Pit and Fissure Sealants

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Preface

Although caries prevalence has declined in developed countries over the past several decades, it still remains the most prevalent infectious disease worldwide, affecting 60 to 90% of school children and the vast majority of adults. In children and adolescents, occlusal surfaces of first and second molars are the sites most likely to have caries experience from the beginning of tooth eruption. Pits and fissures of these surfaces are predestinated to trap debris and microorganisms, making the hygiene procedures of these areas more difficult, and allowing greater plaque aggregation. Sealants were developed to help manage these sites of the tooth and safeguard the surfaces from decay.

This book provides wide-ranging information on current clinical and scientific knowledge on the various aspects of fissure sealing. Trends in the epidemiology of caries are first examined, followed by a thorough description of the morphology of pits and fissures and types of sealant. The role of sealants in the prevention of caries is discussed. Diagnostic parameters are presented, along with step-by-step descriptions of clinical procedures for fissure sealing. Chapters are also included on alternative techniques of fissure sealing, sealing of carious fissures, and therapeutic fissure sealing. The final chapter in the book focuses on the cost effectiveness of the procedure.

The different chapters of this book were written by acknowledged experts in the field. It will be of value for all dental professionals seeking to deepen their understanding of current knowledge on the science and the clinical application of pit and fissure sealants.

Vienna, Austria
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Contents

1 Trends in Caries Epidemiology in Children

Ulrich Schiffner

Abstract

Caries in permanent teeth is still the most prevalent disease worldwide. However, there are numerous reports about a caries decline with respect to caries prevalence and caries experience (DMFT or dmft scores). The most pronounced caries decline has been noticed in 12-year-old children in industrialized countries. These reports might obstruct the view on the epidemiological caries development in the primary dentition, which is not as successful as in the permanent dentition. Regarding the age groups of 3-year-old or even younger children, there are only limited data. These data show considerable differences in caries prevalence, but consistently a caries decline, even of widely varying magnitude. In 5- to 7-year-old children there is indeed an obvious trend for a caries decline over the last decades. However, this decline is only weak since around the year 2000, and in some countries there are indications for a halt or even a reversal of the caries decline in the primary dentition in this age group. The data for 12-year-old children demonstrate a distinct caries decline, which has continued through all last decades and reached DMFT values of 0.5 or less in some countries. However, parallel to the caries decline, there is an increasingly stronger caries polarization. Analytical caries epidemiology provides strong indications for an enhancement of the caries decline by placing fissure sealants. This effect seems to be particularly important in children with low SES background who benefit from this caries preventive measure to higher extents than other children.

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1.1 Introduction

Dental caries is frequently cited as an oral disease with both declining prevalence and average experience. However, taking the whole distribution and severity of caries worldwide into consideration, it turns out that caries in permanent teeth is still the most prevalent condition worldwide, affecting 2.4 billion people, and that untreated caries in deciduous teeth is the tenth most prevalent condition [1]. Globally, the prevalence of untreated caries over all age groups seems to have been static between 1990 and 2010. However, there are considerable variations between regions and countries, and the manifestation of cavitating caries seems to shift from childhood to adulthood [1].

Caries prevalence and caries experience are key figures of oral health in children and other age groups. While the caries prevalence is defined as the percentage of persons in the respective cohort which shows any finding of caries (untreated or treated by restorations or extractions), the caries experience reflects the mean number of such caries affected teeth in a cohort.

Caries experience is expressed as DMFT index which is the average sum of caries affected teeth. The respective teeth exhibit unrestored caries (*D* = "decayed") and restored dentin caries (*F* = "filled") or are extracted due to caries (*M* = "missing"). The teeth are added per individual, the average sum gives the DMFT in a cohort, age cohort or population.

When presenting and discussing trends in caries epidemiology, some general features and limitations regarding the published figures have to be recollected. Most epidemiological data regarding caries are derived from clinical investigations under field conditions, and x-ray findings are not included [2]. In addition, caries scoring is most often restricted to lesions with the involvement of dentin [3]. Limiting the notated caries to such defects overlooks earlier caries stages like initial lesions or those confined to the enamel. Although modern understanding of caries starts at the first noticeable levels of the disease and although the restriction of epidemiological caries scoring has been considered inappropriate [4], the majority of all caries epidemiological studies worldwide still follow this WHO recommended matter. As a consequence, caries will be underscored to an unknown degree. However, as this approach has been followed since decades, it makes the respective studies comparable. Thus, also trend lines can be concluded from these studies with sufficient validity.

The most comprehensive international collection of data on caries prevalence and experience exists for 12-year-olds. This age group is chosen for caries epidemiological surveys as recommended by WHO [3]. Other age groups which are frequently considered in caries epidemiological reports are 3-year-old (2 to 4 years) and 6-year-old (5 to 7 years) children (Country/Area Profile Project 2017 [5]).

In general, both the caries prevalence and the caries experience show a distinct decline in children in many industrialized countries during the last decades. In a number of countries, this caries decline has been demonstrated on the basis of nationally representative surveys. However, it has to be recognized that the successful story of caries decline regards mainly the permanent dentition but not, at least not to the same magnitude, the primary dentition.

Modern caries epidemiology is not only primarily observational and descriptive but also attempts to explain the observed trends by reporting associations with caries relevant variables (analytical epidemiology [2]). Such parameters can be caries etiological factors, preventive measures, behavior, attitudes, and more. For example, caries burden can be related to the presence of fissure sealants. Based on analytical epidemiological approaches, the main reason for the caries decline is judged to be the widespread availability of fluoride. In addition, the increasing application rates of fissure sealants are a further cause for the reduced caries burden in children in some countries.

In the following pages, descriptions of the trends in caries prevalence and experience in different age cohorts in a range of industrialized countries will be given. The main data sources are publications of the Country/Area Profile Project [5] and the OECD [6]. The data selection is based on the availability of nationwide surveys if possible. However, in some countries local surveys have been conducted which are commonly cited as national reports. Furthermore, it should be taken into account that the exact age groups which have been examined differ between some countries. For these reasons the trend lines are not to be used for comparisons between countries. However, as in the included countries epidemiological field studies have been conducted repeatedly, robust conclusions about trends in caries prevalence, experience, and distribution can be drawn.

1.2 3-Year-Old Children

There is common agreement that the prevalence and extent of caries later in life are based on caries in the very early years of childhood, and many dental health problems are caused by inappropriate oral health behavior or life conditions during this time. However, there are only limited data regarding the age groups of 3-year-old or even younger children. The respective reports give mainly data about the prevalence of caries-affected children.

Table 1.1 summarizes data about the caries prevalence in 3-year-old children from countries with repeated surveys. Obviously, the caries prevalence in this age group differs considerably between the different countries. However, in each of these countries, there is a decline in caries prevalence in this age group, even though with widely varying magnitude. In Germany, regional examinations have revealed caries prevalences between 10 and 15% in 3-year-old children from 2000 to 2010 [7]. Hitherto unpublished data from the German city Hamburg show a distinct decline from 32.2 to 15.8% in the period between 1977 and 2006 (Schiffner, unpublished). A considerable decline is also reported from Sweden, with a caries prevalence of 4% in 2011 [5]. Trends in Australia, Poland, and the USA are also declining, but to a less marked degree [5].

1.3 6-Year-Old Children (Primary Dentition)

Data about caries prevalence and experience in the primary dentition of 6-year-old children are available in greater numbers of reports. While the official WHO reference age group are 5-year-old children [3], the majority of countries reports about

6- or 7-year-old children. This is due to the fact that in many countries school starts with 6 years and thus makes it easier to conduct surveys from this age on.

Figure 1.1a, b reflects the trends in caries experience (dmft or dft) in 5- to 7-year-old children in different countries worldwide (Data source: [5, 8]). Again it should be mentioned that these figures are constructed to exhibit trends, not to compare different countries, as the age groups, the nationwide representativeness, and the caries index (dmft or dft) are different.

Table 1.1 Trend in caries prevalence (dmft ≠ 0) in 3-year-old children in different countries

Country	Year	Caries prevalence (%)
Australia	2002	41
	2009	38
Germany[a]	1977	32.2
	1987	33.2
	1993	28.5
	1998	17.6
	2006	15.8
Poland	2002	56.2
	2015	53.8
Sweden	1985	17
	1990	9
	1995	7
	2000	6
	2005	5
	2011	4
USA[b]	1992–2002	27.9
	2011–2012	22.7

Data from [5]
[a]Hamburg, unpublished data
[b]Age 2–5

a

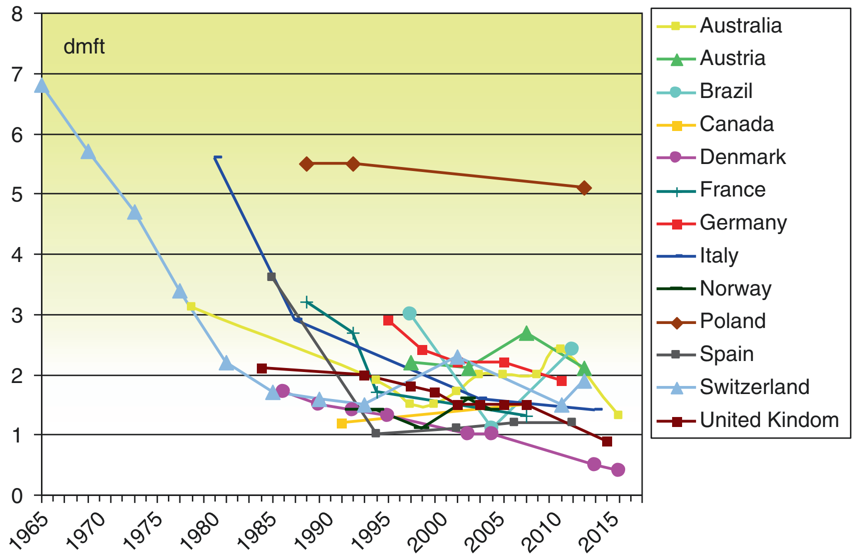


Fig. 1.1 (**a**) Trends in caries experience (dmft/dft) in 5- to 7-year-old children in different countries worldwide (Data from [5, 8]). (**b**) Trends in caries experience (dmft/dft) in 5- to 7-year-old children in different countries worldwide since ~2000 (Data from [5, 8])

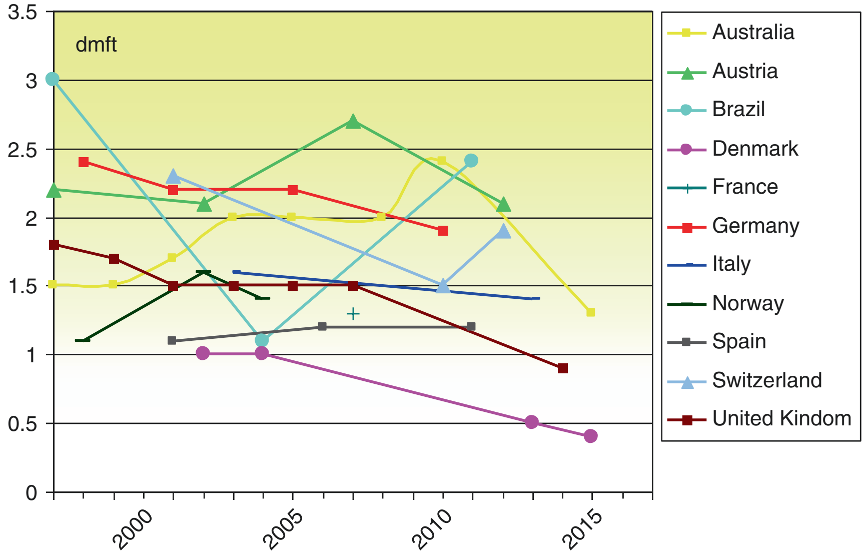
b


Fig. 1.1 (continued)

There is an obvious trend for a caries decline in 5- to 7-year-old children (Fig. 1.1a). However, going closer into detail with respect to the years since 2000, it has to be conceded that there is only a weak decline (Fig. 1.1b). In addition, there are indications for a halt or even a reversal of the caries decline in the primary dentition in some countries in this age group.

1.4 12-Year-Old Children (Permanent Dentition)

There is a huge number of reports about oral health and caries in 12-year-old children, who are an important WHO reference age group [3]. Caries prevalence and experience have been reported for this age group since decades. The country selection for this age group used in this review follows the sample of the 6-year-olds. The data demonstrate a distinct caries decline. However, it should be mentioned that in a comprehensive worldwide perspective, the decline is not convincing, at least not since 2000. Calculation of a global DMFT in 12-year-old children in fact shows a decline from 2.4 in 1980 to 1.9 in 2015, but regarding the years 2001 and 2004, even lower global DMFT values of 1.7 and 1.6, respectively, have been presented [9]. The inconsistent epidemiological development of the caries burden is due to increasing caries scores in some parts of the world, while in industrialized countries a decline predominates.

The declining trend of caries experience (DMFT) in 12-year-olds is illustrated in Fig. 1.2a, b, which are based on different data sources [5, 6, 8, 10]. Again, these illustrations cannot be used for comparisons between countries, but to carve out a trend. There is a strong caries decline over the observation period (Fig. 1.2a). The statement of a caries decline is also valid when going into detail and focusing on the

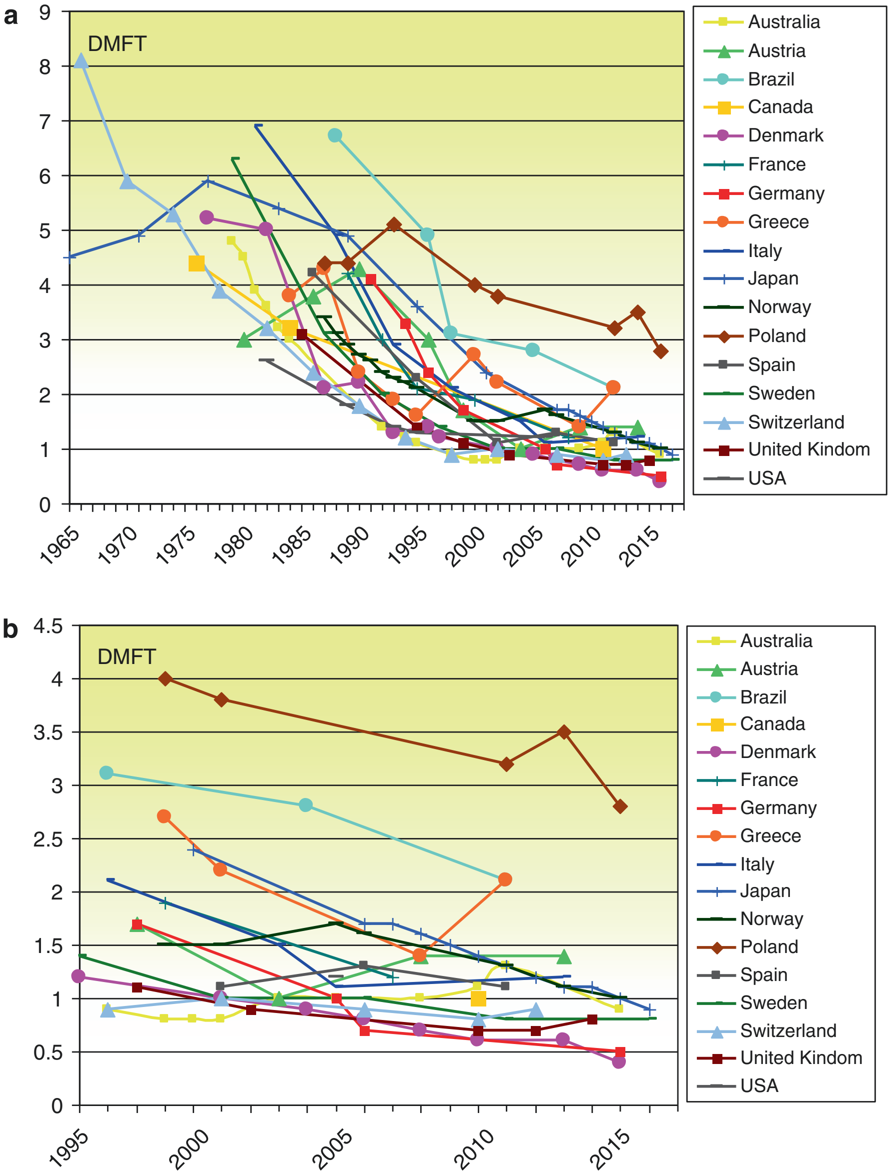


Fig. 1.2 (**a**) Trends in caries experience (DMFT) in 12-year-old children in different countries worldwide (Data from [5, 6, 8, 10]). (**b**) Trends in caries experience (DMFT) in 12-year-old children in different countries worldwide since ~2000 (Data from [5, 6, 8, 10])

development since approximately the year 2000 (Fig. 1.2b): Even in those countries who had reached low DMFT values of about 1.0 around 2000, a further decline can be observed since then.

As an example for the strong caries decline in 12-year-old children in industrialized countries, the figures from Germany can be used. In Germany, nationwide representative oral health studies have repeatedly been conducted since 1989, using the method of cross-sectional studies. The surveys conducted in the years 1997 and 2005 and the recent study from 2014 ("Fifth German Oral Health Study") have used the same examination criteria [11]. Due to this maximization of methodological consistency, a range of validated comparisons is permitted.

In 2014, the teeth of 81.3% of the 12-year-old children in Germany were found to be free of dentine caries experience (DMFT = 0). In comparison to the preceding surveys, showing caries prevalence rates of 41.8% in 1997 and 70.1% in 2005, this means a massive improvement in oral health. Caries experience in 2014 as expressed by the DMFT value averaged 0.5 in this cohort of children which is one of the lowest figures for caries experience hitherto reported worldwide [5]. Caries experience has decreased considerably as compared with the former surveys from 1997 (mean DMFT = 1.7) and 2005 (mean DMFT = 0.7).

Regarding many industrialized countries, the strong caries decline in the permanent dentition of 12-year-olds is particularly striking when being compared with the epidemiological trend in the primary dentition of 5- to 7-year-olds. In the majority of all countries which have published reports about both age groups, the decline in the elder age group's permanent dentition is much more pronounced than that in the primary dentition. As an example, Fig. 1.3 illustrates the different degrees of caries decline in German school children [12]. This difference is remarkable as the examination in both age groups was performed according to the same study protocol by the same investigators. Obviously caries preventive measures show their effect in 12-year-old children to a high extent, while the more or less same measures are of less pronounced effectiveness in the primary dentition of younger children.

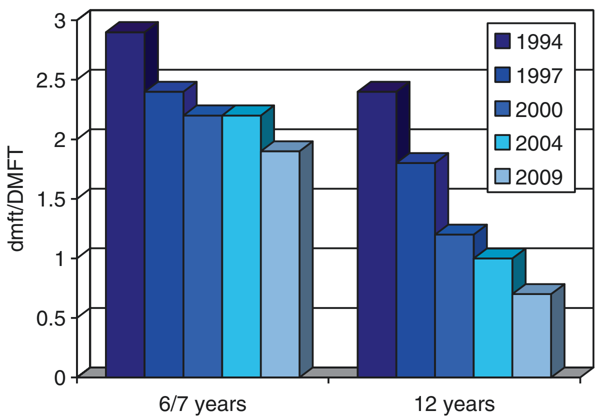


Fig. 1.3 Comparison of the trends in caries experience in 6- to 7-year-old children (primary dentition) and in 12-year-old children (permanent dentition) according to school-based samples in Germany [12]

1.5 Caries Polarization

The statement of the declining caries burden in children does not apply for all children. Parallel to the average decline, the phenomenon of the caries polarization becomes more and more apparent. Caries polarization means that not all individuals participate in the gain of oral health, but that a small group is not involved in this positive development and exhibits many more carious teeth than the majority of the age group [2]. The caries distribution and thus the polarization follow the socioeconomic status (SES) of the children and their families in many countries, with members of the lower social classes experiencing more caries and exhibiting more extracted teeth [2, 13–15]. Even if also children from families with low SES can exhibit improvements of their oral conditions (as shown, e.g., in 12-year-olds in Germany), the caries experience is still higher in these children and often shows higher portions of untreated caries. In the cited German study, children with high SES have a DMFT as low as 0.3, while children with low social background average out at a DMFT of 0.7 [11].

The parallel trend of a caries decline and a stronger polarization is exemplified by the representative German surveys (Table 1.2). Not only the caries prevalence and experience in 12-year-old children have declined but also the risk group which was constantly defined as all children with DMFT >2. As the percentage of these children has fallen from 21.5 to 6.1%, but as these children in all surveys account for nearly two thirds of all DMF teeth of the entire sample, this means a distinct sharpening of caries polarization.

1.6 Association Between Caries Decline and Fissure Sealing

Some comprehensive epidemiological studies also report about the prevalence and mean number of fissure sealants and relate these figures in an approach of analytical epidemiology to caries experience.

Regarding the German Oral Health Studies, one explanation of the significant decline in caries seems to be the increased use of fissure sealing. In 2014, a total of 70.3% of the children had at least one fissure-sealed tooth—an increase of 17.4% points over 1997, when 52.9% of the children had at least one sealed fissure (Table 1.2 [11]). In the 12-year-old children exhibiting fissure sealants, the mean

Table 1.2 Changes in caries prevalence, caries experience, risk group size, and fissure sealants in 12-year-old children in Germany (German Oral Health Studies III–V) [11]

	1997	2005	2014
Caries prevalence (DMFT ≠ 0, %)	58.2	29.9	18.7
DMFT	1.7	0.7	0.5
Risk group (%)[a]	21.5	10.2	6.1
Fissure sealant prevalence	52.9	71.7	70.3
Mean number of sealed teeth[b]	3.6	3.7	4.0

[a]DMFT > 2
[b]In children with sealants

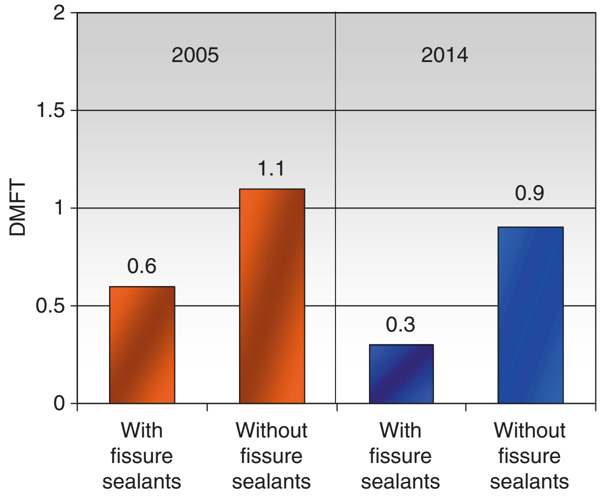


Fig. 1.4 Caries experience (DMFT) in 12-year-old German children related to the presence of at least one fissure sealed tooth in 2005 and 2014 [11]

number of sealed teeth has risen from 3.6 to 4.0 during this time period. The presence of fissure sealants turns out to be strongly related to caries experience in the 2014 survey: Children with at least one sealed fissure have an average DMFT score of just 0.3, while children without any sealant exhibit a DMFT value of 0.9 [11]. In comparison with the earlier study from 2005, the difference in caries experience between children with and without at least one sealed fissure has clearly increased, as the caries decline is particularly strong in children with sealed teeth (Fig. 1.4).

In the context of the social background of the German 12-year-old children, it is remarkable that children with low SES background have less frequent sealants than middle- or upper-class children (64.6 vs. 72.1% vs. 74.7%) and that the mean number of sealed teeth in children with any sealant also differs in relation to SES (3.7 vs. 4.0 vs. 4.3) [11]. However, the caries experience reducing effect of sealing fissures is clearly detectable also in children with low SES: In the representative German survey, the lower-class children with at least one fissure sealant exhibit a DMFT of 0.3, equaling the value of the whole sample and giving evidence for the importance of the sealing measure. In the publication of the Fifth German Oral Health Studies, it is concluded that the greatest oral health gain by sealing fissures is realized in children with low SES and that this measure is able to reduce the commonly noticed differences in caries burden between children with different SES [11].

The same importance of placing dental sealants has recently been estimated for children in the USA [16]. Comparing data for 6- to 11-year-old children from the National Health and Nutrition Examination Survey (NHANES) 2011–2014 with 1999–2004 NHANES data, the authors find an increase in sealant use prevalence by 16.2% points to 38.7% among children from low-income families. However, this is still less than in high-income children. In this study, low-income children without sealants had almost three times more cavities in permanent first molars compared with children with sealants (0.82 decayed or filled first molars vs. 0.29). The authors estimate that providing sealants to all low-income children would prevent 3.4 million cavities in the USA over 4 years [16].

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The Morphology of Pits and Fissures

2

Katrin Bekes, Stefan Tangl, Anton Dobsak,
and Reinhard Gruber

Abstract

Tooth development commences at the end of the fifth week of human gestation. It is commonly divided into the following stages: the initiation stage, the bud stage, the cap stage, the bell stage, and finally maturation. The aim of this chapter is to describe the process of early tooth development, through maturation and culminating in coronal formation. The morphology of pits and fissures is characterized showing serial ground sections and micro-CTs.

