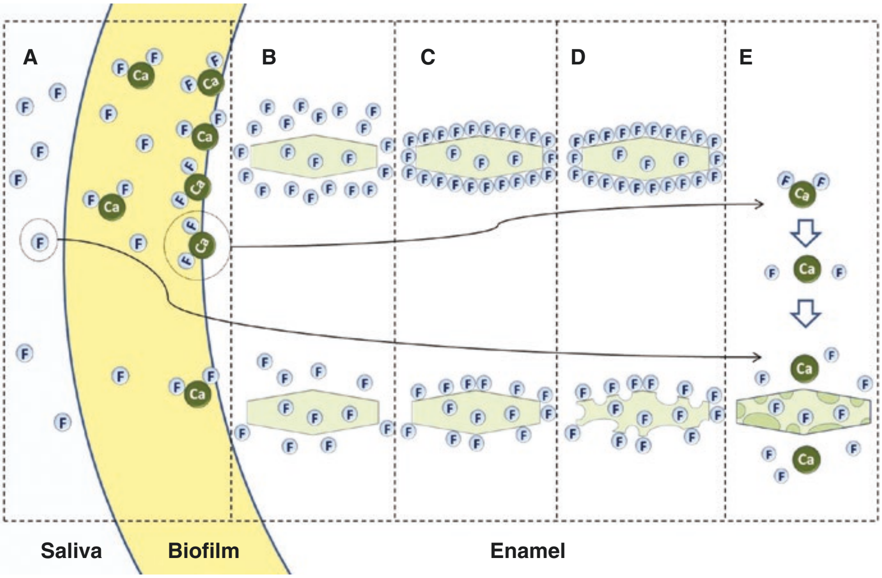


**Fig. 5.1** Schematic representation of the role of fluoride on the dynamics of enamel de- and remineralization. Top and bottom parts of the scheme represent fluoride-rich and fluoride-poor environments, respectively. The amount of fluoride available outside the enamel structure (**a**) determines the amount of fluoride surrounding the enamel crystals (**b**), which reflects on the amount of fluoride adsorbed on the enamel crystals (**c**). Upon acidic conditions (**d**), uncovered parts of the crystals will dissolve (bottom part), while full coverage (top part) protects the crystals against dissolution. Calcium fluoride reservoirs and/or free fluoride ions provide fluoride ions that speed up the process of remineralization of the partially demineralized enamel (light green areas) (**e**), resulting in the precipitation of a fluoride-rich and carbonate-poor crystal (dark green areas), rendering the tooth structure more resistant to future acid challenges (Modified from Arends and Chrstoffersen [8] and Featherstone [11])

in the oral environment [8], according to their location: outside enamel (Fig. 5.1a); firmly bound to the structure of the crystals (Fig. 5.1b–e); in the fluid surrounding the crystals (Fig. 5.1b); loosely bound to the enamel crystals (Fig. 5.1c, d); and as calcium fluoride ($CaF_2$) deposits on the enamel surface and/or dental biofilm. Among these pools, fluoride adsorbed to the crystallites is the fraction that exerts the most protective effect. Given the balance between fluoride levels outside enamel (i.e., saliva and biofilm) and those in the enamel fluid, the maintenance of constant levels of fluoride outside enamel (Fig. 5.1a) ensures the maintenance of constant levels in the space between enamel crystals (Fig. 5.1b), consequently affecting the levels of adsorbed fluoride (Fig. 5.1c) [3, 9].

In addition, the application of high concentrations of fluoride on the dental surfaces leads to the formation of large amounts of $CaF_2$, which serves as a physical-chemical barrier to future pH drops in the dental biofilm. This mineral, which is highly soluble in aqueous medium, is stabilized by salivary proteins at physiological pH, forming $CaF_2$-protein complexes that are destabilized upon acidic pH, releasing $F^-$ and $Ca^{2+}$ ions to the oral environment. The presence of these ions contributes to the maintenance of adequate $F^-$ levels to be adsorbed to crystallites, consequently reducing enamel demineralization and promoting remineralization of previously dissolved crystallites (Fig. 5.1e) [9]. The formation of $CaF_2$, its resistance in the oral environment at neutral pH, and the release of fluoride ions at acidic pH are believed to be the reasons for the long-term effect of topically applied fluoride. Factors including fluoride concentration in the vehicle, time of exposure, and acidic pH are known to significantly influence $CaF_2$ deposition on enamel [10].

It should be emphasized that fluoride acts as a catalyst in the reaction of mineral reprecipitation (resulting from salivary ions) due to its high reactivity. Thus, after partial demineralization of a biological apatite crystallite (which contains several "contaminants," especially carbonate), fluoride accelerates the reprecipitation of these partially dissolved crystals, with the advantage of eliminating carbonate from the enamel structure and incorporating fluoride, which ensures greater resistance to future cariogenic challenges. Thus the effect of fluoride on enamel remineralization also results in a protective effect against future demineralization (due to the production of a more resistant mineral), so that the separation of its effects on de- and remineralization is merely didactical, given that they are part of an extremely dynamic process [3, 9].

### 5.2.2 Effects of Fluoride on Bacterial Metabolism

The concept that fluoride may interfere with the bacterial metabolism of *S. mutans* and *Lactobacilli* involves complex biochemical events that promote the inactivation of important metabolic pathways of these microorganisms [12]. In brief, fluoride bound to biofilm components ionizes in acidic pH, subsequently forming hydrogen fluoride (HF), which is able to cross the bacterial cellular membrane. HF then dissociates into $H^+$ and $F^-$ ions, leading to acidification and increase of fluoride levels in the cytoplasm, respectively. Fluoride then inhibits bacterial metabolism by interfering with the enzyme enolase [9]. Although these biochemical effects are well established in the literature, they are believed to occur at fluoride levels that usually exceed those that prevail in the oral cavity in most clinical situations, so that the effects of fluoride on the de- and remineralization processes (which occur even at fluoride levels below 1 ppm) are more important than those on oral bacteria, from a clinical perspective [3, 9].

## 5.3 Forms of Fluoride Administration

Fluoride is now widely available worldwide in a variety of vehicles (Fig. 5.2), which differ regarding fluoride concentration and mode of use. Based on the current knowledge on the mechanisms of action of fluoride in the dynamics of dental caries, the classification of "topical" and "systemic" does not seem logical, given that the effects of fluoride are essentially topical, even for vehicles that are intended for ingestion and, therefore, involve systemic exposure. Thus, considering the different modes of fluoride administration [13, 14], fluoridated vehicles can be classified as:

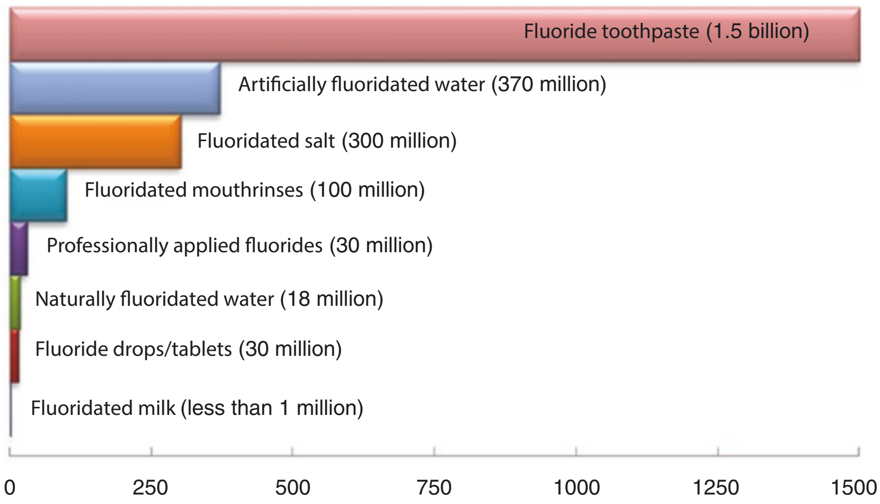


**Fig. 5.2** Estimated number of people (in millions) worldwide using different sources of fluoride. Modified from FDI [2]

a. *Methods of professional application*: applied by professionals at regular intervals (according to age, risk, and caries activity of the patient), presenting high concentrations of fluoride in the formulation. Varnishes, gels, foams, fluoride-releasing restorative materials, and slow-release fluoride devices are some examples of these methods.
b. *Methods for self-application*: these are vehicles used at home by the patient, presenting lower concentrations than products of professional application. A high frequency of exposure is essential to ensure the effectiveness of the method. Examples include dentifrices, mouthrinses, tablets, lozenges, and chewing gums.
c. *Collective or community-based methods*: are those of population reach. Examples include fluoridated water, milk, and salt.

The following section will present the main methods of fluoride delivery, with special emphasis on vehicles for professional application and home use, along with indications, advantages, disadvantages, as well as the clinical evidence in reducing the prevalence of dental caries.

## 5.4 Professionally Applied Vehicles

As described above, the methods for professional application include varnishes, gels, foams, fluoride-releasing restorative materials, and slow-release fluoride devices. The high concentration of fluoride in these products and/or their mode of application hinders their use at home. The most commonly used fluoride products in dentistry are gels, varnishes, and foams, which will be detailed below. As for slow-release devices, the evidence is more sparse and conflicting, according to a recent systematic review [15], and are not available for clinical use. Regarding restorative materials, their use in clinical practice is not intended for caries control per se (in comparison with gels, varnishes, and foams), since the effects of fluoride from these materials are mainly restricted to the treated areas. For these reasons, slow-release devices and restorative materials will not be addressed in this chapter.

### 5.4.1 Gels and Foams

Fluoride gels are widely used in clinical practice, considering their low cost, ease of application, and relative good acceptance by the patient. The viscosity of these products makes it possible to treat an entire arch at the same time (when applied using individual trays), which reduces both the application time and the risk of excessive fluoride intake [14] (Fig. 5.3). Increased penetration of gels between the teeth can be achieved using thixotropic products (which flow under pressure). When the use of trays is not possible (for logistic reasons or considering the age and cooperation of the patient), the gel can be applied with swabs or brushes, but treating one hemiarch at a time (Fig. 5.4) to allow an adequate isolation from saliva and to minimize fluoride ingestion from the product. In addition to the application of gels in a clinical facility, these can be used in preventive programs in school or prescribed for home use, although this practice is not common in several countries. In such cases, gels can be applied either with trays or using a toothbrush.

A recent systematic review of the Cochrane Library [16] concluded that the preventive effect of using gels was 28% for permanent teeth (data from 25 randomized clinical trials) and 20% for primary teeth (data from three randomized clinical trials), as presented in Table 5.1. The effect of the gels was significantly influenced by the application frequency, as well as the application intensity (frequency × concentration) and self-application (which may be associated with a higher frequency of use). Therefore, fluoridated gels should be applied 2–4 times per year for patients at high caries risk and/or activity in order to achieve the expected clinical efficacy.

**Fig. 5.3** Individual trays for gel application. It is important to select size-appropriate trays (left) in order to allow full coverage of all teeth. The gel must be dispensed at a volume enough to treat the entire arch without excess (center and right), in order to minimize fluoride ingestion

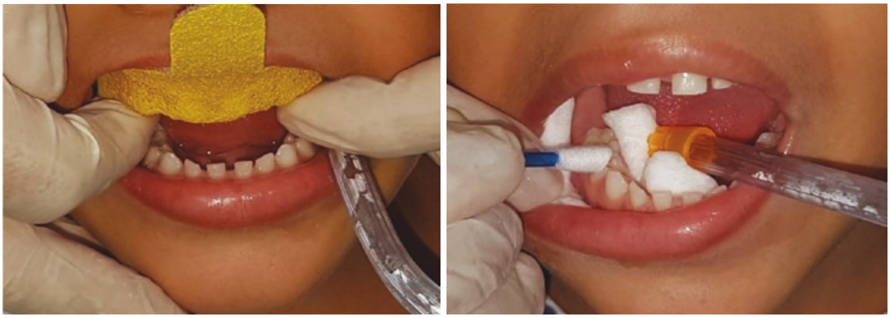

**Fig. 5.4** Application of fluoride gel using a tray (left) covering an entire arch, or with cotton swab (right) treating each hemiarch at a time, allowing adequate moist control (to enhance $CaF_2$ deposition). Suction device must be used under both conditions to minimize fluoride ingestion

**Table 5.1** Caries-preventive effects of fluoridated mouthrinses, gels, varnishes, and toothpastes according to the Cochrane Database of Systematic Reviews

| Year of publication | Fluoride vehicle | Number of participants | Dentition | Number of trials included | DMFS/dmfs pooled prevented fraction (95% confidence interval) | Quality of evidence |
|---|---|---|---|---|---|---|
| 2016 [17] | Mouthrinse | 15,305 | Deciduous | – | Not available | |
| | | | Permanent | 35 | 27% (23–30)[a] | Moderate |
| 2015 [16] | Gel | 9140 | Deciduous | 3 | 20% (11–38) | Poor |
| | | | Permanent | 25 | 28% (19–36) | Moderate |
| 2013 [18] | Varnish | 9595 | Deciduous | 10 | 37% (24–51) | Moderate |
| | | | Permanent | 13 | 43% (30–57) | Moderate |
| 2003 [19] | Toothpaste[b] | 42,300 | Deciduous | – | Not available | |
| | | | Permanent | 70 | 24% (21–28) | High |

[a]The corresponding DMFT prevented fraction for mouthrinses is 23% (18–29%, 95% CI)
[b]This review presents the overall effect of fluoride toothpastes in the prevention of dental caries, without discrimination among the different fluoride concentrations present in the products

Due to the high concentration of fluoride in gels (typically 9,000 and 12,300 ppm F, respectively for neutral and acidified gels), care should be taken when using these products to avoid side effects. Some important recommendations are listed below:

- Gels are usually recommended for children older than 6 years of age.
- The patient should be seated during the application by the professional, with the head slightly bent forward.
- Suction devices should be used during the application.
- The excess of product must be removed with gauze after application, and the patient must be instructed to spit out several times (Fig. 5.5).
- Application should be avoided in patients with empty stomach, to minimize possible systemic side effects (fluoride absorption is faster in this condition).

**Fig. 5.5** After gel application, the excess of gel is gently removed with a gauze (left), and the patient is requested to spit out for 30 s in order to minimize excessive fluoride ingestion from the product

Traditionally, a 4-min application time has been recommended for neutral and acidic products, and the patient should refrain from eating or drinking for 30 min after application. However, evidence from in vitro and in situ studies demonstrate no significant differences in the amount of $CaF_2$ formed on enamel between 1 and 4 min of application [20]. Similarly, rinsing the enamel with water or ingestion of water immediately after gel application was not shown to influence the preventive effect of the gel [21, 22]. As no evidence from randomized clinical trials (RCTs) is available, these findings indicate the need to address this important variable (i.e., time of application) in clinical studies, as it may have important implications related to patient cooperation, possibility of fluoride intake during the application, and cost. Regarding the need for prior prophylaxis, it is a consensus in the literature that this step is not strictly necessary to ensure the efficacy of the product [23, 24], but it is highly recommended considering the benefits of this measure in a preventive program.

As for fluoride foams, these have become available more recently, with a composition similar to that of acidulated phosphate fluoride (APF) gel. However, given that the amount of fluoride in foams is four- to five-fold lower than in gels of the same fluoride concentration (due to the lower density of these in foams), they can be considered as a safer option concerning the risk of fluoride intake. Although no robust evidence is yet available from systematic reviews, isolated RTCs indicate that these products are effective in reducing the progression of dental caries in children and adolescents [25–28].

### 5.4.2 Varnishes

Fluoride varnishes are viscous products containing high concentrations of fluoride, which are applied only by the professional in a dental facility (Fig. 5.6). Typically, varnishes contain 22,600 ppm F (5% NaF), although formulations with other fluoride salts and concentrations are also available. The main advantages of varnishes are the prolonged contact time between fluoride and tooth surfaces, which increases

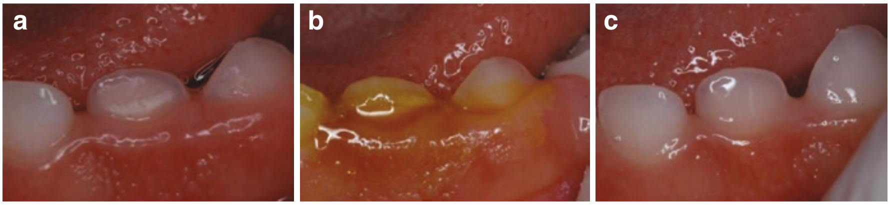


**Fig. 5.6** Fluoride varnish is indicated to arrest or reverse white spot lesions (**a**, **c**). After removal of the dental plaque, the product (previously agitated for its homogenization) should be applied with the aid of a brush on the caries lesions (**b**). The dental surface does not need to be completely dry before application, and light humidification of the varnish after its application helps in its adhesion to the dental structure. Following the varnish application, the child and/or caregiver should be reminded not to allow brushing of the child's teeth or eating crunchy/sticky foods for the rest of the day to maximize the effect of the fluoride varnish. The fluoride is slowly released from varnish and requires at least 6 h in contact with the surface of the teeth

F uptake by hard dental tissues and the formation of $CaF_2$ reservoirs, and the possibility of using very small quantities of the product, which greatly reduces the risk of excessive intake of fluoride. Similarly to gels, fluoride varnishes should be applied 2–4 times/year in patients at high caries risk and activity to maximize the benefits of this measure.

Evidence from the Cochrane Collaboration [18] indicates a substantial effect on the reduction of dental caries prevalence in both permanent teeth (43% reduction in DMFS) and primary teeth (37% reduction in dmfs), considering data from 22 randomized clinical studies (9595 patients). In addition, no association between the effect of the application with previous prophylaxis (despite recommended for the same reasons described for gels and foams), fluoride concentration, and frequency of application was observed. Despite the higher concentrations of fluoride, varnishes can be considered as a safer option when compared to gels due to the small amount used during the application, since the systemic exposure from this source is known to be transient and below the upper limit regarded as safe [29].

Table 5.2 presents evidence-based clinical recommendations for the application of fluoridated varnishes and gels, according to age and caries risk. Due to the low risk of acute toxicity, fluoride varnishes are the only topical fluoride agents recommended for this age group, despite other topical fluorides may have some evidence of a benefit.

## 5.5 Methods for Self-Application

Unlike fluoride products of professional application, methods for self-application involve vehicles with lower fluoride concentrations, which require a higher frequency of exposure in order to achieve benefits in the control of dental caries. Due to its importance in clinical practice and considering the robust evidence available,

**Table 5.2** Evidence-based clinical recommendations for professionally applied topical fluoride (varnishes and gels), according to the age group and caries risk

| Risk category | Age category for recall patients | | |
|---|---|---|---|
| | <6 years | 6–18 years | >18 years |
| Low | May not receive additional benefit from professional topical fluoride application[a] | | May not receive additional benefit from professional topical fluoride application[b] |
| Moderate | Varnish application at 6-month intervals[a] | | Varnish or gel application at 6-month intervals[b] |
| | Gel application at 6-month intervals[a] | | |
| High | Varnish application at 3- or 6-month intervals[a] | | Varnish or gel application at 3- or 6-month intervals[b] |
| | Gel application at 6-month intervals[a] or at 3-month intervals[b] | | |

Modified from American Dental Association Council on Scientific Affairs [30] and Weyant et al. [24]
[a]Evidence from systematic reviews of randomized clinical trials
[b]Evidence from expert committee reports or opinions or clinical experience of respected authorities

the present text will address in detail the use of mouthrinses and fluoridated dentifrices. As reported earlier, fluoride gels may also be prescribed for home use (typically at 1% NaF) in specific conditions.

### 5.5.1 Mouthrinses

These products have been used in dentistry for nearly seven decades, both as a self-care home application method and in community-based preventive programs. NaF solutions are most commonly used, although there are formulations containing other fluoride compounds. Fluoride concentrations typically range from 230 to 900 ppm fluoride, intended for daily use at home or weekly/biweekly use in community programs, respectively. The main advantages of the method are its efficacy, simplicity of use, and the possibility of application by a non-dental professional, which positively impacts the cost-benefit relationship of this measure [14].

Data from the updated Cochrane Collaboration review include data from 35 RTCs (15,305 participants) and attested a 27% caries-preventive effect in permanent teeth [17], with no determined effect for the primary dentition. Interestingly, this review found no association between the effect of the measure on the frequency of exposure and the concentration of fluoride in the product, indicating that the mode of application depends on personal preferences (when used at home) and on the availability of staff to supervise the use of fluoride solutions (in school programs). Due to the possibility of ingestion of the fluoridated solution during application, this measure is not recommended for children under 6 years of age.

### 5.5.2 Toothpastes

The use of fluoride toothpaste is the most widespread form of fluoride use and is currently used by more than 1.5 billion people throughout the World [2]. Considering that dental caries is a biofilm-dependent disease, brushing with a fluoride dentifrice can be considered as the best method of fluoride use, since it combines the mechanical removal or disorganization of the dental biofilm with the caries-protective effects of fluoride [14, 31]. In addition to the therapeutic properties of dentifrices, their cosmetic benefits (related to cleaning, stain removal, whitening capacity, and effects on halitosis) constitute additional reasons for the wide acceptance of this method [14]. Dentifrices should not be confused with prophylactic pastes (which have a higher concentration of fluoride, are more abrasive, and are used less frequently) or with gels (which do not have abrasive particles, have higher concentrations of fluoride, and are used less frequently) [16, 19].

Two systematic reviews of the Cochrane Library attested to the effectiveness of dentifrices in the control of caries in children and adolescents. While the earlier review [19] presented a 24% preventive effect in the permanent dentition (70 studies, 42,300 children) considering dentifrices with varying concentrations of fluoride, the most recent review [32] demonstrated a significant effect only for products with a concentration of 1000 ppm F or above.

The publication of this review had a great impact on professionals and scientific societies around the World, and it has been frequently used as a reason for not recommending formulations with reduced fluoride concentrations (500–550 ppm F). However, it should be noted that while the evidence for dentifrices in the range of 1000–1250 ppm F (compared to fluoride-free dentifrice) was obtained from the inclusion of 54 RTCs, the comparison between products containing 440–550 ppm F and 1000–1250 ppm F was obtained from a single study. In addition, the comparison between the effects of these formulations (440–550 ppm F) and a placebo dentifrice was made by the inclusion of two studies, which had opposite effects. More importantly, the evidence from this review was obtained from studies in permanent teeth only, as scarce and conflicting evidence was available for the primary dentition. Thus, the "absence of evidence" for these formulations has been mistakenly considered as "evidence of absence," which is not true considering the information above.

In fact, evidence from a randomized clinical trial showed similar rates of caries progression in children who were caries-inactive at the beginning of the study, comparing toothpastes containing 500 and 1100 ppm F [33]. For caries-active children, on the other hand, caries progression was significantly lower for those who brushed with the conventional (1100 ppm F) toothpaste. Therefore, considering (1) the increased risk of fluorosis in upper permanent incisors for children under 3 years of age [4, 34], (2) the increased effect of toothpaste in presence of any background fluoride [19], and (3) the influence of caries activity on the clinical performance of low-fluoride toothpastes [33], it has been suggested that toothpastes in the range of 500–550 ppm F could be prescribed for children below the age of 3 years, who are at low risk of caries, especially when exposed to another source of fluoride (e.g., fluoridated water, salt, or milk). In all other situations, a toothpaste containing 1000–1100 ppm F should be used [14].

Another important issue is related to the amount of dentifrice applied on the toothbrush. Recent studies have shown that reducing the amount of toothpaste applied to the brush significantly reduces fluoride levels in saliva [35–37], dental biofilm, and biofilm fluid [38], impacting the development of caries lesions in an in

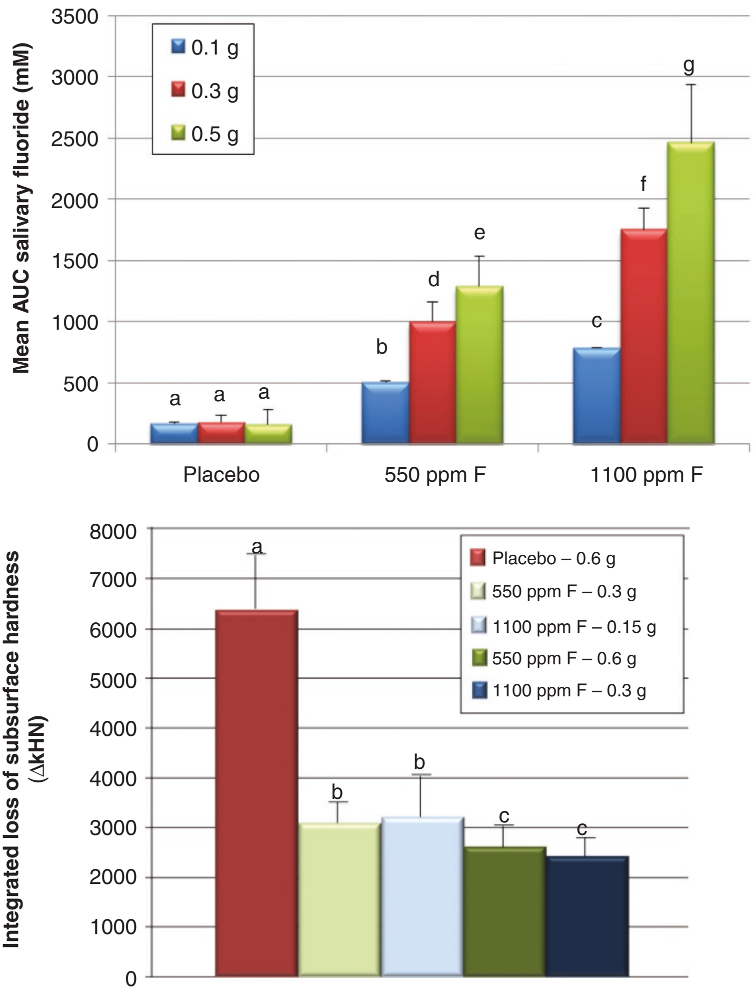


**Fig. 5.7** Mean area under the curve (AUC) of salivary fluoride concentrations in vivo (top) and integrated loss of subsurface hardness of enamel in situ (bottom) after brushing with low-fluoride (550 ppm F) or conventional (1100 ppm F) toothpastes applied at different quantities, resulting in different treatment intensities (i.e., fluoride concentration × amount applied). Bars indicate SD ($n$ = 24 [top] and $n$ = 13 [bottom]). Data from Hall et al. [37] and Paiva et al. [38]

situ model [35, 38]. Furthermore, these studies have demonstrated that the use of suitable amounts of a dentifrice containing 550 ppm F (such as that obtained by the transversal technique) may lead to a greater effect when compared with the use of a conventional formulation (1100 ppm F) applied in a reduced amount [37, 38] (Fig. 5.7). Despite the findings cited above related to low-fluoride dentifrices [33] and the issues related to reduced amounts of the product [35–37], the recommendation of several scientific societies around the World is the use of dentifrices containing 1000 ppm F or above as soon as the first tooth erupts, but applied using very small amounts in children younger than 3 years of age to minimize fluoride intake from this source.

In addition to the fluoride concentration in the product and the amount of dentifrice applied on the toothbrush, other important variables are also known to affect the clinical effectiveness of toothpastes [14], as listed below:

- *Rinsing behavior*: rinsing with large volumes of water reduces the amount of fluoride in the oral cavity, consequently affecting the anticaries effect. Children need to be taught to spit out the excess of toothpaste after brushing (to minimize systemic exposure).
- *Frequency of brushing/when to brush*: a significantly higher preventive effect is observed for children brushing twice/day in comparison with once/day; toothbrushing should be performed before going to bed and on another occasion.
- *Supervision*: higher preventive effect for children who brush under supervision of an adult.
- *Age to start brushing*: start as soon as the first tooth erupts.
- *Background exposure to fluoride*: higher preventive effect when toothpaste is used together with another source of fluoride.

## 5.6 Community-based Methods

Community-based fluoridation schemes are commonly considered as "systemic" methods, since they predicate ingestion and consequently, systemic circulation of fluoride. However, as previously discussed, such vehicles exert their effect primarily by topical action, either by initial contact with dental surfaces (during ingestion) or by the return of fluoride to the oral cavity via saliva. Among the vehicles used, fluoridated water is the most widely used (~400 million people worldwide, considering both naturally and artificially fluoridated water), followed by fluoridated salt (~300 million people), drops/tablets (~15 million people), and milk (less than one million people) [2].

Water fluoridation is considered one of the ten greatest public health achievements of the twentieth century. The measure is based on the controlled addition of fluoride (typically between 0.7 and 1.2 mg F/L, depending on the average temperature of the region) to the public water supply [1]. A review of the recent Cochrane Library [39], including 155 prospective studies, indicated reductions of 35 and 26% in dmfs and DMFS indices, respectively, with a higher proportion of caries-free individuals in fluoridated areas, in both dentitions. Regarding fluoridated salt and milk, such community-based methods are used in regions where water fluoridation is not feasible due to geographic or political reasons. Both methods have been proven to be effective in the control of dental caries [40, 41].

## 5.7 Comparison Between Different Vehicles/Combination of Different Methods

Despite the large body of evidence for professionally applied and self-administered fluoridated vehicles, there is uncertainty on the relative value of such interventions. A systematic review of the Cochrane Collaboration comparing the effectiveness of two different modalities in children found no clear evidence that fluoride varnish is more effective than mouthrinses [42]. Furthermore, no conclusive evidence was determined for the comparative effectiveness of varnishes and gels, and mouthrinses and gels. A similar degree of effectiveness was observed when comparing toothpastes and mouthrinses or gels, despite the substantial heterogeneity.

Considering the wide availability of different fluoridation methods, an important question is related to the additional effect of two different modalities. Based on the mechanisms of action of fluoride in caries control, a significant additional effect would be expected from the association of two or more modalities. However, the results of a Cochrane review [43] indicate that the additional effect is very small (around 10%). It is noteworthy, however, that this review included a low number of trials and not all possible combinations of vehicles were tested, so that the results of this review should be interpreted with caution. Therefore, the strategy of using two or more fluoride vehicles should be aimed only at patients with identified risk and/or high activity of the disease. Table 5.2 presents evidence-based clinical recommendations for professionally applied topical fluoride (varnishes and gels), according to the age group and caries risk, which can be used as a general guide to professionals when determining the best therapy for each individual patient.

## 5.8 Final Considerations

A common report of all the aforementioned systematic reviews was the poor methodological quality of the included studies. In addition, the great majority of the studies that met the inclusion criteria of these reviews were conducted when the incidence and prevalence of dental caries were very high, so that even the most modest interventions led to significant reductions [14]. Considering the substantial reduction in caries prevalence observed in the last decades, it is difficult to determine the real contribution of the different modalities of fluoride use in the control of dental caries. Based on the above, it becomes evident the need to conduct clinical studies with greater methodological quality, since the data obtained could have great impact in the elaboration of preventive strategies both in private practice and in public policies of collective action.

In addition to formulations containing exclusively fluoride, it is worth highlighting the development of new technologies, used or not in combination with fluoride, which have the potential to reduce the dose of fluoride used without affecting its preventive and therapeutic effect, as discussed in Chap. 6. Despite most of these studies are in the laboratory phase, isolated clinical trials evaluating these new technologies show promising results, demonstrating that it is possible to maximize the effects of fluoride while minimizing systemic exposure to the ion, which is highly desirable especially in children in the tooth-forming phase.

Finally, considering the current consensus on the etiology of dental caries [44], fluoride should be regarded as a co-adjuvant in preventive strategies, in which the control of dental biofilm and exposure to sucrose should be prioritized.

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# 6 Alternatives to Enhance the Anticaries Effects of Fluoride

Alberto C. B. Delbem and Juliano P. Pessan

## 6.1 Introduction

The mechanisms by which fluoride affects the de- and remineralization processes of enamel and dentin have been well established and are known to depend on intraoral calcium and phosphate ions when fluoride is applied [1]. It becomes evident, therefore, that the availability of these ions can be a limiting factor for remineralization, reason by which attempts have been made to deliver high amounts of calcium and phosphate in the oral environment. Phosphate-based agents have been investigated alone or in association with fluoride, among which the most studied are amorphous calcium phosphate, functionalized β-tricalcium phosphate, calcium glycerophosphate, and cyclophosphates.

Some of these compounds are intended to act as a source of calcium and phosphate, in order to increase the saturation of the oral medium in relation to hydroxyapatite, which include nanohydroxyapatite, bioactive glass containing calcium sodium phosphosilicate (commercially available as NovaMin), a dual-chambered system in which calcium salts are separated by plastic compartment from phosphate salts and sodium fluoride (commercially known as Enamelon), dicalcium phosphate dehydrate (DCPD), caseinophosphopeptides (CPP) linked with amorphous calcium phosphate (ACP) (commercially available as Recaldent), functionalized β-tricalcium phosphate, and calcium glycerophosphate. In contrast, cyclophosphates are not used as a phosphate source, but instead to act as a barrier against acid diffusion into the dental substrate, to work as nucleators of calcium phosphate, and to enhance the diffusion of calcium and phosphate ions from saliva in depth on the caries lesion. The most widely cyclophosphates studied are sodium trimetaphosphate (TMP) and sodium hexametaphosphate (HMP). In addition to

A. C. B. Delbem (✉) · J. P. Pessan
School of Dentistry, Araçatuba, São Paulo State University (UNESP), Araçatuba, Brazil
e-mail: adelbem@foa.unesp.br



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the use of calcium and/or phosphate salts, other technologies were designed to produce greater deposition of calcium fluoride ($CaF_2$) material on the dental substrate. As described in Chap. 5, $CaF_2$ acts as a source of fluoride and calcium ions and is regarded as one of the main reasons for the clinical efficacy of topically applied fluoridated products. In this regard, the use of low-fluoride toothpastes at acidic pH is known to produce similar $CaF_2$ levels when compared with conventional (1100 ppm F) toothpastes at neutral pH, which have a great impact on several other variables related to the caries dynamics (e.g., influence on de- and remineralization, effects on dental biofilm and saliva).

Despite the recent development of several technologies with potential to boost remineralization and to minimize demineralization, there is still limited evidence from clinical trials to attest the superiority of these products over conventional ones. To explore the different approaches on the dynamics of de- and remineralization of dental hard tissues, the strategies that are used in association with fluoride and formulations with lower fluoride content for children will be described in the present chapter.

### 6.1.1 Amorphous Calcium Phosphate (CPP-ACP)

As a non-fluoride strategy to promote enamel remineralization, one of the most promising is caseinophosphopeptides (CPP) linked with amorphous calcium phosphate (ACP) [2]. CPPs are casein-derived phosphorylated peptides that have the ability to enhance bivalent mineral solubility. CPPs bind to bivalent metals ($Ca^{2+}$, $Zn^{2+}$, $Fe^{2+}$, $Se^{2+}$) at neutral pH, forming soluble complexes. On the other hand, ACPs are precursors of hydroxyapatite, which can be converted into hydroxyapatite when in solution. The link between CPP and ACP (CPP-ACP) promotes a useful tool for remineralization, as CPP binds to form ACP clusters in a metastable solution, preventing their growth to the critical size required for nucleation and precipitation [3, 4]. According to the idealizers, this technology is effective as a remineralizing agent at acidic pH levels (<4.0) as well as in the neutral and alkaline range. CPP-ACP can be combined with fluoride forming a stabilize calcium fluoride phosphate as soluble complexes (CPP-ACFP). In the oral cavity, the CPP-ACP can act on teeth at different levels as follows [4–6]:

1. Enamel and dentin: ACP (through binding to CPP) acts as a nucleate of calcium phosphate on hydroxyapatite.
2. Dental biofilm: CPP-ACP can diffuse into dental biofilm, showing a buffering capacity which counteracts the pH drop caused by acidogenic bacteria; it also promotes an increase in calcium concentrations in the biofilm, resulting in a greater remineralization; CPP has also been reported to localize ACP in dental plaque and prevent enamel from demineralization.

In addition to the above, the association with fluoride (CPP-ACFP) was shown to increase the incorporation of fluoride by dental biofilm and to promote superior remineralization compared to CPP-ACP. CPP-ACP has been incorporated into various products, including commercially available sugar-free chewing gum, mints, toothpastes, mouthrinses, varnishes, and topical gels [5, 6]. Topical creams are commercially available with 900 ppm F (GC Tooth Mousse Plus or MI Paste Plus) or without fluoride (GC Tooth Mousse or MI Paste). These products are indicated for use during tooth bleaching, after professional tooth cleaning, and after application of topical fluorides as remineralizing agents in caries-active patients, for hypomineralized enamel, tooth sensitivity and erosion, as well as for patients with xerostomia or with orthodontic appliances [5, 6]. The posology of CPP-ACP is variable, with no well-established form or frequency of application. Since CPP-ACP is reported to be nontoxic [5], it could be swallowed instead of spat out, allowing the overnight use in a tray by the patient, mainly after dental bleaching. Nevertheless, longer application time was shown to produce no additive effect on the remineralization process in vitro [7].

There is a substantial body of evidence from in vitro and in situ studies attesting the efficacy of CPP-ACP/CPP-ACFP. The clinical evidence, however, is much scarcer and mostly focused on enamel remineralization, so that studies with longer follow-up periods could reduce the uncertainty about the clinical efficacy of CPP-ACP, particularly in comparison with conventional fluoridated compounds, given that the majority of studies compared CPP-ACP with a placebo. Conclusions from recent systematic reviews have varied from showing preventive [8] and therapeutic [9, 10] effects on incipient enamel carious lesions to describing no significant effect over fluoridated toothpastes [10, 11]. Conflicting evidence has also been reported on the clinical efficacy of CPP-ACP when used in conjunction with fluoride toothpastes [11].

### 6.1.2 Functionalized β-Tricalcium Phosphate (β-TCP)

Another promising strategy is the use of functionalized (or modified) beta-tricalcium phosphate. β-TCP is the resultant material derived from the coupling of β-tricalcium phosphate (β-TCP) with organic and/or inorganic moieties such as carboxylic acids and surfactants. It serves as a bioactive source of mineralizing components, especially due to the limited solubility relative to other calcium salts and minerals, which has implications for fluoride compatibility in water-based preparations [12, 13]. Issues related to β-TCP, however, include the formation of calcium-phosphate complexes or the formation of $CaF_2$ when associated with fluoride. This decreases the bioavailability of calcium and fluoride and, consequently, the process of remineralization [12–14].

To make β-TCP more stable, it can be combined with titanium dioxide or other metal oxides [12–14]. Also, by functionalizing β-TCP with organic and/or inorganic molecules, it is possible to create barriers that prevent premature fluoride-calcium interactions, as well as to facilitate targeted delivery when applied to the teeth via common dental preparations (e.g., dentifrice, mouthrinse, etc.). In contact with saliva, the particles dissolve, thus exerting their cariostatic effects.

Some examples include sodium lauryl sulfate, silica, and urea for water-based preparations and fumaric acid for nonaqueous formulations, such as varnishes [14]. A commercial example is the 3 M Espe ClinPro™ fluoride dentifrice that, according to the manufacturer, enhances the remineralization at neutrally or slightly alkaline pH [15].

There are some in vitro and in situ evidence on the effects of β-TCP present in solutions, mouthrinses, dentifrices, and varnishes, showing that the association with fluoride improves enamel rehardening, increases enamel fluoride uptake, remineralizes white spot lesions (measured by QLF), as well as increases calcium release into saliva [13, 16–18]. No clinical evidence, however, is available, so that clinical recommendation of such products might be premature at this stage.

### 6.1.3 Calcium Glycerophosphate (CaGP)

Calcium glycerophosphate (CaGP) is an organic phosphate with great affinity for hydroxyapatite, which presents anticaries effect [19]. The mechanisms of action of CaGP are related to a pH-buffering effect [20], increases in calcium and phosphate concentrations in the biofilm [21], reduction of biofilm volume [22], and effects on dental tissues [23, 24], which consequently reduce enamel demineralization [25]. For this reason, CaGP is commonly used in natural formulations without fluoride and combined with antimicrobial agents (e.g., polyols and plant extracts) in commercial brands.