2.1 Early Tooth Development

Tooth development is a sequential and highly organized process and one that is increasingly understood at the histological, molecular, and cellular level, as exemplified in textbooks [1, 2] and reviews [3, 4]. Here, the histological level is briefly summarized. Tooth development is initiated at around 5 weeks in utero by a complex and continuing interplay of ectodermal epithelial cells derived from the first

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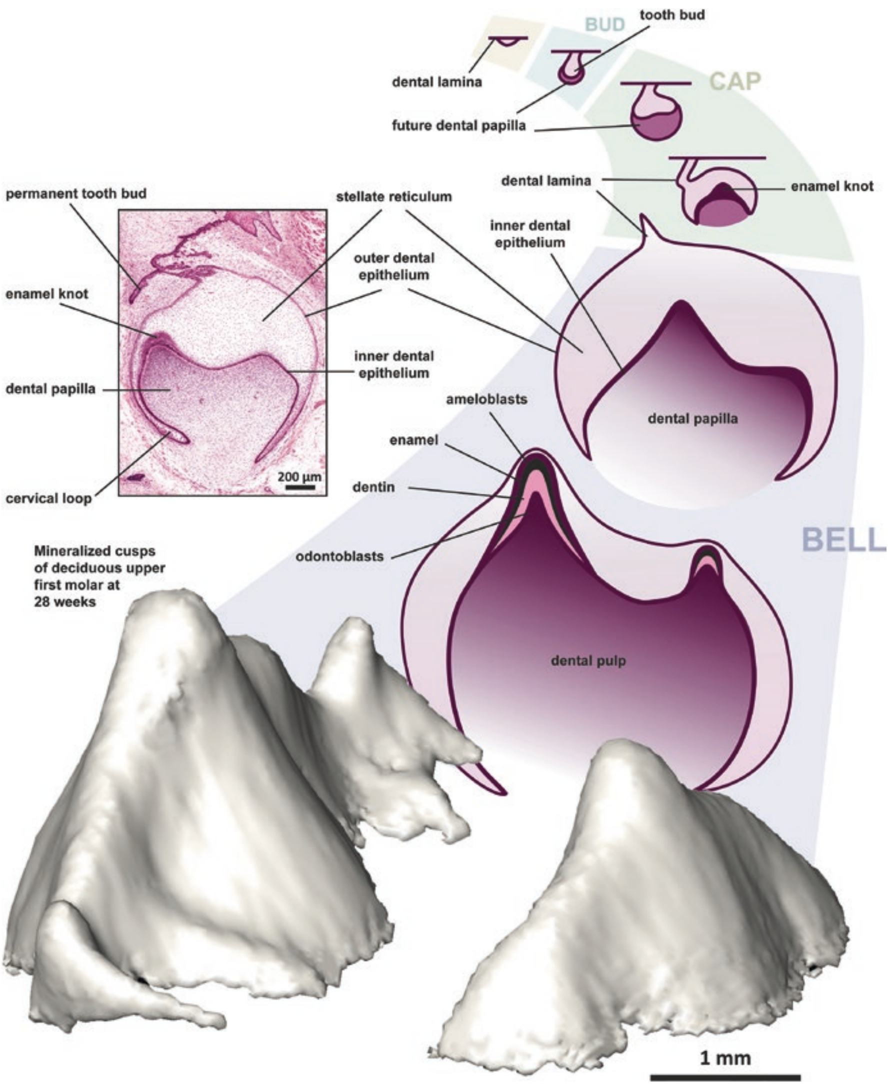

Fig. 2.1 Stages of tooth development

pharyngeal arch and the ectomesenchyme of the neural crest (Fig. 2.1). This interplay is termed reciprocal induction. At sites of the future dental arches, thickening of the dental lamina is followed by the invagination the oral epithelial cells into the underlying mesenchyme creating the tooth bud stage. The buds occur around the eighth week of embryonic development. The mesenchymal cells condense and release signals to initiate the primary enamel knot at the tip of the tooth bud. The primary enamel knot acts as a signaling center controlling the adjacent epithelial cells to form the enamel organ and mesenchymal cells to form the dental papilla.

The epithelium folding around the enamel knot represents the cap stage of the tooth by 11 weeks. Condensing mesenchymal cells surrounding the enamel organ form the dental follicle. The tooth germ is now organized into three parts: the enamel organ, the dental papilla, and the dental follicle — which later form the enamel, the dentin-pulp complex, and the periodontium, respectively.

Secondary enamel knots appear in future multi-cusped teeth representing new signaling centers defining crown morphology. The dental epithelium extends further into the mesenchyme forming the bell stage at around 14 weeks. The bell consists of an inner enamel epithelium enclosing the dental papilla and an outer epithelium covered by the dental follicle. At week 16, mesenchymal cells of the dental papilla differentiate into odontoblasts producing dentin. Epithelial cells of the enamel organ differentiate into ameloblasts producing enamel. Dentin formation begins before enamel formation is initiated. Cells in the cervical loop, at the transition of the inner and outer enamel epithelium (IEE, OEE, respectively), continue to divide creating the Hertwig's epithelial root sheath and define future root formation. The dental follicle cells differentiate into cementocytes, alveolar bone, and the periodontium. Teeth are now ready for eruption. At the age of 1 and 3, coronal and root development is complete in all these teeth, respectively.

The permanent dentition follows the same pattern of odontogenesis. The tooth germs of permanent teeth arise from the dental lamina on the lingual aspect of the deciduous tooth germ. As the permanent molars have no deciduous predecessors, the dental lamina burrows backward beneath the lining epithelium without a connection with the oral epithelium. All permanent molars are successively budded from the growing end. Coronal development of the first molars of the permanent dentition is completed by 3 years of age, and teeth will erupt around the age of 6 years. While the basic principles of odontogenesis are similar, teeth differ in shape and size [5]. Three hypothetic models of tooth patterning and morphogenesis exist. The "field model" presumes that all primordia are identical and three morphogenetic fields define the future tooth shape of incisors, premolars, and molars, respectively [6, 7]. The "clone model" suggests that each primordium is originally similar and the tooth patterning is defined by the sequence of initiation. The "odontogenic homeobox theory" states that a specific pattern of genes controlling tooth morphology defines the future tooth shape, including crown with their cusps, ridges, and fissures [8].

2.2 Cusps and Fissures

2.2.1 Development

The secondary enamel knots are the signaling centers of the developing enamel and therefore define the anatomy of the cusps. Teeth with at least two cusps have fissures, including deciduous molars, permanent premolars, and molars. The distance of the signaling centers affects the enamel thickness of the cusps and defines the morphology of the fissures [9]. Deep fissures are formed if the signaling centers lie far apart and fusion of the cusps occurs late. Pits occur where several developmental lines converge. It is usually situated at the junction of developmental grooves or at terminals of these grooves [10].

Occlusal fissures of human teeth cannot be categorized into specific groups on the basis of morphologic features. The average fissure depth of the individual tooth ranged from 120 to 1050 μm. The average width in the middle part of the fissure varied between 40 and 156 μm, the average thickness of the enamel at the bottom of the fissure was between 270 and 1008 μm, and the occlusal angle was between 51.6 and 84.5° [11]. A pit is a small, deep well originating on the lingual, occlusal, or buccal surface of both maxillary and mandibular molars.

2.2.2 Anatomy of the Crown of Molars and Premolars

2.2.2.1 Molars

The crowns of maxillary molars usually have three or five cusps. When they have four cusps, three are larger (the mesiobuccal, distobuccal, and mesiolingual), and the fourth cusp is smaller (the distolingual). On many maxillary first molars, there is a fifth, much smaller cusp (cusp of Carabelli) located on the lingual surface of the longest and largest cusp, the mesiolingual (Fig. 2.2). On many maxillary second molars, the fourth cup is missing resulting in three cusps [12]. Mandibular molar crowns normally have four or five cusps. Many have four relatively large cusps: two buccal (mesiobuccal and distobuccal) and two lingual (mesiolingual and distolingual). However, most mandibular first molars often show an additional fifth, smaller cusp called a distal cusp that is located on the buccal surface distal to the distobuccal cusp [12] (Fig. 2.3).

The occlusal surface of the first maxillary permanent molar shows two main fissures, one mesial and one distal. The mesial fissure originates between the two buccal cusps, runs diagonally, then turns mesially, and runs longitudinally. The distal fissure has its own origin between the palatinal cups. It runs distobuccally

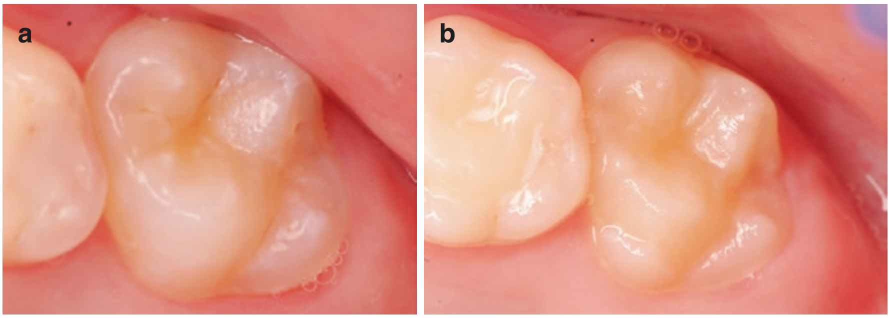

Fig. 2.2 Two upper first molars showing variations in the number of cusps: (**a**) four cusps (**b**) additionally a fifth, much smaller cusp

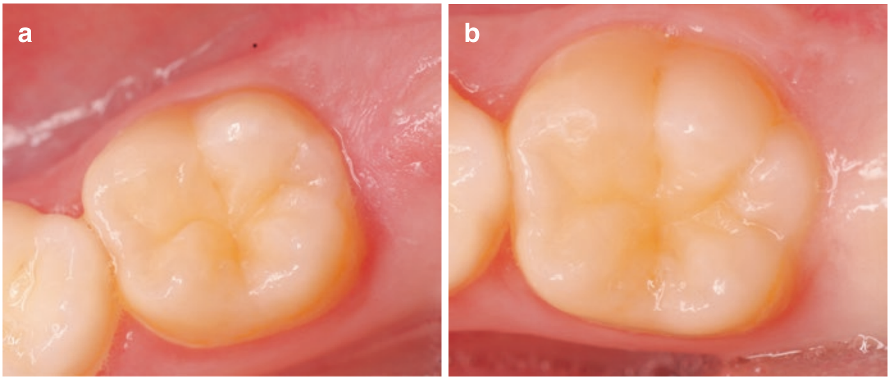

Fig. 2.3 Two lower first molars. The left one exhibits four large cusps, and the right one shows a fifth cusp

and ends in front of the marginal ridge [13]. The mandibular molars exhibit a main fissure running longitudinally from mesial to distal, usually ending in the region of the marginal ridge. Three diagonal fissures branch off from the center. In case of the first molar, one fissure runs toward the lingual and two run toward the buccal side. Depending on the number of cusps, a Y-shaped fissure pattern or an X pattern exists [13].

2.2.2.2 Premolars

Maxillary premolars and the mandibular first premolars usually have two cusps. Mandibular second premolars frequently have three cusps — one buccal and two lingual [12]. The basic fissure shape of the maxillary premolars is usually straight or S-shaped ending in a groove in front of the marginal ridge. The fissure runs from mesiopalatinal to distopalatinal. Variable diagonal fissures which separate the cusps toward the marginal ridges may occur [13]. The first mandibular molars show the greatest variation concerning the number and form of cusps and course of the fissures. The fissure courses of the second mandibular molars are closely related to the number and size of cusps. If the cusps are strongly developed, the fissure is usually Y-shaped, and if they are less developed, the course is half round. In case the tooth has only two cusps, the fissure will be straight [13].

2.2.3 Pit and Fissure Morphology

It is virtually impossible to determine the anatomical complexity and the depth of a fissure system by direct visual or radiographic examination. The first knowledge of pit and fissure morphology was based on examinations of serial ground sections of human teeth [14–16]. Thereby, Nagano classified the shapes of occlusal fissures into five types on the basis of the anatomical form [15] (Fig. 2.4):

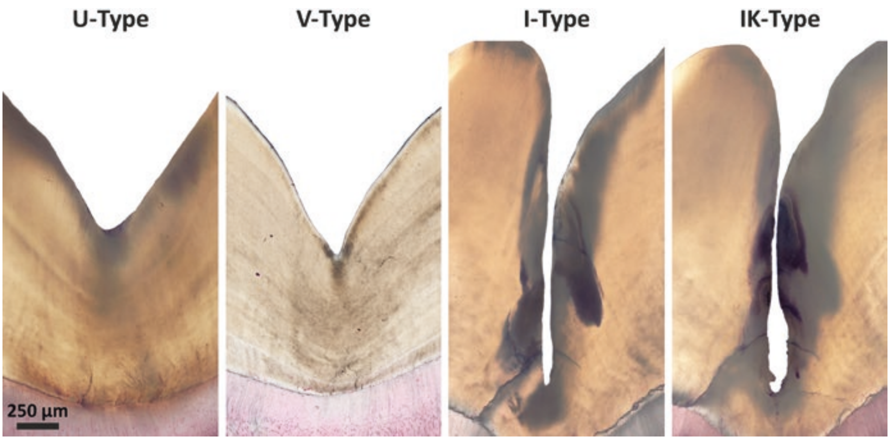

Fig. 2.4 Different shapes of fissures as classified by Nagano [15]

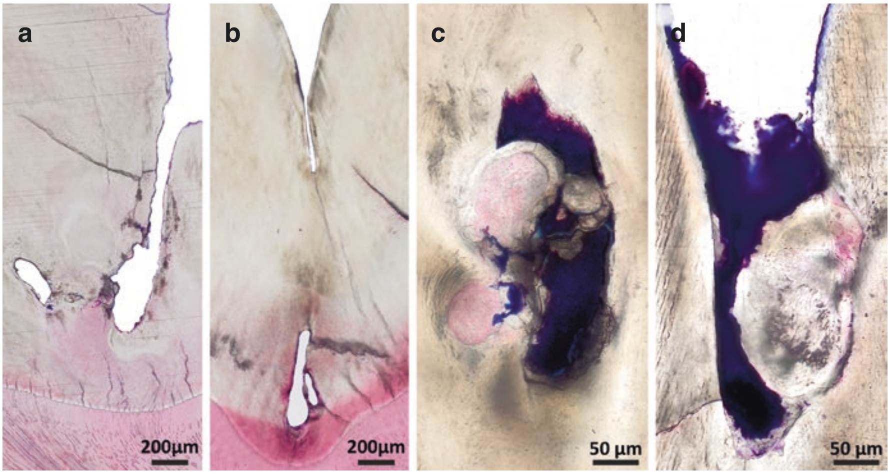

Fig. 2.5 (**a**, **b**) Morphological variants not classifiable after system of Nagano. (**c**, **d**) Pearl-like structures deep within pits. Developmental origin of these structures is not known. (**c**) Pearls with pinkish dentin core and outer enamel layer

(1) V-type, wide at the top and gradually narrowing toward the bottom
(2) U-type, almost the same with from top to bottom
(3) I-type, an extremely narrow slit
(4) IK-type, extremely narrow slit associated with a large space at the bottom
(5) Other types (Fig. 2.5)

In Nagano's study, the V-type occurred in 34%, the IK-type in 26%, the I-type in 1%, the U-type in 14%, and other types in 7%. Nagano also found form and depth of pits and fissures to be closely related, with the V-type being shallow, the U-type of medium depth, and most of the remaining types deep. Moreover, he observed a

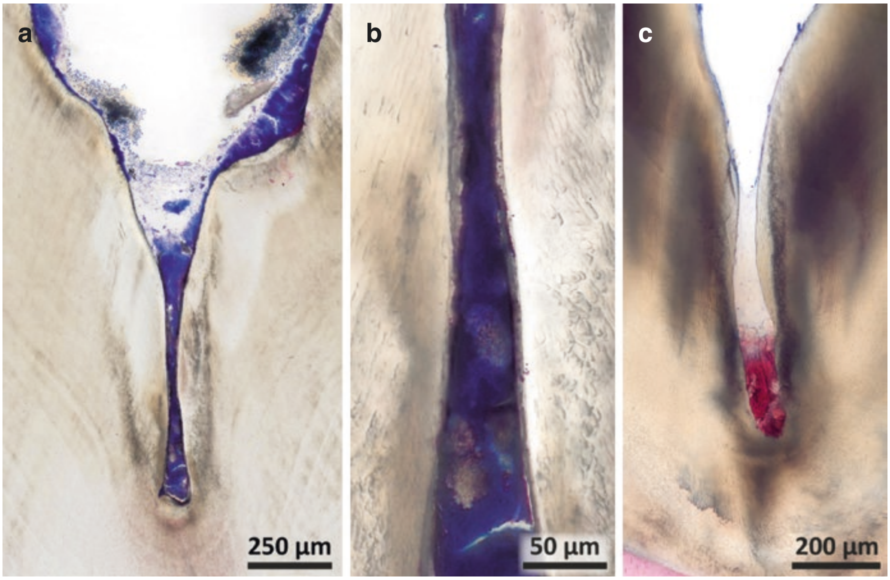

Fig. 2.6 Contents of fissures. (**a**) Amorphous organic mass colored blue in pit of erupted tooth. (**b**) Detail of (**a**). Anorganic mineralization spots are visible in middle and bottom portions, colored in light pink. (**c**) Anorganic mineralizations in the bottom of fissure, characterized by the deeply reddish colors

relation between the localization of a primary lesion and the form and depth of the fissure: in the V-type, shallow in most cases, caries starts from the bottom; it starts halfway down in the U-type, and from the top in the I-type and IK-type.

Galil and Gwinnett [17] examined the histology of fissures in unerupted teeth and demonstrated that the contents of fissures consist mainly of ameloblasts lining the wall of the fissures, remnants of cells constituting the enamel organs, and red blood cells; they suggested that the contents of such pits and fissures might significantly influence the effectiveness of certain caries prevention procedures. In the middle regions, bacteria are more abundant, while in deeper parts at the bottom of the fissures, amorphous masses of material predominate, and stronger mineralization has taken place (Fig. 2.6). Bacteria appear to become calcified deeper down in the fissure. This process may even have a protective effect against the development of caries.

As serial sectioning techniques involve unavoidable loss of tissue. Galil and Gwinnett developed an alternative to sectioning, the vinyl resin replication technique, to get a three-dimensional view of the morphology of pits and fissures. This technique allowed to demonstrate not only the shape and the complex distribution of pits and fissures within the crown but also the relationship of pits to fissures of human molariform teeth in the scanning electron microscope [18]. The general outline of the fissures in different kinds of teeth, as observed with scanning electron microscopy, concurred with what was observed with the light microscope. Generally,

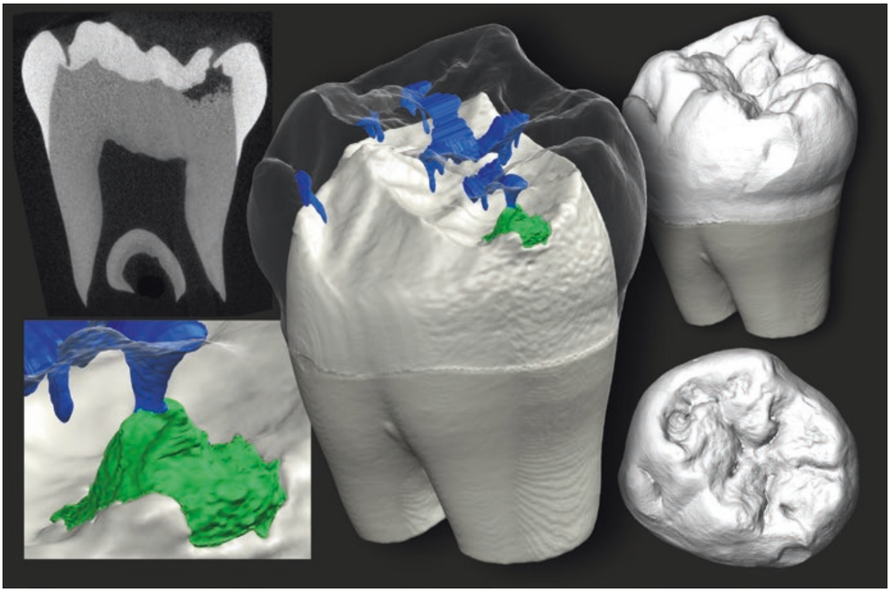

Fig. 2.7 A micro-CT scan of a mandibular wisdom tooth. The course and the depth of the pits and fissure are marked blue. A lesion can be seen localized in the lower part of one fissure

upper premolars exhibited a single main fissure with a straight outline, while lower premolars had a curved fissure, both with three or four pits arising from it. Upper and lower molars showed considerable variability in the outline of their fissures with up to ten pits or occasionally none. The terminal portions of pits often resembled several different shapes, of which the most commonly occurring were pointed, clubbed, and rose-headed (like a dental bur) configurations.

Nowadays, the morphology of pits and fissures can be illustrated and analyzed using 3D images taken by microcomputed tomography (micro-CT). The high-resolution CT technique has proven to be useful as a nondestructive method to precisely visualize the external and internal anatomy of teeth, showing the finest details. In preparation for this chapter, we analyzed two third molars using micro-CT. The hardware device used was a cabinet cone-beam micro-CT scanner (SCANCO μCT 50, SCANCO Medical AG, Brüttisellen, Switzerland). Automated segmentation was performed for further evaluation to distinguish between empty space (pits and fissures) and the filled space (enamel) (Figs. 2.7 and 2.8).

2.2.4 Fissure Morphology and Sealant Success

Fissure morphology might be a significant factor regarding sealant success. Different authors have evaluated the effect of fissure morphology on the microleakage and penetrability of pit and fissure sealants. Selecman et al. found that fissure morphology was not a significant factor regarding microleakage, whereas morphology did

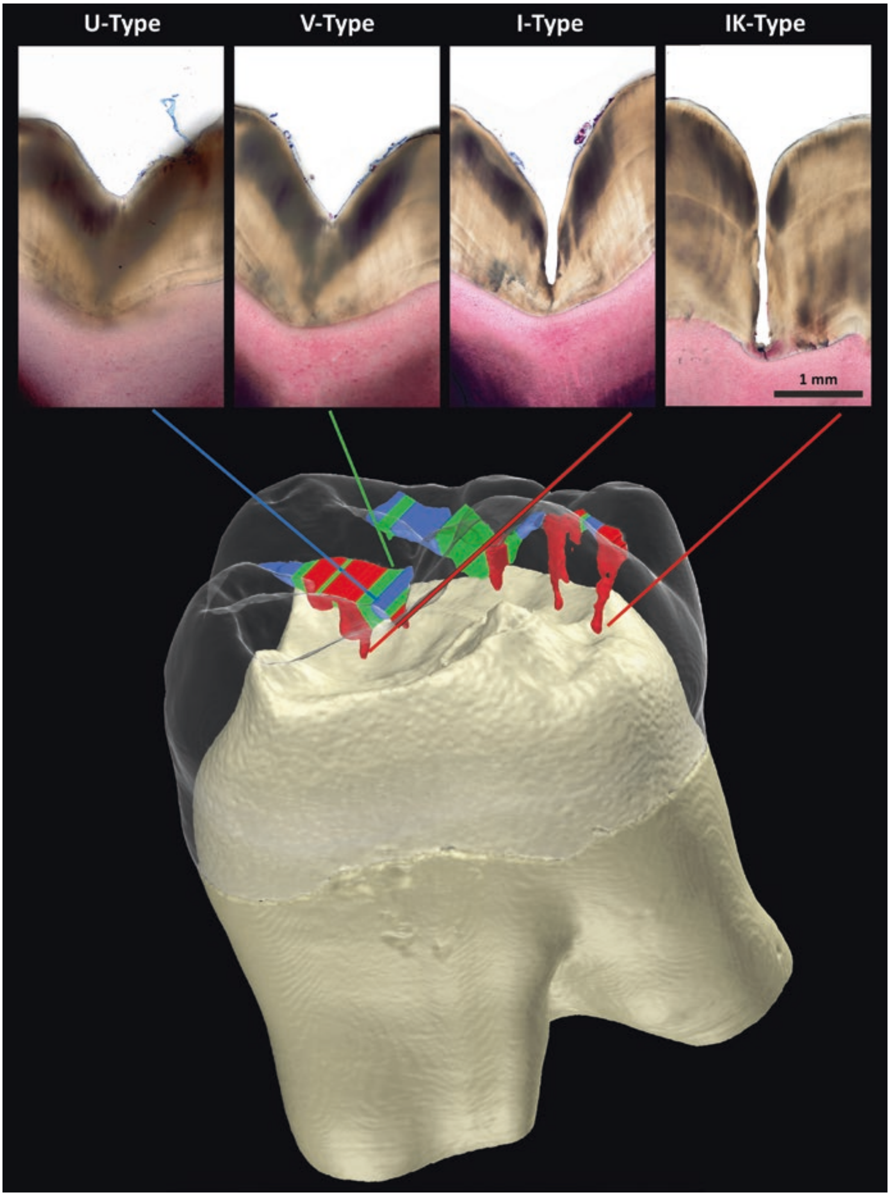

Fig. 2.8 A micro-CT scan of a maxillary wisdom tooth. As serial ground sections were additionally prepared from this tooth, the Nagano classification could be made visible for the corresponding examination points. The different color markings show the different fissure types across the tooth

have a significant impact on sealant penetrability, with U-type fissures displaying the greatest values. No correlation was found between the extent of microleakage and sealant penetrability [19]. On the contrary, Iyer et al. described that fissure

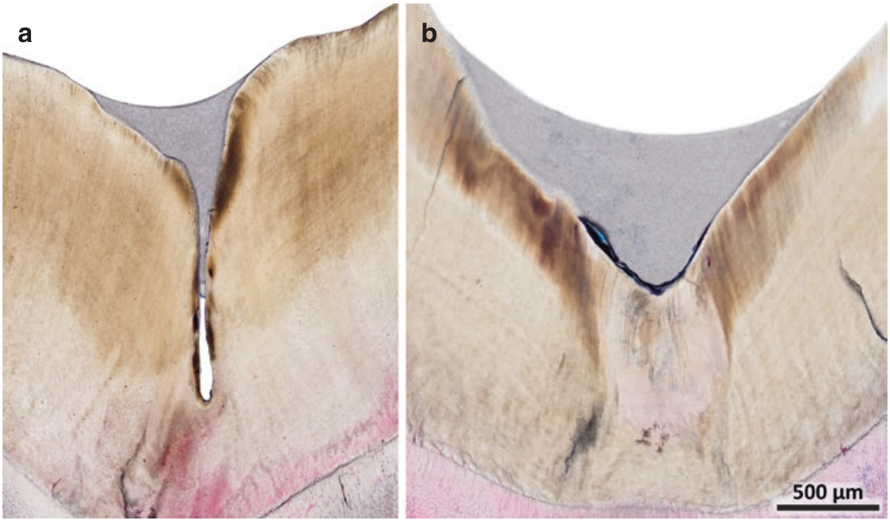

Fig. 2.9 Different penetration depths of a sealant. In the case of the I-fissure, it was very poor compared to the U-fissure

forms significantly affected adaptation but not penetration of sealants [20]. Both studies established that U-shaped fissures showed the highest mean percentage of penetration. The narrower the fissure, the poorer the penetration (Fig. 2.9).

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Pit and Fissure Sealants

3

Sotiria Gizani

Abstract

Among schoolchildren, pit and fissure caries have been accounted for approximately 80–90% of all caries in permanent posterior teeth. The occlusal surfaces of permanent molars are highly susceptible to caries development, especially during eruption in the oral cavity. A fissure sealant is a material that is placed in the pits and fissures of teeth and prevents the entrance of the cariogenic bacteria and their nutrients inside these anatomical features. The aim of this chapter is to give the most updated information about the history and the different types of the pit and fissure sealants used most often in daily practice. The first attempt to prevent occlusal caries by applying silver nitrate to tooth surfaces was carried out by Willoughby Miller, as early as 1905. Since then, the history shows that the evolution in the pit and fissure sealants has started from the materials being activated with ultraviolet light, moved to those which were autopolymerized, then to the sealants which were activated by visible light, from resins and glass ionomer to compomers, resin-modified and flowable composite sealants, unfilled to partially filled, opaque, clear to white or other colors, and those containing fluoride or not. Resin based mainly and glass ionomer secondly remain the materials used as pit and fissure sealants. Other materials such as compomers, resin-modified glass ionomer, and flowable composites were also introduced as sealants. Although their use looked promising, further clinical trials need to be conducted about their effectiveness and retention over time. Literature indicates that pit and fissure sealants are safe to be used.

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3.1 Introduction

Among schoolchildren, pit and fissure caries have been accounted for approximately 80–90% of all caries in permanent posterior teeth [1]. Unfortunately, the rate of occlusal caries has not been reduced to the same extent as caries on smooth surfaces [2].

The occlusal surfaces of permanent molars are highly susceptible to caries development, especially during the first few years after tooth emergence in the oral cavity [3]. Higher plaque accumulation due to the complexity of the morphology of the occlusal surface, which doesn't facilitate efficient toothbrushing, qualitative changes in biofilm with higher levels of non-mutans streptococci and *Actinomyces israelii* than fully erupted teeth [4], and lack of parental awareness on the tooth eruption in this area of the mouth [5] are main reasons for the caries vulnerability of the occlusal surfaces during the eruption of the permanent molars [6]. During this period of time, partial coverage of the tooth surface by gingiva [7] and incomplete posteruptive maturation can be additional risk factors [8].

According to Simonsen and Neal [9], a fissure sealant is a material that is placed in the pits and fissures of teeth and prevents the entrance of the cariogenic bacteria and their nutrients inside these anatomical features. Simonsen (1989) found that at 10 years, it is 1.6 times as costly to restore the carious lesions in the first permanent molars of 5- to 10-year-old children than it is to prevent caries with a single application of pit and fissure sealant [10]. And this was due to the greater number of lesions observed if sealant is not utilized.

The aim of this chapter is to give the most updated information about the history and the different types of the pit and fissure sealants (PFS) used most often in daily practice.

3.2 History

The first attempt to prevent occlusal caries by applying silver nitrate on tooth surfaces chemically treating the biofilm with its antibacterial functions against the caries pathogens *Streptococcus mutans* and *Actinomyces naeslundii* was carried out by Willoughby Miller, as early as 1905. Then in 1921, Hyatt introduced prophylactic odontotomy of pits and fissures by creating Class 1 cavity preparations of teeth that were considered at risk of developing occlusal caries. This technique made pit and fissures wider which were filled, later by amalgam, in order to prevent occlusal caries [11, 12]. Other chemical substances were also used to prevent occlusal caries such as zinc chloride, but without success. Less than 10 years later, a large round bur was used to smooth out the fissures without any filling material since it was believed that this mechanical procedure would be capable to prevent the bacterial colonization in these areas [11]. Then these fissures were filled up with dental cement, such as oxyphosphate cement. All these techniques and products, which have been used until then, were not successful in the caries prevention.

It was in 1955 that Buonocore introduced the acid-etch technique [12, 13], leading to the development of fissure sealants 10 years later by Cueto and Buonocore. In the last study, the researchers used 50% phosphoric acid with 7% zinc oxide and a mixture of methyl cyanoacrylate with silicone cement, as sealant material. The results showed that the retention was 71% after 1 year, while the reduction of caries reached 87% [14]. However this sealant material was susceptible to bacterial breakdown over time and was later replaced by a viscous resin (bisGMA) [15]. The new material had smaller thermal expansion coefficient, produced less heat during polymerization, and was harder than the methyl cyanoacrylate. This viscous resin formed the basis for the development of several resin-based sealants and composites available today.

In 1974, glass ionomer PFS were introduced by McLean and Wilson. Since then other materials have been also introduced for sealing pits and fissures such as compomers (polyacid-modified composite resins) [16] or flowable composite resins [17].

3.3 Types of Sealants

3.3.1 Resins

Resin composite materials consist of a resin-based oligomer matrix, such as a bisphenol-A glycidyl dimethacrylate (bisGMA) and an inorganic filler such as silicon dioxide (silica). A coupling agent such as silane is used to enhance the bond between these two components. A catalyst package can control its speed. In the past, composite resins suffered significant shrinkage during curing, which was improved after the addiction of new materials such as silorane. The last one exhibits lower polymerization shrinkage, compared to the dimethacrylates [18].

Many different types of sealants are available in the market from unfilled to partially filled, opaque, clear to white or other colors, chemically polymerized, or visible light-cure initiated materials, containing fluoride or not [19, 20].

Similar retention and caries preventive effect were found in the literature when self-cured was compared with visible light-cured [21, 22], even after 60 months [23]. The most recent light-cured resin sealants are the material of choice with reduced working time, deeper polymerization, and smaller thermal expansion coefficient especially when this is done by the modern LED devices [24].

The effectiveness of resin-based sealants as it is related to their retention was good in the majority of the literature comparing with a control without sealant. At the 12 and 24 months of follow-up, resin PFS were retained completely on average in 80% of cases, while this rate was remained at 70% even after 48–54 months. Regarding caries preventive effect, Bravo et al. (2005) reported 27% of sealed surfaces to be decayed compared to 77% of surfaces without sealant at 9 years of follow-up [25]. Similar findings were found in the study of Songpaisan et al. (1995) with children aged 12 to 13 years [26].

3.3.1.1 Filled Versus Unfilled Sealants

In an attempt to improve the abrasive wear sealants undergo over time, filler particles such as sodium fluoride, zirconia, or silicon have been added in the materials [27]. But the penetration and retention of the sealant in the fissures are inversely proportional to the viscosity which means that an unfilled resin is thinner and penetrates deeper into the fissure system, and perhaps it is better applied and retained than a filled or partially filled material (such as a filled sealant or a flowable resin composite) [9, 23, 28]. The results of the last study are in agreement with the literature so far. The authors found that at 12 months, 53.57% of resin-based filled (Helioseal F) PFS showed complete retention, 37.50% partial retention, and 8.83% complete missing, while the results were 64.29%, 32.14%, and 3.57% for the resin-based unfilled (Clinpro) PFS, respectively. They concluded that there was no statistically significant difference in the retention rates between resin-based filled (Helioseal F, Ivoclar Vivadent) and unfilled (Clinpro, 3M ESPE) pit and fissure sealants, but the clinical performance was slightly better for the unfilled sealant. However, other authors did not find significant differences in either retention or bond strength between sealants with and without filler [29].

Another matter of the presence or not of fillers in sealants relates to occlusal adjustment. Unfilled sealant will abrade rapidly, usually within 24–48 h, if it is left in occlusion with an opposing cusp tip. Tilliss et al. (1992) found that the occlusion should be routinely checked and, if necessary, adjusted immediately after placement of a filled sealant [30]. Therefore, the occlusal adjustment is considered as a routine part of the filled sealant application procedure which increases the time for the patient spent on the dental chair. This element needs to be seriously considered especially when dental treatment is provided to a young patient.

3.3.1.2 Colored Versus Clear Sealants

Initially all PFS were clear until 1977 when the first white opaque sealant (3M Concise White Sealant) was introduced to the US market. It is easier to check the correct placement of the white sealant when applied on the surface and to assess its retention at follow-up sessions than a clear product [31] (Fig. 3.1). Nevertheless one could argue that the use of a sealant with opaque color makes the dental examination of the sealed fissures underneath difficult during follow-up. However, the application of sealant over carious pits has not indicated any cause for concern when applying sealant to an incipient lesion or a stained fissure [32].

Colorful resin-based pit and fissure sealants have been recently introduced. These products change their color during the curing phase or polymerization which facilitate their proper application on the tooth surface such as Clinpro Sealant (3M ESPE) and Helioseal Clear Chroma (Ivoclar Vivadent), respectively. The first one has a pink color which gradually turns into opaque white after being exposed to a visible light, while the color of the second one changes from clear to green during polymerization (Fig. 3.2).

Although the change in the color after exposure in visible light aims to obtaining an easier and better sealant application, this property wears off during follow-up period which makes someone to wonder about the usefulness of this color change technology in practice. In addition, the effect of this color transformation on the material's retention on the tooth surface should be further investigated.

3.3.1.3 Fluoride-Containing Sealants

The caries preventive properties of sealants are attributed to the mechanical barrier of the pits and fissures to bacterial colonization and growth. The role of fluoride released from dental materials in the prevention of caries has been studied in the

Fig. 3.1 Clear sealant

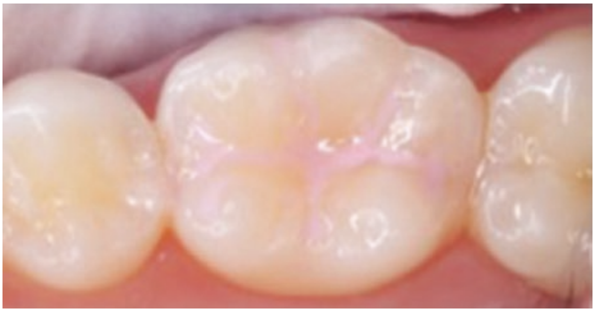

Fig. 3.2 Colorful resin-based pit and fissure sealant which is pink at placement (Clinpro Sealant, 3M ESPE)

literature based on the aspect that frequent supply of fluoride at low concentration decrease the enamel demineralization and accelerates the remineralization process [33].

The fluoride-releasing PFS, which are available in the market, contain either a soluble fluoride salt such as sodium fluoride (NaF) or fluoride-releasing glass filler or both. Glass ionomer cements (GIC) have shown to release fluoride slowly over a period of time into the surrounding enamel yielding cariostatic effects [34].

The literature indicates that the maximum amount of fluoride is released during the first 24 h after sealant application, and it is gradually decreasing since then. In the study by Garcia-Godoy et al. (1997), the highest concentration was 3.5 μg/mL while the lowest was 0.3 [35]. The researchers named this phenomenon of higher fluoride release during the first days as “burst effect” [36], and it occurs during the dissolve of the glass in the acidified water of the hydrogel matrix.

Studies have shown that fluoride release from glass ionomer was bigger compared with resins [9]. This fact can be explained by the loosely bound water and the porous found in the glass ionomer, which may be exchanged with an external medium by passive diffusion. In a recent study by Prabhakar et al., enamel demineralization was least in glass ionomer pit and fissure sealant, while the demineralization exhibited by non-fluoridated and fluoridated resin was comparable [34]. These results are in agreement with the literature that has shown no significant additional benefit of fluoride-containing sealants in caries reduction compared to non-fluoride sealants [22].

Regarding the retention of fluoride-containing PFS, it appears to be comparable to conventional resin pit and fissure sealants [37, 38]. The wear of the material over time because of fluoride release in the oral cavity could be implicated in this result. Therefore there is no evidence based in the literature to support the choice of using a sealant over another because of its fluoride content. One should keep in mind that the oral environment and the appropriate method of application sealants are also determining factors for the reduction of the microleakage which may further lead to formation of caries. However, further long-term clinical trials in patients with various caries risk level are necessary to determine the clinical importance of fluoride in fluoride-containing PFS in caries prevention.

3.3.2 Glass Ionomer Sealants

Glass ionomer (GI) sealants were introduced in 1974 by McLean and Wilson based on the ability of the material to bond chemically to dentine and enamel [39] and the active F release into the surrounding enamel. Since then, studies on these sealants have been conducted by several researchers [40, 41] but with contradictory findings.

All GI contain a basic glass and an acidic polymer liquid, which set by an acid-base reaction. The polymer is an ionomer, containing a small proportion — 5 to 10% — of substituted ionic groups. From this reaction, ions of aluminum, sodium, calcium, and fluoride are released. These ions react with the polyacid products forming calcium polycarboxylate in the initial stage and polycarboxylate aluminum in a later stage [42].

GI present reduced resistance in bending, abrasion, and corrosion, while their main disadvantage has been the inadequate retention. In an attempt to improve the material properties, HEMA (2-hydro-ethyl-methacrylic), photocatalyst was added to glass ionomer pit and fissure sealants. Nevertheless they also resented the disadvantages of the resins such as setting shrinkage, technique sensitivity, and release of monomers in the oral cavity. The GI sealants have a more opaque appearance and accumulate more staining than the resin ones.

Fig. 3.3 Glass ionomer fluoride-releasing material served as pit and fissure sealant on a lower erupting permanent molar (Clinpro XT Varnish, 3M ESPE)

Due to their hydrophilic properties, the application of glass ionomer pit and fissure sealants has been suggested as an alternative method of sealing pit and fissures of permanent molars during eruption when adequate moisture control cannot be achieved (Fig. 3.3). Alves et al. reported that a quarter of molars under eruption presented active caries, decreasing to 6.6% in molars in full occlusion, which suggests that most lesions tend to arrest when the tooth achieves occlusal function [43]. Nevertheless, a relevant proportion of molars remained caries active even in the presence of occlusal contact, justifying the need for special care during the period of eruption. In order to combat the early fissure caries development in erupting molars, a number of topical interventions based on antibacterial agents, fluoride varnish, as well as brushing technique alone have been also introduced with beneficial caries preventive effect until the occlusal surface can be fully protected by a fissure sealant [20, 44, 45].

Although the literature findings about the superiority of glass ionomer over resin sealants are contradictory, the second ones are still considered the material of choice for sealing pit and fissures due to better material properties. Glass ionomer sealants can be placed on partially erupted permanent molars when the moisture control is difficult, especially in high-caries-risk patients. Based on the last available EAPD guidelines for the use of pit and fissure sealants [46], in these situations, glass ionomer sealants can be considered more of a F vehicle than a traditional sealant.

3.3.3 Compomers

During the past decades, other materials than resin and glass ionomer have been also suggested for sealants such as resin-modified glass ionomer compomer or flowable composite resins. The advantages of these materials are good fluidity and low viscosity, while microleakage, fracture toughness, and wear still remain serious problems. Polyacid-modified composite resins, known as compomers, were introduced in the early 1990s [16] and were presented as a new dental material designed to combine the aesthetics of traditional composite resins with the fluoride release and adhesion of glass ionomer cements. The name was given due to its two "parent" materials, the "comp" coming from composite and "omer" from ionomer [16]. The term polyacid-modified composite resin was originally proposed for these materials in 1994 and has been widely adopted by manufacturers and researchers.

Compomers are fundamentally hydrophobic, and they lack the ability to bond to tooth tissues [47], while their fluoride release levels are significantly lower than those of glass ionomer cements [48]. In fact this material has several similar properties with composite resin with some elements from glass ionomer. They have been used as fissure sealants with conflicting results [16].

3.3.4 Resin Modified

Studies have shown that the resin-based pit and fissure sealants have significantly better retention than any glass ionomer sealants [49] (see Chap. 11). This is in agreement with the finding that the majority of resin-modified glass ionomer sealants (RMGI) required retreatment due to retention failures compared to 11% for the resin-based sealant [50]. A 2-year report on the clinical performance of a RMGI sealant compared to a light-initiated resin-based sealant showed 38% complete loss of the RMGI sealant, while this was the case for 10% of the resin-based sealant [51]. In another study, at 36-month follow-up, resin-based pit and fissure sealants showed a mean of retention rate of 94%, while this was the case only for 5% for resin-modified glass ionomers [52].

Hicks and Flaitz compared the formation of lesions similar to caries in occlusal enamel adjacent to light-cured resin-modified glass ionomer sealants and in conventional light-cured resin-based fluoride-releasing sealant [53]. The extent of caries involvement in the adjacent unsealed occlusal area was lower with the resin-modified glass ionomer than with the conventional resin sealant. Further well-designed clinical trials for the preventive caries effectiveness and retention of RMGI sealants should be carried out.

3.3.5 Flowable Composites

As the filler content of composite resin increases, the wear resistance is increased in comparison to unfilled resins like pit and fissure sealants which can help determine the frequency of dental check-up visits [17]. According to Gillet et al. the flowable composite resin Tetric Flow can have no microleakage and can be more efficient than resin pit and fissure sealants (Helioseal F), in sealing deep fissures [54]. A meta-analysis in this field [55] and other clinical studies [56, 57] showed that flowable composite resins can have a retention rate similar to conventional sealants. Taken into consideration the encouraging results of the literature and the fact that flowable composite resins can also easily penetrate into shallow or wide fissures [58], their use as fissure sealant material seems logical. In a recent study, Asefi and co-workers concluded that flowable composite resins may be good alternative sealing material due to their higher wear resistance, longer durability, and impact on reduced office and patient expenditure [17]. Nevertheless more clinical trials about the caries preventive effect and longevity of these materials are necessary.

3.3.6 Safety Concerns

The association of material components leaching from dental biomaterials, such as monomers with cytotoxic reactions in tissues, was reported in the literature. The compound attracting most of the attention of the researchers and the companies during the past several years is bisphenol A or BPA. Dental resins include primarily derivatives (like bisphenol-A glycidyl dimethacrylate or bisGMA and bisphenol A dimethacrylate or bis-DMA) which are hydrolyzed to BPA and not an active ingredient, while most sealants contain only bisGMA [59]. More specifically, BPA release from dental resins has shown potential estrogenicity and has been associated with risk for human fertility [60].

Studies in humans showed high levels of BPA in saliva samples, especially in those collected immediately at 1 or even 3 h after sealant application [61, 62] (see Chap. 6). Nevertheless these levels decreased over time [63]. High levels of BPA were also detected in urinary samples even in long-term measurements after treatment with sealants with concentrations ranged from 0.17 to 45.4 mg/g creatinine [64]. On the contrary, no BPA was traced in any blood serum sample at any time point [64].

The literature has shown that 20–45% of the monomer, which is typically found in a liquid layer on the outer surface of the material, isn't cured during polymerization, and it can be discharged in the oral cavity. The release of monomers, which are not cured, after polymerization has been accused to cause most of the unwanted effects [63]. Rinsing the surface of the sealant after polymerization with water for 30 s using a good suction and removing the surface residual monomer layer with pumice on a cotton pellet or in a rotating rubber dental prophylaxis are recommended as a measure that could reduce substantially the exposure of the patient to the BPA [65].

The American Dental Association concluded that the estimated BPA exposure from dental materials is very low level occurred randomly, compared to the total estimated daily BPA exposure from food and environmental sources which comprises more than 90% of the total BPA exposed to the patients [1]. Therefore the current evidence suggests that patients are not at risk for estrogen-like effects when sealants are used [1, 52], and therefore they are safe to be used. As Kloukos and co-workers suggested in a recent systematic review, further research is necessary to determine the permanent or not absorption of BPA in the systemic circulation and its association with the general health [63].

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4 The Role of Pit and Fissure Sealants in the Prevention of Dental Caries

Luigi Paglia, Gianmaria Ferrazzano, and Matteo Beretta

Abstract

Occlusal surfaces of first permanent molars are the most susceptible sites for the caries in the developing of permanent dentition, but the use of sealants compared to fluoride varnishes on their pit and fissures to limit the onset of tooth decay is still debated today. The application of sealants should be recommended at the first stage of eruption, and they may arrest the progression of non-cavitated occlusal dentinal caries. Resin-based sealants have the disadvantage in that they require an optimal level of moisture control during placement. In children glass ionomer ART sealants, which are more moisture tolerant, can offer a viable alternative. A number of clinical studies indicate that the success of fissure sealants' protective role depends on different aspects, the most relevant of which are the properties of the sealant material, the maintenance of sealant integrity, and the level of sealant retention. The evidence suggests the superiority of resin-based fissure sealants over fluoride varnishes for prevention of occlusal caries in permanent molars, but the available current data do not allow to draw definitive conclusions. It is important to underline the different cost benefit of sealants and fluoride varnishes compared to the socioeconomic contexts and to the timing of execution. Finally, it has to be rated the environmental conditions in which the sealants are applied and the procedures to be used in order to improve their durability and effectiveness, as well as a preliminary surface treatment with ozone (O_3), to reduce or eliminate bacterial contamination.

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4.1 Introduction: The Position of the Literature

Dental sealants were introduced in the 1960s as part of the preventive programs to protect pits and fissures on the occlusal tooth surfaces from dental caries. Since then, the level of tooth decay in children and adolescents has declined in many parts of the world. Nevertheless, caries remains a public health problem in many countries [1] (see Chap. 1). Occlusal surfaces of posterior teeth are the most vulnerable sites due to their anatomy favoring plaque retention. Pits and fissures don't cause caries process. They permit the entrance of microorganisms and food into this sheltered warm moist richly provided incubator, and the dental plaque can be expected to form here. They instead provide a sanctuary to those agents, which cause caries. When carbohydrates in food come in contact with the plaque, acidogenic bacteria in the plaque create acid. This acid damages the enamel walls of the pits and fissures and caries results. Sealants were developed to help manage these sites of dental stagnation forming a hard shield that keeps food and bacteria from getting into the tiny grooves in the teeth and causing decay. Fluorides and other caries preventive approaches (e.g., mechanical plaque control) seem to be less effective for preventing carious lesions in pit and fissure surfaces compared with smooth surfaces [2]. From a secondary prevention perspective, there is evidence that sealants also can inhibit the progression of non-cavitated carious lesions [3]. The use of sealants to arrest or inhibit the progression of carious lesions is important to the clinician when determining the appropriate intervention for non-cavitated carious lesions.

Sealants are still underused despite their documented efficacy and the availability of clinical practice guidelines. New sealant materials and techniques continue to emerge for managing pit and fissure caries, further complicating the clinician's decision-making. Accordingly, continuous critical review of the available evidence is necessary to update evidence-based recommendations and assist healthcare providers in clinical decision-making [4].

4.2 Why: Is it Reasonable?

Carious lesions are preventable by averting onset and manageable by implementing interventions, which may halt progression from early stage of the disease to cavitation, characterized by enamel demineralization, to frank cavitation [2]. Placement of pit and fissure sealants significantly reduces the percentage of non-cavitated carious lesions that progress in children, adolescents, and young adults for as long as 5 years after sealant placement, compared with unsealed [5]. Evidence-based clinical practice guideline recommends the use of sealants, compared with nonuse, in primary and permanent molars with both sound occlusal surfaces and non-cavitated occlusal carious lesions in children and adolescents [6].

The last systematic review of randomized controlled trials by the American Dental Association and the American Academy of Paediatric Dentistry suggests that children and adolescents who receive sealants in sound occlusal surfaces or non-cavitated pit and fissure carious lesions in their primary or permanent molars (compared with a control without sealants) experienced a 76% reduction in the risk of developing new carious lesions after 2 years of follow-up. Even after 7 or more years of follow-up, children and adolescents with sealants had a caries incidence of 29%, whereas those without sealants had a caries incidence of 74% [7].

In addition, sealant use can be increased along with other preventive interventions to manage the caries disease process, especially in patients with an elevated risk of developing caries. Further research is needed to provide more risk-oriented recommendations, particularly regarding the development of a valid and reliable chairside tool for clinicians to assess a patient's caries risk; clinicians should consider carefully individual patient factors, especially where the guideline panel offered conditional recommendations [3].