CaGP has been typically associated with monofluorophosphate (MFP; 1000–1500 ppm F), possibly due to concerns of combining a source of calcium with sodium fluoride. Nevertheless, an in vitro study tested different CaPG concentrations (0.25–2.0%) associated with low-fluoride toothpastes (500 ppm F, NaF), observing that only CaGP at 0.25% of CaGP promoted a synergistic effect against demineralization [26], indicating that an ideal molar ratio is paramount for achieving optimum results. This seems to explain the lack of effect of a toothpaste with higher fluoride concentration (1100 ppm F, MFP) associated with CaGP at a lower concentration (0.13%) on enamel demineralization in a short-term in situ model [27]. Furthermore, the addition of 0.25% CaGP to low-fluoride toothpastes (500 ppm F) with different sources of fluoride (NaF or MFP) promoted a remineralizing effect similar to a standard toothpaste (1100 ppm F) in situ [28], which was subsequently confirmed in a randomized clinical trial conducted in children [29], as shown in Fig. 6.1.

The abovementioned effects are related to the ability of the formulations in providing fluoride and calcium to the dental biofilm, and greater calcium uptake by dental enamel, without compromising enamel fluoride uptake [26, 28, 30]. CaGP has also been investigated in association with other vehicles, including fluoride varnish [31], resin-modified glass ionomer cement [unpublished data], and additives to soft drinks [32], assessing their effects in caries and erosion models, with results varying from no effect to positive effect.

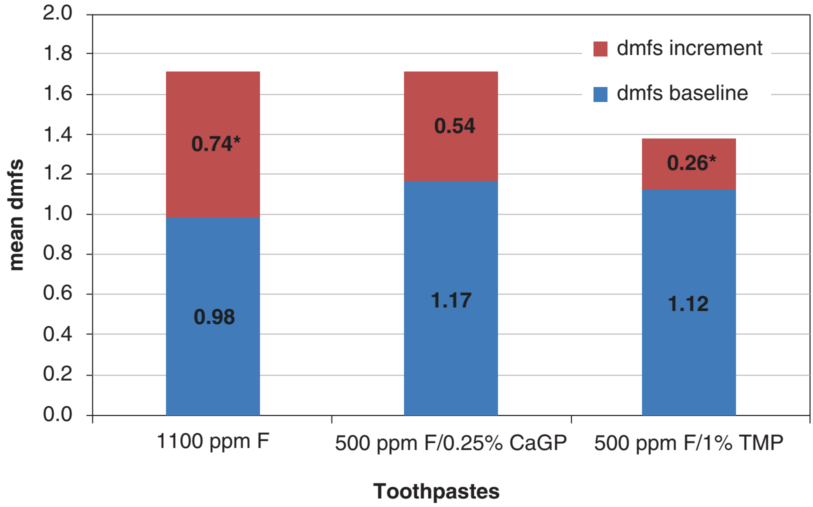


**Fig. 6.1** Mean dmfs (decayed, missing, or filled surfaces) at baseline (blue) and caries increment (red) in children, according to the toothpastes used. *TMP* sodium trimetaphosphate, *CaGP* calcium glycerophosphate; asterisks indicate significant differences among the toothpastes regarding dmfs increment

### 6.1.4 Cyclophosphates: Trimetaphosphate (TMP) and Hexametaphosphate (HMP)

Condensed inorganic phosphates or cyclophosphates (trimetaphosphate (TMP) and hexametaphosphate (HMP)) [33] have been intensively investigated over recent years as an alternative to enhance the effects of fluoride against dental caries, erosion, and dentin sensitivity. This has also been intensified due to concerns about chronic or acute toxicity of fluoride related to the use of toothpastes and gels, respectively [34–37].

In vitro and in situ studies demonstrated that TMP- and HMP-containing fluoridated dentifrices, gels, mouthrinses, and varnishes have a higher protective effect on both dental caries and erosion when compared with products without phosphates. The addition of TMP to fluoride toothpastes was also shown to occlude dentinal tubules, with potential to reduce dentin hypersensitivity [38]. The findings obtained using different formulations and associations between cyclophosphates (TMP and HMP) and fluoride are summarized in Table 6.1, in which the optimum molar ratios between fluoride and TMP were tested in vitro and some confirmed in situ.

Most of the studies focused on toothpastes, in which TMP- or HMP-containing formulations were shown to produce equivalent or superior effects to the 1100 ppm F formulations, despite the fluoride content of the test products were two- [41–44, 46, 47, 49] or four-fold [39, 40, 45, 48] lower. Other studies assessed the effect of these phosphate salts in mouthrinses, gels, varnishes, and fluoride-containing restorative materials.

**Table 6.1** Main results of fluoride-TMP or HMP studies according to type of vehicle and experiment and fluoride and TMP or HMP concentrations

| Vehicle | Enamel caries | | | | Enamel erosive wear | |
|---|---|---|---|---|---|---|
| | In vitro | | In situ | | | |
| | De | Re | De | Re | In vitro | In situ |
| Low-fluoride toothpastes | 250 ppm F/0.25–1% TMP E 1100 ppm F [39]<br>250 ppm F/0.5% HMP >1100 ppm F [40]<br>450 ppm F/0.25% TMP/0.25% CiCa E 1100 ppm F [41]<br>500 ppm F/1–3% TMP >1100 ppm F [42]<br>500 ppm F/3% TMP E 1500 ppm F [43] | 450 ppm F/0.25% TMP/0.25% CiCa E 1100 ppm F [44] | 250 ppm F/0.05% TMPnano >1100 ppm F [45]<br>500 ppm F/1% TMP E 1100 ppm F [46] | 500 ppm F/1% TMP E 1100 ppm F [47] | 250 ppm F/0.25–1% TMP >1425 ppm F/5% $KNO_3$ [48]<br>500 ppm F/3% TMP >1100 ppm F E 5000 ppm F [49] | – |
| Conventional toothpastes | 1500 ppm F/3% TMP E 3000 ppm F [43]<br>1000 ppm F/0.25% TMP/0.25% CiCa >1100 ppm F [41]<br>1100 ppm F/3% TMP >1100 ppm F [50]<br>1100 ppm F/1% HMP >1100 ppm F [51]<br>1100 ppm F/3% TMPnano >1100 ppm F [52]<br>1100 ppm F/0.5% HMPnano >1100 ppm F [53] | – | 1100 ppm F/1% HMP >1100 ppm F [54] | 1100 ppm F/3% TMPnano >1100 ppm F [55] | 1100 ppm F/3% TMPnano >1100 ppm F E 5000 ppm F [56] | – |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mouthrinses | 100 ppm F/0.4% TMP<br>>225 ppm F [50] | – | – | – | 100 ppm F/0.2–0.6% TMP<br>>225 ppm F [57] | – |
| Low-fluoride varnishes | 2.5% NaF/5% TMP<br>E 5% NaF [58] | 2.5% NaF/5% TMP<br>E 5% NaF [59] | – | – | 2.5% NaF/3.5–10% TMP<br>>5% NaF [60] | 2.5% NaF/5% TMP<br>>5% NaF [61] |
| Conventional varnishes | 5% NaF/5% TMP<br>>5% NaF [58] | 5% NaF/5% TMP<br>>5% NaF [59] | – | 5% NaF/5% TMP<br>>5% NaF [62] | – | – |
| Low-fluoride gels | 1% NaF/5% TMP<br>>2% NaF<br>E 1.23% APF [63] | 1% NaF/9% HMP<br>>2% NaF<br>E 1.23% APF [64] | 1% NaF/5% TMP<br>>2% NaF<br>>1.23% APF [65] | 1% NaF/5% TMP<br>>2% NaF<br>E 1.23% APF [66] | 1% NaF/5% TMP<br>>1.23% APF [67]<br>1% NaF/9% HMP<br>E 2% NaF [68] | – |
| Composite resin | 1.6 NaF/14.1% TMP<br>>1.6% NaF [69] | 1.6 NaF/14.1% TMP<br>>1.6% NaF [70] | – | – | – | – |

*De* demineralization study, *Re* remineralization study, *TMP* sodium trimetaphosphate, *HMP* sodium hexametaphosphate, *nano* nanoparticle, *NaF* sodium fluoride, *APF* acidulate phosphate fluoride, *CiCa* calcium citrate, > superior effects, *E* equivalent effects

The use of TMP-containing gels with reduced fluoride concentrations (4500 ppm F) was shown to be a safer alternative for use in children, since the risk of ingestion and adverse events (mainly nausea and vomiting) related to conventional (9000–12,300 ppm F) gels when applied to children under 6 years of age may overcome the potential benefits [34, 35, 37]. In addition, the feasibility and cost of the proposed intervention must be considered in public health. The addition of 5% of TMP to 4500 ppm F gels increases the effect of this formulation in caries and erosion models, achieving levels similar to those of neutral (2% NaF or 9000 ppm F) or acid (12,300 ppm F) gels [63, 65, 66]. Similarly, fluoride varnishes containing 5% of TMP were shown to have a significantly higher protective and remineralizing effect when compared with 5% NaF varnish [58, 59, 62], with a significant protective effect also on enamel erosive wear [61]. A beneficial effect has also been shown when TMP and HMP were added to composite resins [69, 70] or glass ionomer cements [unpublished data], respectively.

The promising results of TMP added to low-fluoride toothpastes were confirmed in a randomized and controlled clinical trial performed in children using 500 ppm F toothpastes supplemented with TMP or CaGP, compared with a conventional formulation (1100 ppm F, positive control). After 18 months, the TMP-containing toothpaste led to significantly lower caries increment when compared to the 1100 ppm F toothpaste [29] (Fig. 6.1). The tested toothpastes can be regarded as safer alternatives to conventional formulations for children under 6 years of age, based on risk-benefit considerations [29, 71].

Studies on the mechanisms of action of TMP and fluoride when co-administered showed that their adsorption involve the same hydroxyl (OH) binding sites in the hydroxyapatite molecule [72–74], what seems to explain the need of an appropriate molar ratio to achieve optimum results. TMP also interferes with F deposition on carbonated hydroxyapatite (CHA) when it is co-administered with fluoride, leading to removal of carbonate-bound (loosely bound) calcium in apatite. The formation of a “TMP layer” involving CHA is believed to limit acid attack and to allow the deposition of $CaF_2$ or calcium phosphate (depending upon the medium composition), which have an important role during demineralization and remineralization processes that the mineralized tissues undergo.

TMP was also shown to enhance the deposition of $CaF_2$ when directly applied to hydroxyapatite or when applied to enamel associated with concentrations 500 or 1100 ppm F [73, 74], despite this is not observed for higher fluoride concentrations (>4500 ppm F) [59, 62, 63, 65, 66]. Notwithstanding, the effects of TMP can be attributed to the reduction of acid diffusion and improved ion diffusion into enamel [43, 63, 66]. This explains the effect of TMP-containing products against dental erosion (Fig. 6.2).

Treatment with cyclophosphates was also shown to change enamel surface free energy, due to the formation of a layer on enamel surface with more electron-donor sites after the treatment with cyclophosphates, what improves calcium absorption [75, 76]. Furthermore, a 1100 ppm F toothpaste supplemented with TMP was recently shown to produce a significantly greater precipitation of calcium phosphate to dentin specimens, leading to obliteration of dentinal tubules and higher mineral concentration [38] (Fig. 6.3), as well as a two-fold reduction in hydraulic conductance of dentin [data not published].

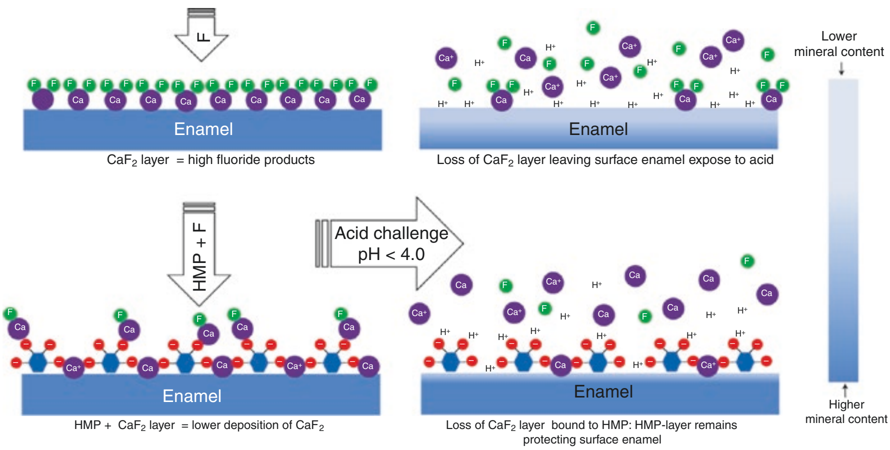


**Fig. 6.2** Schematic illustration on the effects of cyclophosphates (TMP or HMP) upon erosive challenge. High-fluoride levels produce great $CaF_2$ deposition, but it is solubilized in acidic medium (e.g., juices, soft drinks, etc.) leaving the surface enamel exposed to acid attack (top part of the scheme). HMP or TMP associated with high fluoride produce a layer of HMP or TMP adsorbed on enamel that remains after acid attack reducing mineral loss (bottom part of the scheme). Blue vertical bar means the degree of mineral content in enamel

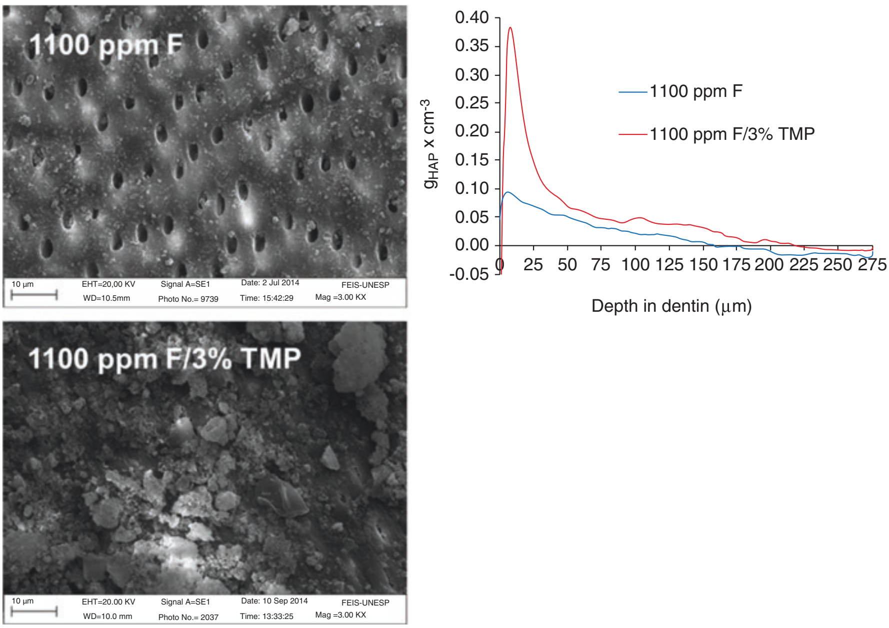


**Fig. 6.3** Photomicrographs of dentin surface according to the fluoride toothpastes obtained by SEM (×3000 magnification). Cross-sectional profile of mineral concentration as a function of dentin depth (µm) after treatment with toothpastes obtained by micro-CT (Skyscan1272, Bruker, Kontich, Belgium) [38]

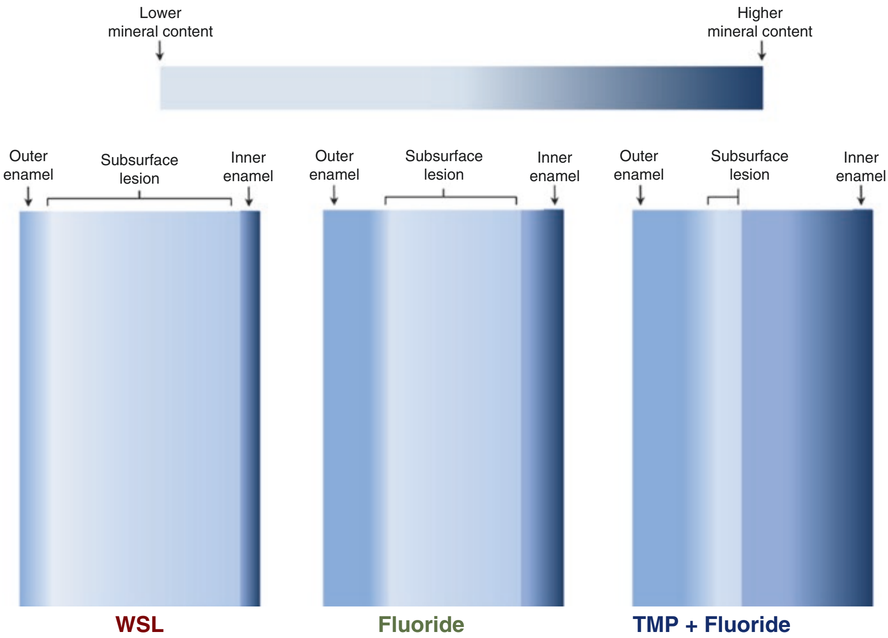


**Fig. 6.4** Effect of TMP associated with fluoride in white spot lesions. Blue horizontal bar means the degree of mineral content in enamel. WLS: untreated white spot lesion; Fluoride: WLS treated with conventional fluoride therapy; TMP + Fluoride: WLS treated with fluoride and TMP in association

One remarkable property of cyclophosphates is their enhanced capacity to promote calcium and phosphate penetration into the enamel subsurface lesion (Fig. 6.4) when co-administered with fluoride [43, 47, 50, 76, 77], in comparison with conventional formulations (i.e., without any cyclophosphate). This is very important from a clinical point of view, given that, in conventional therapies, fluoride produces the hypermineralization of the surface of the white spot lesion, which limits the diffusion of ions to the subsurface, therefore leaving a "scar", clinically known as an inactive enamel caries lesion. For products containing cyclophosphates salts, on the other hand, a clear effect is observed on the surface, but most importantly on the subsurface, what shows a true healing of the carious lesion (Fig. 6.4).

### 6.1.5 Acidic Toothpastes

Based on the concept that $CaF_2$ formation is inversely related to the pH of the medium, toothpastes with acidic pH have been proposed over 40 years ago [78]. Treatment of enamel with low-fluoride toothpastes at acidic pH (5.5) was shown to promote the deposition of fluoride at similar levels to those attained by the use of a conventional (1100 ppm F) toothpaste at neutral pH, using different in vitro protocols [79, 80]. Using pH-cycling models, subsequent studies demonstrated that toothpastes containing 500 ppm F (pH 5.5) promote similar results regarding enamel demineralization (protective effect) and remineralization (therapeutic effect) when compared with a 1100 ppm F toothpaste at neutral pH [81, 82].

It was later demonstrated that toothpastes at even lower pH (4.5) further enhanced the protective effect of the products, so that concentration as low as 412 ppm F was shown to promote a similar effect against enamel demineralization related to a conventional (1100 ppm F) neutral formulation [83], without promoting additional enamel wear due to the low pH [84]. The promising effect of such formulations were confirmed in two randomized clinical trials conducted in children [85, 86], which were also shown to be a safer alternative regarding systemic exposure to fluoride, assessed by using nails as biomarkers [87]. A fluid gel formulation containing 550 ppm F at pH 4.5 for use by children is available in the Brazilian market (Gel Dental Escovinha™). In addition to the increased $CaF_2$ formation promoted by the acidic toothpastes (as described above), the clinical superiority of such formulations may also be explained by the increased fluoride levels in saliva [88], biofilm [87, 89], and biofilm fluid [77] when compared to their neutral counterparts. Table 6.2 summarizes the results of the main studies assessing the effects of acidic toothpastes on several relevant variables to dental caries and erosion.

**Table 6.2** Summary of the main studies assessing the effects of acidic toothpastes related to different variables assessed

| Authors (year of publication) | Study protocol | Main variable(s) studied | Main outcomes |
|---|---|---|---|
| Gerdin (1974) [78] | In vivo | Caries increment (dmfs) | 250 ppm F (pH 5.5) similar to 1000 ppm F |
| Petersson et al. (1989) [79] | In vitro | Enamel fluoride uptake | 250 ppm F (pH 5.5) similar to 1000 or 1500 ppm (neutral pH) |
| Negri and Cury (2002) [80] | In vitro | Enamel fluoride uptake | 550 ppm F (pH 5.5) similar to positive control (1100 ppm F, neutral pH) regarding loosely and firmly bound fluoride |
| Brighenti et al. (2006) [81] | In vitro | Enamel demineralization | 550 ppm F (pH 5.5) similar to 1100 ppm F (neutral pH) |
| Alves et al. (2007) [83] | In vitro | Enamel demineralization | 412 or 550 ppm F (pH 4.5) similar to 1100 ppm F (neutral pH) |
| Nobre dos Santos et al. (2007) [90] | In situ | Enamel remineralization/ enamel fluoride uptake | 550 ppm F (pH 5.5) similar to 1100 ppm F regarding enamel remineralization and firmly bound fluoride |
| Olympio et al. (2007) [88] | In vivo | Salivary fluoride concentration | 550 ppm F (pH 5.5) toothpaste similar to the positive control (1100 ppm F, neutral pH) |
| Alves et al. (2009) [84] | In vitro | Enamel wear (abrasiveness) | 275, 412, 550 and 1100 ppm F (pH 4.5) not significantly different from their neutral counterparts |

(continued)

**Table 6.2** (continued)

| Authors (year of publication) | Study protocol | Main variable(s) studied | Main outcomes |
|---|---|---|---|
| Buzalaf et al. (2009) [87] | In vivo | Biofilm fluoride uptake/fluoride levels in nails | 550 ppm F (pH 4.5) similar to 1100 ppm F (neutral pH) regarding fluoride concentrations in the dental biofilm. Reduction of dentifrice pH did not affect nail fluoride concentration (i.e., systemic effect) |
| Vilhena et al. (2010) [85] | In vivo | Caries progression (dmfs) | 550 ppm F (pH 4.5) similar to 1100 ppm F (neutral pH) |
| Brighenti et al. (2013) [82] | In vitro | Enamel remineralization | 550 ppm F (pH 4.5) similar (surface hardness) or superior (cross-sectional hardness) to 1100 ppm F (neutral pH) |
| Moron et al. (2013) [91] | In vitro | Enamel wear (erosion) | Lower protective effect of 550 ppm F (pH 4.5) compared with 1100 ppm F (neutral pH) |
| Cardoso et al. (2014) [86] | In vivo | Caries progression and regression/toenail fluoride concentration | Significantly lower caries progression and net increment for 550 ppm F (pH 4.5) compared with neutral 1100 ppm F (Nyvad's criteria);<br>550 ppm F (pH 4.5) performed significantly better than neutral 1100 ppm F (QLF analysis);<br>Lower toenail fluoride concentration associated with the low-fluoride toothpaste (i.e., systemic effect) |
| Cardoso et al. (2015) [89] | In vitro<br>In vivo | Enamel demineralization/ biofilm fluoride uptake | Lower effect of 550 ppm F (pH 4.5) on enamel demineralization compared with neutral 1100 ppm F; 550 ppm F (pH 4.5) promoted significantly higher biofilm fluoride uptake compared with neutral 1100 ppm F |
| Kondo et al. (2016) [77] | In vivo | Fluoride levels in saliva and biofilm (solid and fluid phases) | Higher fluoride concentrations in the biofilm 1 h after brushing with acidic toothpastes compared to neutral counterparts, despite differences were not significant; the pH of the toothpaste did not affect salivary fluoride concentrations |
| Ortiz et al. (2016) [92] | In vitro | Enamel demineralization/ enamel fluoride uptake | 550 ppm F (pH 4.5) similar or superior effect than 1100 ppm F (neutral) regarding firmly and loosely bound fluoride; lower effect against demineralization |
| Veloso et al. (2017) [93] | In vivo | Biofilm fluoride uptake | 750 ppm F (pH 4.5) similar to neutral 1100 ppm F 60 min after brushing |
| Campos et al. (2017) [94] | In vivo | Toenail fluoride concentration | 750 ppm F (pH 4.5) led to lower toenail fluoride levels than neutral 1100 ppm F |

## 6.2 Final Considerations

The search for new therapeutic strategies is mainly directed (but not limited) to patients at high caries risk and/or activity. The development of new products has been intensively studied in the last decades, with the goal to minimize enamel demineralization and/or to enhance the remineralizing capacity of oral care formulations while minimizing possible adverse effects of conventional fluoride therapies related to toxicity. There is a substantial body of evidence that it is possible, through different approaches, to achieve similar or superior effects comparing to conventional fluoride products. However, an ideal formulation should combine the ability to enhance remineralization and to reduce mineral loss, erosive wear, and dentinal sensitivity, especially if they are effective and safe for use by both adults and children. Among the therapies described in the present chapter, one of the most promising is the use of cyclophosphates in association with fluoride, as they were shown to act synergistically on all the above situations and in a variety of vehicles for home and professional care. For all the technologies above, however, further clinical evidence is required.

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# 7 Developmental Defects of Enamel

Paulo M. Yamaguti and Renata N. Cabral

## 7.1 Introduction

Developmental defects of enamel (DDE) are clinically characterized by alterations that range from diffuse opacities to total absence of the dental enamel. To date, several local, systemic, environmental, and genetic factors that disturb amelogenesis have been identified either by experimental studies or clinical observation related to DDE's occurrence [1].

DDE classification is based on the enamel clinical aspect of the vestibular surface of the tooth, which may present with demarcated opacity, diffuse opacity, hypoplasia, or a combination of them, independently of their etiology [2]. Three conditions characterized by generalized DDE will be discussed in this chapter. Amelogenesis imperfecta is caused by genetic sequence variations that affect proteins that play important roles during amelogenesis. Fluorosis is caused by an excessive fluoride intake during amelogenesis. And MIH seems to be caused by a systemic imbalance, but its etiology has not been clearly elucidated yet.

To better understand the DDE etiology, it is important to revise the complex process of amelogenesis. There are key proteins and functions crucial for the normal enamel development and mineralization. The knowledge of the biological and molecular processes can help the establishment of a cause-effect correlation and facilitate the diagnosis, the treatment planning, the preventive interventions, and the prognosis.

P. M. Yamaguti (✉)
Oral Care Center for Inherited Diseases, Oral Health Unit, University Hospital of Brasilia, University of Brasilia, Brasilia, Brazil

R. N. Cabral
Pediatric Dentistry in Private Practice, Brasilia, Brazil



S. C. Leal, E. M. Takeshita (eds.), *Pediatric Restorative Dentistry*,
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## 7.2 Amelogenesis

The complex and regulated process of enamel formation is called amelogenesis. It can be divided in four well-defined stages known as pre-secretory, secretory, transition, and maturation stage [3]. In each stage, the control of cells' morphology, orientation, positioning, and function is crucial for normal enamel development. In pre-secretory stage, undifferentiated cells from the inner enamel epithelium differentiate into pre-ameloblasts. During secretory stage, differentiated ameloblasts are organized in a continuous cell layer tightly hold by junctional complexes. It creates a separated compartment where the organic matrix will be deposited and the future enamel will develop [4]. After the initial enamel organic matrix secretion, ameloblasts acquire secretory apical projections called Tomes process. Two secretory sites (the apical and lateral portions of the Tomes processes) deposit the enamel organic matrix in two different directions as the ameloblasts move centrifugally. This deposition pattern determines the rod and interrod organization of the enamel [5].

Enamel organic matrix is mainly composed of amelogenins (90%), enamelin, ameloblastin, and tuftelin. Together with these proteins, ameloblasts secrete a protease called enamelysin (MMP-20), which plays a role in the initial enzymatic processing of the organic matrix [5, 6]. Apparently, part of the smaller peptides generated by this degradation function as mineralization signalers, while others self-assemble into nanospheric structures to coordinate the initial crystal formation [7]. At about 30% of the enamel, mineralization takes place at the secretory stage [8].

There are three main important factors during the secretory stage that may interfere with the final enamel thickness and surface smoothness: (1) the organic matrix content, (2) the total amount deposited, and (3) a normal ameloblasts morphology and physiology. Any local, systemic, or genetic factor that disturbs these factors may interfere with the normal enamel development [1]. When the total thickness of the future enamel is reached, ameloblasts loose the Tomes processes and decrease the protein secretion (transitional stage).

The maturation stage is characterized by the final cleavage of all reminiscent organic matrices and by the hydroxyapatite crystal growth in width [9]. There is an increase in MMP-20 secretion, and ameloblasts begin to secrete another protease called kallicrein-4 (KLK-4) [10]. Ameloblasts are now engaged in different functions. They degrade and reabsorb the organic matrix, while they control the mineral ion influx for the enamel mineralization. To play these different roles, their morphology constantly changes, and they express several different proteins [5]. At the apical ends, they alternate their morphology between a ruffle-ended and smooth-ended type [5]. It helps to increase or decrease the cell surface area and the resorption ability of the cells.

As hydroxyapatite crystals grow, $H^+$ is released and the pH decreases. The pH homeostasis is controlled by a buffering machinery. Several pumps and channels are involved in the mineral ions and bicarbonate transport. It has been demonstrated that an acid-base unbalance could disturb amelogenesis and produce enamel defects [11–16].

During the secretory and maturation stages, the ameloblast layer continuity is essential for the normal enamel development. They express different laminin, claudin, and integrin isoforms in the junctional complexes and basement membrane. These proteins play a role to tighten or loosen the intercellular space and facilitate the passage of ions and solute between the cells. When disturbed, enamel defects have been reported [4, 17–21].

Progressively, ameloblasts decrease in length and enamel becomes more mineralized. The mature enamel is composed of a highly organized crystalline structure constituted almost exclusively of hydroxyapatite crystals [9].

The complex process of amelogenesis has not been completely elucidated. Several transcripts of channels, carriers, anions exchangers, pumps, and other proteins identified during the maturation stage of amelogenesis are still under investigation [22]. After maturation, at about 50% of the ameloblasts suffer apoptosis; the remaining cells reduce their size and form a cell layer that protects the enamel until the tooth eruption in the buccal cavity.

### 7.2.1 Factors that Disturb Amelogenesis

Due to the amelogenesis process complexity, it is comprehensive that several factors may disturb it at any stage inducing DDE. During secretory stage, disturbances may affect the enamel quantity; while during maturation stage, the enamel quality may be affected.

#### 7.2.1.1 Types of Defects

1. *Hypoplasia*: enamel defects that affect the enamel thickness or smoothness. The enamel can be thinner, pitted, grooved, or even absent.
2. *Hypomineralization*: the enamel thickness is normal but it is weak and friable. Clinically, the enamel presents with demarcated or diffuse opacities and may be discolored. It can be divided in two subtypes:
   (a) *Hypomaturated*: characterized by an incomplete removal of the organic matrix (brittle enamel)
   (b) *Hypocalcified*: characterized by insufficient calcification (soft enamel)

Since it is not easy to classify the hypomineralized types into subtypes, many authors suggest the classification as hypoplastic or hypomineralized only. Figure 7.1 shows different types of enamel defects caused by different etiologies. Table 7.1 presents etiologic factors that affect amelogenesis. Some of them have not been scientifically demonstrated.


**Fig. 7.1** Different types of developmental defects of enamel. (**a**) Hypoplastic AI. (**b**) Hypomature AI: upper incisors present demarcated and diffuse opacities. (**c**) Hypocalcified AI. (**d**) Hypoplastic AI: patient present several features commonly associated with AI, anterior open bite, increase of the interproximal spaces, hypersensitivity. (**e**) Hypoplastic AI with retention of deciduous and permanent teeth, thin enamel, and gingival hyperplasia. (**f**) Type 2 fluorosis (TF index) or very mild fluorosis (Dean's index): pronounced lines of opacity that follow the perikymata, with some confluence of adjacent lines. (**g**) Type 4 fluorosis (TF index) or moderate fluorosis (Dean's index): the entire surface exhibits marked opacity or appears chalky white. (**h**) Complete medical history is important for diagnosis. This case, similar to an AI case, was a case of generalized DDE due to repeated blood transfusions

**Table 7.1** Type of injury, etiologic factors, the possible mechanism involved in the development of enamel defects, and the scientific evidences

| Type | Etiologic factor | Mechanism | Evidences | Studies |
|---|---|---|---|---|
| Physical | Trauma | Ameloblasts injury | Strong | Experimental animals [96], case reports [97] |
| | Radiotherapy | Affects ameloblast function | Strong | Cancer patients [98] |
| Chemical | Chemotherapy | Affects ameloblast function | Strong | Cancer patients [99, 100] |
| | BPA | Affects ameloblast proliferation and gene transcription | Weak in experimental animals | Experimental animals [101] |
| | Fluoride | Affects MMP-20 function [102]<br>Creates hypermineralized barriers that impede the proteins resorption and the diffusion of mineral ions [45] | Strong | Populational studies [103]<br>Experimental animals [104] |
| | Antibiotics | Not clear | Weak, not clear | Clinical reports [105]<br>Experimental animals [106] |
| | Dioxin | Arrests the tooth development (?) | Weak, not clear | Experimental studies [107] |
| Biological | Infections | Cytomegalovirus infection | Strong | Clinical reports [108]<br>Experimental animals [109] |
| Systemic condition | Asthma and bronchitis | Not clear | Weak | Clinical reports [110] |
| | Otitis | Not clear | Weak | Clinical reports [105] |
| | Severe hypocalcemia | Affects ameloblast function during secretory and maturation stages and mineralization | Strong | Experimental animals [111, 112] |
| | Hypophosphatemic rickets | Mineralization defects | Strong | Clinical reports review [113] |
| | Coeliac disease | Nutritional effect (?)<br>Cross-reactivity of antibodies to gliadin with the enamel proteins [114] | Under investigation | Systematic review of clinical reports [115]<br>Experimental studies [67] |
| | Repeated blood transfusion | Hydroelectrolytic imbalance | Strong | Clinical reports [116] |
| | Vitamin D deficiency | Mineralization defects | Strong | Clinical reports [117] |
| Genetic | Genetic mutation | Affects protein or cell function and protein quantity or quality | Strong | See Table 7.2 for references |

## 7.3 Amelogenesis Imperfecta (AI)

### 7.3.1 Definition and Diagnosis

Amelogenesis imperfecta (AI) is a heterogeneous group of genetic conditions characterized by generalized DDE. It can affect all or almost all teeth of both dentitions. The first AI-causing gene mutations were identified in two genes that code for the most expressed enamel matrix proteins amelogenin (AMEL-X) and enamelin (ENAM) [23, 24]. Later, studies found mutations in the processing enzymes KLK-4 [25] and MMP-20 [26]. For some years, studies focused in exploring these genes as AI candidate genes and failed to discover the molecular etiology, suggesting that there were other unknown important proteins besides the enamel matrix proteins and proteases [27–29]. AI used to be defined as an isolated condition without the involvement of other structures because amelogenesis was considered a unique biomineralization process in the mammalians. Later, new molecular studies, new technologies, and the comprehension that many other proteins were essential during amelogenesis, other gene mutations were discovered (Table 7.2). Despite unique, the biomineralization process of the enamel formation involves the participation of several proteins that play a role as transcription factors, vesicle transport, and pH control and in cell-cell interaction that are also expressed in other epithelia of the human body. Nowadays, AI is defined as a genetic condition, characterized by generalized enamel defects. It can affect a group or all teeth in both dentitions and can be an isolated disease or a feature of some syndromes and systemic diseases [30–32]. Single gene defect, microdeletion, or chromosomal defects have been described.

The AI prevalence depends on the studied population ranging from 1:700 to 1:14,000 [33, 34]. There is no recent prevalence data. Autosomal-dominant, autosomal-recessive, X-linked, and sporadic inheritance patterns have been reported in either isolated AI or syndromic AI (Table 7.2 presents all AI cases reported in humans which the causative molecular defect was identified).

Actually, more than 300 genes are expressed during the enamel maturation, but their function is unknown [6]. Consequently, there are many AI cases with undefined molecular etiology. New technologies have gradually contributed to understand the protein function and to expand the identification of other mutated genes.

Some features are commonly observed in association with AI and must be considered during diagnosis:

1. Dentin hypersensitivity
2. Skeletal anterior open bite (Fig. 7.1d)
3. Loose of the vertical dimension
4. Taurodontism
5. Presence of unerupted teeth and retention of deciduous teeth (Fig. 7.1e)
6. Presence of spontaneously reabsorbing teeth

7. Relative radiographic contrast between enamel and dentin in hypomineralyzed cases
8. Increase of the interproximal space (Fig. 7.1d)

It is also important to recognize one syndrome with pathognomonic oral phenotype. Patients with *FAM20A* variants present with enamel renal syndrome and can be readily identified upon oral examination and must be referred for specialized renal evaluation and follow-up. They present a distinctive orodental phenotype consisting of generalized hypoplastic AI affecting both the primary and permanent dentition, delayed tooth eruption, pulp stones, hyperplastic dental follicles, and gingival hyperplasia with variable severity and calcified nodules. Nephrocalcinosis is usually asymptomatic and can be revealed by renal ultrasound [35]. Figure 7.1e shows the clinical phenotype of a patient with AI due to *FAM20A* mutation.

**Table 7.2** Isolated and syndromic AI with defined molecular etiology reported in the literature

| | Locus | Gene | Protein function | Phenotype | Inheritance | OMIM/ [reference] |
|---|---|---|---|---|---|---|
| *Isolated AI* | Xp22.2 | *AMEL-X* | Organic matrix protein | Hypoplastic AI | X-linked dominant | 301200 |
| | 4p13.3 | *ENAM* | Organic matrix protein | Hypoplastic AI | AD/AR | 104500, 204650 |
| | 8q24.3 | *FAM83H* | Predicted to have a role in enamel mineralization | Hypocalcified AI | AD | 130900 |
| | 19q13.41 | *KLK4* | Protease | Hypomature AI | AR | 204700 |
| | 11q22.2 | *MMP20* | Protease | Hypomature AI | AR | 612529 |
| | 15q21.3 | *WDR72* | Endocytic vesicle trafficking? | Hypomature AI | AR | 613211 |
| | 4q21.1 | *C4orf26* | Predicted to have a role in enamel mineralization | Hypomature AI | AR | 614832 |
| | 2q24.2 | *ITGB6* | Cell surface glycoprotein | Hypoplastic AI | AR | 616221 |
| | 14q32.12 | *SLC24A4* | Potassium-dependent sodium/calcium exchanger | Hypoplastic AI | AR | 615887 |
| | 10q24.3–25.1 | *COL17A1* | Component of hemidesmosomes sodium/calcium exchanger | Hypoplastic AI | AD | [118] |
| | 18q11.2 | *LAMA3* | Component of the basement membrane | Hypoplastic AI | AD | [118] |
| | 1q32.2 | *LAMB3* | Component of the basement membrane | Hypoplastic AI | AD | 104530 |
| | 4q13.3 | *AMBN* | Organic matrix protein | Hypoplastic AI | AR | 616270 |
| | 14q32.11 | *GPR68* | G-protein coupled receptor | Hypomature AI | AR | [119] |

(continued)

**Table 7.2** (continued)

| | Locus | Gene | Protein function | Phenotype | Inheritance | OMIM/ [reference] |
|---|---|---|---|---|---|---|
| *Syndromic AI* | 10q24.3–25.1 | *COL17A1* | Component of hemidesmosomes | Hypoplastic AI/ Junctional epidermolysis bullosa | AR/AD | 226650 |
| | 17q21.33 | *DLX3* | Transcription factor | Hypomature-hypoplastic AI with taurodontism | AD | 104510 |
| | | | | Hypocalcified-hypoplastic AI/ tricho-dento-osseous syndrome | | 190320 |
| | 2q11.2 | *CNNM4* | Predicted to have a role in metal ion transport and homeostasis | Hypomineralized-hypoplastic AI/Jalili syndrome | AR | 217080 |
| | 17q24.2 | *FAM20A* | Predicted to have a role in the mineralization process | Hypoplastic AI/ enamel renal syndrome | AR | 204690 |
| | 16p13.3 | *ROGDI* | Leucine-zipper protein | Hypoplastic or hypocalcified AI/ Kohlschütter-Tönz syndrome | AR | 226750 |
| | 7p22.3 | *FAM20C* | Predicted to have a role in the mineralization process | Hypoplastic AI/Raine syndrome | AR | 229775 |
| | 18q11.2 | *LAMA3* | Component of the basement membrane | Hypoplastic AI/ junctional epidermolysis bullosa | AR/AD | 226700 |
| | 1q32.2 | *LAMB3* | Component of the basement membrane | Hypoplastic AI/ junctional epidermolysis bullosa | AR/AD | 226700, 226650 |
| | 17q25.1 | *ITGB4* | Cell surface glycoprotein | Hypoplastic AI/ junctional epidermolysis bullosa | AR/AD | 226650, 226730 |
| | 3q28 | *CLDN16* | Tight junction protein | Hypomature AI/ hypomagnesemia 3, renal | AR | 248250 |
| | 1p34.2 | *CLDN19* | Tight junction protein | Hypoplastic or hypomature AI/ hypomagnesemia, renal with ocular involvement | AR | 148290 |
| | 7q21.2 | *PEX1* | Required for peroxisomal matrix protein import | Hypoplastic AI/ Heimler syndrome 1 | AR | 234580 |
| | 6p21.1 | *PEX6* | Required for peroxisomal matrix protein import | Hypoplastic AI/ Heimler syndrome 2 | AR | 616617 |
| | 11q13.1 | *LTBP3* | Modulation of TGF-beta bioavailability | Hypoplastic AI/ platyspondyly | AR | 601216 |
| | 11p15.4 | *STIM1* | Calcium sensor | Hypoplastic AI/ immunodeficiency 10 | AR | 612783 |

The table presents the chromosomal locus, affected gene, normal protein function, enamel phenotype, mode of inheritance, and MIM# or reference

### 7.3.2 Classification

AI first classification was based on the enamel phenotype. It was simply divided in hypoplastic or hypocalcified types. Until the 1970s, they focused in the clinical appearance of the enamel. Later, considering AI as an inherited disease, some authors suggested the association of the phenotype with the mode of inheritance, but the description was still insufficient to characterize the condition, because AI affect heterogeneously the patients from the same family and the teeth of the same patient. In 1995, Aldred and Crawford suggested that AI classification should include the molecular defect and its biochemical result, in order to better define the etiology of the disease [30]. Nowadays, AI classification establishes the predominant type of the enamel defect in the patient, followed by the genetic locus and mode of inheritance (Table 7.2).