The Italian Ministry of Health affirms the use of pit and fissure sealants as a safe and effective method of reducing tooth decay in the occlusal grooves, pits and fissures of posterior teeth (Strength of recommendation A; Level of evidence I).

4.3 Who Should Get Sealant?

Kids are notoriously bad brushers and tend to ignore the problem areas in the back of the mouth that lead to cavities and decay, making them the prime target market for sealants. Anyway, if adults have certain problem areas that could be cured with sealants, this could be an option for them too. The American Dental Association recommends that kids receive dental sealants as soon as their adult teeth erupt. However, the Cochrane systematic review concluded that the effectiveness of sealants was obvious for children at high caries risk, but that information was lacking on the benefits of sealing for different levels of caries risk [8]. Fluoride varnish and sealants, though effective, are expensive and need careful selection of locality and teeth to be efficient [9].

In Italy, the prevalence of caries disease in the young population suggests to define this community, as a whole, potentially at risk of tooth decay. Some of the main dental cavity risk factors are poor maternal oral hygiene, low socioeconomic status, hiring >4/day between meals of sweet foods or drinks, night use of baby bottles with sweet drinks or milk, children affected by mental or physical disability, presence of white spot, enamel defects (also MIH), or reduced salivary flow [10]. General recommendations for the promotion of oral health, dictated by the Italian Society of Paediatric Dentistry (SIOI), recommend applying sealants (and fluoride varnishes, gel, and mouthwash) only in high-risk individuals, over 7 years of age (Fig. 4.1a, b) [11].

Anyway, clinical expertise plays a key role in determining which patients fit into this preventive program which must be align with the values, preferences, and the context of an individual patient [12].

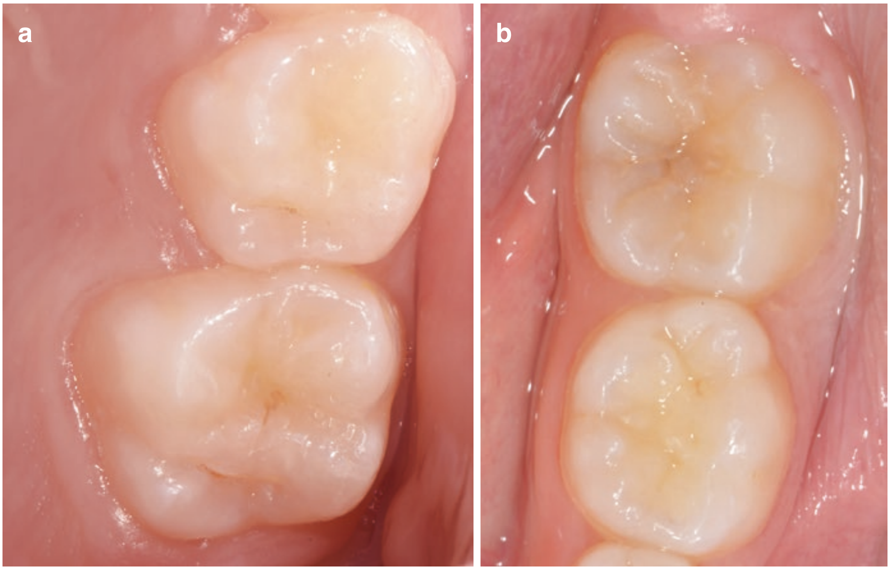

Fig. 4.1 (**a**, **b**) First molars to be sealed in a 7-year-old child

4.4 When: As Soon As Possible?

The best medical procedure that a health worker can do is prevent a disease, so that his patients remain healthy. It means prevention first. In fact, the way of life, environmental conditions, hygiene, and prevention affect the health more than hereditary factors. Also improved diagnostic criteria, with early screening, made a difference in recent years.

Occlusal surfaces of first permanent molars are the most susceptible sites for the caries in the developing of permanent dentition. In fact, the decay of the pits and fissures is the fastest and most prevalent, representing over 80% of caries in permanent teeth in young patients [13].

Secondary prevention should aim to intercept caries lesions and early diagnosis of hereditary or acquired alterations favoring caries in that period of enamel maturation ranging from 6 to 14 years. Teeth just erupted do not have the enamel fully formed and therefore have a high caries susceptibility.

This is the reason why it is essential to make an early prevention or to arrest the progression of non-cavitated occlusal caries. The application of sealants should be recommended to prevent or control caries, especially at the first stage of eruption, because it seems to be essential to seal the molars that just appeared in the dental arch. National guidelines for oral health promotion and oral disease control in children claim that the sealants are shown to prevent tooth decay with a most effective when used in the 2 years following the eruption of the tooth, with the recommendation to control its integrity every 6–12 months [10] (Fig. 4.2).

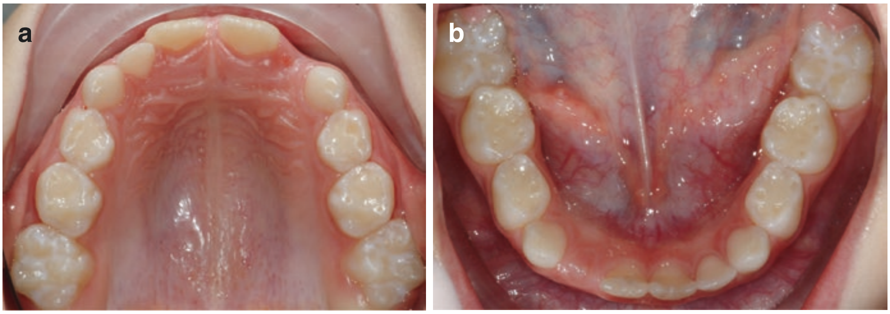

Fig. 4.2 (**a**, **b**) First molars sealed at the early stage of complete eruption

Sealing occlusal surfaces of newly erupted permanent molars in children and teenagers delays caries onset up to 48 months compared with unsealed teeth. On the contrary, some longer follow-ups report a reduction of the preventive effect, because the benefit effects of early sealants in different caries risk populations and condition of application have yet to be established [14]. Moreover, it is important to underline the cost benefit of early sealants compared to the socioeconomic contexts and to the timing of execution (as a patient's age or compliance). While on one hand, we have to evaluate the effectiveness of sealants, on the other we must consider their efficiency in the different contexts in which they can be applied. The effectiveness of sealants in preventing tooth decay is related to their duration in time. The materials to be preferred are those that contain opacifiers products, since the presence of sealants must be verified during the application and the control visits. The clinical diagnosis is based on the absence of obvious signs of decayed or demineralized enamel (white or brown spot) at the bottom of occlusal, vestibular, or lingual fissures, after a net change of enamel translucency after prolonged drying (5 s).

It has to be rated the environmental conditions in which the sealants are applied and the procedures to be used, in order to improve their durability and effectiveness. Although should be fundamental a proper isolation (using the rubber dam) of the tooth to be sealed, in many cases it is too difficult, depending on the compliance of the patient or on his periodontal anatomy that, in the early stage, reveals only the occlusal surface of the molar, making often impossible to isolate the field as a standard procedure.

In this case it is possible to perform an early application of fluoride varnishes, as a preliminary surface treatment, waiting for better conditions to seal pits and fissures (Fig. 4.3).

In other cases glass ionomer cements can be used as transitional sealant materials on the surfaces of teeth considered at high risk of caries development, but which do not allow a good insulation, such as elements with slight MIH [15] (Fig. 4.4).

Moreover, the use of ozone (O_3) seems to be effective to reduce or eliminate bacterial contamination not only of the occlusal surface but also of the deepest part of the fissures, either waiting better conditions to do sealings, in association with

Fig. 4.3 First molar during first stage of eruption to be treated with fluoride varnishes

fluoride varnishes, or just before the application of sealants [16]. On the other hand, the indication for sealing in populations with low prevalence of caries, in which the caries process has a slow evolution, seems to shift from primary prevention to secondary of the micro superficial caries, according to the minimally invasive dentistry. This means that the sealants would lose in importance if adequate daily oral hygiene procedures are adopted. For these reasons, every time we visit a child and we want to do the best for him, for his oral health, we have to do a tailor-made prevention, considering his own risk factors and environmental conditions, where the time factor is important, but not alone.

4.5 Which: Resin-Based or Glass Ionomer Cement?

How sealants are effective in high-risk children is well known. However, informations about the benefits of sealing in other conditions are still scant [8]. Most of the sealants used today are resin-based composite adhesives, with a main component of Bis-GMA, which allows the addition of filler particles to the sealant composition, considerably increasing their wear resistance [17] (see Chap. 3). Fissure sealing with a resin-based sealant is considered effective to arrest the progression of

Fig. 4.4 First molar with MIH sealed with white glass ionomer cement

non-cavitated occlusal dentinal caries. The most used materials are those opaque, white, with little or no filler, and light curing, which allow its accurate application. For their white coloration, it may be applied in a targeted manner, avoiding subsequent corrections and being able to control any loss of material. The material with low fillers is more flowable, in order to be well applied in the fissures, but they are less resistant to abrasion. A mistake that is often made is to use an excessive amount of material, which does not increase protection but is likely to create occlusal interference. Resin-based sealants have the disadvantage in that they require an optimal level of moisture control during placement. In children glass ionomer ART (atraumatic restorative treatment) sealants, which are more moisture tolerant, can offer a viable alternative [18]. In fact, during the eruptive phase of the permanent molars, in addition to a proper oral hygiene and professional fluoride applications, glass ionomer sealants can be applied, because it could be difficult in this stage to use resin-based sealants, neither indicated nor effective in subjects with poor oral hygiene control and high risk of caries. Although less retentive than those resin-based, they provide a slow release of fluoride when cured and not only on the molar surface but also when much of the sealant is lost and remain only residual parts at the bottom of the fissures, offering an obstacle to the possible formation of secondary caries. The release increases in the first week, is reduced in the next 6 months, and then remains more or less constant over time. Glass ionomer cements also act

Fig. 4.5 Partial loss of the resin-based sealant material with underlying caries

as a reservoir of fluoride, as they can absorb it from toothpastes, mouthwashes, gels, and varnishes. During the reaction of curing, the cement ions create a reaction with the ions of calcium and phosphate of the tooth. Differently, a partial loss of the resin-based sealant material leads to the occurrence of marginal leakage and, hence, to caries development underneath the sealant (Fig. 4.5).

This is the reason why we recommend a full periodic check in order to eventually do a secondary seal. Glass ionomer sealants may also be employed in very young child, with difficult cooperation and poor control of saliva at the time of their application. With these kinds of materials, there are some problems regarding their duration in time. Particular attention must be given to the use of resin-modified glass ionomer cement, especially those light curing, that consents ease and speed of application, as for the conservative procedures in the primary teeth. These have better mechanical properties and reduce the solubility after mixing. The setting reaction is characteristic of glass ionomer cements which is associated with a reaction of polymerization light or autoactivated, characteristic of the resins. These materials create a hybrid layer with the dental tissues and a lower solubility in the mouth environment.

After these statements, it would be important to emphasize that on one hand we need materials that last over time as for the conventional restoration, introducing the concept of the permanent filling of the fissures, and, on the other hand, the safety of these materials containing bisphenols, whose behavior is still controversial for the health of the children.

4.6 How to Remember the Importance of a Technique Suitable for a Child

Pit and fissures caries accounts for about 90% of the total incidence of caries in children and adolescents. The use of sealants plays an important role in preventing the development of occlusal caries by isolating the covered tooth surfaces from microorganisms and food particles [19].

Occlusal sealants are considered an effective caries preventive measure, particularly among young patients; their benefits have been demonstrated in several systematical reviews [20, 21]. The overtime effectiveness depends on the correct execution of the clinical protocol [22].

In fact, meticulous application procedures have been resulted in high retention rates and high in vitro bond strengths [23].

On this matter, before sealing, pumice prophylaxis application, removing plaque and debris from the enamel surface, prior to enamel etching, can improve sealant retention and reduce micro-leakage [23]. Furthermore, the type of sealant materials, its viscosity and flow, and the wear resistance of the material are major factors contributing to retention and caries prevention. Most of the sealants used today are resin-based with a main component of Bis-GMA (BPA glycidyl dimethacrylate), which allows the addition of filler particles to the sealant composition, considerably increasing their wear resistance [24]. During sealant application, care should be taken to avoid overfilling. In fact, it was shown that sealant overfilling can lead to an increased detachment from the enamel surface and, subsequently, to greater microleakage [25].

In addition, being resin-based sealants susceptible to saliva contamination, which can lead to a reduction of the mechanical retention [26], rubber dam has to be used to provide the best isolation. Furthermore, the use of flowable composite resins as pit and fissure sealants has been investigated. The higher filler content, causing decrease in the surface wear, is the main logic for using flowable composites as pit and fissure sealants [27]. Several studies concluded that the conventional pit and fissure sealant and the flowable composite resin presented similar results in terms of retention. [27].

Mechanical preparation has been suggested to provide better access to the deeper fissure areas, thus enabling removal of debris, deeper sealant penetration, and improved retention [25]. Many studies have suggested that bur preparation and air abrasion can enhance sealant penetration and adaptation, providing a greater surface area for retention [23]. Controversially, other investigators reported no significant difference between conventional acid etch alone and bur preparation followed by acid etching of pit and fissures [23]. Scientific evidences on this topic are still limited and conflicting [28]. Regarding Er:YAG laser surface pretreatment, it has been shown that either conventional bur or Er:YAG laser preparation, with a subsequent acid conditioning, can enhance the marginal retention of pit and fissure sealants [29]. Instead, Er:YAG laser irradiation pretreatment does not eliminate the need for etching the enamel surface before sealing [30]. Sonoabrasion can be used for preparing dental enamel prior to sealing the tooth, but it does not eliminate the need for etching [31]. Another important factor to consider in the success of sealants is the prevention of micro-leakage: it has been shown that the application of the intermediate adhesive bonding agent between enamel and sealant could increase sealant retention and contribute to prevent the development of micro-leakages [32]. However, available self-etching bonding agents, which do not involve a separate etching step, provide less retention than do bonding agents that involve a separate acid-etching step [33]. Finally, it should be emphasized that, especially in children, when it is impossible to obtain an adequate moisture control, the use of glass ionomer cements, which do not require acid etching of tooth surface, are easier to place than resin-based sealants, and are not as moisture sensitive as their resin-based counterparts, has to be considered [28]. Glass ionomer cements can provide continuous fluoride release, and thus its preventive effect can persist even with visible loss of the material [34]. However, the effect on caries reduction of GIC is equivocal due to its unsatisfactory retention rate [19].

4.7 Controversial

4.7.1 Retention Assessment

The retention of sealants relies upon the ability of the resin sealant to thoroughly fill pits and fissures and/or morphological defects and remain completely intact and bonded to enamel surface for a lifetime [35].

Despite retention rate can be considered a determinant of sealant effectiveness as a caries prevention measure, in literature there is no consensus on how to assess this parameter over time. To maximize effectiveness, the oral healthcare professional should monitor and reapply sealants as needed. The most commonly used method to evaluate sealant retention is visual clinical examination with probing inspection, in which the sealant is recorded as intact, partially lost or completely lost. Aside from being poorly reproducible [36], this method is unable to identify gaps, failures into the internal structure of sealants, which can cause infiltration and loss of material [37]. Another procedure consists of standard color photographs: this technique may be more sensitive than visual clinical examination in measuring the levels of retention and degradation but reflects the difficulty in judging clinically the retention of degraded or worn-out sealant [38]. Researchers also suggest the use of the optical coherence tomography (OCT) in monitoring sealant application and retention in long term. OTC is a noninvasive imaging technique that produces high-resolution, cross-sectional images of biological tissue at a micrometer scale. OCT uses near-infrared light to provide subsurface tissue images without ionizing radiation [39]. Although in vitro and ex vivo studies clearly indicate its potential, OTC is widely far from being clinically used as a conventional method to assess the sealant retention [40]. Only in a very recent study, Ferrazzano et al. elaborated an experimental system able to obtain reproducible and comparable photographs of the occlusal surfaces, usable to monitor sealants retention over time. In this study,

Fig. 4.6 (**a**) Connection between the camera support and the dental arch support; (**b**) sealed areas' computer measurements at T0, T1, and T2, respectively

photographs of the sealed occlusal surfaces were obtained through an experimental two-parts system, consisting of a dental arch support and a camera support (Fig. 4.6a, b) that, allowing a reproducible and stable placement of an intraoral camera in oral cavity, represents a standardized and useful method to observe and monitor dental occlusal sealants retention over time [41].

In particular, a high-definition intraoral camera connected to a computer was used to obtain photos of the occlusal surfaces. A dedicated software (VixWin Platinum 3.3, Digital Imaging Software, Dentsply, Gendex Division, Milan, Italy) was utilized to perform measurements on archived pictures [41].

The above-described system was used to monitor sealant retention over time. One hundred sixty-five teeth were sealed and photographed. For each tooth, one photo was taken after sealing (T0), 6 months (T1), and 1 year later (T2). With the software, the sealed area on each occlusal surface was measured (Fig. 4.3).

The comparison of the identified sealed areas between T0 and T1, T0 and T2, and T1 and T2 determined the percentage of sealant loss after 6 months, after 1 year, and between 6 months and 1 year, respectively [41].

Despite the results of the cited study were encouraging, a great effort is needed to improve the knowledge about sealants retention assessments, in order to include standardized methods in daily routine dental practice.

4.7.2 Safety

Bisphenol A (BPA) is a synthetic chemical resin used worldwide in the production of plastic products, notably polycarbonate plastic food-storage containers, some water bottles, bottle tops, and epoxy resin lacquer linings of metal food cans [42].

It is used in dentistry as a precursor of BPA glycidyl dimethacrylate (Bis-GMA) or BPA dimethacrylate (Bis-DMA) for producing composite resins and fissure sealants [43, 44]. BPA is present as an impurity in some resins or as a degradation product in others [43]. BPA has shown potential estrogenicity in a significant number of studies [44, 45], playing a role in the pathogenesis of several endocrine disorders, including female and male infertility, precocious puberty, and hormone-dependent tumors, such as breast and prostate cancer, and several metabolic disorders, including polycystic ovary syndrome (PCOS) [46, 47]. Researches show that BPA is released after placement of some dental sealant into the saliva [45, 48] (see Chap. 3). The biggest quantities are detected immediately after or 1 hour after sealant placement, and then the BPA levels decreased with time. [44]. No BPA has been detected in blood samples, indicating that there is no detectable systemic exposure to BPA from dental sealants [49].

Unpolymerized BPA after curing has the direct potential to leach into saliva. Dental providers should avoid the potential for BPA toxicity from the dental sealants by treating the surface layer of the sealant to reduce the possibility of unpolymerized BPA remaining on the tooth [44].

Rinsing with water for 30 s after sealant placement and using a mild abrasive, such as pumice, either on a cotton applicator or with a prophy cup can decrease salivary BPA levels [43].

On the basis of the available information, because BPA exposure from dental sealants is minimal, seems to be transitory and can potentially be controlled, patients should not be considered at risks [44, 49]. On the other hand, the evidence is strong that resin-based dental sealants improve children's oral health. Future researches are needed to investigate a possible causal link between BPA leached from sealants to oral environment and negative systemic health effects.

4.8 What's New

Among the most innovative techniques and materials, we can find sealants with antimicrobial properties or microbial repellent because of the residual bacteria which may have persisted in the prepared cavity [50]; measures to help modify the biofilm to reduce the cariogenic challenge, including ozone therapy [17, 51] and probiotics [52]; or measures to increase enamel resistance to demineralization, including laser treatment of enamel [53]. Although many of these techniques show considerable promise and dentists should be aware of these developments and follow their progress, the evidence for each of these novel preventive treatment options is currently insufficient to make widespread recommendations. But is the use of sealant truly better over other methods? Interesting considerations deserve fluoride varnishes; despite a Cochrane review that compared the caries preventive effect of pit and fissure sealants versus fluoride varnish concluded there was some evidence of the superiority of sealants over fluoride varnish in the prevention of occlusal decay [54], where resin-based sealant is indicated but adequate moisture control cannot be achieved, fluoride varnish containing at least 22,600 ppm F should be applied to pits and fissures at intervals of 3–6 months until isolation can be achieved [55]. As a low-cost and easily operated treatment, the use of professionally applied topical fluoride was approved for preventing dental caries, remineralizing early enamel caries or white spot lesions, and arresting dentine caries. Moreover, the further addition of casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) to fluoride varnishes seems to be better in protecting against enamel demineralization [56, 57] by increasing the acid resistance of primary enamel.

These materials are somewhat different types of preventive procedures: sealants are preventive interventions on targeted teeth and surfaces, and their application requires more dental expertise and training than fluoride varnish application; fluoride varnish is generally applied to all erupted surfaces of all teeth and not just molars and to both smooth and pit and fissure surfaces. However, thinking about extensive social projects and considering all the difficulties of implementation and follow-up of dental care in children, the effectiveness of the material and technology collides with the efficiency in clinical practice. Maybe the topical application of fluoride varnish could be the "new" frontier of prevention in large proportions.

However, even if new technologies and research should be pursued, we can't forget that to make significant gains in caries reduction in child and adult population, it is necessary for the dental profession to educate and inform the general public. Teaching children effective brushing and flossing is a priority; nutritional counseling to parents and children is necessary: eating patterns and food choices play an important role in preventing, or promoting, tooth decay. Oral healthcare programs should include as many complementary preventive strategies as possible.

We need to be effective doing the right things and efficient doing things right!

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Detection of Occlusal Caries

5

Klaus W. Neuhaus

Abstract

The detection of occlusal lesions is difficult because of the morphology of molars and premolars. Deep fissures are often plugged with organic material that can be stained over time or that can promote the beginning of the caries process. Deep fissures also often hamper direct sight of an existing incipient caries lesion that might therefore be detected at a relatively advanced stage. While meticulous visual-tactile caries detection is the first and most important method to detect and diagnose occlusal caries lesions, hidden caries can be detected with greater sensitivity by other means such as bitewing radiography and laser fluorescence. However, because there is a great variation between the diagnostic decisions made by different clinicians, additional caries detection aids also help to decrease this variation and help to promote more consistent clinical decision-making.

5.1 Visual-Tactile Inspection

Visual-tactile inspection of the occlusal surfaces of premolars and especially molars can be demanding, because deep fissures or grooves can be stained or plugged with organic material and thus make it impossible to detect a beginning caries process at the bottom of the fissure (Fig. 5.1).

This uncertainty leads to a large variation between different clinicians about which phenomena are attributable to different stages of the caries process. Therefore, several clinical visual caries detection systems have been suggested during the past

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Fig. 5.1 Microradiography of a deep fissure with beginning caries at the bottom of the fissure

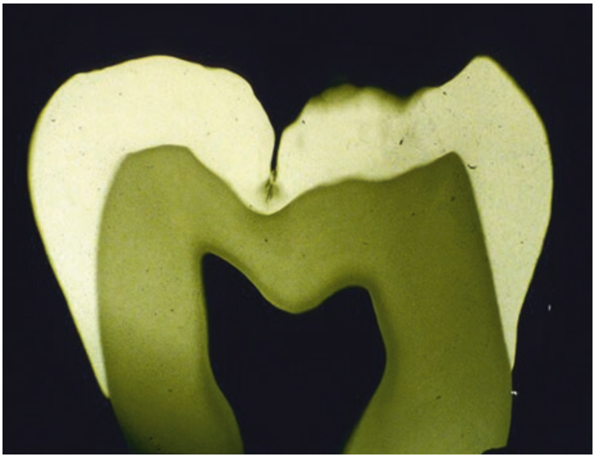

Table 5.1 "Nyvad criteria" restricted to occlusal caries after [1]

Score	Category	Criteria
0	Sound	Normal enamel translucency and texture (slight staining allowed in otherwise sound fissure)
1	Active caries (intact surface)	Surface of enamel is whitish/yellowish opaque with loss of luster, feels rough when the tip of the probe is moved gently across the surface, generally covered with plaque. No clinically detectable loss of substance
		Fissure/pit: Intact fissure morphology, lesion extending along the walls of the fissure
2	Active caries (surface discontinuity)	Same criteria as score 1. Localized surface defect (microcavity) in enamel only. No undermined enamel or softened floor detectable with the explorer
3	Active caries (cavity)	Enamel/dentin cavity easily visible with the naked eye; the surface of cavity feels soft or leathery on gentle probing. There may or may not be pulpal involvement
4	Inactive caries (intact surface)	The surface of enamel is whitish, brownish, or blackish. Enamel may be shiny and feels hard and smooth when the tip of the probe is moved gently across the surface
		No clinically detectable loss of substance. Fissure/pit: Intact fissure morphology, lesion extending along the walls of the fissure
5	Inactive caries (surface discontinuity)	Same criteria as score 4. Localized surface defect (microcavity) in enamel only. No undermined enamel or softened floor detectable with the explorer
6	Inactive caries (cavity)	Enamel/dentin cavity easily visible with the naked eye; the surface of cavity may be shiny and feels hard on probing with gentle pressure. No pulpal involvement
7	Filling (sound surface)	
8	Filling + active caries	Caries lesion may be cavitated or non-cavitated
9	Filling + inactive caries	Caries lesion may be cavitated or non-cavitated

20 years [1–4]. The so-called Nyvad criteria consist of ten categories differentiating between sound, active, and inactive lesions with or without surface discontinuities or cavitations in teeth with or without fillings (Table 5.1) [1].

Table 5.2 ICDAS II codes for primary caries, second digit [2]

Code	Description
0	Sound
1	First visual change in enamel (seen only after prolonged air drying or restricted to within the confines of a pit or fissure)
2	Distinct visual change in enamel
3	Localized enamel breakdown (without clinical visual signs of dentinal involvement)
4	Underlying dark shadow from dentin
5	Distinct cavity with visible dentin
6	Extensive distinct cavity with visible dentin

The seven ICDAS (International Caries Detection and Assessment System) codes for primary caries aim at linking visual appearance to lesion depth (Table 5.2) (Fig. 5.2a–e).

In caries diagnostic experiments using histology [5] as a gold standard, the ICDAS codes are interpreted as follows:

Code 0 $\triangleq$ D_0 (no caries)
Code 1 $\triangleq$ D_1 (caries limited to the outer half of enamel)
Code 2 $\triangleq$ D_2 (caries limited to the inner half of enamel)
Code 3,4 $\triangleq$ D_3 (caries limited to the outer half of dentine)
Code 5,6 $\triangleq$ D_4 (caries reaching to the inner half of dentine)

Both the Nyvad criteria and the ICDAS seem to be most widely used in clinical or epidemiological settings. It should be noted that the Nyvad criteria are applied on teeth before and after cleaning, because mature plaque is a good indicator for lesion activity. On the contrary, ICDAS and most traditional lesion detection systems require professional tooth cleaning before visual inspection. ICDAS, however, also requires two inspections; the first is performed on wet teeth and the second on dry teeth because of the discrimination between ICDAS code 1 and 2.

The UniViSS as reported by Kühnisch et al. [3] combines features of both systems, yet it lacks widespread use. The CAST (Caries Assessment Spectrum and Treatment) index has been developed for epidemiological reasons and takes into account that in severe cases there might be pulpal involvement and signs of periapical disease in the surrounding tissues [4].

For clinical purpose, visual-tactile caries detection should be supported by a dental mirror, adequate light, and an explorer. It should be noted that using a sharp-ended explorer to test a fissure in its resistance to withdrawal ("stickiness") must be discouraged. First, it does not provide any benefit over meticulous visual examination of a dry tooth and does not increase sensitivity or specificity [6]. For non-cavitated surfaces, the reported sensitivity of visual inspection combined with probing was reported to lie between 14% [7] and 24% [8]. Second, probing has been shown to irreversibly damage the tooth surface, to potentially turn a remineralizable subsurface lesion into a frankly cavitated lesion, and to thus promote lesion progression [9] (Fig. 5.3a, b). Both the WHO and ICDAS recommend using a round-ended periodontal probe for caries detection [2]. The use of a sharp probe, however, to detect surface roughness by gently stroking across the tooth surface may have some relevance for the assessment of lesion activity (Table 5.1).

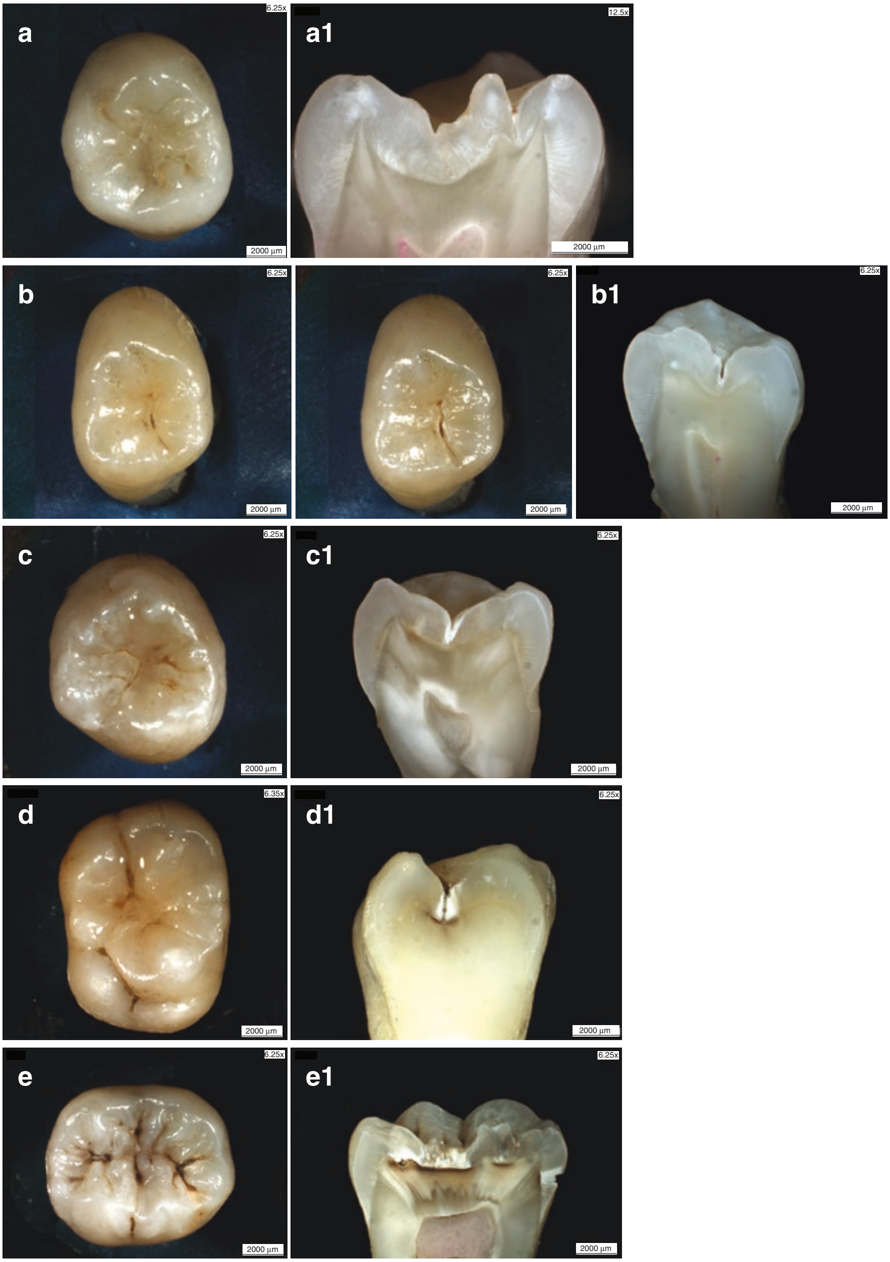

Fig. 5.2 ICDAS: clinical appearance (upper row) and histological match (lower row); (**a**) sound surface, no signs of demineralization; (**b**) incipient enamel lesion visible only after drying, demineralization limited to outer half of enamel; (**c**) established enamel caries, demineralization reaching inner half of enamel; (**d**) localized enamel breakdown in the palatal groove, clear dentine caries present; (**e**) dark underlying shadow, dentine caries present; please note, that ICDAS codes 5 and 6 (open dentine lesions) are not shown in the Figure, because they are not subject to any kind of sealing

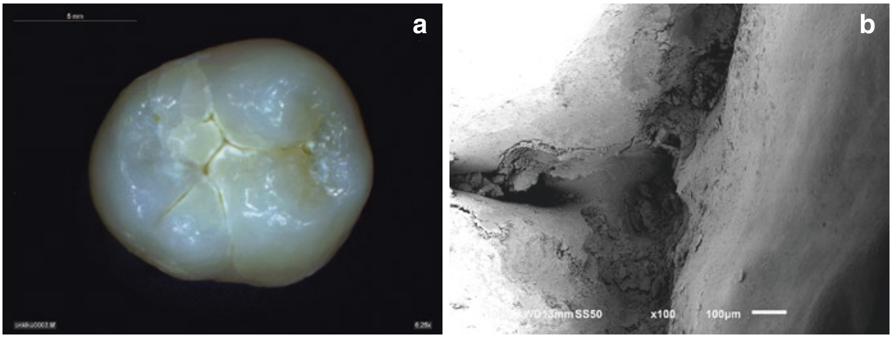

Fig. 5.3 A fissure with enamel caries is brittle (**a**) and should not be probed forcefully because the surface can be irreversibly damaged (**b**)

5.2 Visual Acuity

Visual caries detection is per se dependent on the visual acuity of the examiner. It has been shown in a study with more than 350 dentists and dental students of various ages that there is a considerable variety of visual acuity [10–12]. It was described that at the age of about 40 years, dentists have a significantly worse visual acuity than younger dentists. This might be important to notice because an optimum vision is mandatory for both diagnostic and many therapeutic interventions. Regular checkups with ophthalmologists or opticians should be performed annually in order to also promote reliable visual caries detection [13].

In this regard, it is also noteworthy to discuss illumination conditions during visual inspection. It has been mentioned earlier that visual inspection should be accompanied by “adequate illumination.” What is adequate? Dental companies have been producing brighter and brighter operation lamps during the past seven decades. Nowadays strong LED lamps or even xenon lamps produce an intensive bright light to chase away all shadows from the oral cavity. Furthermore, additional head lamps are being marketed that have a brightness of up to 80,000 lx. It was recently described that for visual caries detection, maximum illumination conditions are potentially detrimental due to reflection glare and loss of contrast [14].

5.3 Use of Magnification

Using magnifying glasses for visual caries detection has been recommended as “the method of choice for detection of occlusal non-cavitated caries” [15]. This is in line with earlier findings that with magnifying loupes, the accuracy of occlusal caries detection improved, i.e., the sensitivity increased with the sensitivity remaining unchanged [16]. However, a recent study showed that there is a limit of using magnification for occlusal caries detection: It was reported that magnification levels >2.5× led to a significant drop of specificity, irrespective of the level of experience of the examiners, especially when the portion of sound and non-cavitated lesions was large [17]. It must be kept in mind that the effective magnification is dependent on the examiner's own visual acuity and the working distance as well. A short-sighted dentist using magnification loupes might still see less than a normal-sighted dentist without loupe. Lastly, because there is no binding norm to report on magnification factors of dental loupes, it was found that there are major differences between measured and self-declared magnification levels in different dental loupes [18]. Generally, magnification can help to assist in visual caries detection, especially when the natural visual acuity decreases starting from an age of about 40 years [11, 12].

5.4 Radiography for Detection of Occlusal Lesions

Because fissure sealants are usually applied in children and adolescents, the adequate technique for application of radiography in terms of the ALARA principle is bitewing radiographs. Taking bitewing radiographs is helpful for approximal caries detection [19]. The detection of occlusal lesions with bitewing radiography, however, is only possible when the caries has penetrated into the dentine. While deep fissures and tight grooves hamper visual occlusal caries detection, addition and subtraction effects of their complex anatomy make it impossible to detect enamel caries in radiographs. Thus, for occlusal sites bitewing radiography helps to identify the so-called hidden caries lesions [20]. In a recent meta-analysis, sensitivity and specificity for detection of occlusal dentine caries lesions gained from in vivo studies were calculated to be 0.56 (95% CI 0.52/0.59) and 0.95 (0.94/0.96), respectively. In in vitro experiments, the respective values were found to be 0.56 (95% CI 0.52/0.59) and 0.87 (0.85/0.89) [21]. Furthermore, it was stated that there was considerable heterogeneity between different caries detection studies that depended, e.g., on number, experience, and education of the examiners involved in experiments. It must be noted that radiography itself is not helpful in detection of surface cavitation and that especially for occlusal surfaces visual inspection is the most accurate method to detect cavitated lesions and to prevent overtreatment in low-caries level populations [22]. Since lesion progression is dependent on the steady presence of bacteria, and lesion arrestment is dependent on the capability to constantly remove them, a treatment decision must not only rely on radiographic lesion extension but also has to take clinical factors into account.

Concerning "secondary" caries detection beneath existing fissure sealants, it is nowadays not clear if radiolucencies in occlusal dentine are new or pre-existing, because sealing of active, non-cavitated lesions has been recommended [23]. If clear fissure sealants have been used, visual inspection using ICDAS or additional caries detection methods such as QLF or laser fluorescence are no worse than bitewing radiographs [23]. If no clear fissure sealants have been used, it seems sensitive to judge with visual-tactile method if the sealant is broken or not, rather than to replace all fissure sealants with a radiolucency [24].

Radiography uses ionizing radiation and should therefore only be applied when the necessary information is decisive for treatment decision and when it cannot be gathered by other means. Especially in patients with high caries risk, taking radiographs (semi-)annually is being recommended by dental societies. However, alternative methods to using ionizing radiation for caries detection should be considered once their diagnostic validity has been clearly established [25].

5.5 Fiber-Optic Transillumination (FOTI), Near-Infrared Light Transillumination (NILT)

The method of tooth transillumination using an intense light source is broadly accepted by many dentists for caries detection in anterior teeth. For this purpose, transillumination is quick and inexpensive.

Fiber-optic transillumination (FOTI) uses the principle of light scattering to increase contrast between normal and carious enamel. Light is applied to the side of the tooth, and its transmission is observed from either the opposing side in front teeth or from the occlusal aspect in molars and premolars. As light is scattered more in demineralized enamel than sound enamel, a lesion appears dark on a light background. In addition to this carious, dentin appears orange, brown, or gray underneath the enamel, and this can significantly aid discrimination between enamel and dentine lesions (Fig. 5.4).

In addition to use in proximal lesions, FOTI has also been used for the detection of enamel and dentinal occlusal caries in combination with visual examination [26]. For enamel lesions the diagnostic performance was similar for visual and FOTI examinations. For the detection of dentine lesions, however, the performance was significantly improved using the FOTI method. A digitized FOTI device (DIFOTI) has been marketed and validated for occlusal lesions [27], but its clinical application has mainly been limited to proximal caries detection.

An updated version based on digital transillumination is the DIAGNOcam (KaVo, Biberach, Germany). It is a camera-based device that uses near-infrared transillumination, i.e., it operates on an invisible wavelength of about 780 nm instead of visible light. Contrary to earlier methods of transillumination, the device has two opposing prolonged branches that carry the optical fibers. The branches are placed on the oral and on the buccal aspect of the alveolar process, and the light is filtered by the mucosa and bone before entering the roots. A wide-angle CCD camera lense then captures the image (Fig. 5.5a–d). This method has been validated for approximal lesions and was found to perform equally compared to bitewing radiography [28]. For occlusal aspects, the DIAGNOcam device has not been validated yet. There is only anecdotal

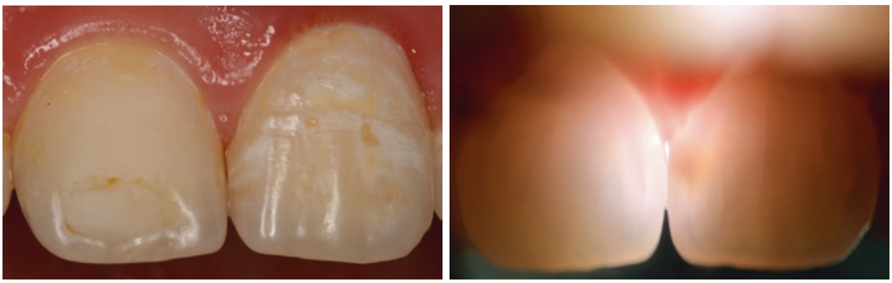

Fig. 5.4 Transillumination of the teeth helps to detect approximal enamel end dentine lesions, especially in front teeth

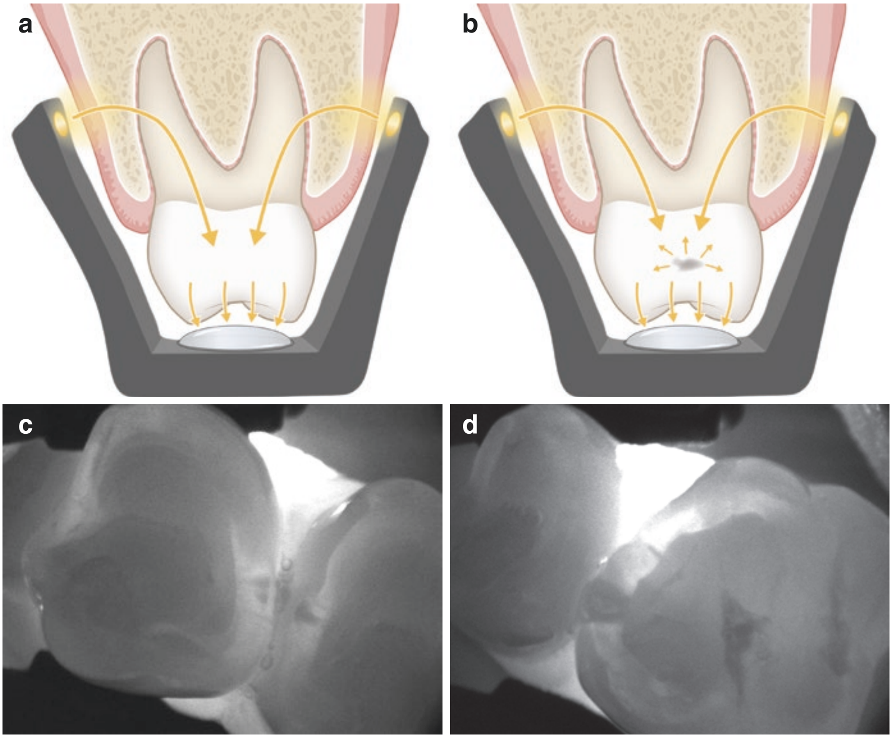

Fig. 5.5 (**a**–**d**): In the NILT technology, the light enters the tooth via the mucosa, bone, and roots (**a**, **b**). If an approximal lesion is present, it creates a shadow in the occlusal image. If the shadow reaches the enamel-dentin junction, a dentine lesion is present (**c**, **d**)

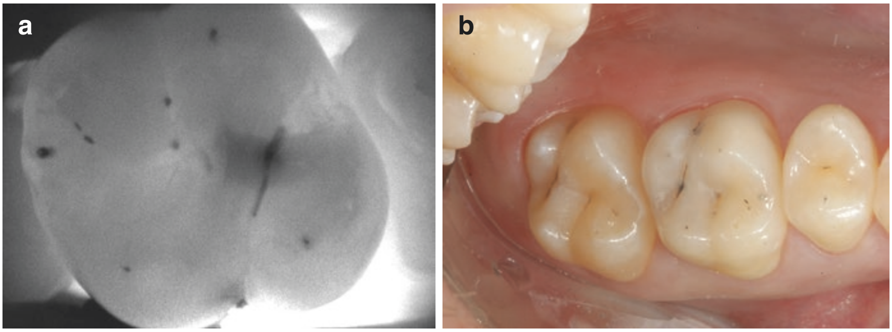

Fig 5.6 (**a**, **b**): A blurred shadow underneath the occlusal surface indicates the presence of dentine caries

information that it could have some diagnostic advantages [29] (Fig. 5.6a, b; Fig. 5.7a–c). Using the roots as light carriers, there seem to be problems in deciduous molars with root resorption, as well as with roots that are widely spread. Furthermore, the NILT technology is barely useful for secondary caries diagnostics.

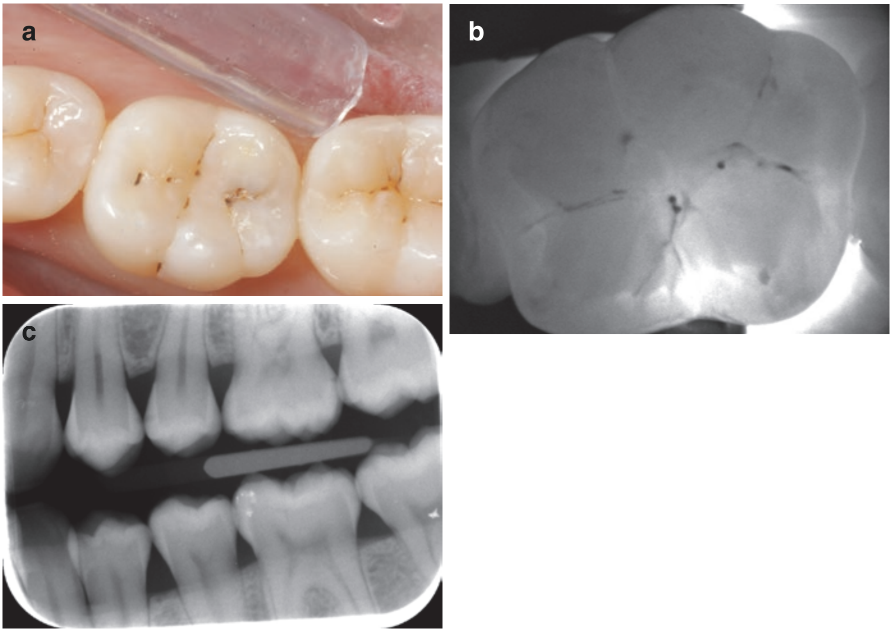

Fig. 5.7 (**a**–**c**): Clinically, ICDAS code 4 indicates dentine caries ("hidden caries"), but the DIAGNOcam image provides little additional information. The bitewing radiograph shows beginning dentine caries, consequently fissurotomy and fissure sealing was applied

5.6 Laser-Induced Fluorescence Methods

The most common laser fluorescence (LF)-based caries detection device is the DIAGNOdent (KaVo, Biberach, Germany), which comes as a pen-type device (LFpen) [30–32]. The design of the tip allows for assessments of occlusal or smooth surfaces including approximal surfaces. It is a laser-based instrument that emits light at 655 nm from a fiber-optic bundle and is able to capture the fluorescence emitted by oral bacterial metabolites (fluorophores) present in the caries lesions; this yields a quantitative measurement of caries development. In the case of 655 nm, the fluorescing objects have been identified as bacterial protoporphyrins [33, 34]. This device is based on the principle that carious tissue fluoresces more strongly than sound tissue. A photodetector quantifies the emitted fluorescence that passes through the filter and displays a real time (moment) and a maximum (peak) value. When a critically increased pore volume is exceeded, the amount of backscattered fluorescence—theoretically—is proportional to the amount of bacterial infection, pore volume, and lesion depth. The measurements of the DIAGNOdent render values between 0 (minimum fluorescence) and 99 (maximum fluorescence) (Fig. 5.8). Changes in emitted fluorescence register as an increase in the digital number displayed on a monitor, thus, making quantitative caries monitoring possible. Two controlled clinical trials showed that the diagnostic accuracy of LFpen was comparable to bitewing

Fig. 5.8 The DIAGNOdent pen device allows for quantitative monitoring of single regions of interest on a tooth surface and serves as second opinion device in decision-making

radiography in occlusal [35] and in approximal lesions [36, 37]. For occlusal lesions on the enamel caries detection threshold, clinical evidence suggests a sensitivity of 0.88 and a specificity of 0.85. On the dentine threshold, the calculated values were 0.67 and 0.79, respectively [35]. For approximal lesions, the sensitivity and specificity values were 0.86 and 0.7 (enamel threshold) and 0.6 and 0.84 (dentine threshold), respectively [37]. However, the method is likely to produce more false-positive estimates because it is also sensitive for some filling materials, to some prophylaxis pastes and to calculus [38–40]. Therefore, there is little advantage of using LFpen for approximal lesion detection at composite margins [41] and no advantage at approximal amalgam margins [42]. Furthermore, in root caries detection, LF is a not reliable method as well [43]. LF devices have been also studied in other clinical situations, e.g., for the detection of residual caries during excavation [44], caries around orthodontic brackets [45], and caries under sealants [46, 47].

Slightly different from laser-induced fluorescence, another device using red LED light fluorescence has been marketed for caries detection purposes (Midwest Caries I.D., Dentsply, USA). The caries detection is semiquantitative, i.e., a green light signals healthy teeth, while red light indicates the presence of caries. The velocity of accompanying beeping noises indicates the severity of the caries process. There is no clinical study at hand that supports the use of this caries detection device. However, limited in vitro evidence shows that it may be useful for occlusal caries detection [48] but has no validity for detection of approximal lesions [49] (Fig. 5.9).

More recently, camera-based devices (VistaProof and VistaCam iX, both Dürr, Germany) (Fig. 5.10a, b) and system were marketed and tested in vitro [50] and in vivo [51–53]. The clinical diagnostic accuracy was reported to be 0.46 for enamel lesions and 0.91 for dentine lesions. However, the reported sensitivity value at the dentine threshold was 0.26 (specificity being 0.98), while at the enamel threshold sensitivity was found to be 0.92 (specificity 0.41). It was concluded that the device could support the treatment decision in combination with meticulous visual-tactile inspection [52]. The advantage of such a camera-based system however is the

Fig. 5.9 The Midwest Caries ID is simple to use but has limited diagnostic value

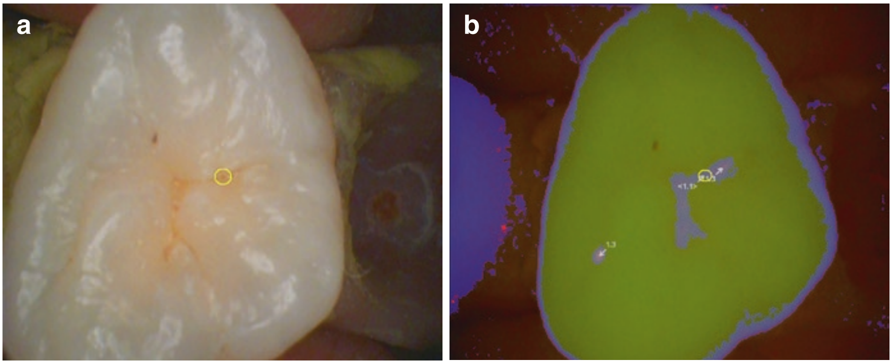

Fig. 5.10 The VistaCam (Dürr) also quantifies regions of interest on a whole tooth surface on a whole tooth sureface (**a**) ROI, daylight mode; (**b**) fluorescence mode with multiple quantitative measurements of fluorescence). In this case, nonoperative treatment was performed

possibility to quantify the caries process and to store the captured images in order to monitor lesions and allow a comparison at later recall appointments. Thus, invasive treatment could be postponed and only be performed when a lesion clearly shows to be progressive.