While isolated AI affects only the tooth enamel, syndromic AI has already been reported in association with cone-rod dystrophy, hearing loss, skin disorder, "curly hair" and bone sclerosis, platyspondyly, nephrocalcinosis, and familial hypomagnesemia and hypercalciuria. Table 7.2 presents all the isolated and syndromic AI that has already been reported, with the genetic locus, the affected gene, the protein function, the predominant phenotype, and the mode of inheritance.

### 7.3.3 Treatment

The most difficult cases to establish a treatment plan are those with problems of discoloration, tooth sensitivity, susceptibility to wear and erosion, poor esthetics, and functional limitation. Besides restorative demand, sometimes, patients need emotional support. Psychological impacts have been commonly reported [36]. In all cases, treatment is as ever based on the principles of prevention before intervention. To date, there is no specific protocol to treat children and adolescents with AI [37]. However, early diagnosis promotes a better outcome. The AI type seems to influence the restorations longevity. The treatment of hypomature/hypocalcified AI presents less longevity than the hypoplastic type due to the enamel quality and less hardness. Adhesive procedures seem to be more effective when hypomineralized teeth are deproteinized with sodium hypochlorite- or papain-based gel after acid etching [38]. Other studies suggest that to improve the results, all defective enamel should be removed [39].

The permanent dentition eruption is a difficult period. In some AI types, first molars and central incisors present with severe hypersensitivity and with chipping enamel while erupting. Restorative procedures are necessary even before the complete crown eruption. It usually requires local analgesia, and it is not easy to decide for the tooth preparation or not and to keep or not the affected enamel. Treatment during childhood has been described as a temporary phase. So, adhesive materials and direct restorations are preferred. Sometimes, primary molars must be protected by the use of preformed metal crowns and indirect or semi-direct composite crowns. In adults, total crowns and veneers present good results and are very well accepted by the patients [40, 41].

When malocclusion, anterior open bite, and loss of vertical dimension are diagnosed, it is important to perform a multi-professional approach in the patient care. The psychosocial impact must always be considered. Even though a prosthetic treatment with total crowns sounds invasive for the clinician, it could be the best solution for the patient. It is important to consider the reestablishment of esthetic and function still in adolescence and young adult stage, avoiding embarrassment, loss of vertical dimension, eating difficulties, and pain.

## 7.4 Fluorosis

### 7.4.1 Definition and Diagnosis

Fluorosis is a developmental enamel defect caused by an excessive chronic ingestion of fluoride during the deciduous and permanent dentition amelogenesis [42]. Macroscopically, the enamel presents with opaque linear bands and diffuse opacities or may also be discolored. Sometimes, in most severe cases, enamel may be pitted, due to the loss of fragile areas as the tooth erupts. Figure 7.1f, g shows two cases of enamel fluorosis.

The mechanism involved in the fluorosis etiology is still not clear. Some authors demonstrated that high fluoride during amelogenesis impairs the MMP-20 activity and reduce amelogenin degradation [43, 44]. More recently, it has been suggested that the higher content of fluoride induces the formation of hypermineralized lines. These lines may form barriers that impede the proteins resorption and the diffusion of mineral ions into the subsurface layers, thereby delaying biomineralization and causing retention of enamel matrix proteins [45]. So, fluorotic enamel has bands with a higher fluoride content, which confers a higher microhardness because fluorapatite is more resistant to acid dissolution than hydroxyapatite. And, by the other side, there are also hypomineralized bands with subsuperficial porosities [42]. *In vitro* studies have been conducted to test whether the higher fluoride content would protect enamel from demineralization, but there is no consensus on the resistance of fluorotic teeth to caries [46–48]. It seems that in mild and moderate fluorosis, enamel is more resistant to caries, and in most severe cases, enamel present a smaller microhardness and less resistance to caries [46, 47, 49].

The effect of fluoride on enamel formation is cumulative, rather than related to a specific threshold dose. It depends on the total fluoride intake from all sources and the fluoride exposure duration. In at least 25 countries across the globe, fluorosis occurs as an endemic condition. Higher fluorosis prevalence has been reported either in fluoridated water areas or in non-fluoridated areas, due to fluoride excess in the ground and natural water.

Public water fluoridation dates from the 1950s to 1970s. The aim of this intervention was to reach the near maximal prevention of caries with no or acceptable levels of fluorosis in the population. The best dosage to produce the preventive effect seems to be of 0.7 mg fluoride ion/L (0.7 ppm F) in the drinking water and the maximum dosage below 1.0 mg fluoride ion/L (1.0 ppm F), to avoid fluorosis.

As expected, the result of the public water fluoridation was caries decrease with low prevalence or with low severity fluorosis [50]. However, along the time, the introduction of other fluoride sources such as tablets, drops, fluoridated toothpaste, and mouthwashes altered the amount of the ingested diary doses. Thus, the relationship of near maximal caries prevention and no or acceptable levels of fluorosis became a concern and occurred an increase of the fluorosis prevalence in fluoridated areas. When all external parameters are excluded, fluoridated toothpaste ingestion by young children seems to be the main cause of fluorosis in the permanent dentition [51].

More than dental fluorosis, skeletal fluorosis may affect the patient in cases of higher ingestion dosages. Despite essential in some metabolical functions in the human body, there is no data indicating the minimum nutritional requirement and the dosage required to produce fluorosis. Besides, the susceptibility pattern differs among individuals living in the same community or having the same environmental exposure. Actually, there is some evidence of the association between genetic polymorphisms in candidate genes. So, fluorosis susceptibility could be increased or decreased according to the individual's genetic background [52].

### 7.4.2 Classification

There are two widely used indices of dental fluorosis: the Dean's index and the Thylstrup and Fejerskov Index (not shown). Both classifications have been used but both present limitations. None of them clearly distinguish between defects caused by fluorosis and caused by other factors. Besides, the differences between some of the diagnostic categories are uncertain (as seen in Figs. 7.1f and 7.1g).

### 7.4.3 Treatment

The treatment of the fluorotic enamel depends on the degree of severity and patient complaint. Several techniques may be applied including in-office bleaching, home bleaching, enamel microabrasion, enamel infiltration, minimally invasive composite restorations, or an association of different techniques [53].

## 7.5 Molar Incisor Hypomineralization

### 7.5.1 Definition and Diagnosis

The term molar incisor hypomineralization (MIH) refers to a condition of systemic origin and still unknown etiology that affects one or more permanent first molars and may or may not affect permanent incisors [54]. Similar defects can also affect second primary molars (HSPM) [55], and association between HSPM and MIH has been reported [56]. The literature shows that MIH results from a disturbance in the

**Table 7.3** MIH criteria proposed by the European Academy of Pediatric Dentistry

| MIH characteristics | Description |
|---|---|
| Demarcated opacities | Change in enamel translucency. The enamel has normal thickness, and color opacities vary from white to brown |
| Posteruptive breakdown | After eruption, tooth presents loss of enamel, which is always associated with a previous demarcated opacity |
| Atypical restoration | MIH restorations usually involve the buccal and palatal smooth surfaces; the presence of a demarcated opacity is often detected at the edge of the restoration |
| Extraction due to MIH | Absence of a first permanent molar should be related to the other teeth of the dentition |

function of the ameloblasts in the late phase of the mineralization during the amelogenesis, characterizing a qualitative enamel defect [57].

The pattern that characterizes MIH consists of asymmetric and well-demarcated opacities. Clinically, the defects may be white, yellowish, or brown. As a consequence of the hypomineralized nature of the enamel, posteruptive breakdowns may occur over time, being more prevalent in the first permanent molars than the incisors due to the intensity of the masticatory forces [58]. Consequently, a rapid caries progression, atypical restorations, or tooth extraction are frequently observed in MIH-affected teeth [59]. Additionally, a systematic review reported that MIH was considered a risk factor for caries development [60].

Regarding MIH diagnosis, the European Academy of Pediatric Dentistry (EAPD) proposed a criterion to be used in epidemiological studies [59]. Considering this diagnostic method, the examinations should be performed in children aged 8 years, and the affected teeth should be examined wet after dental brushing. Each tooth should be examined considering the absence or presence of demarcated opacities, posteruptive enamel breakdown, atypical restoration, extraction due to MIH, and failure of eruption of a molar or incisor (Table 7.3). Figure 7.2 illustrates different types of MIH defects.

In terms of severity, the defects can be classified as mild, moderate, or severe. Regarding this classification, posteruptive breakdown can be classified as moderate or severe depending on exposing only the enamel or already the dentin. Mild defects include demarcated opacities without posteruptive breakdown associated. This severity classification is important once a variation in severity over time is being observed characterizing the dynamic pattern of the defects [61]. Moreover, it has been shown that severe defects such as posteruptive breakdowns are more frequently observed in older children [62]. Figure 7.3 shows examples of different levels of MIH severity.

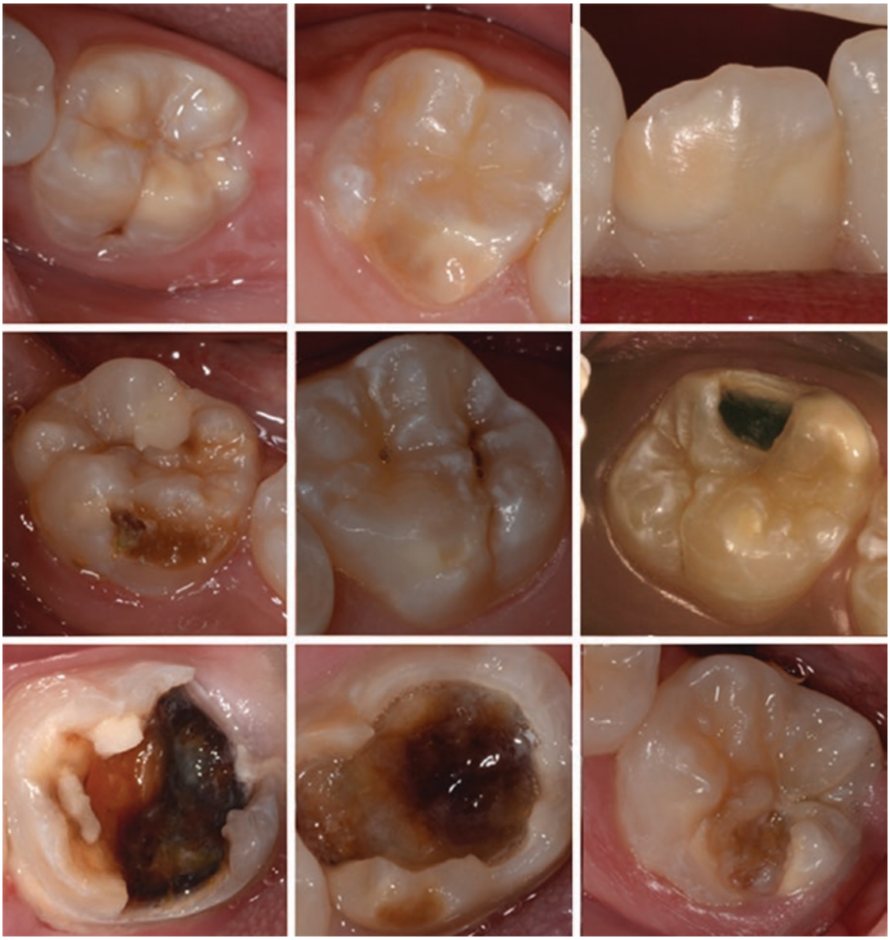

**Fig. 7.2** Different types of MIH defects varying from demarcated opacities to posteruptive breakdown exposing dentin

With respect to the prevalence of MIH, several studies have been published from different parts of the world, and a large variability is reported ranging from 2.8% to 40.2% [63, 64]. A recent systematic review estimated that the prevalence of MIH around the world was 14.2%, with highest values in some regions such as South America (18.0%) and Spain (21.1%) [65]. This variation can be associated to differences between the populations studied but may also be a reflection of different research protocols, calibration methods, sample size, and number of examiners. Standardized methodology is required in order to achieve the goal in performing comparable studies which represent the background population.

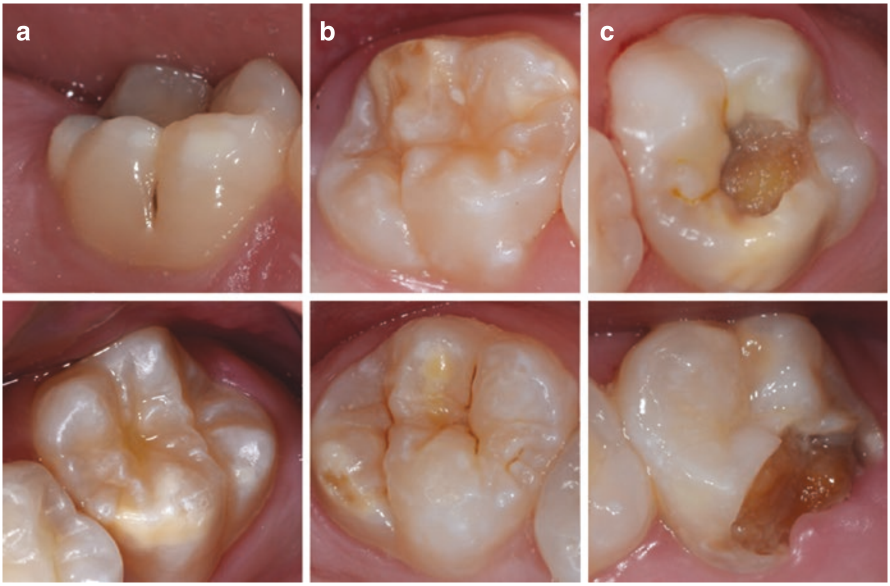


**Fig. 7.3** Different levels of MIH severity. (**a**) Mild defects; (**b**) Moderate; (**c**) Severe MIH defects

### 7.5.2 Etiology

The hypomineralization in permanent teeth has been described since the 1980s [66]. In 2001, the term molar incisor hypomineralization (MIH) was suggested to define a condition of systemic origin [67] which affects the enamel in its formative stage, in particular during the mineralization process [68].

The literature shows that MIH etiology is multifactorial [69] and that both genetic and environmental factors are involved [70]. Considering that the process of amelogenesis is genetically controlled, an association was found between variations in different genes related to amelogenesis and MIH [71]. However, further studies need to be performed to establish this correlation.

As the ameloblasts are very sensitive cells [72], prenatal, perinatal, or early life illnesses have been identified as possible factors related to MIH etiology. However, the systemic causes are still unknown [69]. Regarding prenatal exposures, several studies investigated the association between maternal smoking and maternal medication during pregnancy, and none of them found an association between these variables and MIH [73, 74].

Regarding perinatal exposures, a systematic review showed that there was little evidence of an association between MIH and prematurity, low birthweight, cesarean delivery, and birth complications [69]. However, there is little evidence related to this association.

Children illnesses were also investigated, and it seems to be the only factor associated with MIH [69]. Several children illnesses were evaluated as a possible reason for MIH occurrence such as fever, chicken pox, respiratory diseases, ear infections, and general childhood illnesses [61, 69].

Due to the multifactorial status of MIH etiology, further prospective studies considering several biological factors needed to be delineated in order to identify the main causes related to the condition.

### 7.5.3 Treatment

Molar incisor hypomineralization is being considered an important clinical problem [59] and in the last years has gained attention in pediatric dentistry [75]. The clinical relevance of MIH relies on the high rates of posteruptive breakdown, which occurs over time. It has been reported that teeth with mild MIH can evolve to a worsened condition in a short period of time and also that different factors can influence the chance of posteruptive breakdown occurrence [62, 76].

The occurrence of posteruptive breakdown can be explained by mineral deficiencies, which is related to MIH teeth [77]. It has been reported that the affected enamel presents higher carbon content in comparison to unaffected enamel. Moreover, those affected teeth present deficiencies in the quantity and in the quality of the mineral content [77]. Thus, posteruptive breakdown exposing dentin is frequently observed.

In relation to opacities' color, it has been reported that yellow or brown defects are more porous and present a higher chance to evolve to PEB than white defects [62]. Moreover, several studies reported that, chemically, yellow/brown opacities present lower values of mineral density and enamel hardness in comparison to the white ones [78–80]. Because of these enamel characteristics, MIH teeth tend to be sensitive to temperature and toothbrushing leading to poor oral hygiene and dental caries [81].

Furthermore, treatment of MIH children requires an accurate understanding of those factors and treatment implications [81]. In general, clinical management is challenging—when posteruptive breakdowns occur, MIH-affected teeth require extensive treatment, ranging from prevention to restorations or extractions [82].

Hypersensitivity and difficulty in obtaining adequate local analgesia due to a subclinical pulp inflammation in some MIH-affected teeth are seen as an additional barrier to treatment [83]. Moreover, restorations often fail, and patients tend to be treated more than one time. Because of that, children diagnosed with MIH may present behavioral problems and fear in relation to dental treatments [84]. One study reported that, by the age of 9 years, MIH children had been treated ten times more frequently than unaffected children [85].

Regarding MIH treatment, as MIH-affected teeth evolve to more severe stages over time, clinical management of the defects has become a major challenge for the clinician, especially for those dealing with children. In general, it is recommended that treatment decision should be made based on the severity of the defects, the symptoms presented by the affected tooth, and the patient's age [86].

William and colleagues (2006) [87] proposed a protocol to assist in the clinical management of MIH-affected teeth, which follows:

1. Risk identification
2. Early diagnosis
3. Remineralization and desensitization
4. Prevention of dental caries and posteruptive breakdown
5. Restorations and extractions
6. Maintenance

Another protocol reported in the literature shows different therapeutic procedures according to the type of the defects: mild or severe [86]. For mild defects, which include opacities without posteruptive breakdown, sealants, resin restorations, microabrasion, and dental bleaching for anterior teeth are recommended. For severe cases, which include cases of posteruptive breakdown, the authors recommended glass ionomer or resin restorations, stainless steel crown, and extractions followed by orthodontic treatment [86]. Table 7.4 summarizes different treatment modalities for hypomineralized teeth.

Regarding restorative procedures, materials such as resin composite and glass ionomer can be used. Because of histological and chemical characteristics of the hypomineralized enamel, adhesion to those teeth is compromised [88]. Prior to resin composite restorations, it has been recommended to remove all affected enamel in order to improve adhesion rates [89]. However, care should be taken, since the majority of patients requiring restorative interventions are children who are, on average, above 10 years of age.

Thus, glass ionomer cement (GIC) has been suggested to be used in hypomineralized teeth. GIC contributes to the mineralization process and, because of fluoride

**Table 7.4** Treatment modalities and materials for MIH teeth (Modified from Garg [120])

| Treatment modality | |
|---|---|
| Preventive | Topical fluoride application<br>Desensitizing toothpaste<br>Glass ionomer cement sealants |
| Direct restoration | Amalgam—is not recommended<br>GIC restorations—intermediate or definitive intervention<br>Resin composite—recommended to remove all defective enamel in order to improve adhesion rates |
| Full coverage restoration | Preformed stainless steel crowns—prevent further tooth deterioration and require little time to prepare and insert. Disadvantage: leads to additional wear of healthy dental tissue |
| Extraction and orthodontic treatment | Extraction is indicated—severe hypomineralization, severe sensitivity or pain, and large multi surface lesions in which restorative procedures are difficult[a] |

[a]The ideal dental age for extracting the first permanent molars considering spontaneous dental closure is 8.5–9 years old

release, protects teeth surface from caries lesion development and tooth sensitivity. Additionally, as GIC presents a coefficient of thermal expansion similar to the tooth structure, it can be an option for restorations of MIH teeth [90]. On the other hand, GIC presents lower mechanical properties in comparison to resin composite which can result in reduced longevity of GIC restorations [90]. In this way, some authors reported that GIC should be used as an intermediate intervention [80], while others stated that it should be used as a definitive restorative material, in particular when high viscosity glass ionomer is used [90]. Figure 7.4 illustrates MIH teeth that were restored with high viscosity glass ionomer.

For first permanent molars with extensive defects affecting cusp areas and associated to caries lesion, stainless steel crowns should be used [91]. A disadvantage, however, is associated with the need of slice preparation on the proximal surfaces, which leads to additional wear of healthy dental tissue [89]. In some cases, it is

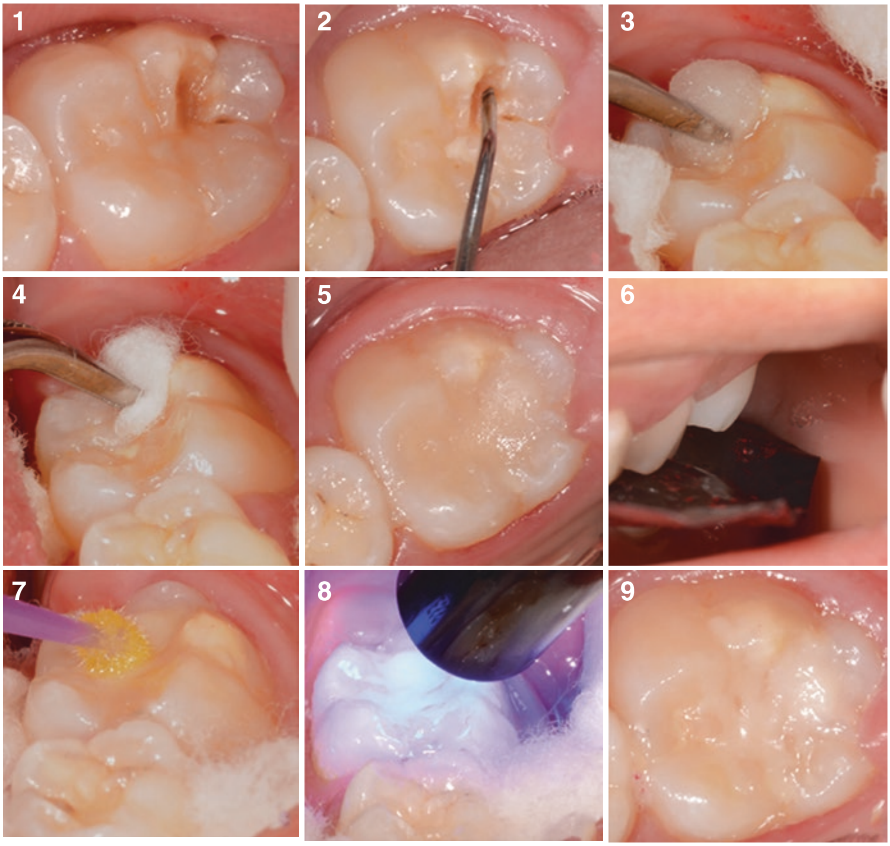


**Fig. 7.4** MIH tooth restored with high viscosity glass ionomer cement. (1) MIH tooth; (2) cavity cleaning; (3) and (4) conditioning with polyacrylic acid, rinsing, and drying; (5) application of glass ionomer cement; (6) checking occlusal contact points; (7) and (8) application and polymerization of finishing gloss; (9) final GIC restoration

better to perform a less invasive procedure such as a GIC restoration in order to postpone treatment until the child's behavior is mature enough to cooperate with more complex rehabilitation [92]. Finally, for the most severe cases, tooth extraction should be considered. It can be an option in order to avoid re-interventions, which, in some cases, can lead to the death spiral of the tooth [93]. Factors that must be taken into account for tooth extraction are children's age, eruption stage of the second permanent molar, and the presence of the permanent third molar germ [93]. It should be emphasized that all treatment should be multidisciplinary and orthodontic planning should be considered in case spontaneous closure does not occur.

Due to the great variability of treatments for MIH teeth, it is observed that there is no defined protocol that can guide clinicians in the management of the condition. This fact shows that randomized clinical trials have to be performed testing different techniques and materials in order to assist clinicians in how to treat this condition, which substantially influences the quality of life of the patients.

## 7.6 Differential Diagnosis

Differential diagnosis considering developmental enamel defects is important to avoid misdiagnosis and ensure best management, including appropriate treatment planning, in order to prevent future complications [94]. When the diagnosis is not established, it is more appropriate to classify the enamel defects as simply DDE. Table 7.5 presents some topics to differentiate AI, fluorosis, MIH/HSPM, and idiopathic DDEs. To distinguish fluorosis from other DDEs, the occurrence of any significant health-related events or fluoride excess intake during childhood must be investigated in a careful inquire. The enamel defects location reflects the time of the event. However, the degree of severity usually does not reflect the amount and intensity of the disturbance. As discussed above, it depends on the individual susceptibility. Differential diagnosis must also include DDE caused by rickets, celiac disease, antileukemic therapy, and idiopathic DDE.

Comparing MIH and fluorosis, while diffuse and symmetric opacities are detected in almost all dentition of patients with fluorosis, demarcated opacities are detected in permanent incisors and molars in MIH. Sometimes, deciduous second molars and canines are also compromised. The main difference between these two conditions is related to the opacities characteristics. Both in fluorosis and MIH cases, posteruptive enamel loss may be present. It is important to differentiate the enamel breakdown from hypoplastic enamel. Hypoplastic enamel usually presents more regular and smooth borders, while in hypomineralization, the enamel borders are sharp and irregular related to the occurrence of posteruptive breakdowns over time [94]. Either in fluorosis or MIH, the defect is only hypomineralization.

Finally, the diagnosis of AI and MIH can be confused, in particular related to severe cases of fluorosis and MIH. It is important to highlight that in AI, all permanent and primary teeth should be affected showing a generalized involvement. Family pedigree may also reveal some additional data for diagnosis, and another features such as taurodontism and other systemic disorders may be present [95].

**Table 7.5** Differential diagnosis between fluorosis, AI, sporadic DDE, and MIH

| | Fluorosis | AI | Sporadic DDE | MIH/HSPM |
|---|---|---|---|---|
| Etiology | Chronic excessive fluoride intake or environmental exposition<br>Genetic susceptibility? | Gene sequence variation affecting the function or quantity of related proteins | Exposure to any disturbance factor during amelogenesis<br>Genetic susceptibility? | Exposure to systemic/environmental factors that affect enamel mineralization<br>Genetic susceptibility? |
| Mechanism | Creation of hypomineralized and hypermineralized layers (barriers) during secretion and maturation phase | Malformed or absent proteins affect amelogenesis during secretory and/or maturation stage | Amelogenesis disorders during secretory and/or maturation stage | Amelogenesis disorders during maturation stage |
| Phenotype | Diffuse or linear opacities affecting homologous teeth | Enamel hypoplasias, demarcated and/or diffuse opacities | Enamel hypoplasias, demarcated and/or diffuse opacities | Demarcated opacities in incisors and permanent molars<br>May be accompanied by second deciduous molars and canines opacities |
| Genotype | Genetic susceptibility?<br>Weak evidence [57] | Several gene mutations have already been described (Table 7.2) | Genetic susceptibility?<br>No evidence | Genetic studies show some association but without scientific evidence |

Comparison of the etiology, mechanism, phenotype, and genotype

## 7.7 Final Considerations

Developmental defects of enamel are frequently observed in primary and permanent dentition. The knowledge of the etiology and clinical features of DDEs is essential in order to assist an adequate treatment plan elaboration and to perform an appropriate parents and patients orientation.

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# Dental Sealants

# 8

Soraya Coelho Leal, Kelly M. S. Moreira,
and José Carlos P. Imparato

## 8.1 Introduction

Untreated dentin carious lesions in permanent teeth is one of the eight chronic diseases that currently affects more than 10% of the world's population [1]. Moreover, there is an estimate that 27 new cavities will develop annually in permanent teeth for each group of 100 subjects that are followed up [2]. These data, when analyzed together, indicate that greater effort should be made to control dental caries in stages where the disease is not yet advanced, as the dental community is unable in providing restorative care for billions of cavities. This in itself is a serious matter, but it becomes more serious once the treatment needed for cavitated dentin carious lesions is a factor that affects children's and adults' quality of life [3, 4].

Contrary to the shown outcomes of the Global Burden of Disease Study [2], dental caries is a preventable disease. The definition of dental caries has changed over time, from an infectious and transmissible disease [5] to a complex interaction between acid-producing bacteria within the biofilm and fermentable carbohydrates [6, 7]. Being time-dependent and modulated by factors such as type of the tooth and patient's behavior, this interaction can lead to an imbalance of the de- and remineralization processes at the tooth-biofilm interface that may or may not be detected clinically. Most probably, the multifactorial etiology of dental caries explains why the prevention of the disease—apparently something easy to be achieved through

S. C. Leal (✉)
Department of Pediatric Dentistry, Faculty of Health Science, University of Brasilia, Brasilia, Brazil

K. M. S. Moreira
Department of Pediatric Dentistry, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil

J. C. P. Imparato
Orthodontics and Pediatric Dentistry Department, Dental School, University of São Paulo, São Paulo, Brazil



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the implementation of simple preventive measures and behavioral changes—actually is not observed in practice.

In terms of susceptibility, it is known that the occlusal surfaces of first permanent molars, followed by the second molars, are the dental surfaces most prone to develop carious lesions [8]. This occurs specially during tooth eruption as a combination of factors—tooth not yet in occlusion and limited mechanical oral function—which facilitates the accumulation of biofilm on the groove-fossa system [9]. Therefore, noninvasive preventive measures (fluoride varnish) and micro-invasive strategies (dental sealants) are indicated to avoid carious lesion development or to arrest active non-cavitated lesions [10].

## 8.2 Dental Sealants

A dental sealant is placed at a tooth surface to function as a physical barrier between microorganisms located in pit and fissures and nutrients from the oral cavity, aiming at avoiding biofilm growth and, subsequently, demineralization of the enamel.

### 8.2.1 Indications

Dental sealants were initially proposed for preventing carious lesions on occlusal surfaces—preventive sealants. Thereafter, its use was extended to also control further development of enamel carious lesions and managing lesions that are located at the outer part of the dentin—therapeutic sealants [11]. This strategy is in line with the philosophy of Minimal Intervention Dentistry, in which sound and remineralizable tooth structure should be fully preserved [12].

### 8.2.2 Preventive Sealants

As mentioned in Chap. 1, any treatment decision should take into consideration the patient's profile (lifestyle) in combination with a detailed dental examination, and this also applies to sealant. Applying a dental sealant in a patient who has no past caries experience, no signs of carious lesion activity and who has a good compliance is, undoubtedly, an overtreatment. The indication for applying a preventive sealant should be restricted to very specific situations [11], such as in permanent teeth of children and adolescents classified as high caries risk as shown in Fig. 8.1.

### 8.2.3 Therapeutic Sealants

Different preventive strategies for managing enamel carious lesions and those in the outer third/half of dentin are available, varying from noninvasive procedures (e.g., fluoride varnish) to micro-invasive approaches, category in which therapeutic

**Fig. 8.1** Newly first permanent molar with no signs of carious lesion in a mouth in which the primary molars are completely destroyed by dental caries (extractions of these teeth are included in the treatment plan care). In this case, a preventive sealant is indicated as the first permanent molar, differently from the primary molars that are already diseased, is at high risk of developing the disease

sealants are included [13]. It is important to highlight that the term micro-invasive refers to the use of an acid—either phosphoric or polyacrilic—prior to placing the sealant material and not to the use of bur. However, treating such lesions nonoperatively is seen as a barrier by many clinicians. A survey carried out among dentists from the USA who attended a dental conference indicated that out of 163, 44% of them judged “the possibility of sealing a carious lesion” with a sealant material a major concern [14].

Most probably, this concern is based on the fact that quite a considerable number of dentists still think that they should not leave bacteria underneath a dental material, no matter whether a sealant or a restoration. This statement is confirmed by a study in which dentists, after being exposed to cases of non-cavitated carious lesions that, according to the American Dental Association, could be treated by sealants, hardly indicated the procedure. One of the reasons pointed out as a barrier by the dentists was that their clinical experience has shown that caries progresses under sealants [15]. However, studies from the 1970s already showed that the count of viable microorganisms in pits and fissures of permanent teeth sealed were greatly reduced and carious lesion progression was not observed [16, 17], indicating that more conservative approaches could be applied for controlling carious lesions progression.

More recently, clinical and radiographical studies had shown that it is possible to arrest non-cavitated dentinal occlusal caries by sealing the pits and fissures [18, 19]. In addition, sealing showed similar efficacy in controlling carious lesion progression in occlusal cavitated primary molars reaching outer half of dentin compared to selective excavation of the carious tissue followed by a composite resin restoration [20]. However, it is paramount to keep these teeth under careful surveillance. A systematic review identified that sealants required more retreatments—in this case, meaning to reseal the occlusal surface—than the minimally invasive method (e.g., “preventive” resin/sealant restoration). Nevertheless, it is worth mentioning, since both treatments seem suitable for treating shallow to moderately deep pit-and-fissure carious lesions in permanent teeth [13], that the sealant repair—Minimal Intervention Dentistry—is less traumatic, faster, and timely than the invasive procedure.

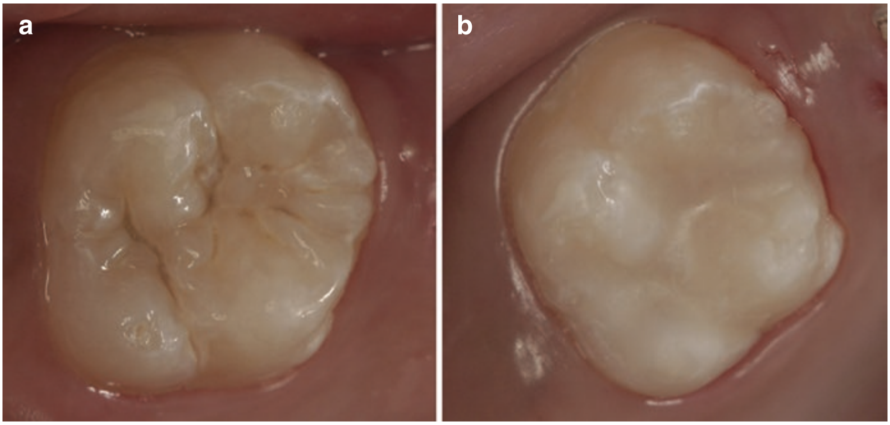


**Fig. 8.2** (**a**) An active enamel carious lesion on the occlusal and lingual surfaces of a first permanent molar. (**b**) Final aspect of the occlusal surface immediately after placing a resin-based sealant material

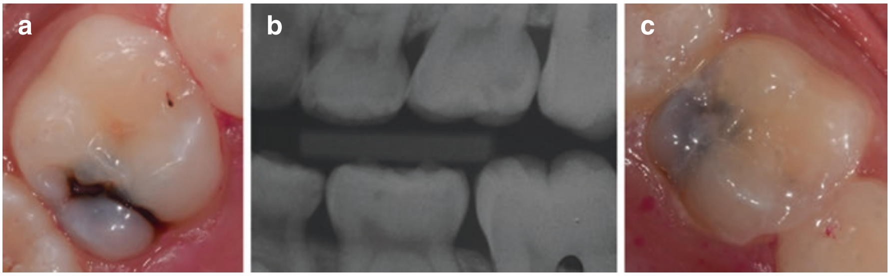


**Fig. 8.3** (**a**) Clinical aspect of a second primary molar presenting an internal caries-related discoloration. (**b**) The radiograph showing that the lesion is located in the outer of the dentin. (**c**) Final aspect immediately after the application of a resin-modified glass-ionomer sealant

The cases presented below are examples of the use of dental sealants to control enamel (Fig. 8.2) and non-cavitated dentin carious lesions (Fig. 8.3) progression.

### 8.2.4 Materials

The major types of materials used as sealants are resin-based and glass-ionomer cement-based (GIC), either chemically or light cured (resin-modified GIC).

Resin-based sealants are classified in generations, being the latest ones, which are polymerized by visible light, of third generation. The intention here is to highlight that since resin-based sealants were developed, many changes have occurred of which are the incorporation of monomers of 2,2-bis (4-(2-hydroxy-3-methacryloxy-propoxy)-phenyl) propane (Bis-GMA) and sodium monofluorophosphate in the polymer matrix, acting as a fluoride reservoir, are highlights. However, the effect of fluoride on caries control is questionable as the fluoride ion is unable to diffuse from a set resin compound. It is, therefore, no surprise that the increase of fluoride levels in saliva and plaque after applying a sealant containing fluoride is insignificant [21, 22].

Glass-ionomer cements are defined as acid-based cements, resulting from the reaction of weak polymeric acids with powdered glasses of basic character [23]. One of the most important advantages of the material is the release of fluoride that can be sustained for very long periods of time [24]. The resin-modified glass ionomers present similar properties to chemically activated GIC but markedly compromised biocompatibility by the incorporation of the resin component (2 hydroxyethyl methacrylate) [23]. Chemically activated high-viscosity GIC is the material of choice to place ART (atraumatic restorative treatment) sealants, in which the material is pressed into pit and fissure by means of the press-finger technique [25].

### 8.2.5 Effectiveness

With respect to effectiveness, two different outcomes are usually used: retention rate and caries-preventive effect. Although retention is an important outcome for the success of the sealants, the most important outcome is the level to which the sealant prevents carious lesions from occurring.

If the retention survival percentages of sealants performed with resin and GIC-based materials are compared, the percentage for resin-based sealants is significantly higher [26]. However, when comparing their preventive effect, this difference is no longer observed [26, 27]. Most probably, it is related to the fact that, even when a GIC sealant is clinically judged as completely lost, scanning electronic microscopy images shows that remnants of the material are present at the bottom of the fissures exercising their preventive effect [28].

With respect to resin-based sealants, attempts to improve the material retention have been made. It has been suggested that the use of an adhesive system under resin-based sealants would increase their retention, improving their effectiveness. To verify whether this hypothesis is plausible, a recent systematic review was conducted and concluded that the use of adhesive systems prior to the application of the resin-based material significantly increased the retention of the sealants [29]. Moreover, etch and rinse systems are preferable in comparison with self-etching systems [29, 30]. However, whether sealant retention is a valid predictor for the occurrence of dental caries is being questioned. According to the analysis of systematic reviews, the use of retention loss of resin sealants to predict caries manifestation was no more accurate than random guesses [31].

### 8.2.6 Technique for Applying Sealants

The technique for placing sealants is determined by the material that is being used. Figure 8.4 summarizes the sequence of applying sealants according to the type of material (resin sealant or glass-ionomer-based sealant) and technique.

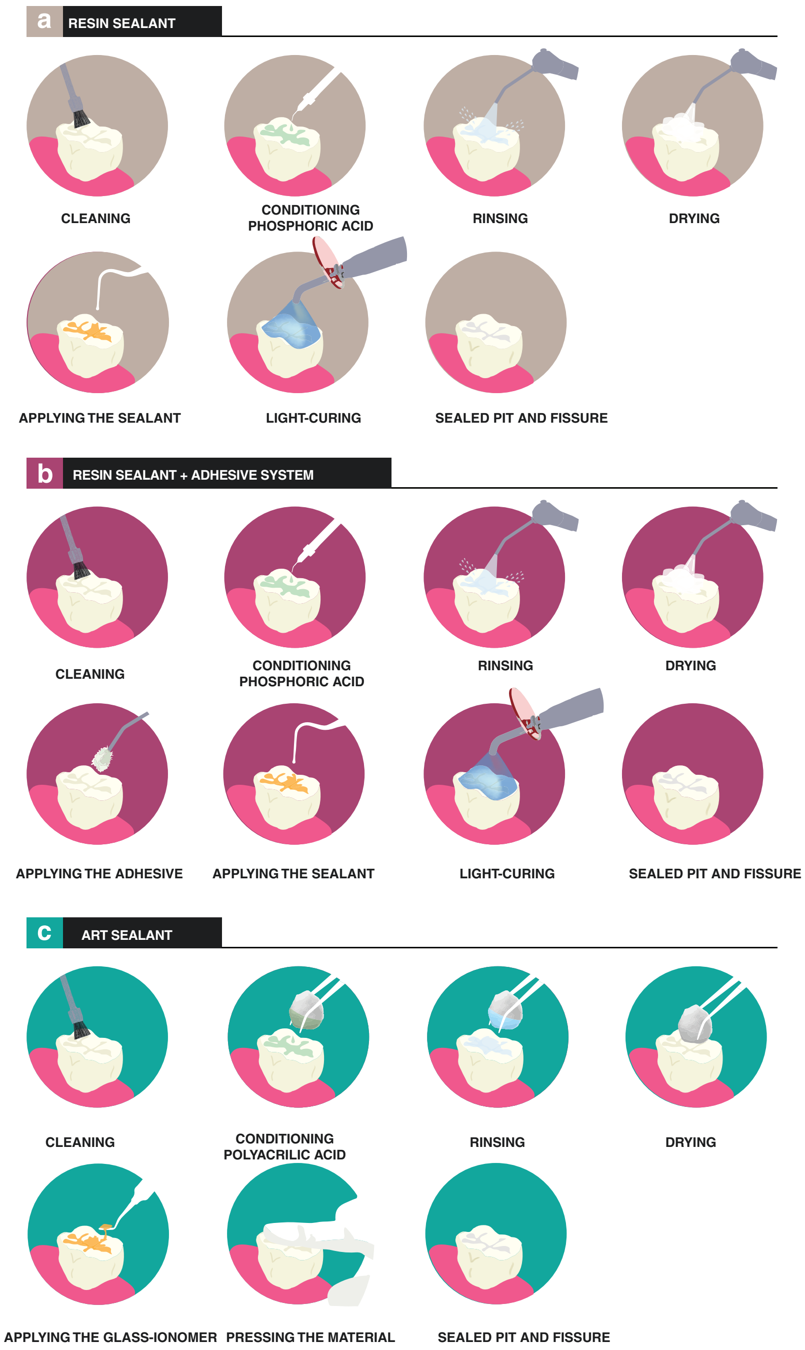


**Fig. 8.4** The step-by-step sequence of placing a resin-based sealant (**a**), a resin-based sealant with an intermediate layer of adhesive system (**b**), and an ART sealant using high-viscosity glass ionomer following the press-finger technique

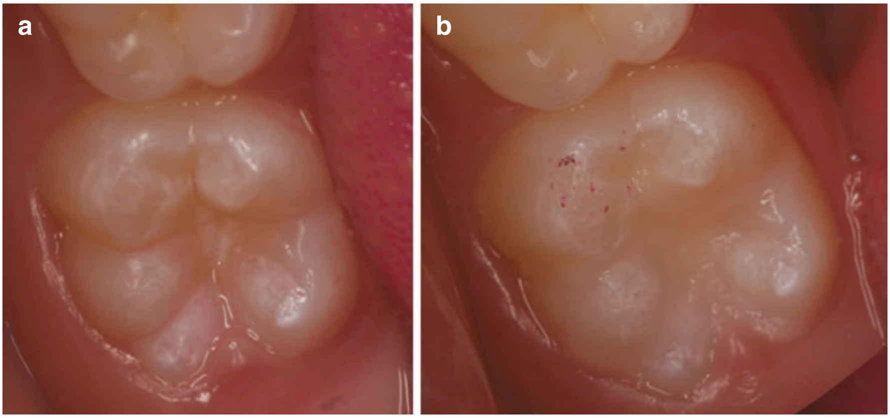


**Fig. 8.5** (**a**) Clinical aspect of the occlusal surface of an erupting first permanent molar indicated to be sealed due to the presence of deep fissures and the high accumulation of biofilm. Observe that the tooth was dried before the picture was taken, but even though, the distal part of the occlusal surface is wet, as the region is partly covered by the gingival operculum, which makes the moisture control difficult. (**b**) An ART sealant has been placed, using a high-viscosity glass ionomer (Fuji IX, GC, America). It is noted that all surface is sealed, showing that the GIC is less sensitive to moisture

Overall, as resin-based and glass-ionomer cement sealants present similar caries-preventive effect [26, 27], both materials can be applied according to the professional preference. Nonetheless, one important aspect that should be considered is the moisture control. It is known that resin-based materials are very sensitive to humidity, and because of that, the use of rubber dam has been recommended. However, there is no evidence that absolute isolation improves the retention rates of resin-based sealants in comparison with sealants placed using a careful isolation with cotton rolls [32]. But, in cases in which moisture control is difficult (Fig. 8.5), like in newly erupted molars, glass-ionomer cement seems to be more suitable. Results from a randomized clinical trial in which two types of glass-ionomer cements were used to seal such teeth showed a preventive effect over 98% during a 24-month period of follow-up [33].

## 8.3 Final Considerations

- Preventive sealants are indicated for specific cases.
- Therapeutic sealants are an effective strategy in controlling caries progression.
- Both resin and GIC-based materials are indicated for sealing pit and fissures showing similar caries-preventive effect.
- Sealed teeth need to be regularly monitored.

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# Caries Infiltration

# 9

Vera M. Soviero

## 9.1 Introduction

Dental caries is still highly prevalent in many countries in both primary and permanent dentition worldwide [1]. Proximal caries is often underestimated in epidemiological surveys, as radiographs usually are not combined to the clinical assessment. When findings from radiographs were added, caries prevalence in primary dentition was significantly raised in an epidemiological study [2, 3]. The prevalence of children with initial proximal carious lesions in primary molars may vary from 33% to 75% in low and high caries prevalence groups, respectively [3–5].

Even in a low caries prevalence population, one third of 5-year-old children and almost half of 9-year-old children benefited from bitewing examination as at least one proximal enamel or dentin lesion was detected in either primary molar or permanent first molar only from the radiograph [4, 5]. The detection of initial lesions is crucial to prevent their progression to more advanced stages where the restorative treatment would be inevitable and more costly. More sensitive methods to detect initial proximal caries (i.e., visual tactile combined with bitewing radiographs) have been shown to be cost-effective if followed by non- or micro-invasive treatments, particularly for high caries risk groups [6].

In populations where a considerable decrease in the number of decayed permanent teeth was observed, proximal surfaces affected by caries showed less reduction over time comparing to occlusal surfaces [7]. In a longitudinal study about the incidence of proximal caries, most of the adolescents who developed proximal caries showed a first lesion up to 15 years old, suggesting that the first 4 or 5 years after eruption represent the period of higher risk for new proximal caries [8, 9].

V. M. Soviero
Department of Preventive and Community Dentistry, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

Dental School, Faculdade Arthur Sá Earp Neto, Petrópolis, Brazil


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Taking into account that the first 2–3 years after eruption is considered of greater risk of developing carious lesions, bitewing radiographs are indicated at the so-called key ages: 5 years old, 8 to 9 years old, 12 to 13 years old, and 15 to 16 years old [10].

In the past, most of the initial proximal lesions detected on radiographs were referred to invasive treatment. The decrease of the progression rate of carious lesions mainly due to the wider contact of the populations with fluoride from water fluoridation and/or dentifrice led to a more conservative approach for carious lesions detected before cavitation [9]. As an option between the non-invasive strategies and the invasive treatment, caries infiltration has been recommended as a micro-invasive treatment for non-cavitated proximal lesions extending up to the outer third of dentin.

## 9.2 Initiation and Progression of Proximal Caries: Understanding the Relevance of Early Diagnosis

Proximal carious lesions initiate between the contact area and the gingival margin where the biofilm stagnates. The constant fluctuations of pH due to the metabolic activity of biofilm on the enamel surface result in the dissolution of the enamel surface that might become visible clinically as white spot [11, 12]. The initial proximal lesions have a kidney-shape appearance, and an extension of the opaque white spot along the gingival margin is often seen on the buccal and lingual tooth surfaces. As the mineral dissolution follows the direction of the rods, the proximal enamel lesions develop a triangular shape easily seen in the bitewing radiographs [12].

Underneath a relatively intact surface zone, which ranges from 20–50 μm in thickness, the body of the lesion is more porous due to the more pronounced loss of mineral in the subsurface. It has been advocated that the surface layer acts as a diffusion barrier against mineral uptake by the subsurface [11, 12]. As the carious lesion progresses, the enamel becomes more porous and permeable [13]. Dentin reactions, mainly tubular sclerosis, occur before the lesion has reached the enamel dentin junction (EDJ). Histologically, once the enamel lesion reaches the EDJ, signs of demineralization of the dentin can be seen [12].

The progression rate of proximal lesions might be considerably slow, especially in low caries risk populations. In permanent teeth, most of the lesions in the inner half of enamel might survive approximately 5 years without reaching the outer dentin. However, the median survival time decreases to 3 years if the lesion was already reaching the EDJ [9]. Nonetheless, even in low-risk populations, it can be assumed that around half of the initial proximal lesions in 15-year-old adolescents progress to cavitated lesions at the age of 20 [14]. Progression is markedly faster in the dentin than in the enamel and in primary molars comparing to permanent. Within a year, it is expected that 20% of the proximal lesions in permanent molars and more than 30% in primary molars will progress from the inner enamel to the outer dentin [15]. This emphasizes the importance of strategies to detect and control initial proximal lesions in the period of late mixed and young permanent dentitions. This is particularly true for high-risk population, as high caries experience significantly increases the progression rate of proximal caries lesions in primary molars and permanent first molars [16].

## 9.3 Treatment Decision: An Option Between Non-invasive and Operative Treatment

Treatment decision for these carious lesions has changed significantly over the years. In the past, the presence of radiolucency in a proximal tooth surface was an indicative for the recommendation of restorative intervention no matter its depth. Even proximal lesions restricted to enamel were treated invasively. When invasive treatment is indicated for proximal carious lesions, sound dental hard tissues are inevitably destroyed during cavity preparation.

Then, the involvement of dentin was considered the threshold to indicate operative intervention, as if the dentin involvement represented a stage of the carious process that only could be arrested by the removal of the carious tissue and placement of a filling. This approach was based on the concept that drilling and filling was the proper treatment to cure dental caries.

Since the 1980s, a shift to a more conservative approach has been reported, mainly initiated by Scandinavian countries [17–19]. It has been largely understood that dentin involvement itself does not represent an irreversible stage of the carious process and that once a tooth is drilled and a restoration is placed, the tooth enters a repetitive restorative cycle [20].

The most contemporary recommendation is that restorative treatment should be restricted to non-cleansable cavitated lesions. Therefore, a radiography showing a carious lesion reaching the dentin should not lead to the decision of operative treatment by itself because lesion depth and radiographic density are not accurate to distinguish between cavitated and non-cavitated proximal lesions [21, 22]. To minimize the need for operative intervention is the key to achieve better clinical outcomes [23].

As deeper the radiolucency is observed in the dentin, the higher is the chance that a proximal cavitation is present [24, 25]. However, the analysis of the radiographic depth alone is not a precise method to predict cavitation. There is an estimate that more than half of the proximal lesions extending to the outer half of dentin might be not cavitated [26]. A careful visual examination after complete removal of interproximal plaque and tactile investigation of the surface with a fine probe is also advisable [27]. When visual examination combined with radiograph is not enough to support the treatment decision, temporary tooth separation is a valuable method to obtain visual and tactile access to the proximal surface and confirm if a cavitation is present [26, 28].

Once a non-cavitated proximal lesion is detected, the most effective strategy to inhibit progression would be the regular and complete elimination of biofilm on the surface of the lesion [29]. The efficiency of regular plaque removal for the inhibition of initial caries has been extensively demonstrated in studies based on in vivo caries models [29–31].

When dealing with proximal caries, proper plaque elimination is not so simple as the proximal surface is not easily accessible for cleaning by brushing. Therefore, clinicians often motivate patients or patients' parents to floss daily. Since dental floss is supposed to disrupt interproximal plaque, it is expected that regular flossing would play an important role in the control of proximal caries. However, only when performed professionally, on a daily basis, flossing was able to reduce the risk of proximal cavities in primary teeth. When self-performed by young adolescents, even under supervision, there is no evidence of the benefit of flossing on arresting proximal caries [32, 33]. This might be due to many reasons including poor flossing techniques, as we know that flossing is not an easy task for most of the individuals. Although non-invasive strategies do not rely only on cleaning but also on the local effect of fluoride from toothpaste and other sources combined with dietary counseling, it has been argued that to permanently arrest carious lesion progression, the tooth surface must be sufficiently accessible to cleaning [27].

In the daily practice, despite the early detection and implementation of non-invasive strategies, many initial carious lesions continuously progress, and operative intervention is only postponed until a cavitation appears sooner or later [34]. Attempting to provide an alternative approach for initial proximal lesions prone to progress, micro-invasive treatment by infiltrating the carious lesion with low viscosity resin has been introduced [35].

## 9.4 Infiltration Concept: The Science Behind the Clinic

Caries infiltration comes as an alternative method to control carious lesions between non-invasive measures and the restorative intervention. As fissure sealants, caries infiltration is considered a micro-invasive treatment that modifies the dental hard tissues creating diffusion barriers with resin [27, 35]. For the occlusal surface, the effectiveness of fissure sealants in preventing and controlling occlusal caries has been supported by several systematic reviews [36–40]. Attempts to transfer the same concept of fissure sealants to proximal surfaces were reported [41, 42], but a practical issue raises as the application of a flowable resin in the interproximal area is rather difficult technically [27]. Moreover, it requires two dental appointments for tooth separation with an elastic band.

Therefore, a different approach, caries infiltration, was suggested [35]. Contrary to fissure sealants where the resin barrier is created on the tooth surface, caries infiltration aims to occlude the pores inside the enamel lesion in the subsurface. The arrestment of carious lesions by penetrating the lesion with resin was first suggested in the 1970s with an experimental resin containing formaldehyde as an antimicrobial agent [43]. Later on, attempts to penetrate enamel lesions with adhesives or sealants generally resulted in superficial or inhomogeneous penetration even after etching the lesion with hydrochloric acid to remove the pseudo-intact surface layer [44–46]. Low-viscosity resins were optimized resulting in higher penetration coefficient to enable more rapid infiltration. This so-called infiltrant was shown to penetrate artificial and natural enamel lesions nearly completely under in vitro [44, 45], in situ [47], and in vivo conditions [48]. Before light curing, the excessive resin must be removed from the tooth surface by air flowing and flossing. A covering resin coat on the enamel surface is not essential to inhibit carious progression because the infiltrant fills the porosities inside the lesion body [44]. Besides acting as a barrier to acids, the infiltrant strengthens the lesion mechanically and prevents cavitation. An advantage is that no sealant margins are created on the tooth surface that could facilitate plaque accumulation and gingival inflammation. Additionally, the treatment is done in a single visit because no previous tooth separation is necessary.

The penetration of the infiltrant into the pores of the lesion body is mainly driven by capillary forces and depends on the penetration coefficient (PC) of the liquid [49, 50]. The PC results from the liquid properties viscosity, surface tension, and contact angle to the solid surface [51]. Other factors that influence on the depth of the penetration reached by the infiltrant and on the homogeneity of the infiltration are the application time [52], the dryness of the surface [53], and the capability of the etching procedure on removing the surface layer [45] that acts as a highly mineralized barrier to the infiltrant.

Of particular importance is the etching procedure. As stated previously in this chapter, in non-cavitated carious lesions, the enamel surface remains relatively intact, while the body of lesion underneath the surface layer presents a considerable mineral loss and increased porosity [1]. Different from artificial lesions, natural lesions are constantly exposed to de- and remineralization cycles in the oral cavity. Therefore, probably due to remineralization effects, the surface layer of natural lesions is thicker and shows higher mineral content compared to artificial ones. That is the reason why in the first laboratorial studies using artificial lesions etching with 37% phosphoric acid ($H_3PO_4$) gel was sufficient to open access to the body of the lesion and subsequently obtain a deep infiltration of the resin [44, 49]. In natural lesions, however, the conventional etching with 37% phosphoric acid gel, as usually done for adhesive restorative purposes, even increasing the etching time to 2 min, is not able to remove the surface layer. In contrast, 15% hydrochloric acid (HCl), same concentration used for microabrasion purposes, applied for 2 min, erodes the surface layer completely making the porosities in the subsurface accessible to the infiltrant [45, 54].

Another critical step of the infiltration technique is drying. It is required that the enamel is extensively dried before applying the infiltrant. The presence of water into the pores hampers resin penetration, and, different from dentin, overdrying does not damage enamel structure. Contrarily, desiccation increases the surface free energy favoring the wettability of the infiltrant that more easily soaks into the porosities of the carious lesion. This is better achieved with ethanol application instead of air-drying only [53]. So, is it recommended that after rinsing the acid gel and air-drying for 30 s, ethanol is applied for 30 s followed by another 30 s air-drying.

At last, but not at least, is the application time. Under laboratory conditions using artificial lesions, it is possible to infiltrate subsurface lesions completely after a very short time, <30 s [49]. However, for natural lesions more time is necessary until the infiltrant reaches the deepest parts of the carious lesion. In the clinical practice, it would be convenient for the patients, particularly children, if a shorter application time could be supported by scientific evidence. Application times of 0.5, 1, 3, and 5 min were tested in permanent and primary teeth. In permanent teeth, almost complete infiltration was observed after 3 or 5 min, while only shallow penetration was seen after 0.5 or 1 min [55]. In primary teeth, although many lesions were completely infiltrated after 1 min, results were less consistent for deeper lesions [48, 52]. Hence, the application time of 3 min is still the standard recommendation for both permanent and primary teeth.

Initial lesions in smooth surfaces infiltrated with low-viscosity resins became more resistant to further demineralization, and the ability to inhibit lesion progression was strongly correlated to the penetration depth and homogeneity of the infiltration of the resin [44]. Therefore, important outcomes from laboratorial analyses support recommendations for the caries infiltration technique that must be strictly followed at the clinic so that better results will be achieved.

- Etching with 15% HCl gel for 2 min
- Overdrying with air, ethanol, and air again
- Application time of 3 min before light curing

## 9.5 Infiltration Concept: The Clinical Practice

### 9.5.1 Indications and Limitations

Caries infiltration is indicated for non-cavitated proximal lesions particularly being radiographically extended in the inner half of enamel (E2) or in the outer third of dentin (D1). Shallower proximal lesions, restricted to the outer half of enamel (E1), might be indicated for non-invasive treatment first. On the other hand, deeper lesions, reaching the middle third of dentin or more [D2 and D3], are probably cavitated and should be treated invasively [27, 35] (Fig. 9.1).

In order to avoid overtreatment, only lesions prone to progress should be infiltrated. A considerable proportion of enamel proximal lesions detected in children during the mixed dentition and in adolescents in the young permanent dentition are

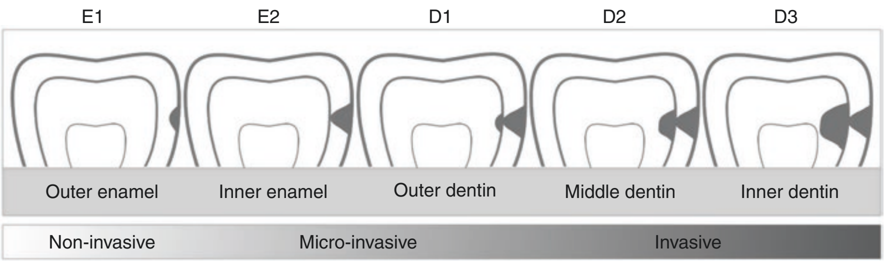


**Fig. 9.1** Proximal caries lesions according to the radiolucency depth assessed on bitewing radiograph. *E1* outer half of enamel, *E2* inner half of enamel, *D1* outer third of dentin, *D2* middle third of dentin, *D3* inner third of dentin

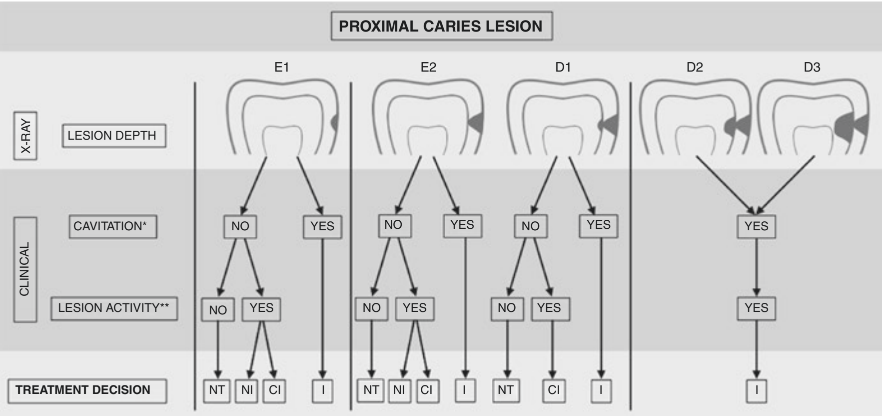


**Fig. 9.2** Flowchart of treatment decision for proximal caries lesions considering radiographic and clinical assessments. *NI* no intervention, *CI* caries infiltration, *I* invasive. *Cavitation assessed by clinical/tactile examination and/or tooth separation. **Caries activity assessed according to clinical predictors. Modified from Meyer-Lueckel and Paris (2016) [27]

expected to progress to dentin and eventually to cavitation if the caries process is not arrested [15]. However, the depth of the lesion assessed in the radiograph alone at a single visit is not sufficient to indicate if a lesion is active (progressing) or not (arrested). Some clinical parameters such as high past caries experience and the presence of advanced carious lesions in occlusal or proximal surfaces are valuable indicators to support micro-invasive treatment [6, 16]. Bleeding of the interproximal gingival beneath the proximal lesion has been also considered an indicative of caries activity and a predictor of caries progression [56].

Therefore, the treatment decision should be preferably supported by the combination of radiographic and clinical assessments. In Fig. 9.2, a decision tree for proximal carious lesions is presented. In the absence of cavitation, active E1 and E2 lesions might be treated non-invasively or by caries infiltration, depending on the compliance of the patient in adhering to nonoperative strategies, i.e., plaque control. However, considering that caries progression is considerably faster after the dentin is reached, caries infiltration should be the first choice treatment for active D1 lesions. As D2 and D3 lesions are presumably cavitated, they should be treated invasively by drilling and placing a restoration.

### 9.5.2 The Technique Step by Step

- Score the proximal lesion according to the radiolucency depth using the identification card (Fig. 9.3a).
- Clean the affected tooth surface with dental floss and water spray.
- Use conventional rubber dam (Fig. 9.3b) or MiniDam (Fig. 9.4a–g) to ensure a dry working field. If rubber dam and dental clamp are used, it might be necessary to anesthetize the papilla.

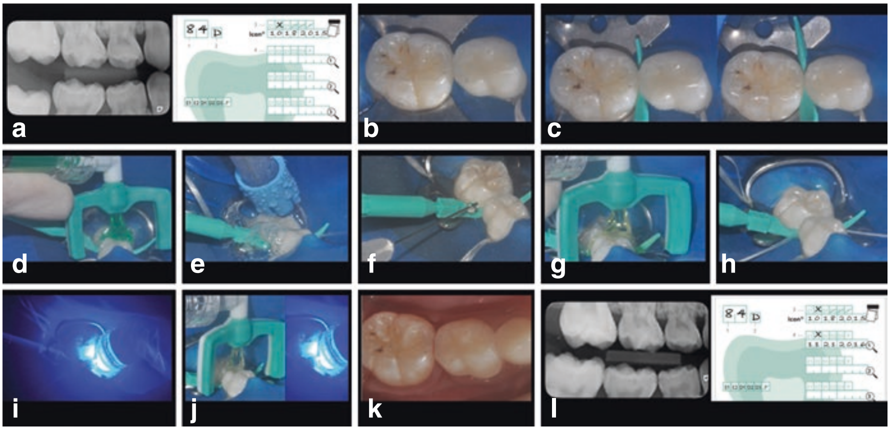

**Fig. 9.3** Clinical case showing the initial diagnosis of a proximal lesion scored as E2 in tooth 84 (**a**); caries infiltration procedure step by step: rubber dam (**b**); insertion of the wedge for tooth separation (**c**); etching with 15% HCl gel for 2 min (**d**); rinsing (**e**) followed by air-drying; ethanol application for 30 s (**f**) followed by air-drying; application of the infiltrant for 3 min (**g**); excess removal with dental floss (**h**); light curing for 40 s (**i**); reapplication of the infiltrant for 1 min followed by light curing for 40 s (**j**); clinical aspect right after removing the rubber dam (**k**); and the follow-up radiograph and the identification card after 1 year (**l**)

- Place the dental wedge to obtain a proximal separation of at least 50 µm. Insert the wedge to the point of resistance, and gradually move it deeper (Fig. 9.3c). Usually, 30–60 s are enough to achieve a proper separation.
- Use the Icon-Etch syringe with the application tip to etch the surface of the lesion. Be sure that the green side of the application tip is aligned with the tooth surface to be treated. With the application tip positioned, 1½–2 turns of the shaft might be enough to deliver a proper amount of the etching gel onto the lesion (Fig. 9.3d). Wait 2 min.
- Rinse the etching gel with water for at least 30 s. Dry with air spray thoroughly (Fig. 9.3e).
- Use the Icon-Dry syringe to apply ethanol for desiccation of the lesion (Fig. 9.3f). Wait 30 s and dry with air spray thoroughly.
- Use the Icon-Infiltrant syringe with a new application tip. Again, be sure that the green side of the applicator is aligned with tooth surface to be treated. At this moment, turn off the operating light in order to avoid premature curing of the infiltrant. With the application tip positioned, 1½–2 turns of the shaft might be enough to deliver a proper amount of the infiltrant onto the lesion (Fig. 9.3g). Wait 3 min until the infiltrant penetrates deeply into the lesion. Small amounts of the infiltrant might be added during the 3 min.
- Remove the application tip, clean all the excess with dental floss (Fig. 9.3h), and air spray and light cure from all sides for at least 40 s (Fig. 9.3i).

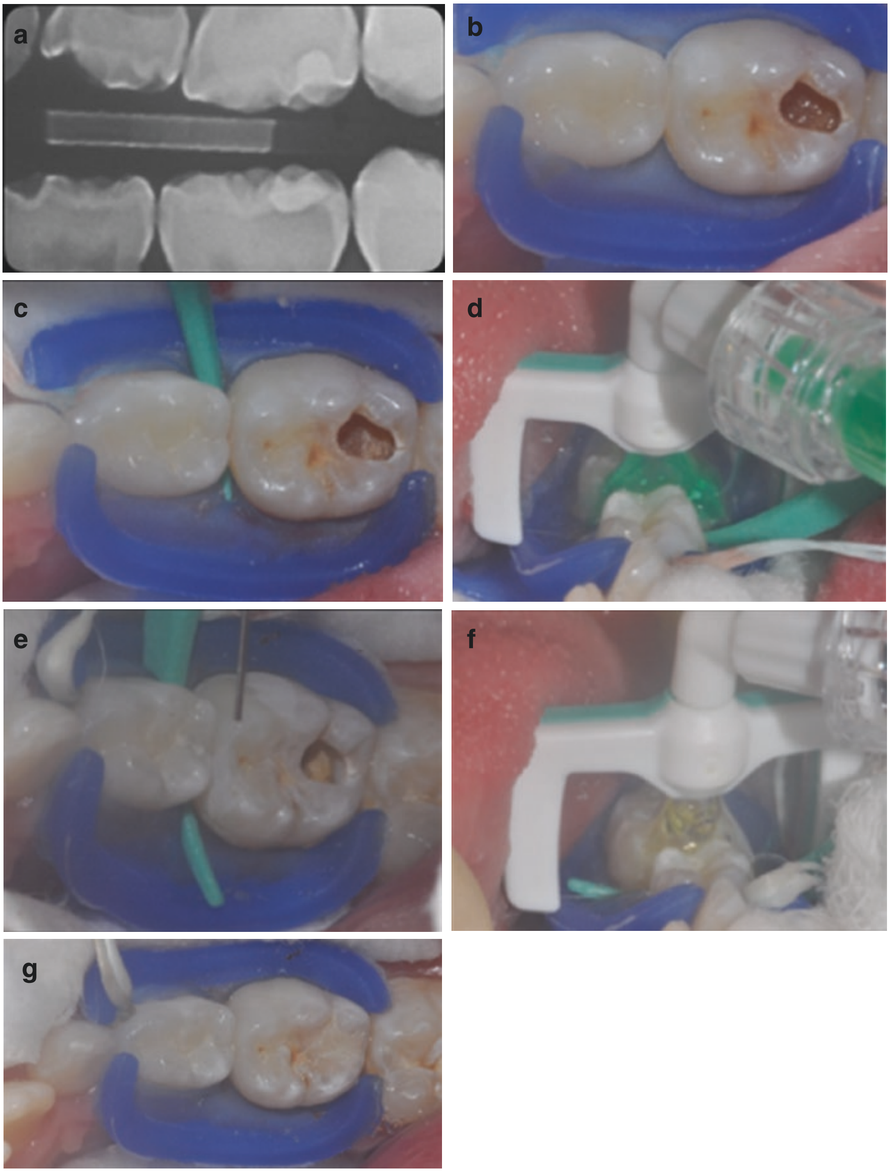


**Fig. 9.4** MiniDam® (DMG, Hamburg, Germany) used for isolation of the working field. Initial radiograph showing an enamel lesion in the mesial surface of tooth 75 (**a**); working field isolated with MiniDam (**b**); tooth separation (**c**); etching (**d**); ethanol application (**e**); application of the infiltrant (**f**); clinical aspect at the end of the procedure that included caries infiltration in the mesial surface and composite restoration in the occlusal surface of tooth 75 (**g**)

- Make a second application of the infiltrant, using a new application tip, for 1 min and light cure from all sides for at least 40 s (Fig. 9.3j). This second application is recommended in order to fill possible remaining porosities.
- Remove the wedge and rubber dam (Fig. 9.3k). Polish the tooth surface using polishing strips.
- A follow-up radiograph is recommended after 1 year. Use the same identification card to register the follow-up score according to the radiolucency depth (Fig. 9.3l).

As infiltrated proximal lesions cannot be differentiated from untreated lesions because the infiltrant is not radiopaque, the manufacture recommends an identification card where the treated lesions are registered. Thus, if the patient goes to another dentist, he/she will have access to detailed information about the infiltrated lesions.

### 9.5.3 Evidence of the Efficacy and Safety of Caries Infiltration

Since the infiltrant became available commercially in 2009 (Icon®, DMG, Hamburg, Germany), several clinical studies on the efficacy of infiltrating proximal lesions in permanent [34, 57–61] and primary teeth [62–64] were published.

Clinical studies mainly conducted with moderate to high caries risk participants concluded that caries infiltration significantly reduced caries progression compared to a placebo treatment [34, 57, 58], to non-invasive approach (flossing and fluoride toothpaste) [62, 65], or to fluoride varnish [63]. The therapeutic effect of caries infiltrations was reported as 21% [62] and 35% in primary teeth after 1 year [63] and higher than 37% in permanent teeth after 3 years [34]. Only one clinical study found no additional benefit of caries infiltration to control proximal lesions. According to the authors, this might have resulted from the fact that only enamel lesions (up to EDJ) were included and that patients showed a significant improvement in interproximal plaque control along the study period leading to a very low progression rate of both test and control lesions [61].

Nonetheless, the effectiveness of caries infiltration in reducing caries progression is supported by two systematic reviews and meta-analyses [66, 67]. The chance of caries progression was significantly reduced when the proximal lesions were treated by micro-invasive methods compared to non-invasive professional or home care. Although further long-term trials with larger samples may be done to increase the quality of this evidence, dentists can consider micro-invasive treatment as additional option for treating non-cavitated proximal lesions between the non-invasive and operative treatment for proximal caries.

Moreover, based on an estimation of the risk of progression of proximal lesions treated non- or micro-invasively and the risk of failure of proximal composite restorations, the analysis of cost-effectiveness supports the micro-invasive approach. Both non- and micro-invasive treatment reduce the long-term costs of the treatment of E2 or D1 lesions in comparison with proximal fillings. Micro-invasive treatment is more effective, but usually more costly than non-invasive therapy. The highest cost-effectiveness of micro-invasive treatment is related to D1 lesions in young patients [68].

It is somehow expected that children report more discomfort with resin infiltration than with non-invasive treatments such as flossing instruction or topical application of fluoridated agents [69]. Nonetheless, caries infiltration can be considered a technique well accepted by children, and the time required for the treatment is suitable, ranging from 10 to 17 min calculated after the isolation of the working field [62].

No unwanted effects in the gingiva (ulcerations or color alterations) or in the treated teeth (pain, loss of vitality, or staining) were observed in clinical studies [34, 57–59, 62, 63, 65]. With regard to the irritant effect of hydrochloric acid gel, it is important to keep in mind that exposure of the soft tissues to the hydrochloric acid gel for 30 s might cause ulcerations. Therefore, accidental contact of the acid with hard or soft tissues should be avoided. However, its application under proper isolation in small amount is safe [70]. One study reported that 4% and 22% of the children complained of bitter taste and pain in the area of the treated tooth immediately after removing rubber dam, respectively [62]. Authors considered that the bitter taste might have resulted from an overflow of remnants of the infiltrant in the rubber dam. Hence, abundant rinsing before removing the rubber dam is advisable. The reported pain was interpreted as a pressure caused by the wedge used for tooth separation reflecting on the periodontal ligament. However, since the reported symptoms disappeared within the next 2 h, they were not considered as adverse effects [62]. Caries infiltration has shown to be a clinically feasible, safe, and efficacious method to treat non-cavitated proximal caries lesions.

## 9.6 Final Considerations

Contemporary dentistry is based on minimal intervention philosophy where operative treatment of dental caries should be limited to cavitated lesions. Moreover, early diagnosis and non-invasive strategies should be implemented in order to detect and arrest initial lesions. Particularly for proximal carious lesions, operative treatment implies that a considerable amount of intact dental tissue is sacrificed. As a micro-invasive technique, caries infiltration represents an option to treat proximal carious lesions nonoperatively when non-invasive approach alone might be not sufficient to arrest caries progression. Several clinical studies have shown that caries infiltration is a clinically feasible, safe, and efficacious method to treat non-cavitated proximal caries lesions filling a gap between non-invasive and invasive strategies in the spectrum of treatment options for proximal carious lesions.

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# 10 Non-restorative Approaches for Managing Cavitated Dentin Carious Lesions

Edward C. M. Lo and Duangporn Duangthip

## 10.1 Introduction

Dental caries is a significant health problem affecting the quality of life of millions of young children worldwide [1]. In many developing countries, most of the decayed primary teeth in preschool children are left untreated [2]. A recent review reported that in Southeast Asia, the median caries prevalence in 5–6-year-old children was 79%, and their dmft (decayed, missing and filled primary teeth) score was 5.1 [2]. In China, the pooled prevalence of dental caries in preschool children found in surveys conducted in 1987–2013 was 65.5%, and the care index (ft/dmft) was 3.6% [3]. Untreated carious lesion can cause difficulties in sleeping and eating and affects children's growth and development. Such problems can become serious and even life-threatening [4].

Conventionally, a restorative approach is adopted when treating cavitated carious lesions that have progressed into dentin. However, due to various reasons such as limited resources and less-developed health-care system, access to conventional restorative dental care services is difficult in many communities. There are also other limitations in using this approach. A systematic review reported that the longevity of two- or multiple-surface dental restorations in primary teeth of preschool children is rather short [5]. Often, young children cannot cope with complicated and lengthy dental procedures. As a result, they are referred to receive dental treatment under conscious sedation or general anaesthesia which is costly and has life-threatening health risk.

Recently, the use of non-restorative approaches to manage cavitated dentin carious lesions has been advocated. Caries management for children may be different from that for adults, as the lifespan of primary teeth is much shorter,

E. C. M. Lo (✉) · D. Duangthip
Faculty of Dentistry, University of Hong Kong, Hong Kong, China
e-mail: hrdplcm@hku.hk



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usually 6–8 years before shedding. Several non-restorative approaches have gained much attention since there is increasing evidence that the progression of dental caries can be halted or slowed down so that a primary tooth with arrested carious lesions can remain in the mouth without causing pain and infection before its natural exfoliation. Caries-arrest treatment can be very helpful in controlling the heavy burden of tooth decay in children, particularly those living in deprived communities.

This chapter will review the literature on the effectiveness of non-restorative approaches in arresting cavitated dentin carious lesions in children. Various non-restorative approaches for treating early childhood caries (ECC) have been proposed, such as brushing with fluoridated toothpaste and the use of fluoride varnish, silver diammine fluoride (SDF) solution, xylitol, chlorhexidine and casein phosphopeptide-amorphous calcium phosphate (CPP-ACP).

## 10.2 Topical Use of Fluorides and Silver Compounds in Arresting Dentin Carious Lesions

The use of topical fluorides in controlling tooth decay can be categorized by the delivery method used into self-applied, professional-administered and community-based. Fluoridated toothpaste is the most commonly used form in topical fluoride delivery. There is strong evidence that the daily use of fluoridated toothpaste has a caries preventive effect in children, with a prevented fraction around 25% [6]. Several factors can significantly affect its anticaries effectiveness, including toothpaste formulation, toothbrushing frequency, brushing time and post-brushing rinsing behaviour [7]. Although there is a substantial effect in preventing dental caries, few studies about the caries arresting effect of fluoride toothpaste were published. In a clinical trial which was initially planned to investigate the caries preventive effect of a kindergarten-based toothbrushing exercise using 1000 ppm fluoride toothpaste, it was found that the intervention could stabilize progression of dentin carious lesions in preschool children [8]. Approximately half of the active carious lesions in the proximal surfaces of primary anterior teeth of the study children became inactive after 2–3 years of teacher-supervised daily toothbrushing in the kindergarten.

Professionally applied topical fluorides are found to be effective in preventing caries and slowing down the progression of dental caries. Systematic review concludes that fluoride varnish has a significant caries-inhibiting effect in primary teeth [9]. Result of the meta-analysis in a recent Cochrane systematic review gives a pooled prevented fraction for primary teeth of 37% [10]. It should be noted that most of the clinical studies focused on inhibiting enamel carious lesions [11]. Only a few clinical studies reported on the effectiveness of fluoride varnish in arresting cavitated dentin carious lesions in primary teeth, and the results showed that it was less effective compared to application of SDF solution [12, 13].