5.7 Quantitative Light-Induced Fluorescence (QLF)

Excitation of dentine with blue light (370 nm) causes it to fluoresce in the green-yellow spectrum. The method that uses this particular wavelength is known as quantitative light-induced fluorescence. The fluorescence is observed through a yellow filter ($\lambda \geq 540$ nm) to cut out the excitation light. An incipient enamel lesion can be observed because of an increase of light scattering relative to the surrounding enamel. Two effects thus occur: (1) because less excitation light reaches the dentine, less fluorescence is produced underneath the lesion; and (2) less fluorescent light is observed because it is scattered through the lesion. Consequently, the contrast between the surrounding sound enamel and the lesion is enhanced. An incipient lesion can be seen as a dark spot on a light green background. In addition to green fluorescence from dentine, the fluorescence of bacterial porphyrins is visible in red [54].

The QLF method was originally developed for intraoral quantification of mineral loss in enamel lesions. A color microvideo CCD camera and computed image analysis were assembled and used (Inspektor Research Systems, the Netherlands) [55]. The software subtracts the digital fluorescence images of the enamel. Three lesion quantities are thus being calculated: fluorescence loss (mean ΔF or ΔFmax), area of the lesion (in mm^2), and their product (ΔQ).

In order to enhance the application in clinical studies at different locations, a smaller, portable system for intraoral use was developed. Data is collected, stored, and analyzed by custom-made software. The portable QLF device was validated against chemical analysis and microradiography for the assessment of mineral changes in enamel and compared with results from laser light measurements [56]. It was concluded that QLF was a valid method for quantification of incipient enamel lesions. However, accurate assessments were limited to a depth of about 400 μm. Thus, the QLF method could be regarded as sensitive enough to measure remineralization in early enamel lesions. Moreover, attempts to establish suitable cutoffs for dentine lesions were made [57].

The in vivo reliability of QLF is excellent for the quantification of smooth-surface caries, with intra-class correlation coefficients for inter-examiner reproducibility of $r = 0.95–0.99$ [58, 59]. The QLF method has been applied in a number of clinical trials. The QLF method has been applied to test the natural behavior of white spot lesions after removal of orthodontic brackets [60, 61], for the evaluation of preventative measures in patients at high caries risk [62] and for comparing different prophylactic means in clinical studies [63, 64]. In a clinical trial with 34 15-year-old students with non-cavitated occlusal surfaces, QLF was more sensitive than meticulous visual inspection and yielded double the number of carious sites [65]. Recently, the QLF method was used as a gold standard in 39 children at nursery schools to compare the effect of a remineralizing agent (CPP-ACP) with toothbrushing with a fluoridated toothpaste [66]. Although QLF is a sensitive and accurate method to assess and monitor enamel lesions, its time-consuming image processing and analysis and its costs are the biggest obstacles for wide use in private dental practice.

An intraoral QLF camera system was lately marketed that offers the choice between white-light mode and fluorescent light mode (Soprolife, Acteon, France) (Fig. 5.11a–e). The fluorescence images are not quantitative but allow qualitative discrimination between autofluorescence and bacterial fluorescence. Effort to translate the images into a clinically relevant classification system has recently been made [67]. It was shown that the Soprolife camera with the blue fluorescence mode yielded a sensitivity at dentine threshold of 0.95 and a specificity of 0.55 in vitro [67]. It must be kept in mind that such a low specificity means a high fraction of false-positive findings, i.e., many teeth would have received unnecessary invasive treatments. Consequently, such a camera-based system should never be a

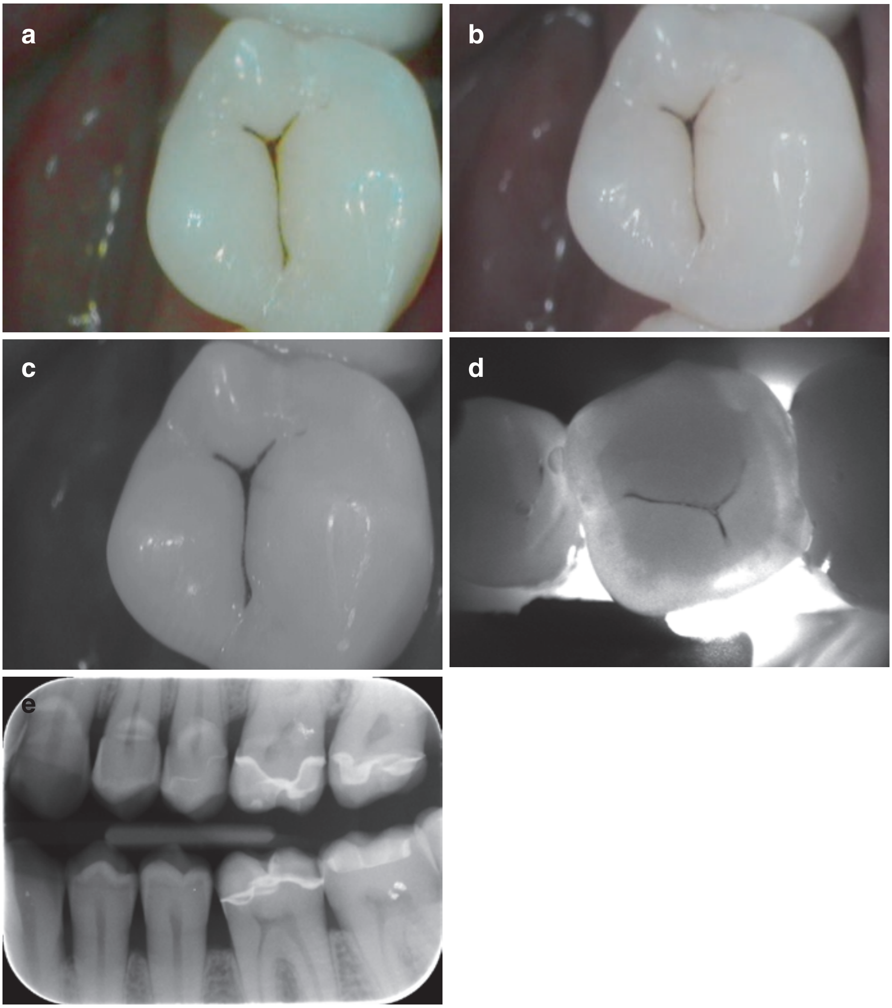

Fig. 5.11 Images of a questionable fissure of tooth 35. (**a**) Soprolife camera, plaque mode. A little yellow stain indicates presence of plaque; (**b**) Soprolife, video mode (white light); (**c**) Soprolife, caries mode. No red fluorescence present; (**d**) DIAGNOcam image. No shadow underneath the stained fissure; (**e**) bitewing radiograph. No occlusal translucency. The tooth was treated nonoperatively

stand-alone device for decision-making. Despite of the limited clinical value in caries diagnostics, with regard to periodontal diseases, the same device was shown to provide reliable information about the presence of microbial plaque and gingival inflammation [68].

It should be noted that neither of the additional caries detection devices is able to detect a cavitation of the surface. This special feature is—as of today—limited to visual-tactile caries detection.

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Which Teeth Have to Be Sealed?

6

Spyridon N. Papageorgiou and Hubertus van Waes

Abstract

The absolute effectiveness of pit and fissure sealants in preventing the development of new caries lesions or the progress of incipient caries lesions has been proved by randomized clinical trials and systematic reviews thereof. Based on the evidence-based assessment of existing randomized clinical trials performed for this chapter, pit and fissure sealants can be effectively applied on any deciduous or permanent posterior teeth without adverse effects on their clinical performance. However, caries susceptibility varies among different patients and among different teeth within a patient. Therefore, a risk-based assessment on a case-by-case manner by an experienced clinician that takes into account factors like tooth morphology, caries history, fluoride intake, oral hygiene, and patient age needs to be undertaken to maximize the cost-to-benefit value of sealant application.

6.1 Introduction

Dental caries remains the most common chronic disease among all oral conditions [1] with prevalence for caries or caries experience ranging between 21% (children 6–11 years old), 58% (adolescents 12–19 years old), and 91% (adults older than 20 years old) [2, 3] and differences according to geographic region [4], family income [5], and social disadvantage [6].

Dental caries manifests itself as a continuous range of disease with increasing severity and tooth destruction, varying from subclinical changes to lesions with dentinal involvement [7, 8]. Although the initial caries stages lack clear symptoms,

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this is not the case when lesions progress into dentine [9]. Dental caries can result in aesthetic, functional, or psychosocial complaints in a child's daily routine that ultimately affect their quality of life, including chewing and speech impairment, school absenteeism, decline in school performance, trouble sleeping, irritability, and refraining from smiling or speaking [10–13], while it is the primary cause of oral pain and tooth loss [9].

6.2 Caries Risk of Various Tooth Surfaces

As far as different teeth are concerned, the highest increment of dental caries among school-attending children is detected on the occlusal surfaces (i.e., the pit and fissure surfaces) of the first and second molars [14]. Overall, about half of all carious lesions are found in the pits and fissures of permanent posterior teeth [14–16], although caries is not confined solely to permanent teeth. This might have to do with the direct influence of internal morphology of the interlobal groove-fossa system (see Chap. 2) and caries progression [17], due to the easier bacterial accumulation, qualitative differences of pit and fissure plaque with smooth-surface plaque, and difficulty of plaque removal from the occlusal surfaces [8, 18]. Other explanations provided include the anatomical differences or different posteruptive maturation of the various tooth surfaces [19]. Additionally, fluoride is less effective at preventing caries in these secluded tooth surfaces than at smooth surfaces [20], due to the anatomical particularities of the former.

6.3 Sealants as a Caries-Preventive Measure

The procedure of "sealing" the pits and fissures of teeth was introduced in the 1960s to protect the tooth from caries and includes the placement of a liquid material onto the occlusal surface (i.e., pits and fissures) of posterior teeth, thereby forming a layer that is bonded micromechanically. The primary modus operandi of this is to act mainly as a barrier against acids and the subsequent mineral loss from within the tooth [21] while secondarily possibly shielding against bacteria that are responsible for caries and making their accumulation on the tooth surface more difficult [22]. Following the adoption of sealants, a decline in caries prevalence was seen in the 1970s and 1980s, which could, at least in part, be attributed to sealants [14]. According to recent surveys, high prevalence rates for sealant use have been seen on the permanent teeth of children and adolescents, ranging from 40.5% for children to 43.1% for adolescents [2] with major disparities in sealant utilization by race/ethnicity and socioeconomic status.

Pit and fissure sealants can be placed on either caries-free posterior teeth to prevent pit and fissure caries or on teeth with incipient caries lesions to prevent their progression to definitive caries [22, 23]. There is a vast wealth of available clinical evidence about the effectiveness of dental sealants, which depends on the longevity of sealant coverage (i.e., clinical retention) [24], with about 8% of sealant retention loss for each additional year of follow-up [25]. Bravo et al. [26] followed 6- to 8-year-old schoolchildren for 9 years after sealant application and reported 27% of sealed surfaces having caries compared to 77% of surfaces having caries without sealant application. Recent systematic reviews and meta-analyses of randomized clinical trials concluded that pit and fissure sealants are effective and safe to prevent or arrest the progression of non-cavitated carious lesions compared with a control without sealants [27, 28] and have a caries-preventive effect equal [29] or better [28, 30] than fluoride varnishes. Additionally, the use of adhesive systems beneath pit and fissure sealants has been reported to increase the sealant's retention, with conventional etch-and-rinse systems being preferable to self-etching systems [22]. Finally, further uses of dental sealants include sealing palatal surfaces of anterior teeth to protect against erosive tooth wear [31], sealing anomalous dental morphologies like talon cusps or hypomineralizations [32, 33], or sealing smooth enamel surfaces to protect against caries during orthodontic treatment [34], but these fall out of the scope of the present review.

6.4 Caries Risk of Different Patients

The assessment of the clinical effectiveness of dental sealants is closely intertwined with the baseline caries risk of each patient. To put it simply, the treatment benefit from sealants might vary among children at low, moderate, and high risk of caries. However, a recent Cochrane review [27] concluded that different outcome measures and follow-up times were found among included studies that made it difficult to compare the results. Additionally, the fact that the caries progression rate has changed and has become slower during recent decades [35] might complicate the drawing of robust conclusions on sealant effectiveness based on baseline risk.

6.5 Review of the Clinical Performance of Sealants on Various Teeth

Although the overall efficacy of dental sealants has long been documented in randomized clinical trials and systematic reviews thereof [27, 28, 30], it remains unclear whether the clinical performance of sealants is affected by the various tooth types. The most recent evidence-based clinical practice guideline for the use of pit and fissure sealants published by the American Dental Association and the American Academy of Pediatric Dentistry in 2016 [36] recommended the use of sealants compared with non-use in primary and permanent molars with both sound occlusal surfaces and non-cavitated occlusal carious lesions in children and adolescents. However, no distinction was made between the first and second molars, and premolars were not mentioned at all. Additionally, the guideline authors highlighted the need for additional studies assessing the effect of sealants in the primary dentition. This information could have direct implications on the clinical decision of which teeth should be sealed by the dentist. Therefore, a systematic review of randomized clinical trials was conducted to attempt to answer the clinical question: "Is the clinical performance of dental sealants affected by tooth characteristics?"

The review's protocol was a priori registered in PROSPERO (CRD42017 058510), and the review was conducted and reported according to Cochrane handbook [37] and PRISMA statement [38], respectively. Details on the methodology and results of the systematic review can be found elsewhere [39]. Included were randomized clinical trials on human patients comparing the clinical performance of pit and fissure sealants of any two or more different tooth types or characteristics. Five electronic databases (MEDLINE via PubMed, Scopus, Web of Science, Cochrane Library's Central Register of Trials, and the Virtual Health Library) were systematically searched without any limitations from inception to February 2017, followed by manual searches. Two persons performed independently study selection, data extraction, and risk of bias assessment with the Cochrane tool. Meta-analyses were performed with a random effects model according to Paule and Mandel [40] to calculate relative risks (RR) with their corresponding 95% confidence intervals (CI), and existing heterogeneity was appropriately calculated, followed by subgroup and sensitivity analyses. Comparisons among the various tooth categories were performed taking the first permanent molar as reference category, since this is the tooth most often being sealed, due to its predilection for dental caries [41]. The overall quality of clinical recommendations for each outcomes was ultimately rated using the Grades of Recommendations, Assessment, Development, and Evaluation (GRADE) approach, as very low, low, moderate, or high [42].

A total of 349 and 7 papers were identified through electronic and manual searches, respectively (Fig. 6.1). After removal of duplicates and initial screening by title or abstract, 100 papers were assessed using the eligibility criteria, and 20 papers were left as potentially eligible for this systematic review (Fig. 6.1). In seven instances, trialists were contacted, as additional data were needed to include their trials, and in three cases raw or aggregate data were provided. Thus, a total of 16 papers, all pertaining to unique trials, were finally included in the systematic review.

6.5.1 Study Characteristics

The characteristics of the included randomized clinical trials can be seen in Table 6.1. Of these, 3 (19%) were parallel and 13 (81%) cluster randomized trials, conducted predominantly in universities (n = 10; 63%) of 12 different countries. They included a total of 2778 patients (median 114 patients per trial; range 16–521) with male patients being the 49.1% (786/1600 patients among the 7 trials that reported patient sex) and with an average age of 8.4 years. Dental sealants were applied on caries-free teeth (n = 8; 50%), on teeth with initial non-cavitated carious lesions (n = 2; 13%), or a combination thereof (n = 6; 38%). Various preparation protocols or sealant materials were tested in the included trials and reported either the review's primary outcome of caries (n = 7; 44%) or the secondary outcome of retention (n = 15; 94%).

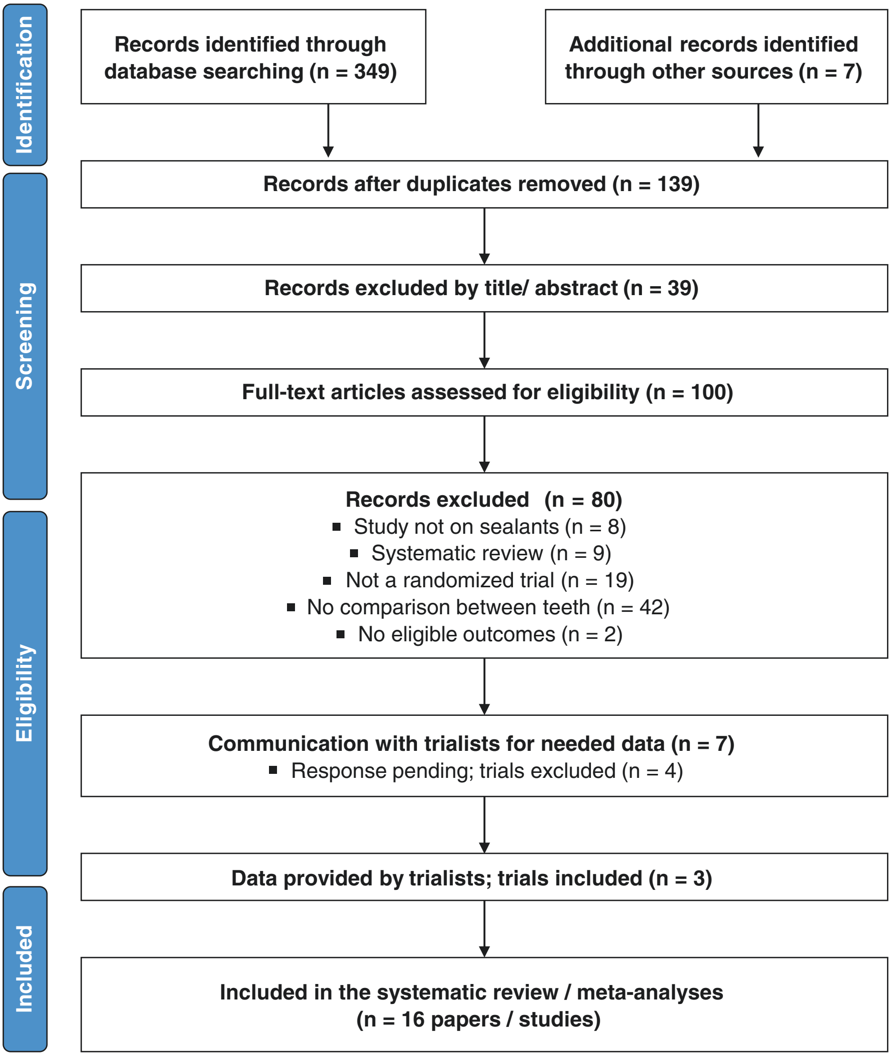

Fig. 6.1 PRISMA flow diagram for the identification and selection of studies eligible for this systematic review

6.5.2 Risk of Bias Within Studies

The risk of bias for the included trials included is summarized in Fig. 6.2. High risk of bias was found in nine (56%) trials for at least one bias domain, with the most problematic being complete blinding of outcome assessments (missing in 50% of the trials), randomization procedure (improper in 19% of the trials), and incomplete outcome data (in 6% of the trials).

Table 6.1 Characteristics of included trials

Nr	Study	Design; setting; country[a]	Patients (M/F); mean age	Caries[b]	Intervention	FU	Outcome
1	Baca 2007	smRCT; Uni; ESP	56 (NR); 7.3 yrs	No	Different materials; SL (Delton; Delton Plus; Concise; OptiBond Solo)	12	Retention (total)
2	Bhushan 2017	smRCT; Uni; IND	50 (NR); (6–8 yrs)	No	AE vs. AE-air abrasion; SL (NR)	6	Retention (Simonsen)
3	Corona 2005	smRCT; Uni; BRA	40 (NR); (4–7 yrs)	No	Different materials; SL (Fluroshield; Bond 1+Flow it!)	12	Retention (Tonn and Ryge)
4	de Oliveira 2013	smRCT; Uni; BRA	80 (NR); (6–8 yrs)	Both	Different materials; SL (GC Fuji Triage) vs. non-SL (F varnish)	18	Retention (Simonsen)
5	Erdemir 2014	smRCT; Uni; TUR	34 (18/16); (16–22 yrs)	Yes	Different materials; SL (Helioseal F; Tetric Evo Flow)	24	Retention (Tonn and Ryge); ICDAS II; caries
6	Grande 2000	smRCT; Uni; BRA	38 (15/23); 14 yrs	No	Different materials; SL (Delton; OptiBond)	30	Retention (Tonn and Ryge)
7	Handelman 1987	smRCT; Uni; GBR	159 (NR); 13.4 yrs	Both	Different materials; SL (Delton; Nuva-Cote)	24	Retention (total and partial)
8	Honkala 2015	smRCT; Uni; KWT	147 (76/71); 4.1 yrs	Both	Different materials; SL (Clinpro) vs. non-SL (F varnish)	12	ICDAS; caries (dev/prog); retention (total and partial)
9	Jodkowska 2008	smRCT; schools; POL	360 (NR); (7–8 yrs)	No	Different materials (Concise Brand White; Concise Enamel Bond; Nuva-Seal)	180	Retention (total and partial); DMFT/DMFS; caries reduction; prevented fraction; net gain;
10	Karaman 2013	smRCT; Uni; TUR	16 (1/15); 21.0 yrs	No	AE vs. Laser-etch; SL (Clinpro)	24	Retention (total and partial)
11	Li 1981	smRCT; clinic; USA	200 (NR); (5–16 yrs)	No	Different materials; SL (Delton; Nuva-Seal)	24	Retention; net gain; reseal need; caries (dev)

(continued)

Table 6.1 (continued)

Nr	Study	Design; setting; country[a]	Patients (M/F); mean age	Caries[b]	Intervention	FU	Outcome
12	Liu 2012	pRCT; schools; CHN	501 (250/251); 9.1 yrs	Both	Different materials; SL (Clinpro) vs. non-SL (F varnish/SDF) vs. placebo	24	ICDAS; retention; dentin caries
13	Muller-Bolla 2013	smRCT; schools; FRA	343 (177/166); 6.4 yrs	Both	Efficacy; SL (Delton Plus) vs. no treatment	12	Retention (total and partial); ICDAS
14	Poulsen 2001	smRCT; health center; SYR	179 (NR); 7 yrs	Both	Different materials; SL (Delton; Fuji III)	36	Retention (total and partial); caries
15	Qvist 2017	pRCT; clinics; DNK	521 (249/272); (6–17 yrs)	Yes	Different materials (SL vs. non-SL)	84	Replacement need; caries progression
16	Sgavioli 2000	pRCT; Uni; BRA	60 (NR); (8–15 yrs)	No	Different materials; SL (Fluroshield) with or without topical F	12	Retention (total and partial)

AE acid-etch-technique, *dev* development *DMFT/DMFS* decayed missing filled teeth/surfaces index, *F* fluoride, *FU* follow-up in months, *ICDAS* International Caries Detection and Assessment System, *M/F* male/female, *NR* not reported, *pRCT* parallel randomized clinical trial, *prog progression*, *SL* sealant, *smRCT* split-mouth randomized clinical trial, *Uni* university clinic, *yrs* years
[a]Countries are reported according to their ISO alpha-3 codes
[b]Sealed tooth caries lesions pertained to initial carious non-cavitated lesions

6.5.3 Results of Individual Studies and Data Synthesis

Focus in this review is given mainly at the review's two predefined outcomes: the primary outcome of caries incidence and the secondary outcome of sealant retention. For the analyses included in the main part of the review, only the longest follow-up is used from each included trial.