## 10.3 Silver Fluoride

The most commonly used form of silver fluoride agent in dentistry is SDF. Regarding the nomenclature of SDF, it has been called in different terms such as “ammoniated silver fluoride” [14], “diamine silver fluoride” [15], “silver diammine fluoride” [13, 16] and “silver diamine fluoride” [12, 17]. The term “silver diammine fluoride” is a more accurate description of its chemical structure since SDF contains two ammine ($NH_3$) groups and not amine ($NH_2$) groups [18]. Despite this, “silver diamine fluoride” still remains a commonly used nomenclature in the dental literature.

The use of silver compounds in dentistry can be traced to more than half a century ago for different purposes, such as cavity sterilization [19], caries prevention [20] and dentin desensitizer [21]. The use of silver fluoride (AgF) followed by stannous fluoride ($SnF_2$) was found to be effective in slowing down the progression of dental caries in primary molars [22]. Silver diammine fluoride [SDF or $Ag(NH_3)_2F$] has been accepted as a therapeutic agent in Japan for more than 40 years [23]. A few cohort studies on the use of SDF in children were conducted some decades ago [24, 25]. SDF has been used in different parts of the world to arrest active dentin carious lesions in primary teeth. If successful, a soft, yellow active carious lesion in dentin will become hard, smooth and black in colour after SDF application (Fig. 10.1).

Several randomized controlled trials on the use of SDF in children have been conducted. A summary of the randomized clinical trials on SDF conducted in preschool children is presented in Table 10.1. In China, a randomized clinical trial found 38% SDF solution more effective than 5% NaF varnish in arresting dentin carious lesions of primary teeth in preschool children [12]. In addition, removing soft carious dentin prior to the application of either SDF solution or NaF varnish showed no additional benefit on caries arrest after 3 years. Another study comparing the effectiveness of interim glass ionomer (GI) restoration and application of SDF solution showed that there was no difference between the caries-arresting effects of annual application of 38% SDF solution and placement of interim GI restoration in

**Fig. 10.1** Arrested caries with a hard and smooth surface, and black in colour after SDF treatment on the labial surface of a primary upper right central incisor

**Table 10.1** Summary of randomized clinical trials of silver diammine fluoride (SDF) and nano-silver fluoride (NSF) in arresting cavitated dentin carious lesions in children (adapted from Duangthip et al. 2017 [26])

| Author, year [Reference] Place | Duration, subject, age | Study groups | Outcome |
|---|---|---|---|
| Chu et al., 2002 [12] China | 30 months, 375 children, 3–5 years | 1. Caries excavation + 38% SDF once/year<br>2. 38% SDF once/year<br>3. Caries excavation + 5% NaF four times/year<br>4. 5% NaF four times/year<br>5. Control | The respective mean numbers of arrested caries tooth surfaces in Groups 1–5 were 2.5, 2.8, 1.5, 1.5 and 1.3, respectively ($p < 0.001$) |
| Yee et al., 2009 [27] Nepal | 976 children aged 3–9 years | 1. 38% SDF<br>2. 38% SDF + tannic acid<br>3. 12% SDF<br>4. Control | Mean no. of arrested caries surfaces in Groups 1–4 were 2.1, 2.2, 1.5 and 1.0, respectively. A single application of 38% SDF was effective in arresting caries in primary teeth |
| Zhi et al., 2012 [28] China | 24 months, 212 children, 3–4 years | 1. 38% SDF once/year<br>2. 38% SDF twice/year<br>3. Flowable GI filling once/year | Caries arrest rates in Groups 1–3 were 79%, 91% and 82%, respectively ($p = 0.007$) |
| dos Santos et al., 2012 [29] Brazil | 12 months, 91 children, 5–6 years | 1. Interim GI filling<br>2. 30% SDF | Caries arrest rates of SDF and GI filling were 67% and 39%, respectively ($p < 0.001$) |
| dos Santos et al., 2014 [30] Brazil | 12 months, 60 children, mean age 6.3 ± 0.6 years | 1. Nano-silver fluoride (NSF)<br>2. Control (no treatment) | At 12 months, 66.7% of the lesions treated with NSF were arrested, while the control group had 34.7% arrested ($p = 0.003$) |
| Duangthip et al., 2016 [13] Hong Kong | 18 months, 371 children, 3–4 years | 1. 30% SDF once/year<br>2. 30% SDF three times weekly at baseline<br>3. 5% NaF three times weekly at baseline | Caries arrest rates in Groups 1–3 were 40%, 35% and 27%, respectively ($p < 0.001$) |
| Fung et al., 2017 [17] Hong Kong | 30 months, 888 children, 3–4 years | 1. 12% SDF once/year<br>2. 12% SDF twice/year<br>3. 38% SDF once/year<br>4. 38% SDF twice/year | Caries arrest rates in Groups 1–4 were 55%, 59%, 67%, 76%, respectively ($p < 0.001$) |

primary teeth at the 2-year follow-up evaluation [28]. A recent clinical trial conducted in Hong Kong found that one-off three applications of SDF solution at weekly interval at baseline were as effective as annual applications of SDF in arresting cavitated caries lesions in primary teeth after 18 months [13]. The effects of different concentrations of SDF solution and different periodicity of application have also been investigated. The 30-month results of a randomized clinical trial show that 38% SDF is more effective than 12% SDF and that applying twice a year is more effective than once a year in arresting dentin caries in primary teeth of preschool children [17].

In Brazil, a study conducted in preschool children concluded that the use of SDF was more effective than the interim GI restorations (caries arrest rate 67% vs 39%) in arresting dentin carious lesions in primary teeth [29]. Another form of silver fluoride agent, nano-silver fluoride (NSF), was developed and investigated in a clinical trial [30]. It was reported that NSF could arrest dentin caries and did not stain the lesions after application. However, further studies are required to confirm if NSF will not cause staining on the arrested lesion in the long term.

There are other two published clinical trials on the use of SDF in children: one investigated the efficacy of SDF on caries prevention [31] and one on caries arrest [16]. Their results were positive and supported the use of SDF in preventing and inhibiting initial carious lesions in young children. In a study conducted in Nepal, a one-off application of 38% SDF solution was found to be able to arrest dentin carious lesions in primary teeth of children aged 3–9 years, but the treatment effectiveness diminished over time [27].

In the USA in 2014, SDF was cleared by the US Food and Drug Administration as a “medical device” for reducing tooth sensitivity [32]. Currently, the use of SDF for caries arrest or caries prevention is off-label which is similar to the use of fluoride varnish for these purposes. In a cohort study conducted in the USA among 32 children aged 2–5 years attending a dental clinic, SDF treatment was well accepted by parents of the children who would otherwise receive restorative dental treatments under general anaesthesia [33]. In that study, SDF was applied directly onto the lesion with a microbrush and allowed to be absorbed for 30 s to 2 min (depending on the child’s behaviour). Almost all (98%) of the active carious lesions became arrested after a single application of 38% SDF solution.

A summary of systematic reviews on the effectiveness of SDF in treating dental caries in children is shown in Table 10.2. In a recent systematic review and meta-analysis carried out by Gao et al., a high caries-arrest rate of 81% (95% CI, 68–89%) in primary teeth after 38% SDF application was reported [36]. Another recent systematic review conducted by Chibinski et al. found that the 12-month caries-arrest rate of using SDF in children was 89% higher (95% CI, 49–138%) than those of using placebo or other agents [38]. Active dentin carious lesions in primary teeth can become arrested after repeated applications of SDF, and the arrested carious lesions usually have a dark, shiny and smooth surface (Fig. 10.2). The concept of caries-arrest treatment using SDF is in line with the clinical recommendations of the International Caries Consensus Collaboration meeting [39] which state that for children with cavitated carious lesions, plaque control should be reinforced and dental practitioners should preserve tooth structure and retain the natural teeth by delaying the cycle of dental restoration as far as possible. The American Academy of Pediatric Dentistry has recently accepted SDF for caries management and published guidelines aiming to inform clinicians regarding the use of SDF to enhance caries management in children including those with

**Table 10.2** Summary of systematic reviews on the effectiveness of silver diammine fluoride in treating dental caries in children (adapted from Duangthip et al. 2017 [26])

| Authors, year [Reference] | No. of papers (patients) included | Meta-analysis | Summary findings |
|---|---|---|---|
| Rosenblatt et al., 2009 [34] | 2 (827) | No | SDF's lowest prevented fractions for caries arrest and caries prevention were 96% and 70%, respectively. Sodium fluoride varnish's highest prevented fractions for caries arrest and caries prevention were 21% and 56%, respectively |
| Peng et al., 2012 [18] | 15 (NA) | No | Silver compounds are viable agents for preventing and arresting caries |
| Duangthip et al., 2015 [35] | 4 (967) | No | SDF applications or daily toothbrushing with fluoride toothpaste is effective in arresting caries in primary teeth |
| Gao et al., 2016 [9] | 17 (NA) | Yes | 5% sodium fluoride varnish can remineralize early enamel caries, and 38% SDF can arrest dentin caries. The overall proportion of arrested dentin caries by 38% SDF was 66% (95% CI: 41–91%) |
| Gao et al., 2016 [36] | 19 (NA) | Yes | The overall percentage of caries arrest of 38% SDF in primary teeth was 81% (95% CI, 68–89%) |
| Contreras et al., 2017 [37] | 7 (3073) | No | 30% or 38% SDF shows potential as an alternative treatment for caries arrest in primary teeth |

*NA* number of included patients not available, *CI* confidence interval


**Fig. 10.2** (**a**) Severe early childhood caries in a child aged 3 years old. (**b**) After 2 years, the SDF-treated caries lesions became arrested without causing pain or infection

**Table 10.3** Summary of various SDF products, manufacturers, country of origin, concentration and major ingredients (adapted from Mei et al. 2016 [41])

| Product name | % SDF | Manufacturer | Country | Main ingredient | Package |
|---|---|---|---|---|---|
| Advantage arrest | 38% | Elevate oral care | USA | Silver diammine fluoride | 8-ml dropper bottle |
| Bioride | 38% | Dentsply Industria e Comercio Ltda | Brazil | Silver diammine fluoride | 5-ml dropper bottle |
| Cariostatic | 10% | Inodon Laboratorio | Brazil | Silver diammine fluoride | 5-ml dropper bottle |
| Cariestop | 12%, 38% | Biodinamica Quimica e Farmaceutica Ltda | Brazil | Fluoridic acid, silver nitrate, ammonia | 5-ml or 10-ml dropper bottle |
| Fagamin | 38% | Tedequim SRL | Argentina | Silver diammine fluoride | 5-ml dropper bottle |
| Fluoroplat | 38% | NAF Laboratorios | Argentina | Silver diammine fluoride | 5-ml dropper bottle |
| Saforide | 38% | Toyo Seiyaku Kasei Co. Ltd. | Japan | Silver diammine fluoride | 5-ml dropper bottle |
| Riva star | 30–35% | SDI Dental Limited | Australia | Unit 1: silver fluoride, ammonia | Unit 1: 0.05 ml |
| | | | | Unit 2: potassium iodine, methacrylates | Unit 2: 0.10 ml |

special needs [40]. In general, the benefits of providing SDF treatment in targeted populations outweigh its potential undesirable effects when considering the low cost of the treatment and the burden of dental caries in children [26]. Products containing different concentration (12%, 30% and 38%) of SDF solution are available in the market [41]. A summary of various SDF products, manufacturers, country of origin, concentration and major ingredients is presented in Table 10.3.

## 10.4 Mechanism of Actions of SDF

Although the mechanism of actions of SDF is not fully understood, several in vitro studies proposed possible mechanisms including inhibition of demineralization and preserving dental collagen from degradation [42], antibacterial effect on plaque biofilm [43] as well as increasing microhardness of the treated carious lesions [44]. Recently, it was found that SDF can react with calcium and phosphate ions to produce fluorohydroxyapatite which has a lower solubility than hydroxyapatite [45]. This precipitation of fluorohydroxyapatite may be one of the main mechanisms of caries arrest in lesions treated with SDF. A systematic review on mechanism of SDF concluded that SDF is a bactericidal agent and can hinder the growth of cariogenic bacteria [46]. It can slow down the demineralization and promote the remineralization of both the enamel and dentin as well as reduce the degradation of collagen in the dentin.

## 10.5 Biocompatibility and Adverse Effects of SDF

In clinical studies that had included recording adverse effects of SDF in a longitudinal manner, no major adverse effects of topical SDF application were found, except dark staining on SDF-treated carious lesions [12, 13, 17]. It should be noted that SDF only stains carious dentin but not the enamel or sound dentin. In a survey of directors of paediatric training programmes in the USA, it was found that black staining on the arrested carious lesion was the most-cited barrier preventing adoption of SDF treatment [47]. In view of this unwanted aesthetic side effect, it is important that the patient and parents are informed and a proper discussion is carried out before application of SDF. Parental acceptability and preference should be acknowledged in order to plan adequately when using SDF to manage dental caries in young children. Information on the benefits, side effects and other factors to be considered should be provided, and parental consent should be obtained. It is suggested that application of potassium iodide (KI) following the application of SDF would decrease staining [48]. However, a recent randomized clinical trial reported no significant difference in the colour/staining between the arrested root caries lesions treated by applying SDF alone and those treated by applying SDF and KI [49].

SDF is found to be biocompatible to the dental pulp. After applying a 38% SDF solution on cavitated carious lesions in molars of rats, minimal adverse effects were observed [50]. Similarly, there are no observed inflammatory changes after the use of SDF as indirect pulp treatment [51]. No pulpal damages attributable to the application of SDF onto deep carious lesions in primary teeth of preschool children were found in a clinical trial [12]. Pulpal and gingival irritations were hypothesized as adverse effects after SDF application. Based on the observations of thousands of children in several clinical trials, only a few children in a study reported having mild painful white lesion on their mucosa which disappeared after 2 days without any treatment [31]. To prevent tissue irritation, applying Vaseline at the adjacent gingiva was suggested [29].

## 10.6 Safety of SDF

SDF has been used in Japan and Australia for several decades. The expected concentrations of fluoride ions and silver ions in a 38% SDF solution are 44,800 ppm and 255,000 ppm, respectively. Although SDF consists of a high concentration of fluoride and silver, no major adverse effects have been reported in the literature, probably because the amount of SDF applied is very small and is well below the known toxicity of silver and fluoride. In general, health risks associated with absorption of silver ions are low. For the safety of exposure to silver, the average median lethal dose ($LD_{50}$) of silver observed in rat studies was approximately 520 mg/kg by oral administration and 380 mg/kg by subcutaneous administration, respectively [32].

In a clinical study, the mean amount of 38% SDF solution applied onto three teeth of an adult was reported to be 7.6 mg, and thus the amount of silver applied was approximately 1.50 mg [52]. In other words, the amount of silver applied on each tooth would be 0.5 mg. Deducing from this finding, the maximum amount of silver applied on 20 decayed primary teeth would be <10 mg (0.5 mg Ag × 20 teeth). If all the primary teeth of a small preschool child weighting 10 kg is treated with a 38% SDF solution, the highest dose of silver will not be >10 mg/10 kg or 1 mg/kg. Using the $LD_{50}$ by subcutaneous route (380 mg/kg) as reference, the relative safety margin of applying SDF on all decayed primary teeth of a small child would be at least 380-fold. When considering the periodicity of application (once or twice a year), the risk of cumulative silver exposure is also minimal. For long-term adverse effect of the topical use of SDF, there is no scientific evidence that professionally applied SDF causes dental fluorosis.

Regarding the toxicity of fluoride, the mean amount of fluoride from application of a 38% SDF solution onto three teeth of adult volunteers in a clinical study was 0.33 mg, and thus the amount of fluoride applied on each tooth would be approximately 0.11 mg [52]. The "probably toxic dose" (PTD) of fluoride is suggested at 5 mg fluoride per kg body weight [53]. If a small child weighting 10 kg receives topical application of a 38% SDF solution on 20 primary teeth, this child will receive a maximum dose of 2.2 mg fluoride (0.11 mg F × 20 teeth) or 0.22 mg/kg. Even in this scenario, the safety margin of fluoride would be at least 23-fold.

## 10.7 Factors Related to the Success of Caries-Arrest Treatment by SDF

Effects of a number of factors on the effectiveness of SDF in arresting active dentin carious lesions in primary teeth have been investigated in clinical studies. These are discussed below:

1. Concentration: As can be expected, the concentration of fluoride can influence the effects of a fluoride agent on dental caries. In a randomized clinical trial which compared the effectiveness of two SDF solutions at different concentrations in arresting active dentin carious lesions in primary teeth of preschool children, it was found that a significantly higher proportion of the lesions treated with 38% SDF than those treated with 12% SDF became arrested after 30 months, 66.9% vs 55.2% for annual applications of SDF [17]. In another clinical trial, a significantly higher proportion of active dentin carious lesions in primary teeth were found to have become arrested 24 months after a one-off application of 38% SDF solution than the lesion that had received a one-off application of 12% SDF solution, 31% vs 22% [27].
2. Frequency of application: Different protocols regarding the frequency of SDF applications have been used in different clinical trials. The most commonly adopted protocols are reapplication every 12 months (annual application) and reapplication every 6 months (semi-annual application) [36]. In clinical trials which involved the use of two SDF application frequency protocols, the caries-arrest effectiveness of semi-annual application was found to be higher than that of the annual application [17, 28]. Annual applications of SDF on carious lesions extending into dentin of primary teeth, even without excavation of the carious tissues, can result in a high caries-arrest rate [12], while a single application

seems insufficient for a sustained caries-arrest effect [27]. It is recommended that for young children with poor oral hygiene or high caries risk, semi-annual application of SDF solution is required to increase the caries-arresting effect [17]. For mobile populations or in mobile dental service in which reapplication of SDF at semi-annual or annual interval is difficult to implement, a one-off repeated application of SDF solution at weekly intervals may be used to arrest the active dentin carious lesions in primary teeth [13]. It should be noted that regular monitoring of the SDF-treated carious lesions and reapplication of SDF is required to achieve high success of caries-arrest treatment. In addition, if situation allows, follow-up and re-counselling based on patients' caries risk assessment should be complemented as a part of a caries management programme, aiming not only to slow down the progression of existing carious lesions but also to prevent new caries development.

3. Application time: There is not much information about the application time of SDF solution (time during which the solution is held in contact with the carious lesion) and its effectiveness in arresting active carious lesions. A clinical study on the effectiveness of SDF solution in arresting dentin carious lesions in primary teeth reported that there was no significant difference between application times of 30 s and 2 min [33].
4. Oral hygiene: Maintaining good oral hygiene and keeping the carious lesion plaque free are very important for the success of caries-arrest treatment. Randomized clinical trials on primary teeth of preschool children found that active dentin carious lesion that had no plaque on its surface was more likely to become arrested, regardless of the SDF application protocol [13, 17]. To enhance the efficacy of SDF treatment in managing ECC, training on effective plaque control should be included in the oral health programme for preschool children. It is necessary to empower stakeholders, such as the children's parents and teachers, to improve children's oral hygiene through encouraging parents to supervise and assist their child in daily toothbrushing. Teachers should also reinforce oral hygiene practice in kindergarten and school.
5. Tooth type and tooth surface type: Clinical studies found that the cavitated carious lesions in anterior primary teeth were more likely to become arrested after application of SDF solution than those in posterior primary teeth [13, 28]. Besides, active carious lesions on the buccal and lingual surfaces of primary teeth have higher chance to be arrested by SDF treatment, compared to those on occlusal and proximal surfaces [13, 17]. This is probably because the smooth buccal and lingual tooth surfaces are easier to clean.
6. Background of children: Many child background and socioeconomic factors have been found to be related with ECC [54]. Despite this, randomized clinical trials on preschool children found that the children's background factors such as socioeconomic status did not have a significant effect on the outcomes when SDF was used to arrest cavitated carious lesions in primary teeth [13, 17]. Thus, it can be expected that in different populations, including the disadvantaged communities where untreated ECC is usually prevalent, SDF treatment will be effective in arresting active dentin carious lesions in primary teeth.

## 10.8 Practical Guides for Using SDF in Caries-Arrest Treatment

### 10.8.1 Preparation of Dental Practitioners and Patients

Although SDF is not toxic and does not cause irritation, health-care practitioners who use SDF should be aware that accidental contact with SDF on the skin, if not completely removed immediately, can cause a brown stain that is difficult to remove (Fig. 10.3a). Other than the surface staining, this will not cause any harm to the body, and the stain will completely disappear within a week due to the natural exfoliation of the dead outer skin tissues (Fig. 10.3b). Thus, it is advised that the practitioner should wear rubber gloves when handling SDF solution and take special care to avoid accidental contact of the SDF solution with the skin of the practitioner or the patient. SDF can also cause stains on clothes and work surfaces which are very hard to remove. Extra care needs to be paid to avoid accidental dropping of the SDF solution on clothes and fabrics. The work surface should be covered by water-proof barrier, and disposable paper towel or gauze should be used to remove spilled SDF solution. Prior to SDF application, the materials to be used, such as plastic dappen dish, micro-applicators, cotton rolls, gauze, dental mirror and the bottle of SDF solution, should be set out nicely to facilitate smooth operation (Fig. 10.4).

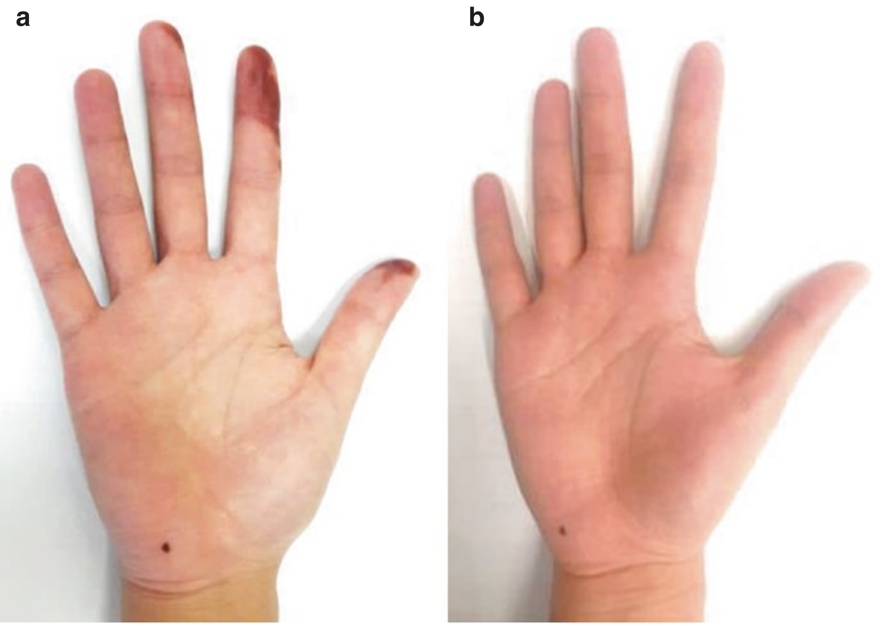

**Fig. 10.3** (**a**) The skin on fingers stained after inadvertent contact with SDF. (**b**) The stain disappeared after 7 days without treatment

**Fig. 10.4** Materials used for SDF treatment in a community setting

Since dark stain on the surface of the arrested dentin carious lesion is an expected outcome after application of SDF, obtaining informed consent from the patient or the child's parent/guardian is essential before the use of SDF. Information on the expected staining of treated lesions and the possible need for regular reapplication of SDF to maintain high treatment success rate should be provided to the people involved. The dark stain on the surface of the SDF-treated lesion will not fade away over time but can be removed by dental instruments or burs. It can also be masked by placing a dental restoration with an opaque material.

Studies on parental acceptance of SDF treatment on their children have been conducted. In a clinical trial conducted among 888 kindergarten children in Hong Kong, China, it was found that at the 30-month follow-up, most of the parents were satisfied with the appearance of their child's teeth irrespective of the SDF application protocol used [55]. Another study conducted in New York, USA, found that black stains on posterior primary teeth were more acceptable than those on anterior teeth [56]. Furthermore, in that study, even though the stain on anterior teeth was perceived as unwanted, majority of the parent respondents preferred SDF treatment rather than the use of general anaesthesia to deliver conventional restorative care to their child. For parents with high concern for aesthetics, a thorough parental informed consent, preferably with photographs showing typical tooth staining, is suggested [57]. To improve dental aesthetics, the arrested cavitated caries lesions can be restored when the child patient is cooperative and circumstances allow [40]. To reduce unnecessary worry, patients should be informed that SDF does not stain sound teeth. In addition, SDF can be specifically applied to carious lesions in nonaesthetic zone only such as those in primary molars, and this will not cause staining in other lesions which are not directly in contact with SDF.

### 10.8.2 Indications and Contraindications for SDF Application

As a non-invasive treatment that is effective in arresting cavitated carious lesions in primary teeth, SDF can be applied in many situations. Indications for the use of SDF include:

- Children with severe ECC or children who are at high caries risk
- Children who are not able to cooperate during dental restorative treatment due to their medical or behavioural problems
- Children who have multiple carious lesions and require more than one dental visit for treatment, such that active dentin carious lesions needs to be managed and remain asymptomatic during the waiting time for completion of treatment
- Children who have limited access to conventional dental restorative care
- Children who have carious lesions which are difficult to treat such as those in partially erupted teeth which pose a challenge to access and isolation as well as ability to clean after the restorative treatment

Since SDF is very safe when used appropriately in dental treatments, its contradictions are few. The major ones include:

- Children and whose parents have high aesthetic concerns regarding dark stains on tooth surfaces
- Children who are allergy to fluoride or silver

### 10.8.3 Clinical Procedures for Applying SDF on Carious Lesions

The following clinical procedures are recommended for enhancing safety, efficiency and effectiveness of using SDF to arrest active dentin carious lesions in primary teeth of young children (Fig. 10.5):

- Remove the retained food debris and plaque from the carious cavity to allow good contact between the SDF solution and the carious dental tissues.
- Check that the carious lesion does not extend into the pulp and the affected tooth remains vital.
- Operative intervention such as removal of carious tissues is not required to achieve caries arrest, but removal of the soft carious dentin can shorten the time for achieving caries arrest [58].
- Isolate the decayed tooth with cotton roll or gauze.
- Use a plastic dappen dish to contain a small drop of SDF solution.
- Slightly bend a micro-applicator; dip it in the SDF solution.
- Remove excessive SDF solution after taking the micro-applicator out from the SDF solution.
- Apply the SDF solution with the micro-applicator directly onto the affected tooth surface only.
- Gently rub the lesion surfaces with the micro-applicator while continuing to isolate the decayed tooth for around 1 min when possible, and ensure that the entire carious lesion is wetted by the SDF solution.
- If necessary, remove the excess SDF solution with a gauze or cotton roll.
- Minimize the contact of SDF solution with gingiva or mucosa adjacent to the carious lesion to avoid potential soft-tissue irritation.

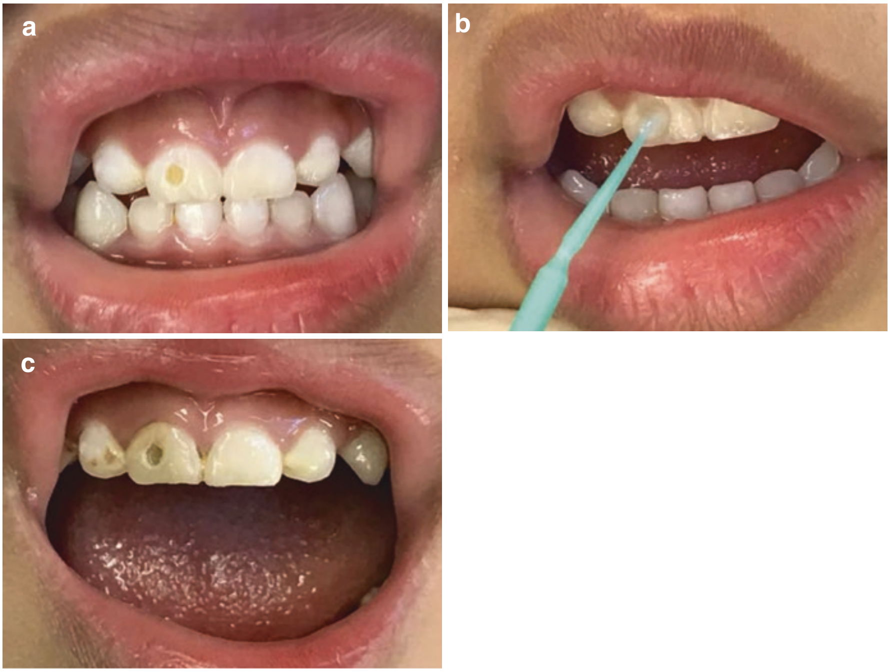


**Fig. 10.5** (**a**) Active carious lesions on labial surfaces of primary right incisors. (**b**) SDF applied with a micro-applicator onto the carious lesions. (**c**) After 30 min, the treated lesions became darker in colour

- Carefully dispose of used gloves, micro-applicator and materials contaminated with SDF into a plastic waste bag.
- Inform the parent/guardians that the treated child should avoid eating, drinking or rinsing the mouth within 30 min after treatment so as not to remove or dilute the SDF solution on the carious lesion.

When making decision on the adoption of SDF treatment in a clinical setting or in a community-based programme, the dental health professionals should have a good understanding of the evidence-based information regarding the safety and effectiveness of SDF in the management of dental caries. Usually the benefits of SDF treatment far outweigh the possible undesirable or adverse effects. The use of SDF treatment should be based on patient's caries risk, preferences of the patient and parents and practicality of implementation. Whether the carious lesions are in the aesthetic zone of the mouth and the parents' concern for aesthetics are also factors that need to be taken into consideration in the management of ECC with SDF treatment. If SDF is widely adopted by dental health professionals and allied health-care workers for caries management, the heavy burden of untreated tooth decay will be significantly reduced. Since the procedures for SDF application and

**Fig. 10.6** SDF treatment used for caries management in a kindergarten

the instruments required are simple, it can be easily carried out in a community setting in outreach dental services (Fig. 10.6). Consequently, this will reduce the negative impact of untreated decayed teeth in children, especially those who usually have limited access to conventional dental care. To conclude, SDF is a very valuable agent for caries management in children due to its safety, high efficacy, low cost and ease of application.

## 10.9 Silver Nitrate

The history of using silver nitrate ($AgNO_3$) for caries-arrest treatment can be traced back to more than a century ago [59]. In the 1910s, Howe added ammonia to silver nitrate to make it more effective and stable as an antimicrobial agent for treating dentin carious lesions and infected root canals [60]. After the introduction of fluoride use and the development of local anaesthesia to reduce the pain during dental restorative treatment, the use of silver nitrate had stopped since the 1950s. Recently, the use of silver nitrate was reintroduced in the USA. Application of 25% silver nitrate solution followed by a 5% NaF varnish was proposed and used as a non-restorative approach for caries management in children. In a clinical study, the cavitated carious lesions in the primary teeth of over 5000 children were treated with this protocol at baseline, 2 weeks, 1 month, 2 months and 3 months [61]. In that study, almost all of the treated active carious lesions were arrested, and it was reported that the treatment was well-accepted by children and parents, as well as reduced children's anxiety related to dental visit. In a randomized clinical trial, it was found that at the 12-month follow-up, the caries-arrest effectiveness of an adjunctive application of 25% silver nitrate solution followed by 5% sodium fluoride varnish was comparable to that of applying 38% SDF solution on cavitated carious lesions in primary teeth of preschool children [62]. Since SDF is not yet available or approved in many countries, the combined use of 25% silver nitrate and 5% NaF varnish may be an alternative option for controlling ECC in these places.

## 10.10 Xylitol

Although xylitol has a suppressive effect on mutans streptococci, the therapeutic effect of xylitol on caries arrest in children has seldom been reported in the literature [63]. In a clinical study conducted on primary teeth of children aged 6 years, different types of polyol chewing gums were chewed for 5 min with episodes three to five times daily [64]. In that study, it was found that chewing xylitol gum was associated with caries arrest in primary teeth without other dental treatments. Notwithstanding this, the possible adverse effect of xylitol in young children is a concern. In another clinical trial, approximately 10% of the preschool children experienced diarrhoea after chewing xylitol gum [65]. Moreover, choking hazard is a major concern when recommending chewing gum for preschool children. There is limited evidence to support the use of xylitol chewing gum or lozenge by preschool children to arrest dentin carious lesions [66].

## 10.11 Chlorhexidine

Chlorhexidine has been investigated for its potential in preventing and arresting dental caries. Different formulae and concentration (varnish, gel, toothpaste and mouthrinse) are available. Based on eight included clinical studies on chlorhexidine gel and varnish, a recent Cochrane review concluded that there was limited evidence to support or refute the effectiveness of chlorhexidine in decreasing the level of mutans streptococci or preventing dental caries in adolescents and children [67]. A clinical study in children found the combined use of chlorhexidine varnish and fluoride varnish more effective in enhancing the remineralization of white spot carious lesions after 3 months than the separate applications of the same agents [68]. So far, there is no published study on using chlorhexidine in arresting dentin carious lesions in primary teeth of young children.

## 10.12 Calcium Phosphate-Based Remineralization System

Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) provides calcium and phosphate ions as a reservoir to buffer plaque pH and maintains a state of supersaturation of the ions with respect to tooth enamel, eventually enhancing the remineralization process [69]. CPP-ACP can be incorporated into different products such as chewing gums or mouthwashes. In a clinical study, the sugar-free gum containing CPP-ACP produced greater remineralization than the other sugar-free chewing gums without CPP-ACP [70]. In a 2-year clinical trial on school children, it was found that chewing sugar-free gum with CPP-ACP three times daily halted the progression of proximal carious lesions and enhanced the regression of proximal lesions, compared to chewing the control gum [71]. In contrast, a clinical study on 296 preschool children did not find daily application of CPP-APC paste on school days had any significant on dental caries prevention [72]. A recent systematic review concluded that CPP-ACP has a remineralizing effect on early enamel lesions but seems not significantly different compared to that of fluorides [73]. There is no clinical study using CPP-ACP to arrest cavitated dentin carious lesions in children.

## 10.13 Final Considerations

Prevalence and severity of ECC in children remain high in many countries and disadvantaged communities. Untreated tooth decay in primary teeth is a heavy burden for the health-care services. It is not practical to use the conventional restorative approach alone to manage this global dental health problem in children due to the insufficient resources, especially in underprivileged communities. Promoting oral self-care through toothbrushing with fluoridated toothpaste can have favourable results. However, this alone would not be sufficient in managing ECC in all children. Evidence exists that the use of fluoride varnish is safe and effective for preventing new dental caries and slowing down the progression of incipient caries in children. For treating established dentin carious lesions, SDF is a useful agent for controlling dental caries and arresting active carious lesions in the primary teeth of young children. SDF may revolutionize paediatric and community dentistry and may be a breakthrough dental agent in this century due to its safety, feasibility, efficiency and effectiveness in preventing and arresting dentin carious lesions. Although staining of the arrested carious lesions is a common side effect of SDF treatment, the health benefits of having no dental pain and infection far outweigh this drawback, particularly in places where access to restorative dental care is limited. Regardless of the use of various non-restorative approaches, good plaque control remains important for the success of caries management in children.

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# Restorative Materials in Pediatric Dentistry

# 11

Jonas A. Rodrigues, Luciano Casagrande, Fernando B. Araújo, Tathiane L. Lenzi, and Adriela A. S. Mariath

## 11.1 Introduction

The occurrence of cavitated carious lesions is still a current oral health problem, and, according to the World Health Organization, the prevalence of caries in the primary dentition varies between 60% and 90% worldwide [1]. Untreated carious lesions in primary teeth are estimated to be present in 621 million children, which makes it the tenth most prevalent disease on global population [2]. Primary teeth in young children are vital to their development, and every effort should be made to retain these teeth functionally for as long as it is possible. If left untreated, dental caries will progress leading to pain and infection, consequences that cause unnecessary suffering and lost days at school [3]. There is evidence of a linear relationship between higher levels of untreated caries and anthropometric outcomes (height, weight, and body mass index) [4].

Also, it has been mightily evidenced that untreated caries negatively impacts on the oral health-related quality of life of children and their families [5, 6]. In this sense, dental fillings have been used to restore the tooth structure integrity, reducing provoked pain in deep dentin lesions and helping in controlling the caries disease process. Thus, oral health professionals need to make wise decisions about the type of restorative material they choose to best manage their patients with childhood caries. This is not an easy decision, since over the past 10 years, notable advances in dental restorative materials have widened the market.

J. A. Rodrigues (✉) · L. Casagrande · F. B. Araújo · T. L. Lenzi · A. A. S. Mariath
Department of Surgery and Orthopedics, Faculty of Dentistry, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
e-mail: jorodrigues@ufrgs.br


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## 11.2 Restorative Dental Materials for Primary Teeth

The conventional restorative materials available for restoring primary teeth are amalgam (AMG), conventional glass-ionomer cement (GIC), resin-modified glass-ionomer cement (RMGIC), high-viscous glass-ionomer cement (HVGIC), compomer (CP), and resin composite (RC) [7]. Although amalgam has been considered the gold standard in restorative dentistry [8], its use has decreased mainly because of the potential toxicity of mercury and higher health tissue removal during cavity preparation [9]. Therefore, restorative materials with adhesive properties have been widely used since fit with concept of minimally invasive dentistry, providing good handling and functional performance besides meeting patients' demands regarding aesthetics [7].

Although the placement of restorations is a frequent treatment approach in clinical practice, it has pointed out that there is no sufficient scientific evidence about which is the best filling material for treating caries in the primary dentition [10]. Only three trials comparing four different types of materials (crown restoration, aesthetic and stainless steel crowns, RMGIC, AMG, and CP) were included in the systematic review. Another recent systematic review and network meta-analysis [11] was carried out to evaluate the clinical performance of different conventional restorative materials placed in posterior primary teeth. Conventional GIC had more risk to failure of restorations placed in primary molars than other restorative materials. Conventional GIC presents disadvantages such as low wear resistance and inferior flexural strength. In view of the brittle nature of this cement, modifications on its original composition were developed aiming to improve the physical properties, becoming available the RMGIC or HVGIC [12].

There was no evidence of superiority among restorative treatments using CP, RMGIC, AMG, and RC [11]. Thus, in clinical decision-making, choosing one of these materials will depend on the professional ability, the individuality, and the patient's wish. Factors such as aesthetic requirement, friendly technique, caries activity, type of substrate, and cavity to be restored also should be considered for selecting the restorative material [13].

Worldwide, RC associated to adhesive system is, in approximately 25% of cases, the material of choice for restoring primary teeth [14, 15]. This material shows satisfactory efficacy when used under local anesthesia and rubber dam, regardless of the brand of RC [16], presenting a success rate around 90% on occlusal and occlusoproximal surfaces of primary teeth [16, 17].

In order to reduce the clinical time of the conventional restorative procedure, a new concept in RC is emerging [18]. The "bulk-fill" composite, which intended to reduce the polymerization shrinkage stress (main drawback of RC), has been gaining strength in the dental market. "Bulk-fill" composites were developed to be inserted in a single increment (up to 4 mm) for restoring posterior teeth, optimizing clinical time, and minimizing operative errors, being especially attractive for use in the pediatric dentistry clinic. Nonetheless, no clinical trial assessed the performance of bulk-fill composites in the primary dentition until the present date.

When it is considered the adhesive system, a systematic review suggests superior performance of etch-and-rinse adhesives in primary teeth in comparison with self-etch systems [19]. It is important to highlight that this review only considered in vitro studies and these results should be interpreted with caution.

Manufacturers' instructions for using adhesive systems on the primary dentition are not yet firmly established, and the same protocols have been indicated for permanent and primary teeth. Nevertheless, primary tooth dentin presents chemical and micromorphological differences [20, 21] in comparison with permanent ones that may jeopardize the adhesion in this substrate [22]. Greater density and larger diameter of the tubules [21] result in a reduced area of intertubular dentin available for bonding. Chemically, the lower mineral content [20] reduces the buffering capacity and increases the reactivity of primary tooth dentin to acidic solutions. Consequently, a thicker hybrid layer [23] and lower bond strength values [22] are produced in primary dentin compared with permanent teeth when the same adhesive protocol is used.

One of the proposals to improve the bond stability of restorations placed in primary teeth is shortening the etching time in dentin for etch-and-rinse adhesive systems. This protocol is based on good results of in vitro studies [24, 25]. It has been suggested the dentin etching of 35–37% acid phosphoric for 7 s before the adhesive system application [24, 25]. Etching enamel remains in 15 s.

A novel category of one-bottle adhesives, so-called universal or multimode, has recently been proposed to give dentists the opportunity to decide which of the two adhesive strategies to use, depending on each clinical situation: etch-and-rinse or self-etch [26]. A recent randomized clinical trial [27] evaluated the 18-month clinical performance of a universal adhesive, applied under different adhesion strategies, after selective carious tissue removal in primary molars. Self-etch and etch-and-rinse strategies did not influence the clinical behavior of universal adhesive used in primary molars, although there was a tendency for better outcome of the self-etch strategy [27]. Based on the current trends toward ease of use and fewer clinical application steps, the use of universal adhesive in the self-etch approach is an interesting option in pediatric dentistry, since it reduces technique sensitivity and clinical chair time relative to the etch-and-rinse mode.

One important point to be pondered is that the main failure reason of RC restorations is caries around restorations [28]. Due to that, other options of restorative materials may be considered. It has been evidenced the effect of the RMGIC restoration in prevention of secondary caries when compared to RC [29], probably due to fluoride release and uptake of the GICs. However, this material contains resin monomers in its composition and may increase susceptibility to the presence of humidity compared to other GICs. This characteristic associated to the need of a light source to polymerization of the material can be pointed as disadvantages of using RMGIC.

Similar trend regarding the protection of the margin of restorations can be observed with atraumatic restorative treatment (ART), since this approach has HVGIC as the material of choice [30]. A systematic review showed that ART restorations performed with HVGIC present similar survival/success rates to conventional approach using RC or AMG for occlusoproximal restorations in primary teeth [31]. Other properties of GIC may also contribute to this choice, i.e., ability to chemically bond to enamel and dentin with insignificant heat formation or shrinkage, biocompatibility with the pulp and periodontal tissues, and a similar coefficient of thermal expansion to tooth structure [32].

Recently, a practice-based study showed that the progression rate of carious lesion on tooth surfaces adjacent to AMG restorations was 30%, while to GIC restorations was only 16% [33]. This positive aspect associated with the rare need of local anesthesia and no need of rubber dam application has contributed for indicating HVGIC restoration associated to partial carious tissue removal as a good option to treat cavitated lesions in primary molars.

Encapsulated GICs are also available in the market. Although the cost of these materials is slightly higher, there is a greater ease and speed for handling and insertion in the cavity, besides eliminating operative errors of dosage and manipulation.

CP was developed during the 1990s, aiming to overcome problems with handling and mechanical properties of conventional GIC while maintaining the ability to release fluoride. Different from GIC, the CP does not contain water in its composition. This material is a polyacid-modified RC with some GIC components. Considering the aesthetic value and simple handling properties of CP, it can be useful in pediatric dentistry [7]. However, this material is unavailable in many countries, such as Brazil. Furthermore, restorative treatment of primary teeth using CP is not more effective than treatment with AMG in preventing new tooth decay in children [34].

## 11.3 Crowns for Decayed Primary Teeth

Crowns for primary molars are preformed and come in a variety of sizes and materials to be placed over decayed or developmentally defective teeth. They can be made completely of stainless steel (known as “preformed metal crowns” or PMCs) or, to give better aesthetics, may be made of stainless steel with a white veneer cover or made wholly of a white ceramic material. In most cases, teeth are trimmed for the crowns to be fitted conventionally using a local anesthetic.

Crowns are recommended for restoring primary molar teeth that have had a pulp treatment, are very decayed, or are badly broken down. However, few dental practitioners use them in clinical practice [35].

In case of indication of the Hall Technique (HT), PMCs are cemented, using GIC, over the carious tooth, without local anesthetic, carious tissue removal or tooth preparation. This seals the cariogenic biofilm under the crown [36], arresting the carious process. Studies have reported high survival rates of HT, with results of 98% and 95% success rate after 1 year [37] and 48 months [38] of evaluation, respectively (see more in Chapter 13).

A retrospective study [39] showed that stainless steel crowns placed under general anesthesia for early childhood caries had better survival than RC restorations over 3-year follow-up. Furthermore, zirconia crowns have been shown clinically satisfactory and very acceptable by parents [40]. A recent systematic review [35] investigated the clinical effectiveness and safety of all types of preformed crowns for restoring primary teeth compared with conventional filling materials, other types of crowns or methods of crown placement, and non-restorative caries treatment or no treatment. Despite the high risk of bias of the included studies, the data has shown that teeth restored with preformed crowns are less likely to develop endodontic outcomes (pain and abscess) in the long term compared to dental fillings. Moreover, crowns fitted using HT may reduce discomfort at the time of treatment compared to fillings. There were insufficient data regarding comparison of non-restorative caries treatment with crowns, and for metal compared with aesthetic crowns. Further studies assessing relevant outcomes such as time to restoration failure or retreatment, patient satisfaction, and costs are required.

## 11.4 Final Considerations

Restorative dentistry undoubtedly plays a role in recovering function and aesthetics and allowing biofilm control by the patient/family, but healing the disease cannot be credited solely to the restoration, as it is associated with the control of etiological factors. Furthermore, restorations in the oral environment are exposed to stresses of different origins that limit their longevity by interfacial degradation. Restoration failures lead to replacement that implies further removal of dental structure, causing repetition of the restorative cycle.

Factors related to the patients such as caries risk and socioeconomic factors may affect the survival of restorations [41]. Cavity features such as the number of restored surfaces, presence of endodontic treatment, and standard fluoride toothpaste use are of major importance and may dictate the service time of the restorative treatment [41–43]. Thus, the decision to restore and the choice of the material involve determining the patient's caries activity, the immediate requirements, and the notion of what the patient is able to receive in terms of dental procedures.

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# The Atraumatic Restorative Treatment

# 12

Daniela P. Raggio, Isabel C. Olegário, Tamara K. Tedesco, Ana L. Pássaro, Mariana P. Araujo, and Nathália de M. Ladewig

## 12.1 Introduction

The atraumatic restorative treatment (ART) was launched in the mid-1980s in Tanzania to overcome the lack of treatment that would enable the preservation of decayed teeth in communities where technologies such as electricity, piped water, and conventional dental equipment were not available [1]. Prior to ART, carious lesions in populations living in underprivileged areas tended to progress until the only remaining option was the tooth extraction [2].

The ART approach consists in sealing pit and fissures that are prone to develop carious lesions or those which already presents non-cavitated carious lesions (ART sealants) or removing demineralized carious dentin using only hand instruments and restoring the cavity with an adhesive material, currently the high-viscosity glass ionomer (ART restoration) [3–5]. Among the advantages of the ART are the low cost when compared to traditional restorative approaches and easiness of execution [6, 7]. In addition, the use of local anesthesia is rarely required making the technique less painful and more comfortable for the patient [7–9].

Although ART was firstly implemented to treat carious lesions in low- and middle-income countries, its application has spread to many places in the world [10],

D. P. Raggio (✉) · I. C. Olegário · A. L. Pássaro · M. P. Araujo · N. d. M. Ladewig
Orthodontics and Pediatric Dentistry Department, Dental School, University of São Paulo, São Paulo, Brazil
e-mail: danielar@usp.br

T. K. Tedesco
Orthodontics and Pediatric Dentistry Department, Dental School, University of São Paulo, São Paulo, Brazil

Ibirapuera University, São Paulo, Brazil


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being used in both public oral health systems and in private practice worldwide [1]. The ART methodology has evolved and improved through the years, and it is considered a reliable approach that fits into the minimal intervention dentistry (MID) concept [1, 10]. By reducing the removal of healthy tooth tissues and using adhesive materials, the ART approach results in more conservative cavity preparations and, consequently, smaller restorations when compared to the traditional restorative procedures [11–13].

## 12.2 ART Technique

This technique follows the protocol proposed by Frencken et al. [7].

### 12.2.1 Instruments and Materials

The ART technique requires only hand instruments such as dental mirror, periodontal probe (WHO ball point), tweezer, dental hatch, small- and medium-sized dentin excavators, spatula, and an applier. Consumption materials used in ART are pair of gloves, cotton wool rolls and pallets, high-viscosity glass ionomer (powder and liquid or encapsulated), polyacrilic acid used as conditioner, petroleum jelly, wedges, matrix strip, and clean water. Occasionally, local anesthesia is required.

The patient-to-operator position is not a problem in a dental clinic environment but has particularities when performed in other settings. In field conditions, a table or a portable bed is usually used, and a small pillow can be positioned behind the patient's neck, providing him/her more comfort. Then the operator sits at the edge of the tables.

### 12.2.2 The ART Restoration

Plaque is removed with a toothbrush or by a cotton pellet. A clean surface improves the visibility of the tooth, allowing the observation of the correct extension of the lesion and the unsupported enamel. The tooth to be treated must be isolated with cotton wool rolls, considering that the moisture can disrupt the proper adhesion of the material to the tooth.

When the cavity opening is too small, it is necessary to widen it with the dental hatch rotating it backward and forward to enlarge the cavity entrance by removing the unsupported enamel. Then, the excavator should be used to remove the infected dentin (soft tissue) and thin unsupported enamel if present. The carious tissue removal should start at the dentin-enamel junction that must be completely cleaned, exposing sound tissues that are essential for a good material adhesion, which in turn will guarantee the sealing of the cavity in order to avoid carious lesion progression. The cavity floor must be excavated very carefully, and only the soft tissue is removed with the view to avoiding the pulp exposure.

During the carious tissue removal, in case of deep cavities, a soft dentin layer may be left in the cavity in order to avoid pulpal exposure. The surrounding dentin (enamel-dentinal junction) should be cleaned in order to promote and ensure adhesion in sound tissue. Thus, following the concept of selective carious removal, when a hardened dentin is reached, carious removal should be stopped. After removing the carious tissue, the cavity and the tooth occlusal surface is conditioned with a dentin conditioner for 10–15 s (a micro-brush or a cotton wool pellet can be used) to remove the smear layer created during excavation and to increase the glass ionomer bond strength. The conditioned surfaces must be cleaned with three wet cotton wool pellets sequentially and right after dried with three cotton wool pellets. The ART technique also involves pit and fissures sealants. After cleaning the cavity with a toothbrush or a cotton roll, the GIC is inserted in the same way as described below. High-viscosity glass ionomer should be mixed right before insertion in the cavity. If it is powder-liquid, the professional should not alter the proportion following the manufacturer's instructions. When available in capsules, it must be inserted in the cavity immediately after the capsule activation and mixing.

With the help of the flat part of the applier, the mixed glass ionomer cement (GIC) is inserted against the cavity wall in order to prevent the inclusion of air bubbles, which weakens the resistance of the GIC. Encapsulated GICs have an applicator tip, which helps inserting the material from the bottom of the cavity avoiding air bubble inclusion. Overfill the cavity slightly, applying the GIC over adjacent pits and fissures.

Petroleum-jelly-coated glove finger is used to slightly press the material against the occlusal surface for about 40 s. Besides avoiding the sticking of GIC to the glove, petroleum jelly prevents syneresis and imbibition of GIC. The finger should be removed laterally and not in the axial direction. The excess of GIC will overflow and can be removed easily (Fig. 12.1).

The occlusion must be checked with occlusion paper. Remove the excess with an excavator or carver, usually small adjustments are needed. Apply the petroleum jelly again over the restoration, recheck the bite, and adjust until it's comfortable for the patient. Finally, apply the petroleum jelly once again. Some GIC brands have also a light-cured coat that is used for protecting the restoration instead of petroleum jelly. The patient must be instructed to not eat for at least 1 h.

During all the procedure, the professional should carefully control moisture by means of a proper relative isolation. Whenever saturated with saliva, they should be replaced.

For approximal lesions and cavities, a matrix and wedge must be used to give the tooth the correct contour and proximal contact point (Fig. 12.2).

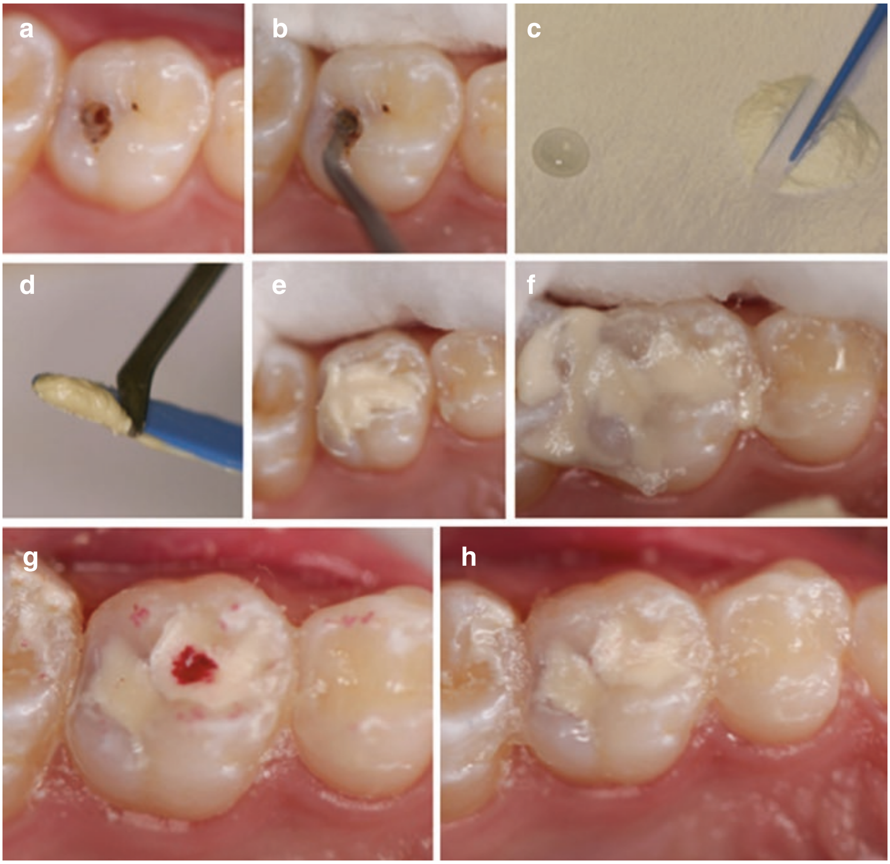


**Fig. 12.1** Occlusal ART restoration. (**a**) Occlusal cavity; (**b**) Removing the soft carious tissue with the excavator; (**c**) Mixing the powder-liquid GIC; (**d**) GIC after mixed and ready to be inserted in the occlusal cavity; (**e**) GIC inserted over the cavity and pits and fissures; (**f**) Aspect of the tooth and GIC after petroleum-jelly-coated glove finger pressure; (**g**) Tooth after removing the excess of GIC and checking the bite with occlusion paper; (**h**) Tooth's final aspect after all adjustments

## 12.3 ART Restoration Longevity

ART approach has been described as an effective, minimal invasive, evidence-based alternative option for managing carious lesions. The survival of ART restorations can be compared to amalgam and composites [14, 15]. The discomfort, acceptability, and treatment cost of ART are much beneficial for the children, parents, and dentists when compared to the conventional treatment [16]. In this way, during the decision-making process, ART is no longer considered a treatment option, but the first-choice treatment for pediatric dentistry, at least for single surfaces.

**Fig. 12.2** Occluso-proximal ART restoration. (**a**) A carious lesion involving the occlusal distal surfaces of a second primary molar; (**b**) Carious tissue removal, also removing the unsupported enamel; (**b**) Aspect of the cavity after carious tissue removal; (**c**) The wedge and matrix in place; (**d**) Cavity conditioner being applied for 10–15 s; (**e**) Wet cotton wool pellets washing the cavity; (**f**) Dry cotton wool pellets applied to take the moisture out of the tooth; (**g**) High-viscosity GIC being applied; (**h**) High-viscosity GIC being pressed against the cavity using a petroleum-jelly gloved finger; (**i**) Restoration immediately after removing the finger; (**j**, **k**) Checking the bite; (**l**) Restoration final aspect after adjustments (Courtesy: Dr. Leal SC and Takeshita EM)

When compared to amalgam restorations, the current evidence indicates that the failure rate of high-viscosity GIC/ART restorations of any class in primary and permanent teeth is not higher than, but is similar to that of, conventional amalgam fillings after periods longer than 6 years [17].

Even though the survival rate of occluso-proximal cavities is lower when compared to single surface ones [14], an updated systematic review showed that ART restorations have similar survival rate compared to conventional treatment and can be considered an option to restore occluso-proximal cavities in primary molars [15].

When we compared the full and partial retention survival percentage of resin-based sealants to the retention of ART sealants, the results are lower [18]. However, the main aim of sealing a cavity or surface is to avoid caries progression into dentin. When we look into the dentin carious lesion prevention survival percentage between the two types of sealants, there is no difference between their survivals [17]. The ART/GIC sealant is most indicated in erupting molars and where moisture control is compromised, since the hydrophilic nature of GIC compared to hydrophobic resin-based materials does not require rubber dam isolation.

## 12.4 Patient-Reported Outcomes and ART

Studies focusing on patient perspective are an emerging metric in the healthcare field to ensure individual engagement in medical decision-making [19, 20]. When questions that are central to patients are considered, it is possible to avoid intervention pitfalls and to take full advantage of its benefits [21]. There are three methods of measuring patient's preferences regarding a health intervention, which are external observations, proxy measures, and patient-reported outcome measures.

External observations are performed by the operator or an external researcher, and it usually involves behavior assessment [6, 22, 23]. Although the measure is patient-centered, there is no direct involvement of the patient in the treatment impact analysis. The same happens when proxy measures are used. However, the answers are reported by proxies, such as parents, legal guardians, or caregivers. Although it is not the most reliable measure of the patient's voice [24], sometimes it is the only one available, as in case of very young and/or special need patients. At last, patient-reported outcome measure (PROM) is an assessment of health status reported by the patients themselves without interpretation of an observer. PROMs ensure that research questions lead to a holistic and meaningful conclusion [25]. Regarding dental care, the provision of high quality treatment is inwardly related to the patients' ability to cope with the dental anxiety and to cooperate with the clinical circumstances needs [26]. In the pediatric dental clinic, patient-reported measures take a major role since unpleasant dental experiences in childhood reverberate into adulthood [27] leading to patient apprehension [28] or even treatment avoidance [29].

As the ART dismisses the use of needles/anesthesia and high-speed hand piece, which are trigging factors often related to adverse emotional reactions during dental procedures [30], it has been considered a patient-friendly referral approach. Some studies have been developed to better understand the impact of ART on patient dental experience. Due to its most reliable results, this chapter will only focus on PROMs. The most common outcomes studied are discomfort, anxiety, pain, and quality of life.

Regarding discomfort, ART has been mostly compared to treatments using rotary instruments [31–34], and/or local anesthesia [32], being unanimously reported as the most comfortable procedure by patients. When no comparison group is used, ART was also described as a low-discomfort procedure [35, 36]. The results concerning pain have a similar pattern. Procedures using rotary instruments were reported as more painful than ART [37–39]. However, no difference was found when ART was compared to air-abrasion caries tissue removal. Both approaches are considered painless treatments [39].

On the other hand, a recent systematic review regarding anxiety among children who received restorative dental care did not find difference between ART and conventional treatment [40]. However, an inadequate number of studies were analyzed due to the low amount of papers that matched the inclusion criteria. The lack of information and rigor in the methodologies described also represent an important limitation. It is important to highlight that despite the comparative results, ART was able to reduce the levels of anxiety among children in all studies, reassuring its profile as a patient-friendly approach.

In relation to quality of life, the majority of studies still use proxies, mainly parents [41, 42], instead of PROMs [43], to report this outcome. Regardless of the measure used, ART demonstrated a positive impact in the children's quality of life.

Other outcomes can also be found in the literature such as treatment acceptance [22, 44, 45] and feasibility and perceived satisfaction (b). ART demonstrates a positive effect in all of them.

## 12.5 Final Considerations

- ART is a safe and effective treatment for caries lesions in primary and permanent teeth.
- The survival of the restorations is higher for single surfaces when compared to multiple ones. However, since there is no difference against conventional treatment, ART is considered a treatment option for restoring children and anxious patients.
- Nowadays ART can be used regardless the treatment environment: schools, hospitals, or and dental offices.

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# The Hall Technique

# 13

Ruth M. Santamaría, Christian H. Splieth,
Mark Robertson and Nicola Innes

## 13.1 Introduction

The Hall Technique offers an effective approach to manage carious lesions in primary molars where no carious tissue is removed but the lesion is sealed under a preformed metal crown (PMC). This biologically based concept of caries control aims to influence the carious lesion and biofilm activity at the tooth level, separating the lesion and cariogenic biofilm from the oral environment. It is suitable for primary teeth and has successfully been employed in different pediatric dentistry settings (Fig. 13.1).

The main characteristics of the Hall Technique are:

– None of the carious lesion is removed.
– The carious lesion is sealed under a PMC using glass ionomer cement (GIC).
– No local anesthesia is required.
– No tooth preparation is carried out.

### 13.1.1 Is It Acceptable to Leave Carious Tissue in a Tooth?

Traditionally, complete carious lesion removal with subsequent placement of a restoration was considered the standard treatment for carious teeth. Over several decades, there has been a paradigm shift in how the caries process is understood and consequently managed [1, 2].

R. M. Santamaría (✉) · C. H. Splieth
Department of Preventive and Pediatric Dentistry, Faculty of Dentistry, Ernst Moritz Arndt University of Greifswald, Greifswald, Germany
e-mail: ruth.santamaria@uni-greifswald.de

M. Robertson · N. Innes
Department of Paediatric Dentistry, School of Dentistry, University of Dundee, Dundee, UK



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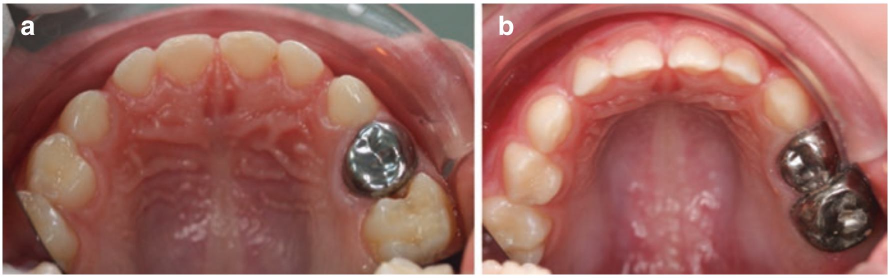



**Fig. 13.1** (**a**, **b**) A maxillary second primary molar (tooth 65) (**a**) before and (**b**) immediately after a preformed metal crown was fitted using the Hall Technique

Caries is no longer understood as an infectious disease; instead it is considered the result of an ecological imbalance mediated by the composition and activity of the oral biofilm and triggered, for example, by the frequent consumption of fermentable carbohydrates [3]. The biofilm needs a sheltered micro-niche or so-called stagnation areas (e.g., fissures, area below contact points, etc.) for it to become actively cariogenic. In these areas, over time and by being protected, the biofilm matures to the level where the acidogenic bacteria dominate the biofilm, the pH drops and the hydroxyapatite becomes soluble, and minerals' dissolution becomes inevitable leaving microporosities at the enamel level. If this imbalance is not modified by influencing the biofilm and reversing mineralization, the caries process that started at the enamel surface will progress into deeper layers reaching the dentin and causing cavitation. How fast caries develops depends on complex relationships; however the dynamic character of the caries process enables the disease to be influenced and controlled at any stage of the lesion development [4].

The Hall Technique controls the biofilm's environment by sealing it into the tooth, separating the lesion from the oral environment, which provides the essential substrates for bacterial nutrition. There is good evidence that if caries is effectively sealed from the oral environment, there will be a dramatic reduction in the number of viable cariogenic microorganisms [4, 5]. On the other hand, there is scarce evidence showing that dentin must be removed before making a restoration or that leaving infected dentin into the cavity results in caries progression [6, 7].

## 13.2 Background and Evidence

The first report on the Hall Technique was a retrospective study, published in 2007 [8]. This study presented the analysis of the practice records of a general dental practitioner from Aberdeen/Scotland, Dr. Norna Hall. Dr. Hall successfully used PMCs for over a decade to restore carious primary molars; however, rather than using the standard technique, she placed them using a simplified method, today known as the Hall Technique. This retrospective study involved 259 children and a total of 978 crowns, which were mostly placed in teeth with clinical evidence of proximal caries into dentin and marginal ridge breakdown. Survival rates (probability of the tooth not needing to be extracted or the crown being lost) were 73% at 3 years and 68% at 5 years. The rates for avoiding extraction were 86% (3 years) and 81% (5 years), rates comparable with those reported in the literature for conventional restorations. Further evaluations of the effectivity of the Hall Technique using randomized clinical trial designs have been performed across different countries and in a variety of settings. A summary of these studies is presented in Table 13.1.

In addition, to support this body of evidence, retrospective studies [14–16], which have also assessed the success of the Hall Technique over a 1.5–5-year time span, have shown high success rates (>95%), similar to conventional crowns. The success of the Hall Technique has consistently been high, independent of the type of study (retrospective or prospective/observational or randomized control), setting (primary or secondary care), or country where it has been used (Australia, Belgium, Brazil, Chile, Germany, India, Netherlands, New Zealand, UAE, the UK, and the USA). This has possibly influenced the Hall Technique dissemination, increasing its use as a caries management option for carious primary molars [17].

## 13.3 Technique Acceptance

The ideal "child-friendly" therapy for carious primary teeth would be to manage the lesion without causing the child any pain or discomfort. Presence of pain or discomfort is a factor that directly influences child patients' behavior during treatment [18–20]. In terms of children's pain perception and behavior, the Hall Technique has shown favorable results, when compared with other treatments. Santamaria et al. [21] showed that children presented significantly more negative behavior when undergoing conventional fillings compared to the Hall Technique (37% vs. 13%). In addition, this technique is well accepted by clinicians and parents. Innes et al. [8] reported that 81% of clinicians and 83% of parents preferred the Hall Technique compared to conventional fillings. Similarly, Santamaria et al. [21] reported that more than three quarters of clinicians (77%) rated the Hall Technique as a very simple procedure to perform compared to 50% in the conventional filling arm.

The appearance of a metal crown can be a problem for esthetically orientated parents/carers. In a study performed in the UK, there were few objections to the appearance of the PMCs reported by parents (around 5%) [22]. In addition, children seem to like the appearance of PMCs, tending to prefer a crown to other commonly used restorative materials [23, 24].

Behavior during treatment is widely agreed to be a crucial element that influences the provision of dental care in pediatric patients. Age-related ability to cope, procedure duration, and increased requirements for patient's cooperation when placing restorations, mainly by resin-based fillings, are factors that influence children behavior during treatment. The Hall Technique does not suit every tooth, child, parent, or dentist. However, it significantly reduces some of the treatment-related barriers and at the same time offers a simple and effective option to use, which may reduce treatment-induced anxiety and encourage future patient's cooperation.

> The use of the Hall Technique reduces pain and discomfort during treatment. Thus, the use of this technique may help to reduce anxiety, build confidence, and consequently encourage a better relationship between the clinician and the child.

**Table 13.1** Success rate for four randomized control trials of the Hall Technique and their comparator interventions

| Study | Country and study details | Age group (years) | Sample | Intervention | Results | | |
|---|---|---|---|---|---|---|---|
| | | | | | Success[a] | Minor failures[b] | Major failures[c] |
| Innes et al. [8, 9] | *UK*<br>General dentists in NHS practice<br>Lesions: occlusal and proximal | 3–10 years<br>Mean = 6.8 years; SD 1.58 | 66 children/132 teeth (split mouth design)<br>HT = 132<br>CR = 132 | Hall technique | 2 years: 93%<br>5 years: 92% | 2 years: 5%<br>5 years: 5% | 2 years: 2%<br>5 years: 3% |
| | | | | Complete and selective removal and restoration according to GDP preference | 2 years: 39%<br>5 years: 41.5% | 2 years: 46%<br>5 years: 42% | 2 years: 15%<br>5 years: 16.5% |
| Santamaria et al. [10, 11] | *Germany*<br>Specialists in hospital<br>Lesions: cavitated proximal | 3–8 years<br>Mean = 5.6 years; SD 1.5 | 169 children/teeth.<br>HT = 52<br>NRCT = 52<br>CR = 65 | Hall Technique | 1 year: 98%<br>2.5 years: 92.5% | 1 year: 2%<br>2.5 years: 5% | 1 year: 0%<br>2.5 years: 2.5% |
| | | | | Complete caries removal and compomer restoration | 1 year: 71%<br>2.5 years: 67% | 1 year: 20%<br>2.5 years: 24% | 1 year: 9%<br>2.5 years: 9% |
| | | | | Non-restorative cavity control | 1 year: 75%<br>2.5 years: 70% | 1 year: 17%<br>2.5 years: 21% | 1 year: 8%<br>2.5 years:9% |
| Narbutait et al. [12] | *Lithuania*<br>Specialists in hospital<br>Lesions: cavitated proximal | 3–8 years<br>Mean = 5.69 years; SD 1.23 | 122 children/teeth.<br>HT = 35<br>NRCT = 35;<br>CR = 52 | Hall Technique | 1 year: 94% | 1 year: 0% | 1 year: 6% |
| | | | | Caries removal and restoration according to GDP preference | 1 year: 73% | 1 year: 16% | 1 year:12% |
| | | | | Non-restorative cavity control | 1 year: 47% | 1 year:35% | 1 year:18% |
| Araujo et al. [13] | *Brazil*<br>Specialists and undergraduate students in field school setting<br>Lesions: cavitated proximal | 5–10 years<br>Mean = 8.08 years; SD 1.11 | 131 children/teeth<br>HT = 66; ART = 65 | Hall Technique | 1 year: 98.5% | – | – |
| | | | | Atraumatic restorative treatment | 1 year: 58.5% | – | – |

*GDPs* general dental practitioners, *HT* Hall Technique, *NRCC* non-restorative cavity control, *CR* conventional restoration, *ART* atraumatic restorative treatment

[a]Overall success: no minor or major failure

[b]Minor failures: signs or symptoms of reversible pulpitis treated without requiring pulpotomy or extraction, restoration loss, fracture or wear requiring intervention

[c]Major failure: irreversible pulpitis or dental abscess requiring pulpotomy or extraction, unrestorable tooth

## 13.4 Cost-Effectiveness

The Hall Technique's cost-effectiveness has been compared, using modeling, to other therapy options (conventional fillings and pulpotomies) for treating cavitated asymptomatic carious primary molars. The results of these analysis showed that the Hall Technique was the most cost-effective therapy [25] option with costs per year of 9.77€ as compared to 13.31€ for conventional fillings and 11.75€ when an immediate pulpotomy is performed.

The Hall Technique has the potential to reduce the costs of treatment, including avoiding repeat treatment. It could be also beneficial for health insurance.

## 13.5 Indications

In general, for medically healthy children, the Hall Technique is indicated for management of asymptomatic dentin carious primary molars; however, its use is only indicated after conducting a detailed clinical examination. Since this technique does not require carious lesion excavation, teeth with clinical suspicion of pulpal involvement should be excluded. In addition, the tooth to be treated should have sufficient sound coronal tissue to retain the crown, and radiographically (if it is available) there should be no evidence of periapical pathology at the furcation or periapical area of the surrounding bone. In addition, the presence of a dentin bridge (at less 1 mm) between the advancing edge of the carious lesion and the pulp (Fig. 13.2) seems to favor the success of the Hall Technique [26]. Unquestionably, the use of baseline radiographs to assess the total hard tissue thickness and the presence of interradicular/periapical pathology will supplement clinical diagnosis. However, a clinical study assessing the effectiveness of the Hall Technique did not include baseline radiographs (because the studies were in school settings), but it still showed comparably high success rates (>95%) after 1-year follow-up to other studies including baseline radiographs [13]. In another study including only occluso-proximal lesions, the tooth had to have no symptoms of irreversible pulpitis and be judged in the clinician's view as not having reached the dental pulp to have a crown fitted. There was a 98.5% success rate after 1 year [13].

At the patient level, the Hall Technique is particularly useful for:

- Anxious children with specific fears (e.g., injections and drilling)
- Moderate cooperation to standard restorative treatment
- Behavioral disorders (e.g., attention-deficit hyperactivity disorder) and young children with limited attention spans
- As an alternative therapy for improving patient's cooperation and building confidence

On the other hand, the Hall Technique should not be seen as a quick solution to treat carious primary molars for uncooperative children; therefore it is contraindicated when there is no cooperation, as there is a risk of crown aspiration or

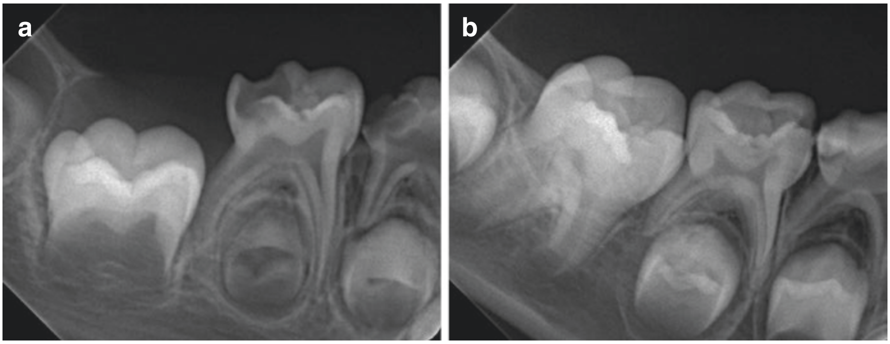


**Fig. 13.2** (**a**) The mandibular first (84) and second primary molars (85) have large disto-occusal cavities. They are symptomless, with no interradicular pathology visible. The cavity extension specially on 84 would make it difficult to obtain a good seal using an adhesive restorative material. (**b**) The mandibular second primary molar (85) has a mesio-occlusal cavity; it is symptomless, and a band of normal dentin between the carious lesion and the pulp chamber is visible

**Table 13.2** Indications and contraindications of the Hall Technique

| Indications | Contraindications |
|---|---|
| – Asymptomatic proximal and multisurface carious lesions in primary molars (cavitated or non-cavitated, active or inactive[a]) | – Signs or symptoms of irreversible pulpitis or dental abscess/fistula |
| – Asymptomatic occlusal lesions (class I), (cavitated or non-cavitated, active or inactive[a]) if the patient is unable to accept a conventional restoration | – Radiographic signs of pulpal involvement or periradicular pathology |
| – Hypoplastic primary molars | – Lack of sufficient sound tissue to retain the crown |
| – Asymptomatic carious lesions in primary molars, regardless of the surfaces involved, where the patient is high caries risk | – Atypical tooth shape, so that a crown cannot be easily fitted |

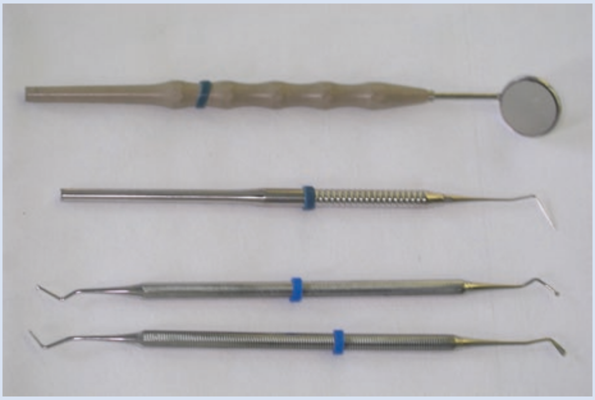
[a]The decision to place a Hall crown on an inactive and/or non-cavitated carious lesion should be based on the individual caries risk, lesion activity, attendance pattern, and the overall likely benefit to patient

swallowing. In addition, it is not indicated in patients at risk of infective endocarditis or immunocompromised children. Table 13.2 shows the general indications and contraindications of the Hall Technique at the tooth level.

## 13.6 Materials Needed

The dental instruments and consumable materials used for the Hall Technique are all commonly found in a dental practice, such as dental mirror, excavator, or cotton wool rolls. The essential instruments and materials needed are presented in (Table 13.3).

**Table 13.3** Instruments and materials to perform the Hall Technique

| Material | Comment |
|---|---|
| Dental mirror, straight probe, and excavator | |
|  | (a) Straight probe or excavator can be used to remove orthodontic separators, if placed<br>Excavator can be used to remove the crown if this becomes necessary or to remove excess GIC |
| Toothbrush or a bristle brush | |
|  | (b) To clean the tooth before crown cementation |
| Heidemann spatula and glass ionomer cement | |
|  | (c) Luting cement should be used for crown cementation using a Heidemann spatula (or another filling spatula) to load the crown<br>Handmixed cement can also be used |

(continued)

**Table 13.3** (continued)

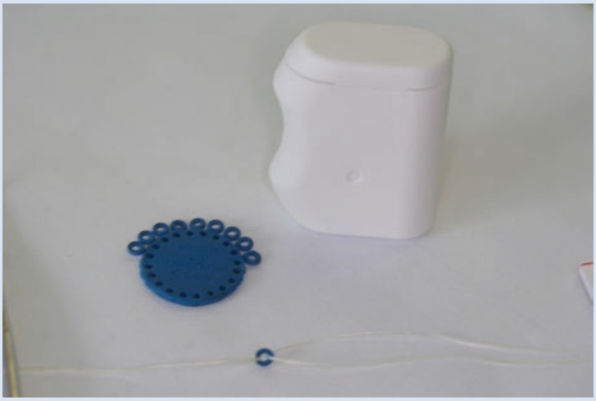
| Material | Comment |
|---|---|
| Stainless steel crowns | |
|    | (d) Preformed crowns are suitable for the Hall Technique. Although all crown sizes (1–7) should be available, the most commonly used are 4–6 |
| Orthodontic elastic separators and dental floss | |
|  | (e) To gain some space mesially/distally where there are tight contact areas |

**Table 13.3** (continued)

| Material | Comment |
|---|---|
| Band-forming pliers | |
|  | (f) To adjust the crown, mainly if the primary molars have lost mesiodistal length due to cavitated proximal carious lesions |

## 13.7 Benefits of the Hall Technique

- No risk of pulp exposure or irritation
- High patient compliance of treatment
- Less anxiety during treatment, especially important in young children with limited ability to cooperate
- Shortened treatment time
- No use of local anesthesia, which may be challenging in children
- Well accepted by patients, parents, and children
- High clinical effectiveness, especially for proximal or multisurface lesions in primary molars
- High cost-effectiveness as compared to more conventional treatments

## 13.8 The Hall Technique in Five Steps

The Hall Technique is a technically less complex procedure to perform in terms of the clinician's dexterity, and it can be performed successfully in five steps; see Fig. 13.3.

Nonetheless, the suitability of the Hall Technique for the specific patient and tooth both clinically and radiographically should be carefully considered bearing in mind the indications previously mentioned.

In addition, for success, the Hall Technique requires good patient management and parental cooperation. The practice of regularly used behavioral management techniques, such as "tell, show, do," to introduce the child to the procedure is recommended, e.g., the Hall crown is like "a shiny helmet, just like soldiers wear to protect their heads," or "a precious, shiny, princess crown" or it being a "twinkle tooth" or "Iron Man tooth" and also allowing the patient to handle a spare crown, all of these accompanied by verbal reassurance. Parents should be informed about the technique characteristics, such as no caries removal or increase of the occlusal vertical dimension (OVD).

### 13.8.1 Step 1: Assess Crown Morphology, Contact Areas, and Occlusion

The assessment of the crown morphology is decisive before performing a Hall crown. Anomalies of tooth size and form can make placing a Hall crown more challenging. This can also be problematic when there is a proximal carious lesion with marginal ridge breakdown in one of the primary molars, causing migration of the adjacent molar into the cavitated area as this leaves less mesio-distal space to place the crown. The margin of the crown can be adjusted to accommodate the intruding margin of the adjacent tooth (Fig. 13.4).