As far as the caries incidence of sealed teeth is concerned, no significant differences could be found between teeth in the right or left side of the mouth and between maxillary and mandibular teeth (Table 6.2). However, compared to sealed first permanent molars, sealed premolars were significantly less likely to develop caries (three trials; RR = 0.07; 95% CI = 0.01–0.61; $P = 0.013$). However, since heterogeneity of the initial meta-analysis was very high ($I^2 = 82\%$; 95% CI = 66–99%), a shorter follow-up was chosen for one of the meta-analyzed trials [43] (5-year instead of 15-year follow-up) in order to make the three trials more compatible. Subsequently, sealed premolars were significantly less likely to develop caries than sealed molars (three trials; RR = 0.12; 95% CI = 0.03–0.44; $P = 0.001$) with moderate

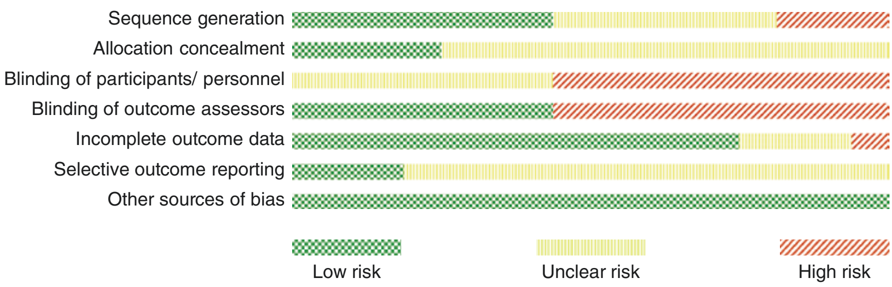

Fig. 6.2 Risk of bias summary of the included trials

Table 6.2 Random effects meta-analyses on the primary outcome of this review (caries incidence of the sealed tooth)

Referent	Experimental	Trials	RR (95% CI)	*P*	tau^2 (95% CI)	I^2 (95% CI)	95% prediction
Right	Left	4	1.49 (0.62,3.55)	0.372	0.56 (0,5.46)	74 (0,96)	0.04,63.43
Maxilla	Mandible	8	1.28 (0.62,2.62)	0.503	0.74 (0,2.26)	80 (0,92)	0.13,12.56
Permanent M1	Permanent PMs	3[a]	0.09 (0.01,0.72)	0.023	2.43 (0,50.00)	75 (0,99)	0.00,>1000
Permanent M1	Permanent M2	3	0.91 (0.40,2.06)	0.817	0.44 (0,14.69)	86 (0,100)	0.00,>1000
Deciduous M1	Deciduous M2	1	1.06 (0.45,2.49)	0.899	na	na	na

RR relative risk, *CI* confidence interval, *PM* premolar, *M* molar, *na* not applicable
[a]Initial meta-analysis (three trials; RR [95% CI] = 0.07 [0.01,0.61]; *P* = 0.015; tau^2 [95% CI] = 2.79 [1.18,50.00]; I^2 [95% CI] = 82% [66%,99%]; 95% prediction = 0,>1000) modified by including a shorter follow-up for one trial (5 years instead of 15 years) to make it more homogenous

heterogeneity (Fig. 6.3). This was translated to an NNT = 8.6 (rounded up to 9), which meant that an extra carious lesion would be avoided for every ninth premolar sealed. Finally, no significant difference in the caries incidence was found between sealed first and second permanent molars or between the first and second deciduous molars.

As far as sealant retention is concerned, this was assessed as combined loss, by grouping total and partial loss of the sealant together (Table 6.3). No statistically significant difference in combined loss of the sealant could be found according to mouth side (right versus left side), jaw (upper versus lower), and tooth type (permanent first molar versus permanent second molar/permanent first molar versus deciduous second molar/deciduous first molar versus deciduous second molar), with high heterogeneity in most cases, which was interpreted as statistical "noise" (Fig. 6.3). The only significant difference in sealant retention found pertained to tooth type, where sealants on first or second premolars were significantly less likely to be lost compared to sealants placed on first permanent molars (seven studies; RR = 0.42; 95% CI = 0.21–0.83; *P* = 0.013). However, since heterogeneity of the initial

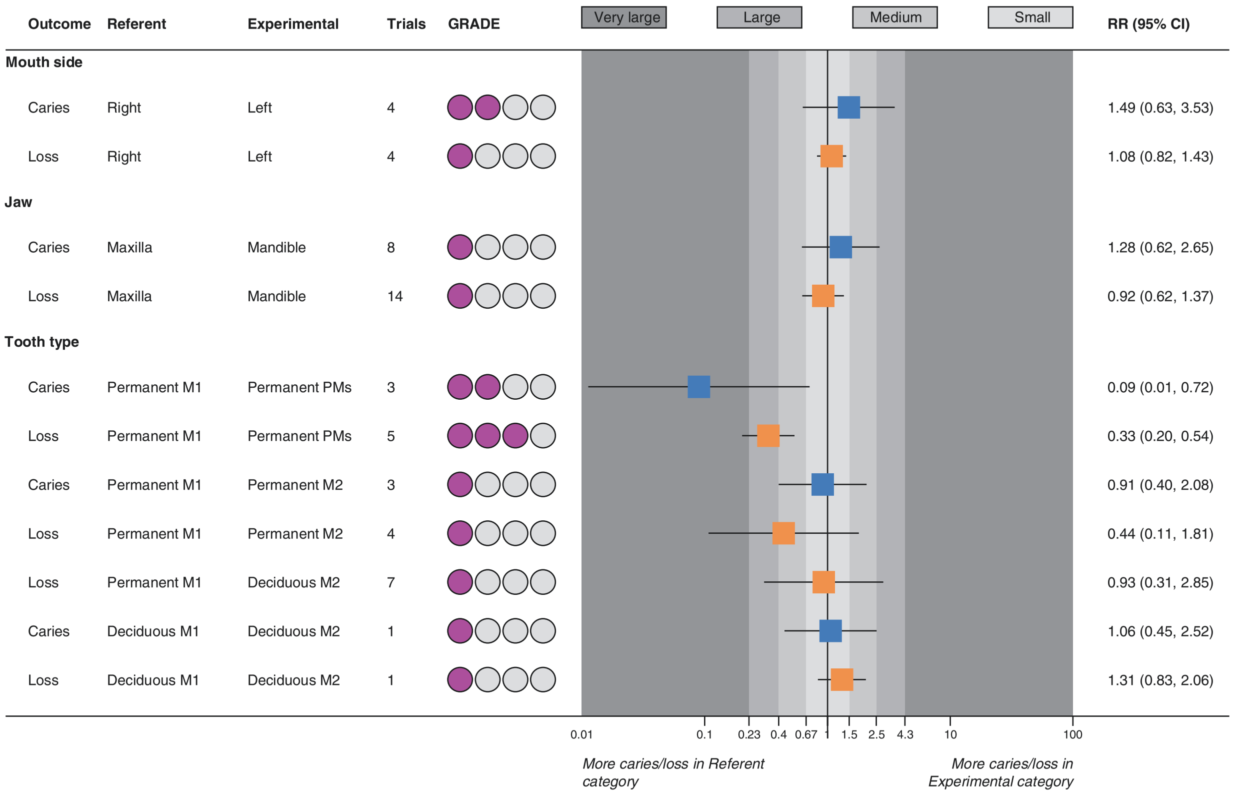

Fig. 6.3 Contour-enhanced cumulative forest plot presenting the results of random effects meta-analyses for the primary and secondary outcome of this systematic review. The forest plot has been enhanced with gray contours starting from small effect magnitude (lighter gray in the middle) and moving outward to areas of medium, large, and very large effect magnitude, based on relative risk cutoffs of 1.5, 2.5, and 4.3 (or 0.67, 0.4, 0.23)

Table 6.3 Random effects meta-analyses on the secondary outcome of this review (total or partial loss of the sealant)

Referent	Experimental	Studies	RR (95% CI)	*P*	tau^2 (95% CI)	I^2 (95% CI)	95% prediction
Right	Left	4	1.08 (0.82,1.43)	0.576	0.06 (0,0.84)	97 (0,100)	0.31,3.75
Maxilla	Mandible	14	0.92 (0.62,1.37)	0.692	0.44 (0.25,1.11)	99 (99,100)	0.20,4.16
Permanent M1	Permanent PMs[a, b]	5	0.33 (0.20,0.54)	<0.001	0.23 (0,1.40)	81 (0,96)	0.06,1.85
Permanent M1	Permanent M2	4	0.44 (0.11,1.80)	0.255	1.64 (0,19.74)	95 (0,100)	0.00,244.40
Permanent M1	Deciduous M2	7	0.93 (0.31,2.83)	0.900	1.74 (0.91,7.38)	89 (82,97)	0.02,36.82
Deciduous M1	Deciduous M2	1	1.31 (0.83,2.06)	0.249	na	na	na

RR relative risk, *CI* confidence interval, *PM* premolar, *M* molar, *na* not applicable

[a]Separate meta-analyses of first permanent molars versus first premolars (two trials) or first permanent molars versus second premolars (two trials) omitted and incorporated into overall meta-analysis of first permanent molars versus first/second premolars (seven trials)

[b]Initial meta-analysis: (seven trials; RR [95% CI] = 0.42 [0.21,0.83]; $P = 0.013$; tau^2 [95% CI] = 0.69 [0.32,3.51]; I^2 [95% CI] = 96% [91%,99%]; 95% prediction = 0.04,4.25); one trial omitted (Jodkowska 2005) and two trial arms [44] pertaining to the same material combined to reduce heterogeneity

meta-analysis was very high ($I^2 = 96\%$; 95% CI = 91–99%), one trial [43] was omitted, and two arms pertaining to the same sealant material from the same trial [44] were pooled in order to reduce heterogeneity. Subsequently, sealants on premolars were significantly less likely to be lost than sealed first permanent molars (five trials; RR = 0.33; 95% CI = 0.20–0.54; $P = 0.001$). Residual heterogeneity still remained high, but it affected only the magnitude and not the direction of effects (i.e., all trials were on the same side of the forest plot), and high uncertainty around the heterogeneity estimates was seen ($I^2 = 81\%$; 95% CI = 0–96%). We therefore decided that heterogeneity posed no threat to the validity of meta-analyses results, which were translated to an NNT = 5.5 (rounded up to 6), which meant that an additional sealant loss would be avoided for every sixth premolar sealed.

6.5.4 Additional Analyses

Subgroup analyses could be performed only for a handful of meta-analyses that included at least five trials. Apart from minor differences according to the trial's follow-up, significant subgroup effects were seen according to the sealant material, where resin sealants with fluoride used on deciduous molars were more likely to be lost compared to first permanent molars, which was the opposite of what was seen for resin sealants without fluoride ($P < 0.10$). Additionally, sealed lower teeth were more likely to develop caries than upper sealed teeth, when either a fluoride resin sealant or a glass ionomer cement sealant was used than a resin sealant ($P < 0.10$).

As however only a limited number of trials contributed to the analysis and no concrete conclusions could be drawn, caution is warranted until further research confirms or rejects these.

Reporting biases could be assessed only for one meta-analysis that included at least ten trials (Tables 6.2 and 6.3): the comparison of the secondary outcome (sealant loss) between maxillary and mandibular teeth. As such, both the contour-enhanced funnel plot and Egger's test (coefficient = −0.54; 95% CI = −1.89–0.81; $P = 0.400$) indicated no significant signs of bias.

6.5.5 Risk of Bias Across Studies

Assessment of existing meta-evidence with the GRADE approach (Tables 6.4 and 6.5) indicated that very low- to low-quality evidence supported all assessed comparisons, with the main limitation being inconsistency among trials (heterogeneity) and the fact that essentially observational data were extracted from the included randomized trials. For the statistically significant differences between sealants placed on premolars or first permanent molars (both for caries and sealant loss), low to moderate quality of meta-evidence was found, with the main limitation being the different baseline caries risk of untreated premolars and molars.

6.5.6 Sensitivity Analyses

Sensitivity analyses could not be performed for any of the meta-analyses, as the main reason for downgrading the quality of evidence was inconsistency (heterogeneity). However, this was due to a general scattering of trials on both sides of the forest plot, characteristic of the absence of a specific treatment relationship, and omission of single trials could not produce a homogenous group of trials. The two instances of statistically significant meta-analyses were on the other side supported by high-quality evidence, and therefore no sensitivity analysis was needed.

6.5.7 Summary of Evidence from the Review

The present systematic review evaluated the clinical performance of pit and fissure sealants placed on the occlusal surfaces of caries-free or non-cavitated carious posterior teeth to prevent caries and its progression. According to existing evidence from 16 identified randomized clinical trials including 2778 patients, tooth-related characteristics had little to no influence on the clinical performance of pit and fissure sealants.

According to the results of the meta-analyses, no significant difference between sealants placed on upper and lower teeth could be seen in terms of either dental caries or retention of the sealant ($P > 0.05$ for both; Tables 6.2 and 6.3). Potential differences in the bonding performance of dental materials (including pit and fissure

Table 6.4 GRADE summary of findings table for the primary outcome (caries of sealed teeth)

Outcome studies (teeth)	RR (95% CI)	Anticipated absolute effects[a] (95% CI)			Quality of the evidence (GRADE)[b]	What happens
		Referent[a]	Experimental	Difference		
Caries by mouth side 4 trials (1044 teeth)	1.49 (0.62,3.55)	*Right side* 7.0%	*Left side* 10.4% (4.3–24.9%)	3.4% more caries (2.7% less to 17.9% more)	⊕⊕OO low	There may be little or no difference
Caries by jaw 8 trials (2136 teeth)	1.28 (0.62, 2.62)	*Upper jaw* 7.0%	*Lower jaw* 9.0% (4.3–18.3%)	2.0% more caries (2.7% less to 11.3% more)	⊕OOO very low[c] due to inconsistency	There may be little or no difference
Caries by tooth type 3 trials (1395 teeth)	0.09 (0.01,0.72)	$_{perm}$*M1* 13.2%	$_{perm}$*PMs* 1.2% (0.1–9.5%)	12.0% less caries (3.7% to 13.1% less)	⊕⊕OO low[d] due to effect magnitude	There might be less caries under sealed premolars
Caries by tooth type 3 trials (1117 teeth)	0.91 (0.40,2.06)	$_{perm}$*M1* 18.7%	$_{perm}$*M2* 17.0% (7.5–38.5%)	0.3% less caries (11.2% less to 19.8% more)	⊕OOO very low[c] due to inconsistency	There may be little or no difference
Caries by tooth type 1 trial (265 teeth)	1.06 (0.45,2.49)	$_{decid}$*M1* 6.6%	$_{decid}$*M2* 7.0% (3.0–16.4%)	0.4% more caries (3.6% less to 9.8% more)	⊕OOO very low[c] due to inconsistency	There may be little or no difference

Clinical performance of pit and fissure sealants placed on various teeth
Patient or population: patients receiving pit and fissure sealants for caries prevention
Settings: universities, schools, health centers, and clinics (Brazil, China, Denmark, France, Great Britain, India, Kuwait, Poland, Spain, Syria, Turkey, USA)
CI Confidence interval, *RR* relative risk, *GRADE* Grading of Recommendations Assessment, Development and Evaluation
[a]Response or risk in the control group is based on the average of included studies
[b]Although randomized trials were included, essentially observational data is used from them. They are therefore treated as non-randomized trials in terms of quality of evidence, which starts from low
[c]Downgraded by one due to high heterogeneity, which remained unexplained
[d]GRADE for this could have been upgraded, since a very large effect magnitude was seen. As, however, untreated premolars and molars have different caries prevalence, which could have confounded the results, GRADE was not upgraded

sealants) between maxillary and mandibular teeth have been attributed to the greater sensitivity to saliva contamination of the latter. This is reflected in the superior retention of fissure sealants on maxillary molars than on the occlusal surface of mandibular molars found by some studies [45, 46], although these were not consistent [47]. Another proposed hypothesis for differences between upper and lower

Table 6.5 GRADE Summary of findings table for the secondary outcome (combined loss of the sealant)

Outcome studies (teeth)	RR (95% CI)	Anticipated absolute effects[a] (95% CI)			Quality of the evidence (GRADE)[b]	What happens
		Referent[a]	Experimental	Difference		
Sealant loss by mouth side 4 trials (1029 teeth)	1.08 (0.82,1.43)	*Right side* 57.9%	*Left side* 62.5% (47.5–82.8%)	4.6% more loss (10.4% less to 24.9% more)	⊕○○○ very low[c] due to inconsistency	There may be little or no difference
Sealant loss by jaw 14 trials (2995 teeth)	0.92 (0.62,1.37)	*Upper* 36.4%	*Lower* 33.5% (22.6–49.9%)	2.9% less loss (13.8% less to 13.5% more)	⊕○○○ very low[c] due to inconsistency	There may be little or no difference
Sealant loss by tooth type 5 trials (2931 teeth)	0.33 (0.20,0.54)	$_{perm}$*M1* 26.8%	$_{perm}$*PMs* 8.6% (5.4–14.5%)	18.2 less loss (12.3% to 21.4% less)	⊕⊕⊕○ moderate[d] due to effect magnitude	Less sealants loss with premolars
Sealant loss by tooth type 4 trials (1117 teeth)	0.44 (0.11,1.80)	$_{perm}$*M1* 31.1%	$_{perm}$*M2* 13.7% (3.4–56.0%)	17.4% less loss (27.7% less to 24.9% more)	⊕○○○ very low[c] due to inconsistency	There may be little or no difference
Sealant loss by tooth type 7 trials (826 teeth)	0.93 (0.31,2.83)	$_{perm}$*M1* 21.7%	$_{decid}$*M2* 20.2% (6.7–61.4%)	1.5% less loss (15.0% less to 39.7% more)	⊕○○○ very low[c] due to inconsistency	There may be little or no difference
Sealant loss by tooth type 1 trial (265 teeth)	1.31 (0.83,2.06)	$_{decid}$*M1* 19.3%	$_{decid}$*M2* 25.3% (16.0–39.8%)	6.0% more loss (3.3% less to 20.5% more)	⊕○○○ very low[c] due to inconsistency	There may be little or no difference

Clinical performance of pit and fissure sealants placed on various teeth
Patient or population: patients receiving pit and fissure sealants for caries prevention
Settings: universities, schools, health centers, and clinics (Brazil, China, Denmark, France, Great Britain, India, Kuwait, Poland, Spain, Syria, Turkey, USA)
CI Confidence interval, *RR* relative risk, *GRADE* Grading of Recommendations Assessment, Development and Evaluation
[a]Response or risk in the control group is based on the average of included studies
[b]Although randomized trials were included, essentially observational data is used from them. They are therefore treated as non-randomized trials in terms of quality of evidence, which starts from low
[c]Downgraded by one due to high heterogeneity, which remained unexplained
[d]Upgraded for large effect magnitude; high heterogeneity still remained after modifications, but it affected only the effect magnitude and not direction, and high uncertainty around the heterogeneity estimates was seen; we therefore decided that heterogeneity posed no threat to the results validity

teeth pertains to the markedly longer grooves of permanent mandibular molars, which might limit the retention of the sealant [48]. However, reported differences between maxillary and mandibular teeth in the literature are not consistent [49–51], and no clear relationship can be established.

As far as differences between different permanent posterior teeth are concerned, similar clinical performance of sealants, placed on the first and second permanent molars, was seen. The occlusal surface of second primary molars is larger than first primary molars, enabling convenience in the placement and visual assessment of sealants because of broader occlusal surface. However, the caries susceptibility of the second permanent molars is similar to that of the first permanent molars, and therefore, the benefit from sealing should not be underestimated.

On the other side, sealants placed on premolars had significantly less caries of the sealed tooth (NNT of 9) and significantly better retention (NNT of 6) than first permanent molars. This is in agreement with previous studies that report higher sealant retention rates than of premolars compared to first molars [51–54] and has been attributed by Handelman et al. [51] not to inherent difference in the anatomy of these teeth, but rather the much larger total area of the pit and fissure system. In this sense, Jensen et al. [53] reported that the amount of sealant material placed on the molar teeth is twice as much as the amount placed on premolars and therefore is exposed to overall twice the risk of failure within the material. Other explanations for this include easier access to the premolar's surface [43], easier isolation [54], variations in the morphology and microscopic structure of the enamel in the different tooth types [43], and exposure to lower occlusal loading than molars [54]. However, it is important here to stress out that the observed difference in the caries incidence of sealed teeth does not lie solely with the significant better retention of premolar sealant but also to the inherent lower caries incidence of premolars compared to molars, even when left untreated [41, 55]. The caries susceptibility of premolars should not be overall underestimated, since they are the second most prone to caries permanent tooth after permanent molars [55]. However, they are significantly less prone to pit and fissure caries than molars [55], which might confound the comparative effectiveness of sealants in safeguarding against pit and fissure caries, and no robust conclusions can be drawn regarding this outcome.

Results of the present meta-analysis seem to support the recent guideline of the American Dental Association suggesting the sealing of primary and permanent molars [36], as no significant difference in sealant performance between primary and permanent molars was seen (Tables 6.2 and 6.3). Potential differences in the retention of sealants placed in deciduous or permanent teeth have been attributed to the shallower pit and fissures of the former [56], which might support the use of low-viscosity composite resins over conventional ones to enhance the penetration of the sealant [57]. Likewise, dental sealants seemed to work similarly good on first or second deciduous molars in terms of caries prevention and sealant retention, although only one trial contributed to this analysis (Tables 6.2 and 6.3).

6.5.8 Strengths and Limitations

The strengths of this systematic review include the a priori registration in PROSPERO and the use of robust systematic review and meta-analysis procedures [40, 58–62].

As no specific patient- or tooth-related eligibility criteria were adopted and a wide array of clinical settings in the private or public sector were included in the present systematic review, its conclusions could be generalized to the average patient.

However, some limitations are also present in this study. First and foremost, additional individual patient data couldn't be obtained in many instances through attempts to communicate with trialists, which precluded reanalysis to take into account baseline confounding and clustering effects. This precluded the direct assessment of the influence of many factors important to the performance of dental sealants, including among others the patient's age, which can have a direct effect. Although multiple attempts were made to request patient raw data and reanalyze clustering adjusted estimates incorporating confounding effects, these were met predominantly with failure, and additional research is needed to clarify this. Moreover, the limited number of included trials means that meta-analyses of some outcomes might lack sufficient power and did not enable robust assessments of heterogeneity, subgroup analyses, small-study effects, and reporting biases for most of the outcomes. This limitation is exacerbated by the fact that many potentially eligible trials either did not report or reported incompletely if any comparisons between different teeth were made and, therefore, might not have been identified or could not contribute to the analyses. Finally, although randomized trials were included in the present review, essentially observational data were extracted from them, as no randomization according to tooth characteristics could be performed.

6.6 The Decision to Seal a Tooth or Not

Based on the results of this comprehensive systematic review of randomized clinical trials, the performance of pit and fissure sealants in terms of caries of the sealed tooth or retention loss of the sealant does not seem to be negatively affected by mouth side, jaw, and tooth type. The only exception was the use of pit and fissure sealants on premolars, which was associated with lower sealant failure rate compared to the use of pit and fissure sealants on the first permanent molar, indicating favorable performance. From the perspective of the sealant's clinical performance, all deciduous or permanent posterior teeth could be effectively sealed.

However, even though from a practical viewpoint dental sealants could successfully be applied on all deciduous or permanent posterior teeth, this does not mean they should be. Casual recommendations on a universal level cannot be made for the various deciduous and permanent posterior teeth without taking into considerations other factors including cost-effectiveness [63, 64] and potential side effects in terms of bisphenol A release [65] or estrogenicity [66]. Bisphenol A has been detected in the saliva for up to 3 hours after application of resin sealants; however, the quantity and duration of systemic bisphenol A absorption after resin placement are not clear from the available data [67]. Additionally, although the absolute effectiveness of dental sealants has been proved by many clinical studies, their cost-effectiveness relative to the decision to seal a specific tooth or not is more complex. Sealants are considered to be more cost-effective in both private practice and public health settings, when they are provided to higher-risk individuals, while evidence about low- or moderate-risk individuals/teeth is scarce [68, 69].

In this matter, the concept of risk-based sealant application [70] has been widely adopted [71, 72] and can form the basis of the rationale for efficacious sealant placement. Based on this concept, initially sound tooth surfaces are unlikely to become decayed within a timeframe of 5 years and do not benefit greatly from the application of sealants. On the other hand, there are clear efficiencies in sealing incipient, but not sound, surfaces, and therefore the targeting of teeth with incipient caries for sealants is recommended [70]. Specific considerations like tooth morphology, caries history, fluoride intake, oral hygiene, and patient age can be assessed by an experienced clinician in terms of indication for sealant placement [17, 73].

As far as tooth morphology is concerned, Klein and Palmer [74] were the first to report that the relative susceptibility of a tooth to caries was directly associated with the various morphological tooth types. A subsequent investigation 60 years later [41], building on the Klein and Palmer study [74] using data from the Third National Health and Nutrition Examination Survey (NHANES III), indicated that six categories of relative susceptibility to caries exist, in decreasing caries risk order: (a) mandibular second molars, (b) maxillary first/second molars and mandibular first molars, (c) maxillary/mandibular second premolars, (d) maxillary/mandibular first premolars, (e) maxillary central/lateral incisors, and (f) maxillary/mandibular canines and mandibular central/lateral incisors [41]. Dentists often make the decision to place sealants in permanent molars based on the perceived depth of the occlusal fissures [75], due to its role in caries development, by sealing the occlusal surfaces of posterior teeth with deep fissures. The rationale for this is based on the study of Ekstrand et al. [17, 76] that assessed the relationship between the morphology of the groove-fossa system and the histological features of caries and whether the morphology of the converging ridges (interlobal grooves) influences microorganism viability. They concluded that the internal morphology of the interlobal grooves influences the conditions for bacterial growth and this determines the location for caries progression within the groove-fossa system. Low caries activity at the deepest portion of the grooves implies a low level of bacterial viability in these sites [17, 76]. Several studies have therefore reported that pediatric dentists can visually assess fossae depth primarily by the angles of the cusps' slopes and less so by an overview of the tooth's morphology [17, 77, 78], even though others found issues in the correct classification of fissure depth [79].

Klein and Palmer [74] also reported that the relative susceptibility of a tooth to caries was directly associated with both tooth morphology and with the length of time each tooth is in the oral cavity. For example, higher prevalence of caries can be seen in women due to their earlier eruption of permanent teeth and the subsequent longer exposure of their teeth to the risk of decay [55, 80]—a finding that persists even after adjusting for their greater number of teeth [81]. This includes primary teeth of children and permanent teeth of adolescents and adults, although the first and second permanent molars receive the highest priority, due to their indisputable value in oral function. On the other hand, posteruptive age alone should not be used as a major criterion for decision-making, as the caries risk on surfaces with pits and fissures might continue into adulthood, and therefore, potential benefits from sealing the occlusal surfaces may exist in any tooth with a pit or fissure at any age [73]. Additionally, patient age might play an important role in sealant retention, due to the increased compliance of older patients that might lead to higher sealant retention rates.