In addition to crown morphology, the contact areas of the molar to be treated should be carefully assessed. Absence of interdental spaces can make it difficult to

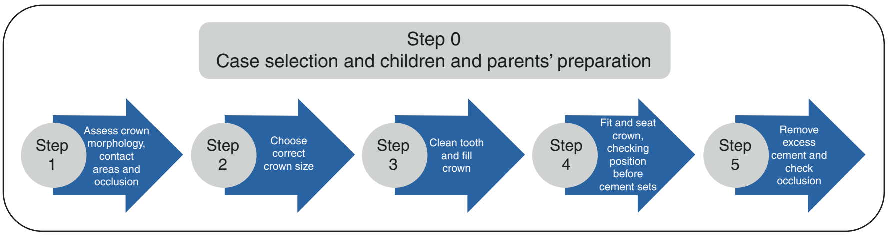



**Fig. 13.3** Hall Technique five-step diagram

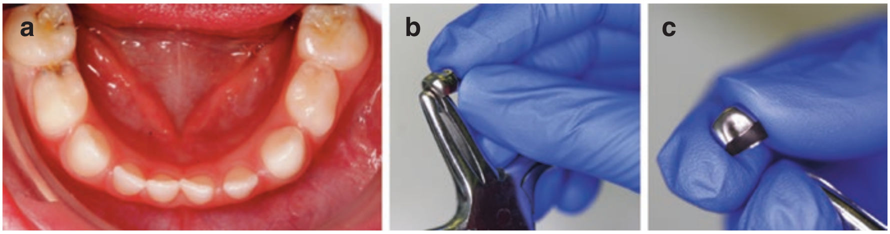



**Fig. 13.4** (**a**) A mandibular right first primary molar (tooth 84) with distal drift and loss of mesio-distal dimension leaving less space to place a Hall crown. (**b**, **c**) Band-forming pliers are used to adjust the crown margins making a concavity to adapt the intruding marginal ridge of the adjacent tooth

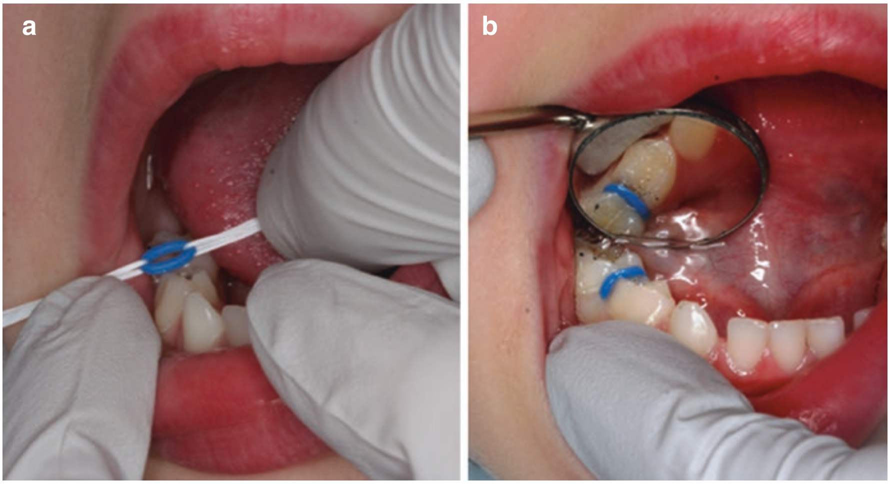



**Fig. 13.5** (**a**) An orthodontic elastic separator placed distal to a mandibular first primary molar (84) using two lengths of dental floss and (**b**) immediately after the separator was placed between the two contact areas

place a Hall crown. In contrast, Hall crowns can be easily fitted in Type I arches, where the marginal ridge is still intact. For closed contacts, it can be necessary to create a small amount of space for the crown by using orthodontic separators. These should be placed 2–3 days before fitting the Hall crown and removed immediately prior to crown placement (Fig. 13.5).

Placing a Hall crown will cause an increase in the OVD as no tooth preparation is carried out. This should be explained before treatment, and the patient and parents should be advised that the child may notice the crown as being "high in the bite," although reassured that this does not cause pain.

### 13.8.2 Step 2: Size the Hall Crown

The smallest crown size, which will seat over, and cover the whole tooth, should be selected. The clinician should have the sensation of a slight feeling of "spring back" when trying on the crown (Fig. 13.6). Do not fully seat the crown through the contact points before cementation; it can be very hard to remove. As described above, orthodontic separators may be placed in the interproximal spaces 2–3 days before fitting the Hall crown to facilitate the crown placement.

Care must be taken to protect the airway, and the child should be seated upright so that if the crown falls into the mouth, it lands on the floor of the mouth rather than the throat.

### 13.8.3 Step 3: Clean the Tooth and Fill the Crown

Before placing the Hall crown, clean the tooth and dry the crown. To remove the residual bacterial plaque covering the tooth, use a rotary bristle brush or a toothbrush. Use the triple syringe or cotton wool rolls to clean and dry the crown, and then place glass ionomer luting cement into the crown to fill approximately two-thirds of the crown ensuring that all inner surfaces are covered (Fig. 13.7). Be careful to avoid air blows and gaps.

### 13.8.4 Step 4: Fit and Seat the Crown

To seat the crown, it is placed on top of the tooth and pushed straight down (Fig 13.6b). The clinician should seat the crown by finger pressure ensuring the crown seats evenly over the tooth and between the contact points. As the crown is seated over the

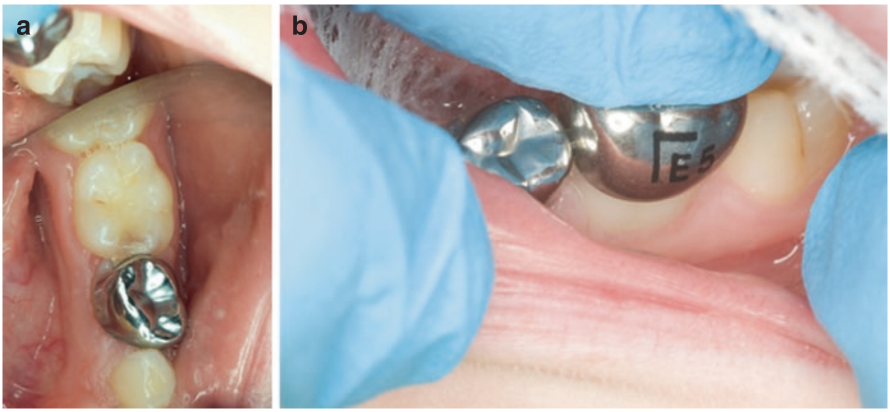



**Fig. 13.6** (**a**) A mandibular second primary molar (75) with a mesio-occlusal carious lesion. (**b**) Selecting the correct crown size to fit a Hall crown

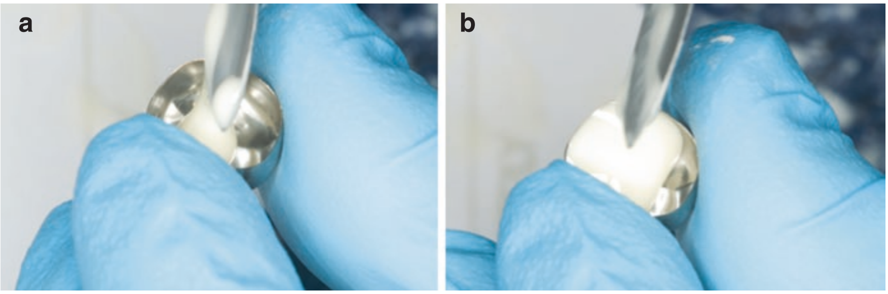



**Fig. 13.7** Loading the Hall crown with a glass ionomer luting cement (at least two thirds full)

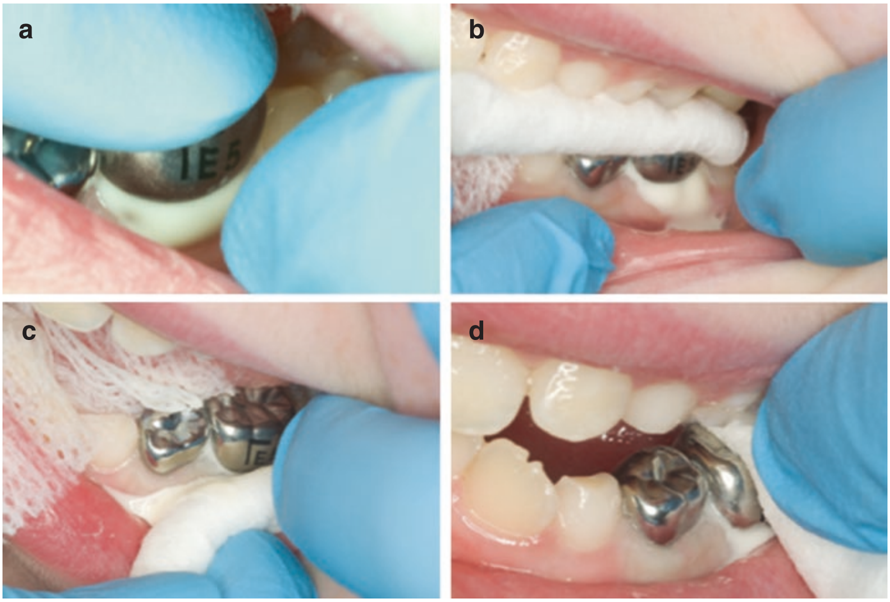



**Fig. 13.8** Fitting the crown on a mandibular second primary molar (85). (**a**) The clinician pushes the crown down with finger pressure. (**b**) The child seats the crown by biting firmly on it. (**c**) The crown position is checked and excess cement removed. (**d**) The child bites down firmly again on a cotton wool roll, maintaining pressure for around 3 min until the cement has set

tooth, excess cement will flow out from the margins (Fig. 13.8). As soon as the crown is seated, and before the cement sets, the patient should be asked to open their mouth to allow the crown position to be checked and to remove the excess cement. If the crown fails to fully seat, it should be removed rapidly, using a spoon excavator.

There are then two options to further seat the crown: The child is asked to bite down on the crown, or the clinician pushes the crown down with finger pressure. Usually a combination between these two options is used.

If the crown is in the ideal position, the child should be instructed to bite down firmly again on the crown (or cotton wool) for 2–3 min until the cement has set

(Fig. 13.8). Alternatively, the clinician should hold down the crown with firm finger pressure to prevent the crown from springing back up as this would compromise the seal and unnecessarily increase the degree of occlusal opening.

### 13.8.5 Step 5: Remove Excess Cement and Check Occlusion

The final step is to clean around the teeth with a hand excavator to remove any excess cement and floss between the contacts (Fig. 13.9). It is important to remind the parents that the child will notice the crown being high in the bite (Fig. 13.10) and that this should resolve in a few days to a week, with full occlusion equilibration within a few weeks. Many children even do not consider the increase in the OVD as something uncomfortable or even notice it. The primary dentition has great ability to adjust to a slightly opened bite over a few days, with full reestablishment within a few weeks with no evidence of adverse effects [27].

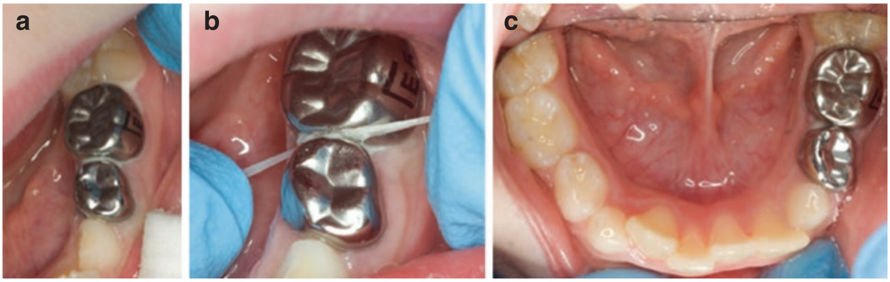



**Fig. 13.9** Any residual cement interproximally should be removed using dental floss before discharging the patient

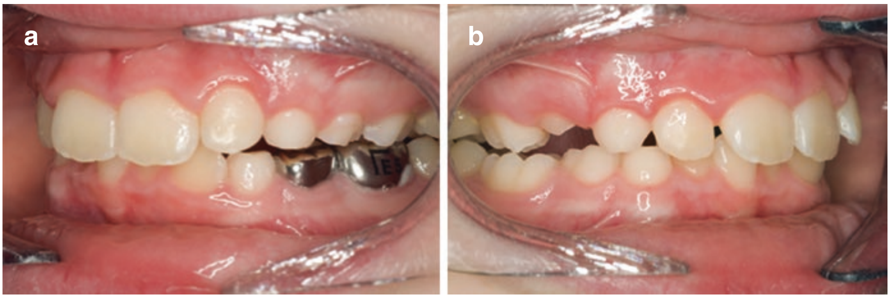



**Fig. 13.10** A mandibular second primary molar (85) immediately after crown cementation. (**a**) Right and (**b**) left lateral views. An increase of around 1.5 mm in the OVD can be observed. This will resolve in a few weeks

## 13.9 Final Considerations

The Hall Technique is a biologically based, effective management option to treat asymptomatic carious primary molars. This technique not only reduces the possibility of pulp exposure or irritation during carious lesion excavation but also offers the benefit of full coronal coverage reducing the risk of future carious lesion development on another surface of the tooth. Its high success rates (> 90%) compared to conventional restorations (50% to 80%) [8–13] and the comparably high success rates between the Hall Technique (97%) and crowns placed using conventional techniques (94%) [14] make this procedure essential for everyday use in pediatric dentistry. As with all clinical procedures, careful case selection with accurate lesion and pulp status diagnoses (clinically and radiographically) is essential for success. The clinician must also be able to explain clearly to the parents and child what is involved and have good child management skills. Parents have to be happy with the appearance before placement although children generally like the appearance of them [24]. The Hall Technique has a high rate of success, is durable, and provides a cost-effective option for primary molars.

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# Esthetic Restorations

# 14

Luciano Casagrande, Jonas A. Rodrigues,
Adriela A. S. Mariath, Tathiane L. Lenzi,
and Fernando B. Araujo

## 14.1 Introduction

Caries is still one of the major reasons for tooth loss worldwide. There is a paradigm shift in dentistry toward noninvasive and minimally invasive approaches, which account for a continuum update in daily practice.

Current literature discusses about the need to restore decayed primary teeth or if they should be left without restorations [1]. Some studies have shown that maintaining cavities opened without cariogenic biofilm might be a treatment option beyond the conventional restorations or atraumatic restorative treatment (ART) [2, 3], especially considering the time that these teeth remain in the oral cavity due to its lifespan. On the other hand, studies have demonstrated that the presence of carious lesions not restored in the primary dentition is the major cause of pain [4], which leads to dental fear [5].

Noncleansable active carious lesions in primary teeth require invasive intervention. Restorative procedures in the primary dentition have as the main objective the maintenance of primary teeth in the arch until physiological exfoliation, which is justified from the functional, esthetic, and psychological reasons [6, 7]. Thus, restorations in primary teeth should last until tooth exfoliation.

For many years, amalgam was among the most used restorative materials for the functional recovery of primary teeth [8, 9]. However, much concern has been reported on potential toxic effects of mercury, although studies have failed to show harmful effects on patients [10]. Under clinical perspectives, what discourages the

L. Casagrande (✉) · J. A. Rodrigues · A. A. S. Mariath · T. L. Lenzi · F. B. Araujo
Department of Surgery and Orthopedic, Faculty of Dentistry, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
e-mail: luciano.casagrande@ufrgs.br


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use of amalgam is the removal of a great amount of the sound tissue to suit the characteristics of the material, which is not compatible with the present minimally invasive concepts. The same reasoning applies to prefabricated zirconia crowns that, despite being esthetic and having a low wear rate, require a greater wear of sound dental structure to be placed and adjusted.

Currently, glass ionomer cements and resin composites are the direct restorative materials most used in pediatric dentistry. Their indications are not based solely on their physical and chemical properties, but are especially related to the dental care needs of the child, such as degree of dental destruction, functional and esthetic sequelae caused by caries, as well as the child's behavior [11].

Following the minimal intervention philosophy, the aim of this chapter is to present more simplified and "patient-friendly" restorative techniques for posterior and anterior primary teeth, helping clinicians in their daily clinical practice.

## 14.2 Selective Carious Tissue Removal

With the development of adhesive restorative materials and less invasive techniques, the restorative procedures are restricted in removing infected carious tissue without the need for additional retention to provide a predefined geometric configuration of the cavities in order to improve the clinical performance of the material. Thus, the "adhesive preparations" have an essential biological purpose, allowing for the removal of most infected dentin tissue and limiting bacterial penetration through the sealed marginal interface, favoring clinical performance in terms of sensitivity and esthetics [12].

The contemporary approach of managing carious lesions recommends that for teeth with shallow or moderately deep cavitated lesions, carious tissue removal should be performed according to selective removal to firm dentin (Fig. 14.1), once restoration longevity might be more important. However, for deep lesions of vital teeth, preserving pulp health should be prioritized. In this case, the technique involves selective removal to soft dentin over the pulp site to avoid its exposure, while the cavity margins (i.e., peripheral dentin) are left hard (scratchy) [13] (Fig. 14.2). Studies have shown that the remaining carious tissue becomes more hardened, darkened, and less contaminated, regardless of the use of calcium hydroxide liner [14–16]. Recently, a randomized clinical trial demonstrated high rates of clinical and radiographic success of Selective caries removal (SCR) to soft dentin in primary teeth with deep carious lesions. Moreover, as an additional advantage, one-step incomplete excavation (selective) requires less treatment time and results in lower levels of discomfort for the patients, which is especially important when treating children [17].

**Fig. 14.1**

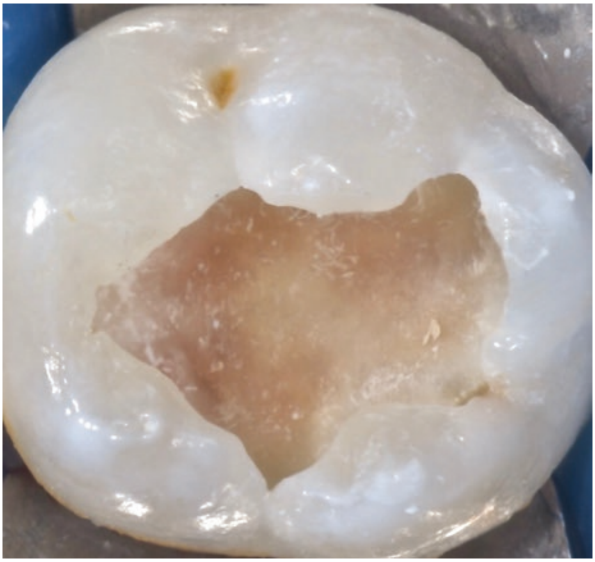
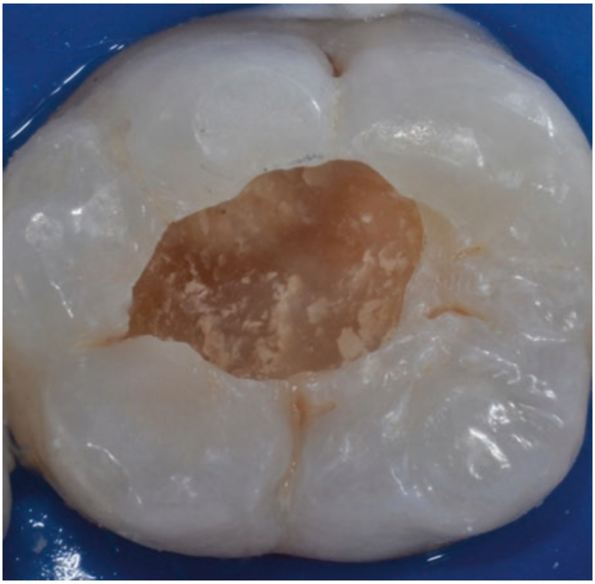


**Fig. 14.2**



The greatest benefit in keeping demineralized dentin at the bottom of a deep cavity is to avoid pulp exposure, making the restorative technique simpler and more effective. This alternative therapy is particularly interesting in pediatric dentistry due to the variable "behavior," since young children are less cooperative, demanding agility in treatments.

## 14.3 Restorative Procedures in Anterior and Posterior Primary Teeth

### 14.3.1 Case 1 (Composite Restoration After SCR Performed in a Primary Molar Under Relative Isolation)

Studies in adults have shown that the use of rubber dam for direct composite restorations is not an essential prerequisite for producing long-lasting restorations [18, 19]. However, this observation may not be true for children, due to the "behavior" factor. Several factors have been related to failure of restorative procedures in children. The clinical experience of the professional and the use of absolute isolation of the operative field seem to contribute to a greater success of the restorative procedure [20].

Rubber dam isolation in children has the main objective to control the humidity and movements of the patient's tongue, also conferring a mucosal protection. However, its use requires local anesthesia, which is not always accepted by the parents. Therefore, relative isolation of the operatory field with cotton rolls has constituted an alternative approach for managing carious lesions when there is no risk of pulpal exposure, especially for occlusal cavities, once proximal restorations require the use of a wedge and interproximal matrix, which can cause pain and discomfort to the patient.

Figure 14.3 illustrates the clinical sequence of a restorative treatment for an active carious lesion on the occlusal-palatal surfaces of a maxillary second molar, in a 3-year-old cooperating patient. After clinical examination, diagnostic radiograph was obtained to visualize the depth of the lesion and the furcation/periapical regions. Carious lesion was located in the inner half of dentin (a), and no symptom or sign suggesting irreversible pulp involvement was observed (b). Carious tissue removal was undertaken by using low-speed stainless steel burs (c) and hand excavators (d). Lateral dentin walls were prepared to hard dentin, and selective removal to soft dentin was performed in the pulp floor using visual and tactile criteria (e). The cavity was filled with composite (f) (Filtek™ Z350, dentin A2; 3 M) using an etch-and-rinse adhesive system (Adper Single Bond; 3 M). The central pit was sealed with a pit and fissure sealant to prevent biofilm accumulation.

This technique is a simple, rapid, and minimally invasive alternative for oral health recovery in patients of young age.

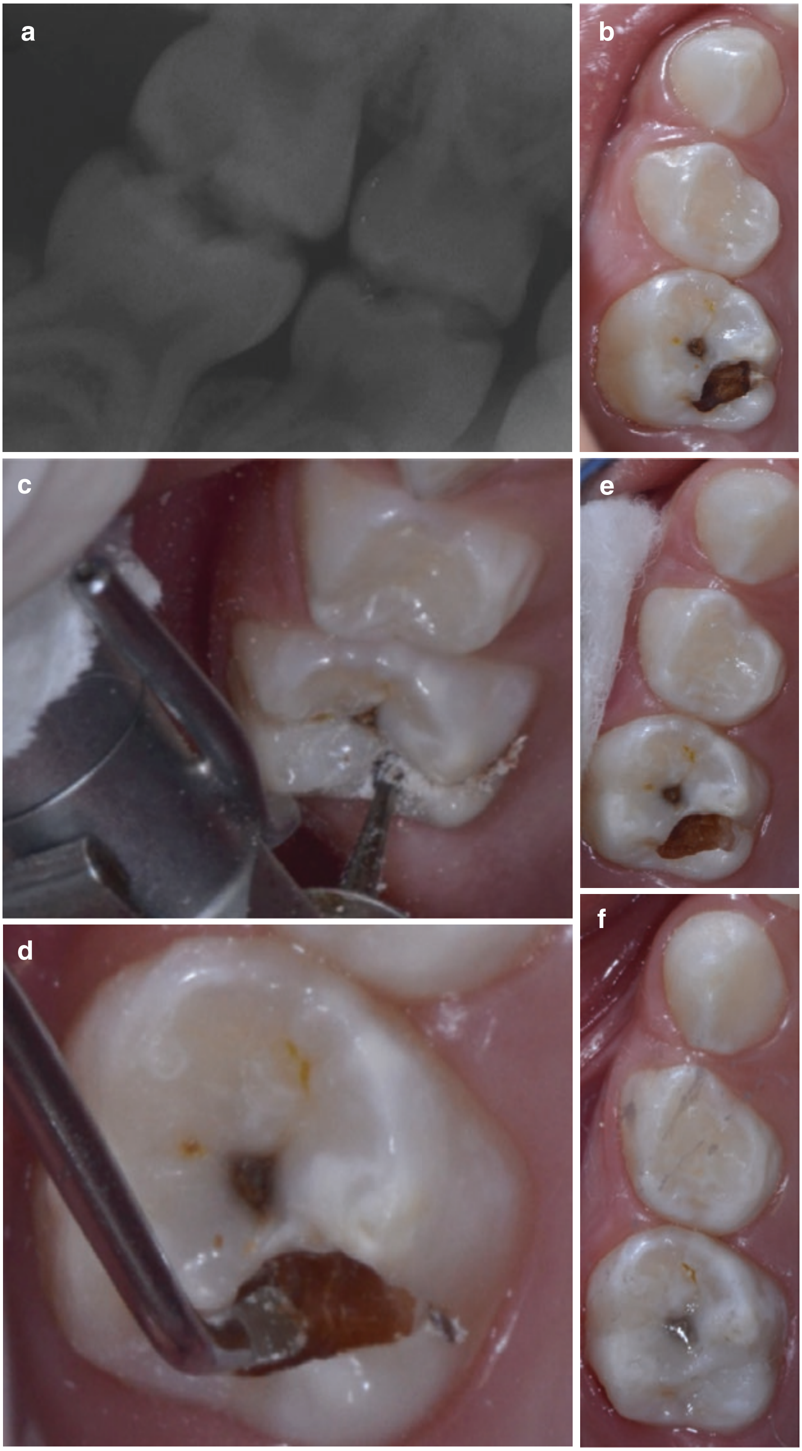



**Fig. 14.3**

### 14.3.2 Case 2 (Minimal Intervention in a Primary Molar with a Failed Restoration)

As far as possible, defective restorations in primary teeth should be clinically maintained until tooth exfoliation, without requiring re-intervention [21]. However, critical size defects in tooth restorations must be retreated by the risk of biofilm accumulation and caries recurrence or to prevent fracture of the enamel walls.

Figure 14.4 shows a defective restoration in a first primary molar that was replaced by a composite restoration (a, b). During restorative procedures, relative isolation of the operatory field was provided with cotton rolls to promote moisture control. Based on the philosophy of minimal intervention, no anesthesia was performed, and selective carious tissue removal was done by using low-speed stainless steel burs and hand excavators up to firm dentin (c, d). To restore the

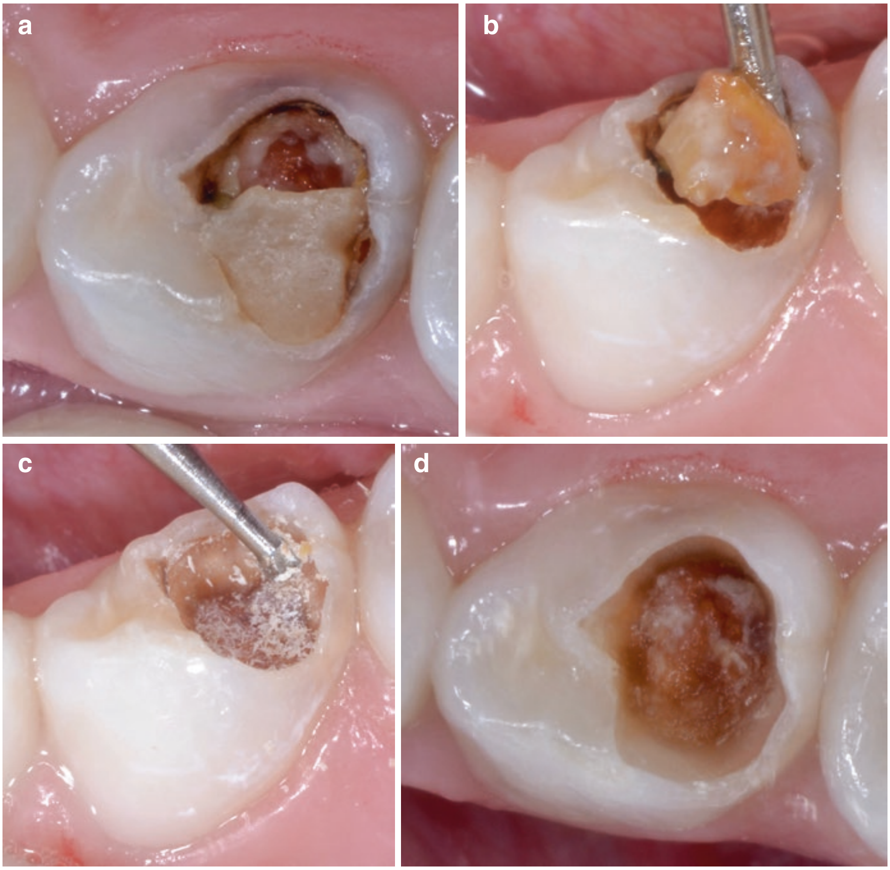



**Fig. 14.4**

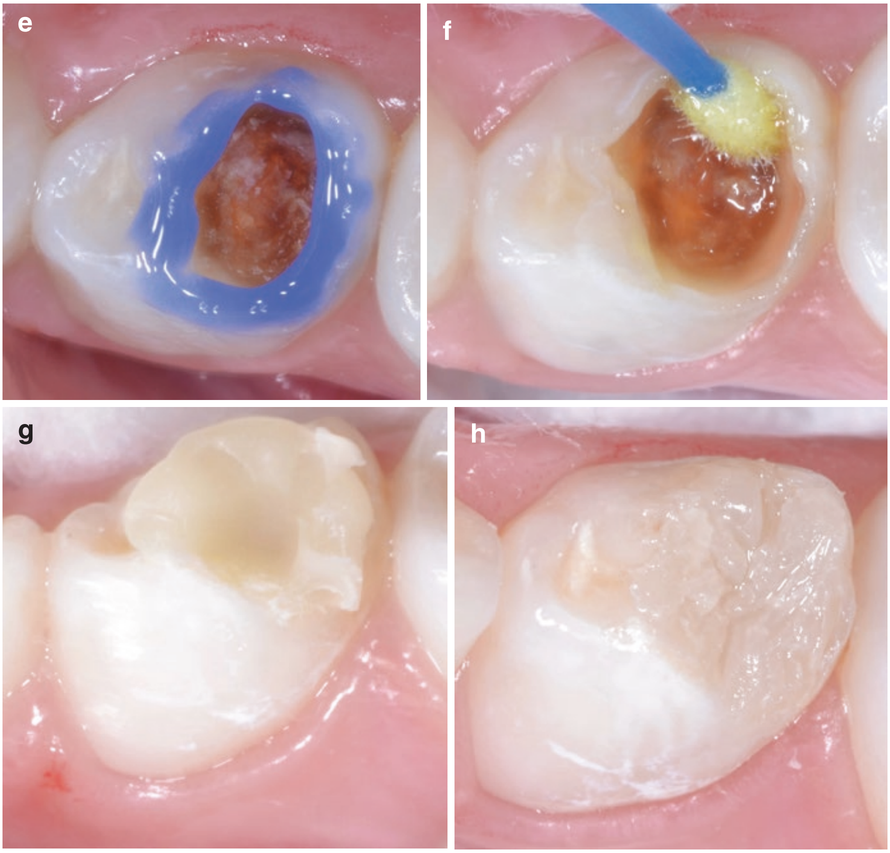



**Fig. 4** (continued)

cavity, a simplified restorative system was placed (e–h), by using a self-etching adhesive (Scotchbond Universal; 3 M), associated with an easy one-step placement bulk fill composite (Filtek™ Bulk Fill; 3 M ESPE), which provides good handling and adaptation. This technique involves eliminating additional composite layers and multiple steps, providing less time-consuming and patient-friendly restorations.

### 14.3.3 Case 3 (Resin Composite Restorations in Primary Molars After Selective and *No* Caries Removal)

This clinical case illustrates minimally invasive procedures for the treatment of a shallow and a deep carious lesion located in dentin of two primary molars, respectively. After intraoral examination, two symptomless active cavitated carious lesions were detected: one in the proximo-occlusal surfaces of a first left inferior primary molar (74) and the other in the occlusal surface of a second left mandibular primary molar (75). Periapical radiography was obtained to visualize the furcation/periapical regions (a). Lesions were located in superficial dentin (75), and in the inner half of dentin (74), with no radiographic sign suggesting irreversible pulp involvement. Patient was given local anesthetics, and treatment was performed under rubber dam isolation (b). For the first molar, carious tissue removal was undertaken by using low-speed stainless steel burs and hand excavators (c). Peripheral enamel and dentin were prepared to hard dentin (scratchy). At the site of "risk for pulp exposure," selective removal to soft dentin was performed using visual and tactile criteria (confirmed by using a blunt-tipped probe). Calcium hydroxide liner (Dycal; Dentsply Caulk, Milford, DE, USA) was placed prior to the restoration (d). A matrix and wedge were placed, and the cavity was filled with composite (Filtek™ Z350; 3 M) using an etch-and-rinse adhesive system (Adper Single Bond; 3 M). For the second molar, no carious tissue removal was performed, and the cavity was filled by using the same restorative system (e). Bitewing radiography shows the adaptation on cervical margin of the occluso-proximal restoration (f) (Fig. 14.5).

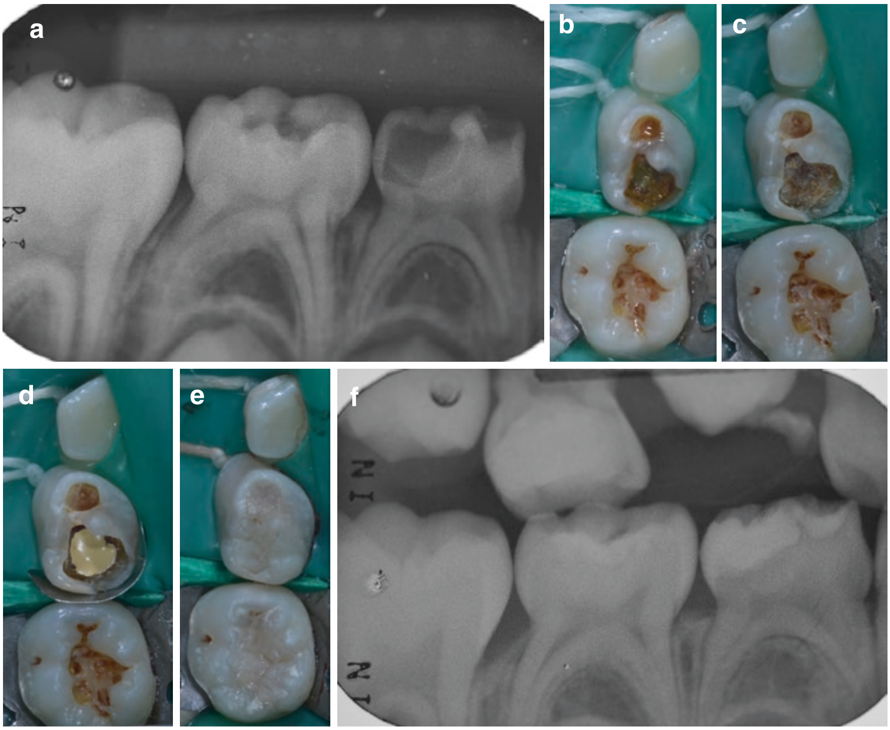



**Fig. 14.5**

### 14.3.4 Case 4 (Esthetic Restorations in Primary Incisor After Minimally Invasive Preparation)

This case illustrates the approach of an active carious lesion (Fig. 14.6) in a right upper central incisive of a 4-year-old child (a, b). Focused on preserving dental structure, dental separation (c, d) was performed for 48 h in order to access the lesion (e, f). Due to the inflammatory periodontal condition in the interproximal papilla, the absolute isolation of the operative field became necessary. Prior to isolation, a straightening of the incisal edge of the upper incisors was performed aiming to provide harmonization to the smile (g).

Under local anesthesia and rubber dam isolation, a wedge was placed in order to maintain the interproximal space obtained by previous separation (h). With a diamond point accessing by buccal site (i), a conservative enamel preparation was

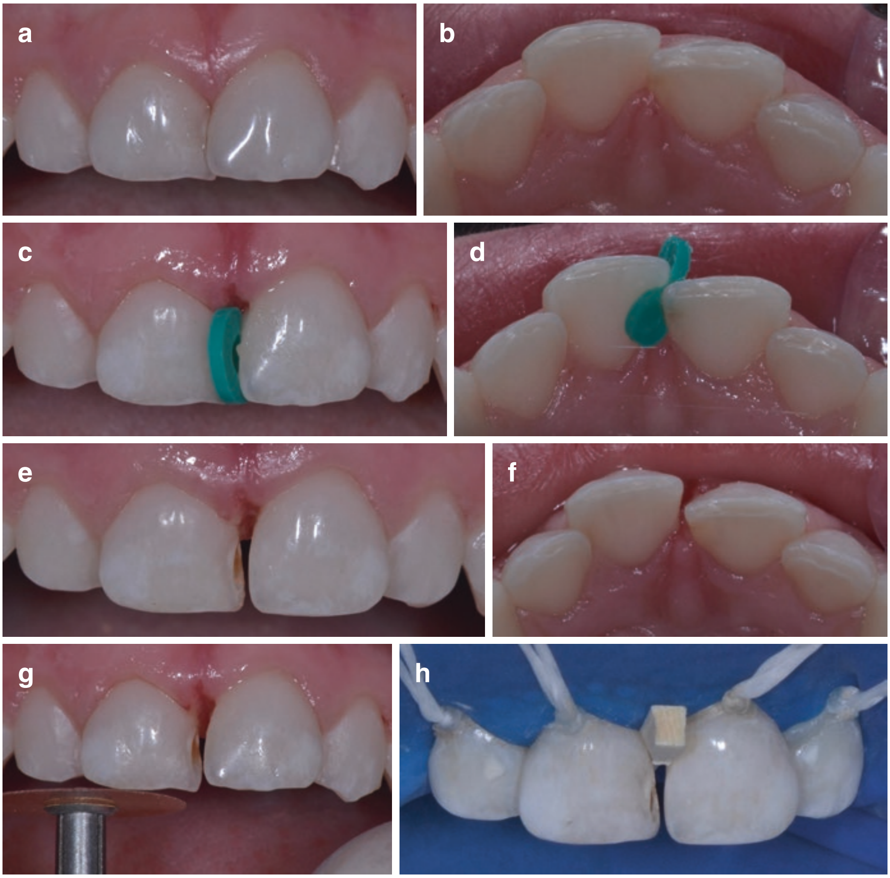


**Fig. 14.6**

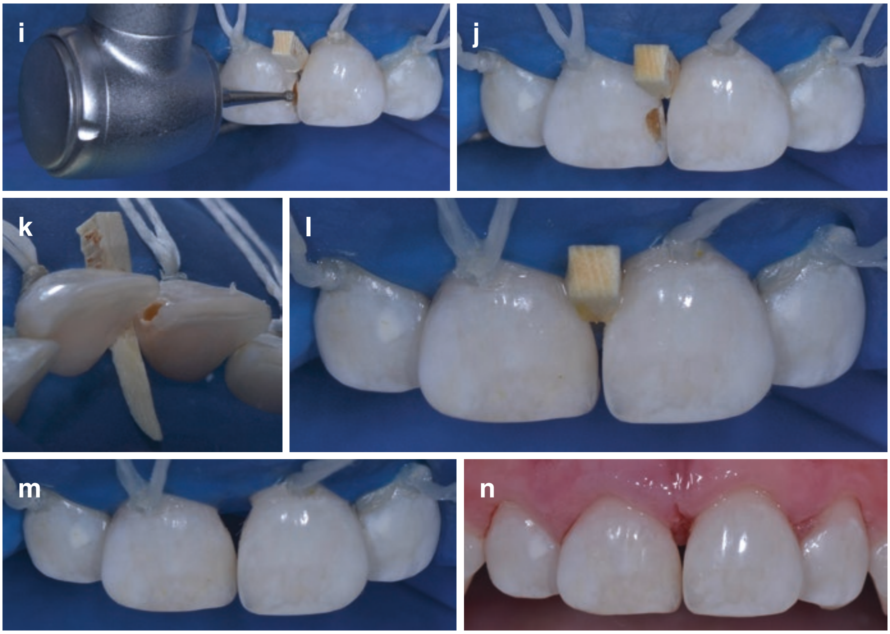


**Fig. 6** (continued)

performed to access the dentin lesion (j, k). Carious tissue removal was carried out with stainless steel burs at low speed.

Cavity was restored with an etch-and-rinse adhesive system (Adper Single Bond; 3 M) followed by composite (Filtek Z350 A1 Dentin and Filtek Z350 A1Enamel; 3 M), (l, m, n).

### 14.3.5 Case 5 (Composite Resin Restorations in Primary Incisors with Severe ECC)

Clinical case of a 4-year-old cooperative boy with severe early childhood caries in the four upper incisors (a). The child reported no spontaneous pain, and no periapical lesion was detected in radiographic exam. Firstly, a dental impression with alginate was carried out to reproduce the palatine guide from the obtained dental cast, which was then molded with silicone impression (b) to facilitate restorative procedures (c).

Without local anesthesia and under relative isolation of operatory field, a gingival retraction cord was used to access the cervical margins of the cavity and control the gingival crevicular fluid (d, e).

The sequence of restorative protocol is shown in Fig. 14.7. Etch-and-rinse adhesive system (Adper Single Bond; 3 M) (f, g) followed by composite stratification

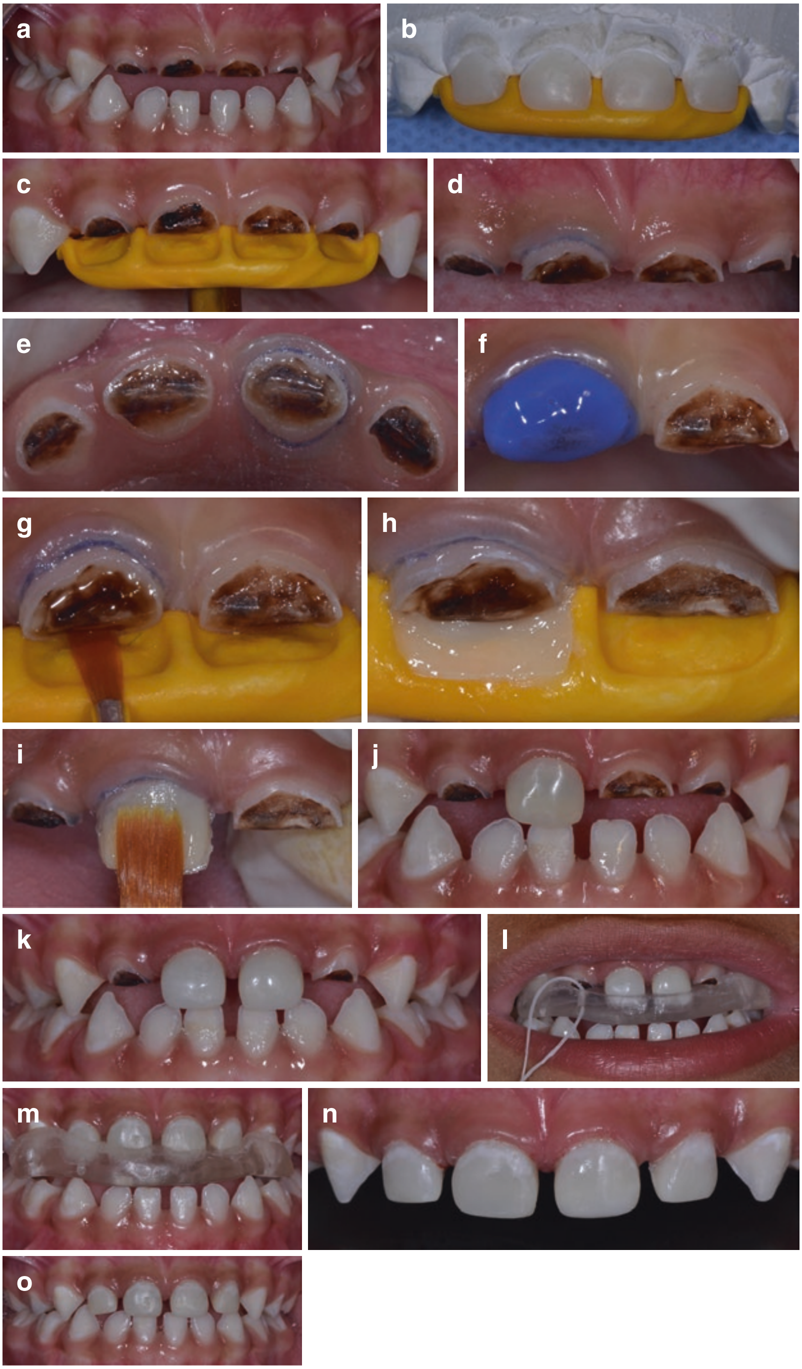



**Fig. 14.7**

(Filtek Z350 A1 Dentin and A1 Enamel, 3 M) (h) was used to restore the upper central incisors (i, j, k).

A rigid anterior protective plate (with extension until canines) was made with the objective of avoiding the fracture of the restoration (l, m). The patient was advised to use it especially during the night, when involuntary eccentric movements are most frequent. To prevent the risk of swallowing, a dental floss was tied to the plate. One week later, the superior lateral incisors were restored through the same technique with additional opaque white resin that was placed on cervical portion in the four incisors to simulate “arrested white spot lesions” that were present in the canines (n), creating an esthetic clinical condition that was extremely satisfactory for the child (o), which immediate recovery of his self-esteem.

### 14.3.6 Case 6 (Resin-Modified Glass Ionomer Cement Restoration in a Primary Molar)

This case shows a cavitated dentin carious lesion that was restored with a resin-modified glass ionomer cement (RMGIC) in a 6-year-old child (a). The mother reported an unsuccessful attempt to treat that tooth, due to the child’s lack of collaboration at the moment the drill was started. As the cavity allowed the entrance of the excavator, the cleaning was performed using only hand instruments up to firm dentin (b). The decision to use a RMGIC (Gold Label 2 LC, GC) was based on the easiness of the technique and also considering the child’s behavior. The final aspect of the restoration is observed in Fig. 14.8c. Notice that the same approach was used to repair the restoration on the distal surface of the first primary molar (Courtesey: Dr Leal SC).

## 14.4 Final Considerations

Restorations are placed in cavitated carious lesions to help the patient in plaque control, to protect the dentin-pulp complex, and to restore the function and esthetics of the tooth, while causing no unnecessary harm. The carious tissue removal stage aims to create conditions for a long-lasting restoration, preserve healthy and remineralizable tissue, achieve a sufficient seal, maintain pulpal health, and maximize success of the restoration [13].

Selective caries removal aims to avoid the pulp exposure while creating conditions for pulp healing by eliminating the nonremineralizable infected dentin, which constitutes a more simplified and “patient-friendly” technique, once requiring less treatment time and producing lower levels of anxiety and discomfort for the patients, especially important in pediatric dentistry.

Dentists should manage the dental caries disease and control caries activity of existing cavitated lesions to preserve hard tissues and retain teeth for a long term [13], avoiding, as far as possible, entering in the restorative cycle.

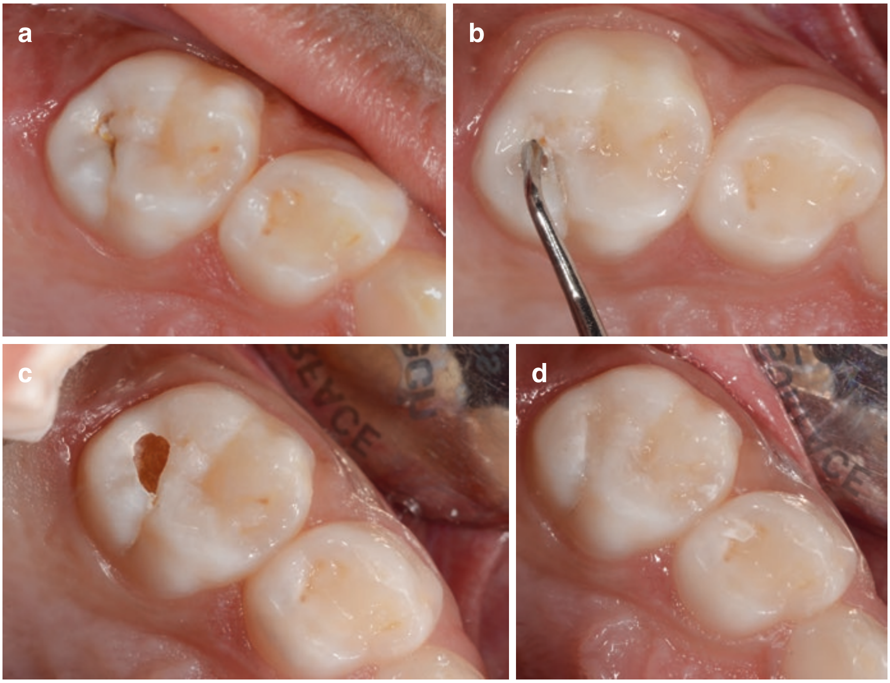



**Fig. 14.8**

The contemporary literature has demonstrated that patient-related factors, such as oral hygiene and caries experience, may play an important role in the survival of restorative treatments. Patients, who successfully followed an oral health program focusing on education and motivation, showed a better restoration survival.

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# Early Childhood Caries

# 15

Soraya Coelho Leal and Eliana Mitsue Takeshita

## 15.1 Introduction

Early childhood caries (ECC) is considered a public health problem all over the world, as more than 600,000 children are living with untreated cavitated dentin lesions in the primary teeth [1]. The negative impact of ECC on children's lives is unquestionable and includes difficulties in mastication, loss of appetite and weight, irritability, difficulties in sleeping, low self-esteem and poor school performance [2–5].

Severe ECC (sECC) can lead to a complete destruction of the primary dentition (Fig. 15.1) and, if not treated, can result in toothache, infection and abscess [6, 7]. Additionally, expenses related to dental treatment are usually high. In some cases, general anaesthesia and hospitalisation are needed, being sECC the main reason for hospital admissions due to oral health problems in infants [8–10].

Finally, families of children with a history of tooth extraction, fistula/abscess or pulp exposure due to dental caries are likely to report poorer quality of life. Parents, to a large extent, tend to feel guilty about their children's oral health condition and, frequently, miss working days trying to solve the problem [6].

## 15.2 Prevention and Treatment

ECC prevention should start during the prenatal period. Expectant mothers are the ideal target of health education programs as they multiply attitudes within the family network, influencing the whole family dietary and hygiene habits [11]. In addition, mothers are the key person involved in the implementation of the child's

S. C. Leal (✉) · E. M. Takeshita
Department of Pediatric Dentistry, Faculty of Health Science, University of Brasilia, Brasília, Brazil



S. C. Leal, E. M. Takeshita (eds.), *Pediatric Restorative Dentistry*,
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**Fig. 15.1** All teeth of a 26-month-old child affected by dental caries characterising a typical clinical condition of sECC

oral health habits [12, 13]. However, in order to do it properly, they should be instructed on how to correctly perform the child's oral hygiene and be motivated to put what they had learned into practice. Moreover, they should receive anticipatory dietary counselling as diet is a key point in sECC prevention. Children who are early exposed to sugar-sweetened beverages are more likely to develop sECC [14, 15].

The prevention of (s)ECC is more cost-effective and less traumatic in comparison to treating advanced dentin carious lesions. An oral health program that was addressed toward pregnant women of low education level in combination with regular preventive oral visits for their infants during the first years of life has shown to be very effective in the prevention of the disease. The mean dmfs of children who attended the program at least once a year was 0.25 (SD = 0.93), while those who did not follow the program was 4.12 (SD = 6.56) [13]. These results corroborate the recommendation that the first child dental visit should take place around the age of 12 months, or when the first tooth erupts [16, 17].

In general, infants' oral health visit should include a detailed interview with the parents aiming to collect information to subside the child's caries risk assessment, followed by a clinical oral examination that will guide the professional in establishing individualised preventive strategies and recall intervals [18].

During the interview, the professional should advise parents/guardians with respect to healthy diet habits and highlight the importance of using fluoridated toothpaste in adequate amounts according to the child's age (Chap. 3). Pictures and illustrations showing the spectrum of dental caries—from sound to tooth loss—might be used in order to facilitate parents' understanding on the caries progress (Fig. 15.2).

Afterwards, an oral examination should be performed, positioning the child according to his/her age. If very young, knee-to-knee position is preferred (Fig. 15.3).

Prior to examining the teeth, a toothbrushing is performed, as the detection of enamel carious lesions—mandatory to the diagnosis of sECC—can only be carried out in cleaned teeth (Fig. 15.4a). Detecting such lesions is extremely important as the disease is still in a stage that can be controlled through non-operative measures [19–21] (Fig. 15.4b).

**Fig. 15.2** Child's first dental visit where a PowerPoint presentation is being used to assist the professional in explaining important aspects related to the prevention of ECC

**Fig. 15.3** The dentist is sitting knee-to-knee opposite to the mother with the child lying across their laps, allowing the dentist to assess the child's oral health status

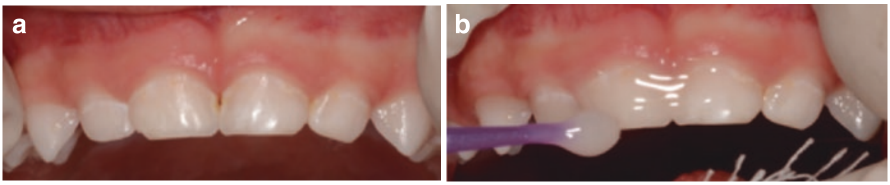


**Fig. 15.4** (**a**) Cleaned teeth showing non-cavitated enamel carious lesions at the buccal surfaces of teeth 52, 51, 61 and 62. A cavitated dentin carious lesion is observed at the mesial surface of the 51. (**b**) fluoride varnish is being applied to control caries progression of both cavitated and non-cavitated lesions

## 15.3 Management of Cavitated Dentin Carious Lesions

As presented in previous chapters, noninvasive, conservative and conventional approaches can be used to manage a cavitated dentin carious lesion (Table 15.1).

Whether the professional will opt for a noninvasive approach rather than a conservative or conventional intervention will depend on a variety of factors such as the

**Table 15.1** Noninvasive, conservative and conventional approaches for managing cavitated dentin carious lesions

| *Approaches for managing cavitated dentin carious lesions* | | |
|---|---|---|
| Noninvasive | Conservative | Conventional |
| Silver diamine fluoride | Atraumatic restorative treatment | Metal/zirconia crowns |
| Ultraconservative approach | Hall technique | Resin composite |

**Fig. 15.5** Primary first molar and canine presenting cavitated dentin carious lesions that are being controlled through the ultraconservative approach in a noncollaborative child

child's age, child's and parent's cooperation, cultural aspects, dental setting and facilities, dentist's expertise and treatment costs [22]. There is no need, for example, to place a restoration in a cavitated primary tooth that can be regularly cleaned with a toothbrush and fluoridated toothpaste in a child who does not collaborate with the dental treatment (Fig. 15.5). Such ultraconservative approach has shown successful control caries progression at cavitation level in dentin [23].

Although this is not the focus of this book, it is important to stress that in case of toothache, the relief of pain should be prioritised by means of extraction or endodontic treatment. Whether the treatment will be offered in a dental office or under general anaesthesia is a decision that should be made together with the family, considering the child's clinical condition, his/her ability to collaborate and the costs.

Three clinical cases that exemplify noninvasive, conservative and conventional approaches in treating sECC are presented hereafter.

## 15.4 Noninvasive Approach: Silver Diamine Fluoride

### 15.4.1 Complaint

The mother sought for dental treatment complaining that her 14-month-old daughter's teeth were "breaking apart" (Fig. 15.6a, b). She reported that an attempt to restore the teeth had been made by another professional but without success. The only restoration that partially remained was the one placed on the 71.

### 15.4.2 Anamnesis

During the interview the mother informed that her daughter was still breastfed at free demand, that she has already been introduced to sugar-containing food and that the oral hygiene was not being performed regularly. In addition, problems during pregnancy, resulting in premature delivery (32 weeks) and the child living for 4 weeks in an incubator, were reported.

### 15.4.3 Oral Examination Findings

Demarcated opacities were observed on teeth 61, 62 and 72 (Fig. 15.6a, b), and an enamel breakdown was detected on the buccal surface of the 82 (Fig. 15.6a).


**Fig. 15.6** (**a**) Clinical aspect of the front teeth of a 14-month-old child, where cavitated dentin carious lesions on teeth 52, 51, 62 and 81 are observed. Moreover, demarcated opacities are present on teeth 61, 62, 72 and 82, which already evolved to a posteruptive enamel breakdown. (**b**) active dentin carious lesions are observed. (**c**, **d**) a microbrush is being used to apply SDF on the cavitated lesions. (**e**, **f**) clinical aspect after 15 days of having applied the SDF

Moreover, cavitated dentin carious lesions were observed on teeth 52, 51, 61, 62 and 81 (Fig. 15.6a, b). Considering the clinical aspect of the dentin—wet and soft—(Fig. 15.6b), the lesions were judged active.

### 15.4.4 Diagnosis and Treatment

An atypical pattern of sECC is observed, as the lesions are not located at the gingival margin but at the incisal area of the front teeth. This might be explained by the fact that amelogenesis was probably negatively affected by the problems faced by the child during pre-/perinatal phases, resulting in a hypomineralised enamel that, as soon as the teeth erupted, evolved to posteruptive breakdown (PEB). The combination of a poor oral hygiene, a high frequency of fermentable carbohydrates and the presence of PEB is the possible cause of such an aggressive and rampant form of dental caries.

In terms of treatment care, the mother was instructed regarding behavioural changes required at home with respect to diet and the use of fluoridated toothpaste on daily basis. As shown in Chap. 1, the success of the treatment depends, to a large extent, on convincing the parents about their responsibility regarding their children's oral health.

Considering the child's lack of collaboration, and the need to immediately stop the caries progression, a decision to apply silver diamine fluoride (SDF) was made. As presented in Chap. 7, one of the main disadvantages of the product is the potential of black staining the carious tissue. Therefore, the parents were informed about this negative aspect of SDF but, even so, agreed with the dental care plan by signing an informed consent.

The application of the SDF is shown in Fig. 15.6c, d, and the final aspect, 15 days later, can be observed in Fig. 15.6e, f. It is interesting to highlight that the mother, although dissatisfied with the black appearance of the teeth, said that the stained areas became hard, allowing her to properly brush, something that was not being performed prior to the application of the SDF.

## 15.5 Conservative Approach: Atraumatic Restorative Treatment

### 15.5.1 Complaint

The mother's main complaint referred to the presence of dental caries in the front teeth of her son aged 30 months.

### 15.5.2 Anamnesis

Child's general health was considered good. During anamnesis the mother stated that toothbrushing was performed by the own child once a day (usually after lunch), who was put to sleep with a bottle containing sweetened milk flavoured with chocolate.

### 15.5.3 Oral Examination Findings

The oral examination revealed cavitated dentin carious lesions affecting the mesial surfaces of teeth 51 and 61 and active enamel carious lesions on the buccal surfaces of teeth 52, 62, 74, 72, 82 and 84 (Fig. 15.7).


**Fig. 15.7** (**a**) Cavitated dentin carious lesions involving the mesial surfaces of teeth 51 and 61. (**b**) the cavities are opened and easily accessible with hand instruments. (**c**) note that enamel and the enamel-dentin junction are completely free of carious tissue. (**d**, **e**) final aspect of the restorations immediately after being placed

### 15.5.4 Diagnosis and Treatment

The patient was collaborative, but, considering his age and the number of active lesions, a decision to restore the cavities with high-viscosity glass ionomer following the ART protocol was made. However, before implementing the restorative treatment, the mother received information on how to perform the child's toothbrushing and about the importance of using fluoridated toothpaste. Additionally, the whole of sugar in the caries development was discussed, allowing the mother to conclude that the bottle was no longer an option.

A thin unsupported carious enamel that could be easily removed by hand instruments is observed at the mesial of the 51 (Fig. 15.7b). By breaking the enamel, both cavities could be cleaned up to firm dentin, while all carious tissue was removed from the enamel-dentin junction (Fig. 15.7c). The cavities were filled in with chemically activated high-viscosity glass ionomer (Fuji IX®, GC America), and the restorations' final aspect is presented in Fig. 15.7d, e.

## 15.6 Conventional Approach: Resin Composite

### 15.6.1 Complaint

Aesthetics of the front teeth was the chief complaint by both mother and child. It is important to highlight that the patient, a girl of only 4 years old, reported that she did not like to smile because her teeth "did not look nice" and her mates at school would "laugh at her over this".

### 15.6.2 Anamnesis

The mother reported an attempt to treat the child a year ago, but, due to the lack of collaboration, they decided to postpone the restorative treatment. Meanwhile, the parents stopped bottle feeding the child during the night and implemented daily toothbrushing practices with 1100 ppm fluoridated toothpaste.

### 15.6.3 Oral Examination Findings

During oral examination, cavitated dentin carious lesions involving the teeth 51, 52, 61 and 62 were observed (Fig. 15.8a). Carious lesions were judged to be inactive, but very deep cavities were present on teeth 52 and 62 (Fig. 15.7b). There was no report of spontaneous pain. The X-ray confirmed the clinical diagnostic (Fig. 15.8c), but the decision whether the tooth would need an endodontic treatment would be made only during the transoperative procedure.


**Fig. 15.8** (**a**) Initial clinical aspect of the front teeth of a 4-year-old girl showing cavitated dentin carious lesions on the buccal surfaces of teeth 51, 61 and 62. (**b**) cavitated dentin carious lesions are observed on the lingual of all front teeth, including the 52. (**c**) the X-ray confirms that the cavities present on teeth 52 and 62 are very deep. (**d**) the aspect of all cavities after carious tissue removal. (**e**) restorations immediately being placed

### 15.6.4 Diagnosis and Treatment

Considering the inactivity of the carious lesions and that aesthetics was the concern, composite resin was considered the most suitable restorative material for this specific case.

Local anaesthesia was required before placing the rubber dam. Carious tissue was removed using a low-speed bur. All teeth were cleaned up to firm dentin. Pulp exposure was not observed (Fig. 15.8d). The final aspect of the restorations is shown in Fig. 15.8e.

## 15.7 Final Considerations

- (s)ECC prevention lies through parents/guardians' education with respect to good oral health hygiene and diet habits.
- The first child dental visit should take place around the age of 12 months, or when the first tooth erupts.
- Recording enamel carious lesions is essential to non-operatively control the disease in its initial stage.
- Once cavitated dentin carious lesions are observed, different strategies to manage ECC are available. The decision-making process should be based on aspects such as the child's age, child's and parent's cooperation, cultural aspects, dental setting and facilities, dentist's expertise and treatment costs.

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# Oral Health Maintenance

# 16

Eliana Mitsue Takeshita, Fernanda Raposo, Lúcia R. M. Baumotte, Vanessa R. Carvalho, Ana Cristina C. Rodrigues, and Soraya Coelho Leal

## 16.1 Introduction

The commitment between the family—child and parents—and the professional is an important way to ensure the treatment success and to maintain the child's oral health. For this, the family should be motivated to keep the good habits that must have been adopted at home while the dental treatment was being provided. This is not an easy task, and the professional should be aware that different ways of communication are required considering the oral health literacy, defined as the "degree to which individuals have the capacity to obtain, process and understand basic oral health information and services needed to make appropriate health decisions" [1], of those who are being approached.

Basically, a maintenance plan care aims to preserve the patient's oral health and to avoid the recurrence of dental caries and/or periodontal disease and malocclusions and, in the meantime, to diagnose early stages of new manifestation of oral diseases, in case they occur. So, as soon as the treatment is completed, the patient should be included in a preventive program that must be designed according to his/her individual needs; otherwise, the disease control might not be efficient. This initiative increases the odds of a successful dental treatment.

Placing a restoration does not mean that caries disease is controlled or arrested. In fact, restorations are the best strategy to manage cleansable cavitated carious lesions, to avoid plaque accumulation, and to protect the pulp-dentin complex and arrest the lesion by sealing it [2, 3], but they do not address the cause of the problem. As shown in Chaps. 4 and 5, oral hygiene and diet habits, as well as the exposure to fluoride, are essential in controlling the disease.

E. M. Takeshita (✉) · F. Raposo · L. R. M. Baumotte · V. R. Carvalho
A. C. C. Rodrigues · S. C. Leal
Department of Dentistry, Faculty of Health Science, University of Brasilia, Brasilia, Brazil



S. C. Leal, E. M. Takeshita (eds.), *Pediatric Restorative Dentistry*,
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The most common and effective way to supervise patient's oral health status is supposed to be through "recall" visit, which is defined as "the planned, unprecipitated return of a patient who, when last seen, was in good oral health" [4]. During the recall visit, a clinical examination should be carried out to evaluate the presence of signs and symptoms of oral diseases and to reevaluate dental treatments previously provided, including restorative care. However, although dental associations worldwide recommend such follow-up visits, a Cochrane systematic review concluded that insufficient evidence exists for making any recommendations about the beneficial effects of the recall visits, as well as the optimal interval for dental checkups [4]. This does not mean that they are not effective but that more longitudinal studies about the topic are required. Meanwhile, the professional should be attentive to the patient's individual needs and on this basis design his/her maintenance oral health plan care.

## 16.2 Recall Visits

Traditionally, many dental professionals from different countries recommend dental visits at 6-month intervals. However, as just discussed above, there is no evidence to support this recommendation [4]. In that way, the UK National Institute for Health and Care Excellence (NICE) proposed, in 2004, that, in general, patient's recall intervals should be based on individual risk status and a recall interval with an upper limit of 12 months for patients younger than 18 years old [5]. In each recall visit, the interval should be adjusted according to the patient's caries risk and oral health-maintaining skills, which can vary from 3 to 12 months. This is in line with the American Academy of Pediatric Dentistry (AAPD) guideline, which recommends that the follow-up visits should be based on patient's individual needs and on risk indicators and that intervals can be more or less frequently than 6 months [6].

With respect to dental caries, one strategy that can assist the professional in determining the periodicity of follow-up visits is to make use of the caries risk assessment (CRA) tools presented in Chap. 1, or even any other system used by the dentist to identify patient's caries risk profile. The recommendation is that at every dental checkup, a new CRA is carried out to estimate the probability of new carious lesions to develop [7], and thus, on the basis of this new evaluation, the recall interval is then established. In order to facilitate the link between what is being observed clinically and the recall intervals, a set of variables were used to classify the child in "low," "moderate," and "high" risk [8] as shown in Table 16.1.

According to this model, patients will be allocated in different recall intervals, on the basis of their own specific needs (Fig. 16.1).

A systematic review concluded that early preventive dental visits are associated with more subsequent preventive dental visits and may be associated with reduced restorative dental care visits [9]. Moreover, a gradual exposure of children to the dental environment in sequential dental visits has shown to reduce their levels of

**Table 16.1** Risk assessment and recall intervals[a]

| Classification | Group | Clinical conditions | Recall interval |
|---|---|---|---|
| Low risk | A | Absence of cavitated caries lesions or restored teeth, without dental plaque, without gingivitis, and/or without active initial caries lesions | 12 months |
| Moderate risk | B | Presence of restored teeth. Absence of dental plaque, gingivitis, and/or active initial caries lesions | 6 months |
| | C | Presence of only inactive caries lesions associated with absence of dental plaque or gingivitis | 6 months |
| High risk | D | Presence of dental plaque, gingivitis, and/or active initial caries lesions associated with absence of cavitated caries lesion or restored teeth | 3 months |
| | E | Presence of one or more active cavitated caries lesions | 3 months |

[a]Adapted from Abanto et al. [8]

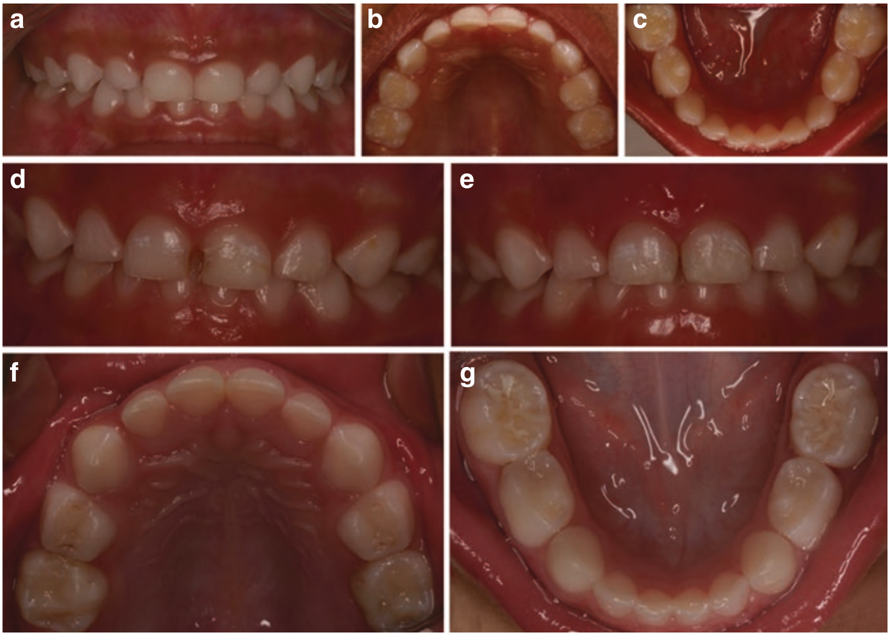


**Fig. 16.1** (**a**–**c**) The mouth of a 4-year-old child presenting a healthy dentition with no past caries experience. The recall interval was scheduled within 12 months; (**d**) clinical aspect of the front teeth of a 3-year-old child, where cavitated and non-cavitated lesions are observed; (**e**–**g**) the clinical aspect immediately after placing the restorations (front teeth and proximal surfaces of teeth 74 and 84) and ART sealants on the occlusal surfaces of the 75 and 85. This recall visit was planned within 3 months due to the number of enamel lesions and restorations placed

dental anxiety [10], not to mention the gain in oral health-related quality of life. It is known that poor oral health conditions can negatively interfere with eating, speaking, self-esteem, and growth. Children with dental pain may be irritable, withdrawn, or unable to concentrate and entail on absent from school at least a day per year [11]. Therefore, by means of regular dental visits, it is possible to prevent that, for example, a margin defect in a restoration evolves to a more serious condition that might end up in causing infection and dental pain.

## 16.3 What to Be Evaluated During a Recall Visit

In addition to the use of CRA tools, some important aspects should also be taken into account when determining the child's recall visit intervals, which may vary in importance according to child's age. For children during the primary dentition (0–5 years old), factors such as the frequency of carbohydrate consumption, oral hygiene habits, and exposure to fluoride are of great relevance. As discussed in previous chapters, dental caries is a biofilm-dependent disease. The frequent sugar intake promotes a low pH environment in the oral cavity, unbalancing the demineralization and remineralization process, leading to an initial damage to the enamel surface that can progress to cavitation depending on time. In this age group, it is not unusual to observe the presence of early childhood caries that, if not treated in early stages, can lead to a premature tooth loss as shown in Chap. 15. Therefore, during the recall visit, diet counseling should be reinforced to parents and caregivers, following the recommendations provided in Chap. 4.

Oral hygiene should be evaluated by checking the presence of biofilm on vulnerable dental surfaces. For this age group, dental surfaces that are most prone to develop carious lesions are the occlusal surfaces of the mandibular and maxillary second molars, followed by the occlusal surfaces of the mandibular first molars and the buccal and mesial surfaces of the maxillary central incisors [12, 13]. Therefore, parents should be advised that certain areas require from them special attention during brushing. Moreover, they should be aware that initial carious lesions can be controlled or arrested by regularly biofilm removal with fluoridated toothpaste [14, 15].

In combination with oral hygiene, the use of topical fluoride is an important strategy to prevent the demineralization and promote the remineralization process. It is recommended the daily use of fluoride-containing dentifrice starting with the eruption of the first tooth, irrespective to the child's caries risk [16]. Parents should be guided in terms of the amount of toothpaste to be used, as presented in Chap. 5.

Finally, parents should be taught that caries experience in the primary dentition, the consumption of sweets and soft drinks, and low brushing frequency have been reported as predictor for caries in the permanent dentition [17, 18]. More than two surfaces of the primary second molars affected by dental caries in a child at 5 years of age are considered to be a clinically useful predictor for that child to be at high risk at the age of 10 [19].

Children in mixed dentition (6–11 years old) are at the most vulnerable period for the development of carious lesion in the permanent teeth, mainly for the occlusal surface of the first permanent molars, due to biofilm accumulation associated to an ineffective brushing technique, while occlusion with their antagonists is not yet established [20]. In addition, newly erupted teeth are under post-eruption maturation process, which increases the susceptibility of caries development [21]. At last, a recently developmental enamel defect described in the literature termed molar incisor hypomineralization (Chap. 7) has shown to increase the chances of a first permanent molar to develop dental caries. Strategies to manage these clinical conditions are presented in Chaps. 5, 7, and 8. Therefore, special attention should be given to these factors when determining the interval period of dental visits for a child at this age group or to any other atypical condition identified.

Independent of the child's age, the detection of an active carious lesion during a follow-up visit is a warning sign that the child does not only require care at that moment but that the intervals between further dental visits should be shortened. The same concern applies to children who received a large number of restorations as they cannot be considered as a definitive treatment. In some cases the "restorative cycle" is expected, meaning that some teeth will undergo a number of restorations over time [22]. Moreover, secondary caries can develop at the margin of an existing restorative material [23] increasing the risk of restoration failure.

Cariogenic biofilm has shown to negatively affect on the survival of restorations, probably by acting directly on the material deterioration and, particularly, on the development of new carious lesions of rapid progression [24]. A systematic review on the survival of primary teeth restorations and reasons for failures found a high number of failures associated with restorations in primary teeth, and the main reason of failure was secondary caries, indicating the need for professionals to work with a health-promoting approach [25].

> The restorative procedure should be part of a care plan in which preventive measures, including diet counseling and positive reinforcement in terms of good oral hygiene habits, are implemented along with the provision of the dental treatment and will be part of the maintenance oral health plan care

Lastly, it is important to address the need and in which situations a dental filling needs to be replaced, since the procedure can promote the loss of sound tissue during the removal of the remaining restoration. Regarding that, special attention should be given to the fact that, if selective carious removal was used to clean the cavity, a dark zone under the restoration, especially in deep and very deep carious lesions, might be present in a follow-up radiographic exam (Fig. 16.2). Therefore, the professional should carefully describe in the child's chart what has been done as well as having collected the parents' informed consent. This strategy will assist the professional in not misdiagnosing this situation with secondary caries. Other

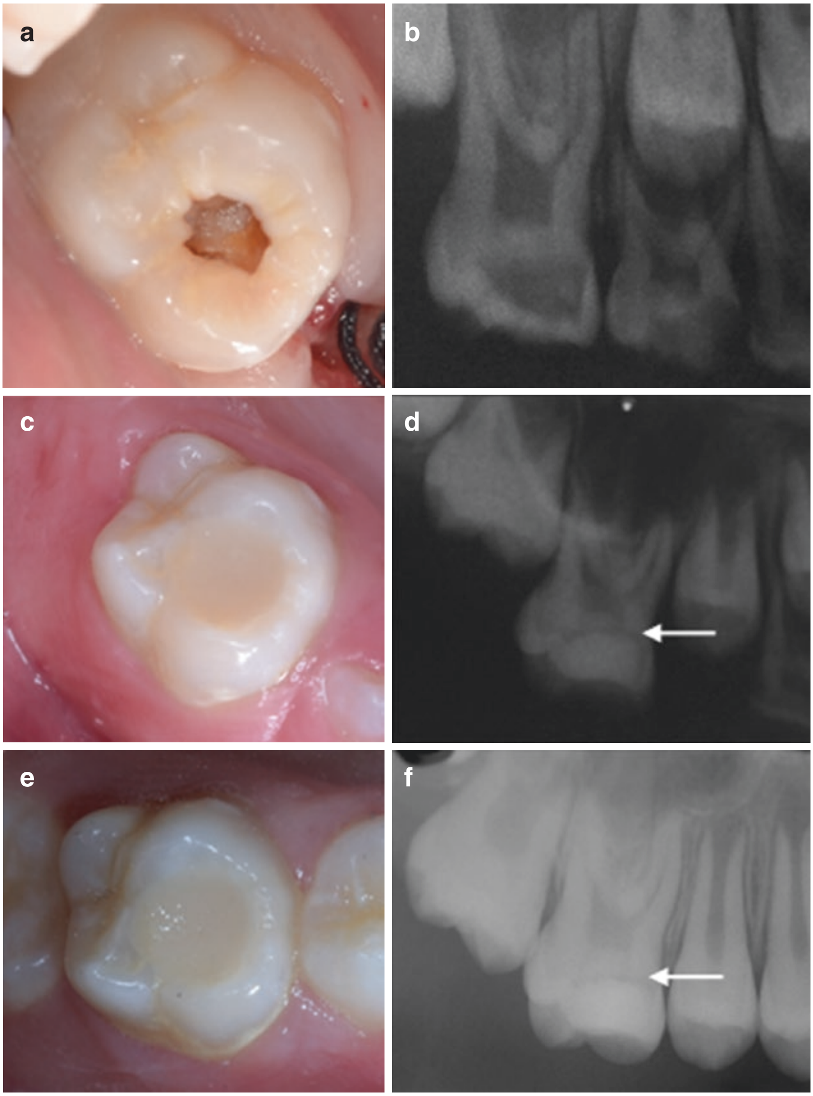


**Fig. 16.2** (**a**) Clinical aspect of a cavitated dentin carious lesion on the occlusal surface of a first permanent molar; (**b**) the radiography in which a deep carious lesion is observed; (**c**) the same tooth after 8 months of receiving a restoration; (**d**) the arrow indicates a dark zone underneath the restoration, indicating that selective carious removal was used to clean the cavity to avoid pulp exposure; (**e**) the clinical aspect of the restoration after 24 months; (**f**) the procedure is radiographically successful, although a demineralized zone under the restoration is still observed (arrow)

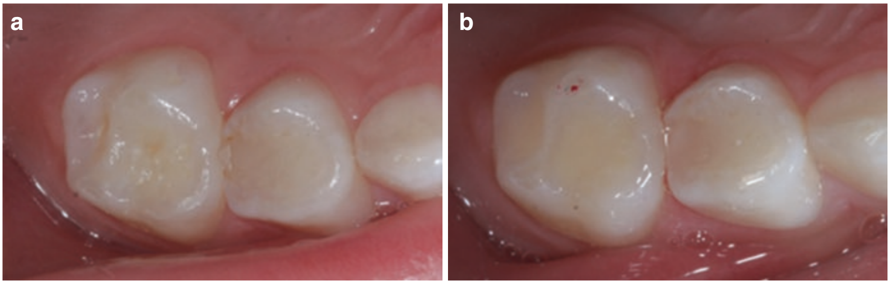


**Fig. 16.3** (**a**) An initial active enamel carious lesion on the occlusal surface of the second primary molar (55) and a defect on the proximal restoration of the first primary molar (54) were observed in a 4-year-old child; (**b**) an ART sealant was placed on the 55, and a repair was made on the proximal restoration of the 54

clinical aspects should be observed such as the presence of fistula and the report of dental pain.

In case of defective restorations, re-restoring primary molars may not always be necessary [26]. A careful clinical assessment is recommended in order to determine whether the re-exposed cavity is easily cleansable or not [26]. Moreover, before deciding to remove completely the restoration, it is worth considering repairing the restoration instead of replacing it (Fig. 16.3).

## 16.4 Final Considerations

Although there is insufficient evidence regarding the beneficial effects of recall visits, an organized and well-planned treatment is important to control the dental disease and to achieve the success of maintaining a good oral health. In practice, the compliance among parents, patient, and professional is constructed over time, and the recall visits are the instrument to fortify this alliance, as well as counseling about the factors that might influence on the recurrence of oral disease.

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