Still there are factors like the presence of early childhood caries, which have been clearly established as a high-risk indicator for future caries development [82] and could be used to aid the clinician in the decision to apply dental sealants. Likewise, Sheiham and Sabbah [83] based on universal caries patterns propose that, if all the first permanent molars have caries, then there is a high probability that the second molars will also be affected. On the same basis, they support a left-right and a maxilla-mandible symmetry in the caries incidence of posterior teeth [83]. Therefore, these patterns could be used to prevent future caries activity and identify patients as candidates for dental sealants.

On the contrary, there are specific factors that have been shown to have a direct impact on sealing success. For example, sealants placed on newly erupted permanent first molars are more likely to require replacement of the sealant, possibly due to the isolation difficulties making it difficult to place sealant on such "sticky" pit and fissure surfaces [84]. In this case, provisional glass ionomer sealants or materials used as an intermediate layer between enamel and sealant might be helpful in protecting against the detrimental effect of saliva contamination [85].

An exception to the abovementioned criteria for the identification of high caries risk patients is the targeted application of school-based sealing programs, in which decisions regarding who should receive sealants are generally made on the basis of population risk factors (e.g., schools with high numbers of low-income children), not on each child's risk factors. As these programs are mostly targeted to high-risk children or children in high-risk schools (i.e., those with a high proportion of low-income students), risk assessments for each individual child are impractical. This is however a specific decision pathway that falls in the category of geographic targeting [86] and has distinct differences with the sealant guidelines used in traditional clinical practice settings.

Finally, it is important to stress out that dental sealants are only as effective as they remain retained on the pit and fissure surface, while evidence indicates that approximately 40% of all sealants require reapplication over 2 years of follow-up due to partial or total loss of retention [87, 88]. It is logical to expect that as teeth remain at risk throughout life, it might be necessary to reapply sealants continuously. No clear difference in the caries experience can be seen between originally sealed teeth that lost their sealant and those that retained their sealant, indicating that teeth that have lost their sealant are at least not more susceptible to caries than unsealed teeth [89, 90].

Conclusions

Pit and fissure sealants as a preventive measure against dental caries seem to be from a practical point of view applicable to any kind of posterior tooth of the primary or permanent dentition, with relatively similar retention rates. As, however, not all patients and not all teeth are equally susceptible to caries, careful identification of patients and teeth based on risk-based assessments on a separate case basis from experienced clinicians is important to ensure high cost-to-benefit value.

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7 Clinical Recommendations for the Placement of Pit and Fissure Sealants

Katrin Bekes and Christian Hirsch

Abstract

Fissure sealants are effective in preventing and arresting pit and fissure caries lesions in children and adolescents. Once penetrated into the anatomic surface of pits and fissures, sealants form a physical barrier to the ingress of dietary debris and microbes on the tooth surface. However, the ability of pit and fissure sealants to protect the tooth is determined by their retention to the surface. Improper application technique is the major cause of failure or early loss of sealants. Therefore, it is imperative that the operator strictly adheres to proper sealant placement procedures evidenced in the literature. The protocol for sealant placement includes the cleaning and isolation of the tooth, enamel surface pretreatment, and the application of the sealant followed by evaluation and monitoring of the sealing. Post-restoratively, sealants should be checked by patients during routine home care procedures for loss or breakage as well as in regular dental recall examinations in practice and should be replaced when indicated. The aims of this chapter are to present current evidence driving clinical recommendations for the placement and use of pit and fissure sealants and to discuss clinical questions about various techniques that optimize retention and effectiveness.

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7.1 Introduction

Pit and fissure sealants are one of the most highly recommended and widely accepted preventive dental procedures. Their effectiveness for caries management in the pits and fissures of mainly the occlusal tooth surfaces in children and adolescents has been documented in numerous clinical studies. A Cochrane review found that sealants placed on the occlusal surfaces of permanent molars in children and adolescents reduced caries up to 48 months when compared to the no sealant control [1]. According to a meta-analysis of 24 studies, the overall effectiveness of autopolymerized fissure sealants in preventing dental decay was 71% [2].

Pit and fissure sealants act as a physical barrier to decay. They prevent access by cariogenic bacteria to their source of fermentable nutrients [3]. The ability to protect is determined by and directly correlated to the sealant retention to the tooth surface. The protection afforded by this layer is reduced or lost when the marginal seal between the tooth and the sealant is compromised [2, 4]. Success with dental sealants is very dependent on the correct application protocol. The application, while inherently simple, is very technique-sensitive, requiring attention to detail at all stages [5]. While there is no guarantee that a sealant is going to survive on any particular surface for a specified period of time, studies show that correctly placed sealants are likely to be retained over a period of years rather than months or weeks [6].

Each sealant material requires specific techniques for their designed adhesion onto enamel. Resin-based sealants rely on a micromechanical bond made possible by the use of an acid-etch technique, which creates micropores in the enamel that interlock the resin and enamel. Glass ionomer sealants bond chemically to the enamel without the use of the acid-etch technique, which makes them less vulnerable to moisture. The choice between resin/composite and glass ionomer sealants should be based on suitability of moisture control. Because resins are most durable, they should generally be preferred. However, glass ionomer sealants should be used in patients where moisture control is difficult (e.g., in erupting or newly erupted teeth). In these cases, a fissure sealing with glass ionomer is regarded more as a provisional therapy [7].

7.2 The Clinical Procedure

7.2.1 Operator

The literature features few studies on the effectiveness and performance of fissure sealants placed by auxiliary dental operators. A literature review identified ten studies which allowed indirect comparison of the retention rates of sealants provided by different dental operators [8]. The results showed that there was little evidence that the effectiveness of sealants placed by dental assistants was any different from those placed by dentists. Nevertheless, the cost analysis showed that operator type had impact on costs. The cost per sealant was lower when done by a dental hygienist rather than a dentist.

In the opinion of Holst et al., sealing of fissures is a method well suited for delegation to dental assistants after proper education and training but should be followed up, as the rate of success varies greatly from case to case [9].

7.2.2 Cleaning of the Tooth Surface

The tooth surface must be thoroughly cleaned in order to remove adherent plaque and debris as much as possible prior to the placement of the sealant (Figs. 7.1 and 7.2). Cleaning can be accomplished in different ways. Traditionally, it has been suggested to clean the tooth with pumice and a prophylaxis cup or bristle brush [10]. Debris can also be removed using an explorer through the fissure and rinsing with air-water spray or with a dry bristle toothbrush. Air polishing and air abrasion are also possible. Only a few clinical studies have directly compared different cleaning methods, while the influence of the cleaning on the retention rate has mainly been investigated in laboratory studies, thus rendering the level of evidence regarding this matter limited [11].

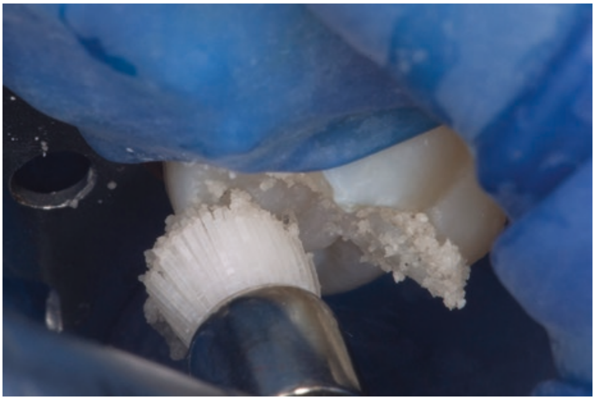

Fig. 7.1 Cleaning of an upper first molar using pumice and a bristle brush prior to sealant application

Fig. 7.2 Cleaning of a first molar using a toothbrush prophylaxis

Two systematic reviews have shown that teeth cleaned with toothbrush prophylaxis prior to sealant application exhibited a similar or higher success rate compared to those sealed after handpiece prophylaxis [12, 13]. Furthermore, a double-blind, split-mouth randomized trial showed no difference in sealant retention after 12 months when teeth were cleaned with pumice prophylaxis compared to when teeth were cleaned with a sharp probe and forceful washing from a three-in-one syringe prior to sealant application [14]. As a disadvantage, a lack of "deep cleaning" of narrow fissures when using brushes can be discussed. In order to compensate for such drawbacks, the use of air polishing or air abrasion for fissure cleaning has been recommended. Nevertheless, evidence is limited and conflicting as results in the literature are heterogeneous for both procedures. While air polishing resulted in reduced micro-leakage in in vitro experiments [15–17], a clinical study showed no improvement in the retention rate using this procedure [18]. Concerning air abrasion, various laboratory studies also demonstrated advantages with respect to micro-leakage [19–22], whereas clinically, only a 2-year study is available [23] which is of limited significance due to the low number of patients monitored. A number of authors have also looked at other more aggressive methods of fissure preparation prior to sealant application. While a large body of laboratory studies show potential benefits to mechanical preparation prior to etching ("enameloplasty"), e.g., with deeper sealant penetration and a superior sealant adaptation, only a small number of short-term clinical studies with small samples support this technique as equal to, but not better than, sealant placement without this technique [24, 25]. Beyond that, mechanical preparation may make a tooth more prone to caries in case of resin-based sealant loss [26].

In summary, the best method of cleaning cannot be defined from the literature. From current point of view, the cleaning of the teeth with a bristle brush with or without the use of a prophylaxis paste can be seen as the routine procedure since it has been used in a large number of available clinical studies because of its simple, fast, and child-friendly practicability [11, 14, 27]. Furthermore, it serves as a basis for a correct caries diagnostic examination.

7.2.3 Isolation

Isolation is the most critical issue in the proper placement of sealants. If the enamel porosity created by the etching procedure is filled by any kind of liquid other than the adhesive primer, the formation of resin tags in the enamel will be blocked or reduced, and the resin will be poorly retained. Salivary contamination, during and after acid etching, also allows the precipitation of glycoproteins onto the enamel surface, greatly decreasing bond strength to the fissure sealant [14, 28]. Sealant loss and immediate failure of retention are most often linked to moisture or salivary contamination.

Isolation can be achieved in different ways (Figs. 7.3 and 7.4). A rubber dam, when properly placed, provides the ideal, most controllable isolation, and for an operator working alone, it ensures isolation from start to finish. However, it is not

Fig. 7.3 Isolation of a tooth during fissure sealing procedure using four-hand technique and cotton rolls

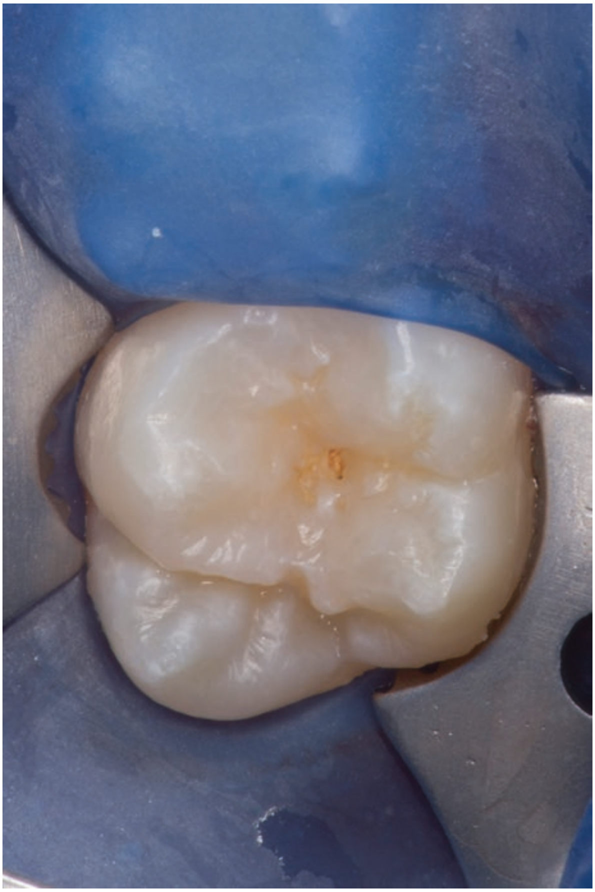

Fig. 7.4 Rubber dam isolation for the placement of a fissure sealant

always possible or appropriate for young children [11]. In newly erupted teeth, this is usually not practical as it demands the use of local analgesia for placement of the clamp [7]. Cotton rolls, dry field pads, dry field kits, and single tooth isolation can also be used. In these cases, a four-hand technique should be used [12]. A systematic review of sealant retention [29] identified three split-mouth trials, and one prospective observational study evaluated the effect of tooth isolation using rubber dam or cotton wool rolls on sealant retention [30–33]. The results indicated no difference in retention was found between the two methods of isolation for autopolymerized sealants after 24 months [30–32].

Another alternative to rubber dam might be moisture control systems that produce sealant retention rates comparable to cotton roll isolation or rubber dam, while decreasing procedure time [34]. Collette et al. showed in their study that sealant application time might be decreased with the Isolite™ system compared to cotton roll isolation only negated by the minor discomfort of Isolite™.

In conclusion, the isolation procedure may frequently be extremely challenging, particularly in partially erupted teeth or when used on children with poor cooperation [7].

7.2.4 Etching

In 1955, Buonocore reported that bonding of acrylic filling materials to enamel surface could be increased by conditioning the surface with phosphoric acid [35]. Since this study, bonding technology has been developed progressively, and acid etching has been widely used to prepare the tooth substrate for bonding. The goals of enamel etching are to remove the organic pellicle, to remove the aprismatic layer in uncut enamel, and to partially dissolve the mineral crystallites to create irregular topographical microretentive patterns [36] for the infiltration of resinous materials. There is a general consensus that acid etching increases the surface energy and lowers the contact angle of resins to enamel [37–39].

Today, etching the surface of the tooth for fissure sealing is most commonly accomplished by using 35–37% phosphoric acid [5]. The etchant (which is available in liquid and gel formats) can be applied liberally and should flow onto and into all of the susceptible pits and fissures (Fig. 7.5). This also notably includes lingual grooves of maxillary molars as well as buccal pits of mandibular molars. The goal of etching is to remove the most upper, aprismatic layer of the enamel resulting in an exposure of the underlying enamel prisms.

The influence of the acid type (phosphoric or maleic) on the retention of sealants was studied in an in vivo study [40]. It was found that there was no statistically significant difference between the two groups (37% phosphoric and 10% maleic acid) in the two test periods nor were there differences in the same group at the different periods.

Originally, 60 s of etching time have been recommended (first used by Ripa and Cole [41]). Since then, several clinical and laboratory studies have investigated if shorter etching times (e.g., 15 or 20 s) might be acceptable for conditioning of the enamel of permanent teeth [42–46]. This would be of particular clinical benefit, because reduced etching

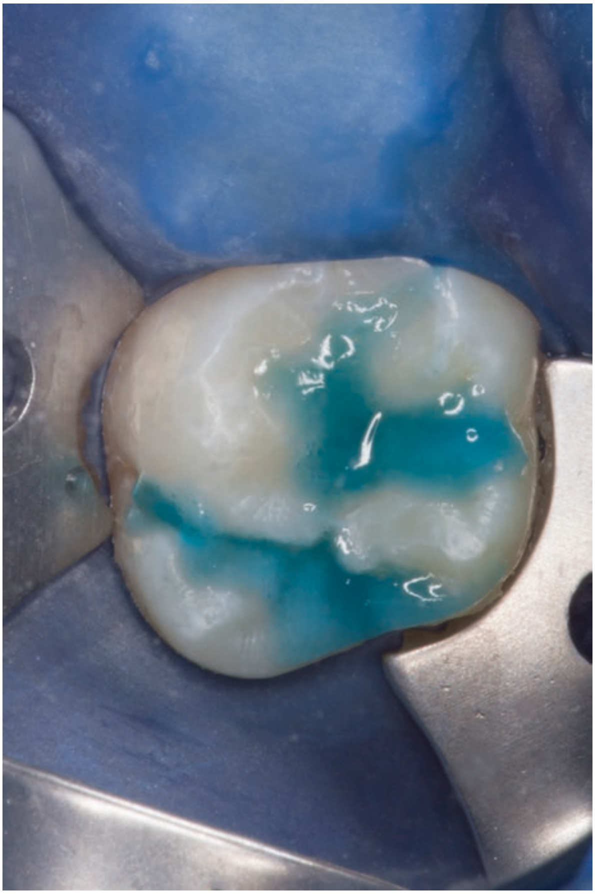

Fig. 7.5 Etching of the tooth surface using 37% phosphoric acid

times mean shorter chair time and greater potential for cooperation from younger child patients. Nevertheless, as results are heterogeneous and long-term studies are lacking, Kühnisch et al. still recommend an etching time of 60 s [11].

In primary molars, longer etching periods have been discussed due to the presence of a classically thicker aprismatic enamel layer. Previous recommendations called for doubling the etching time that was initially proposed for etching permanent enamel (120 s versus 60 s) [47–49]. Nevertheless, the evidence that the "prismless" layer has any effect on the retention of fissure sealants is inconclusive, while its presence has been questioned [50]. Clinical studies reporting on sealant success when applied to primary molars are rare. Those that have been published report retention and success equivalent to permanent molar sealants [51].

Beyond that, it should be noted that several alternative methods of enamel preparation have been tested in an effort to improve retention, reduce the procedure time, or both. For example, self-etch adhesive systems (which require no rinsing) have been tested as an alternative to acid etching prior to sealant application [5] and will be discussed in Chap. 8.

In the case of glass ionomer products, an etching step is not necessary. However, a surface conditioner may be used.

7.2.5 Rinsing and Drying

After etching, the surface needs to be rinsed with air-water spray and high-volume suction [10]. The aim of rinsing is to remove all of the etchant from the tooth surface. Most manufacturers recommend a rinsing time of 20–30 s. Studies have shown that shorter rinsing times are acceptable as well [52, 53]. An exact rinse time is probably not as important as ensuring that the rinse is long enough and thorough enough to remove all of the etchant from the surface. Afterward, the tooth must be thoroughly dried, and a chalky white surface should become visible. From this point, it is extremely important to avoid salivary contamination [10]. If the tooth surface is contaminated by saliva, it will be necessary to repeat the etching process.

7.2.6 Application and Polymerization

All the susceptible pits and fissures should be sealed for maximum caries protection. This includes lingual grooves of maxillary molars and the buccal pits of mandibular molars. The sealant may be applied with a variety of instruments: an explorer tip, a placement instrument, a small brush, or the dispenser system offered by various manufacturers, which may consist of a preloaded syringe with a small tip so that the sealant can be applied directly from the syringe to the tooth (Fig. 7.6). A minimum amount of sealant to adequately cover the pit and fissure network should be applied so that no overfilling occurs. In case of overfilling, the excess material can be removed with a small brush. If air bubbles are present, these should be teased out of the material before curing the sealant. If the material has been satisfactory placed on all susceptible surfaces, the curing light tip should be placed as close as possible to the surface, and each sealed surface should be polymerized as long as recommended by the manufacturer. Conventional halogen and LED units, with sufficient wavelength and intensity, are regarded equivalent and can both be used [54].

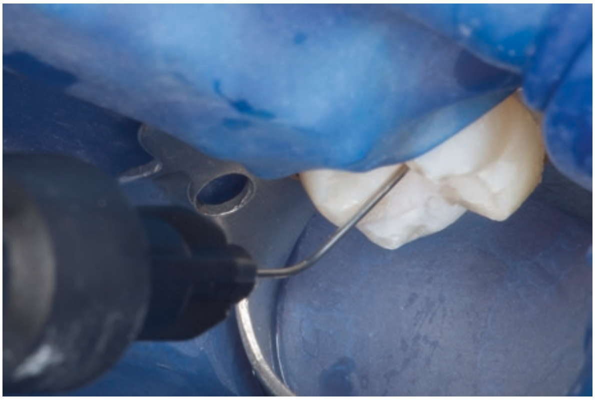

Fig. 7.6 Application of a fissure sealant using the dispenser system offered by the manufacturer

7.2.7 Evaluation and Monitoring

After polymerization, the operator should visually and tactilely examine the sealant before removing the isolation materials. If bubbles, voids, or areas of deficient material are observed, sealant material can be directly added at this time because the oxygen-inhibited layer has not been disturbed [10]. Sealant retention should be checked with a probe after polymerization to ensure that all fissures are completely sealed. If any material is dislodged, the sealant should be reapplied after recleaning (if necessary) and reetching of the exposed fissure [5]. If any sealant material is misplaced into some areas, it should be removed [10].

Finally, occlusion control should be performed using articulating paper. If necessary, adjustments with composite finishing burs are possible. Besides this, a removal of the superficial non-polymerized oxygen inhibition layer with a polishing bur is necessary. The remineralization of etched, but not sealed, enamel areas is supported by the local application of a fluoride compound [11].

Once applied, sealants need to be monitored (Fig. 7.7). A clinical review of sealant retention should be part of the recall visit [5]. Additionally, bitewing radiographs should be taken at a frequency which is consistent with the patient's risk status [7]. The exact intervals between radiographic review will depend not only on risk factors, which might change over time, but also on monitoring of other susceptible sites, for example, proximal surfaces [55].

If sealants are gradually lost over time, they should be repaired in order to maintain the marginal integrity [56].

Fig. 7.7 Sealed lower molar 1 year after placement of the fissure sealant colored with a plaque dye liquid. Bubbles can be seen within the sealant

Conclusions

Although the application of a pit and fissure sealant is a noninvasive and less time-intensive procedure compared to restorative therapies, it is very technique-sensitive, requiring quality assurance. The dental practitioner should be familiar with the application methods of the pit and fissure sealant. With proper placement and maintenance, sealants can last for many years.

Figures 7.8, 7.9, 7.10, 7.11, 7.12, 7.13, and 7.14 demonstrate the placement of an opaque resin-based fissure sealant on a lower first molar using four-hand technique.

Fig. 7.8 Lower left first molar of an 8-year-old girl with deep pits and fissures

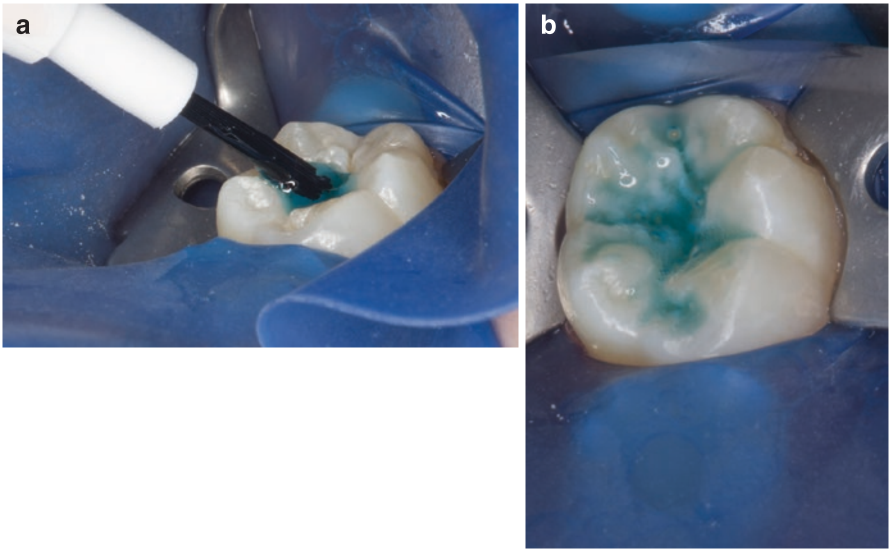

Fig. 7.9 Application of 37% phosphoric acid for etching the enamel surface with rubber dam isolation

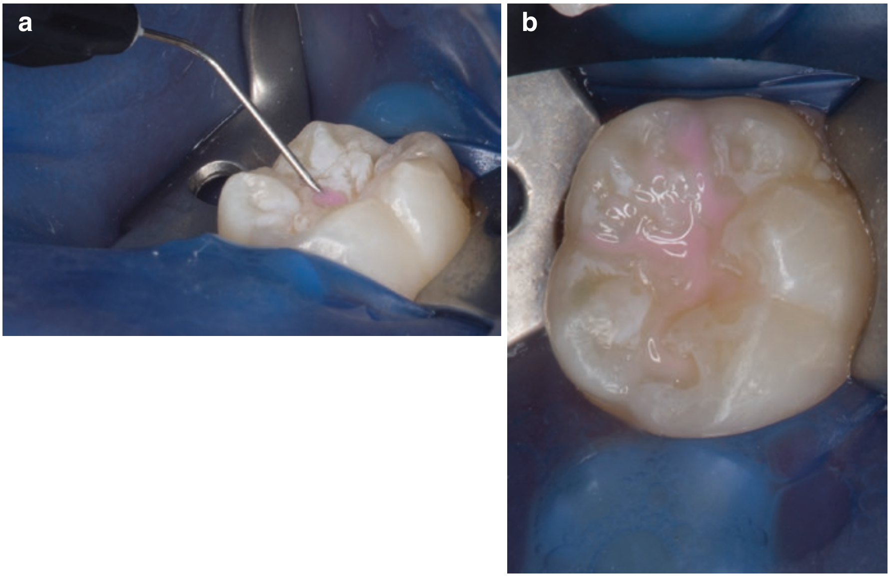

Fig. 7.10 Application of a fissure sealant with smart color-change technology to see placement

Fig. 7.11 Polymerization of the fissure sealant

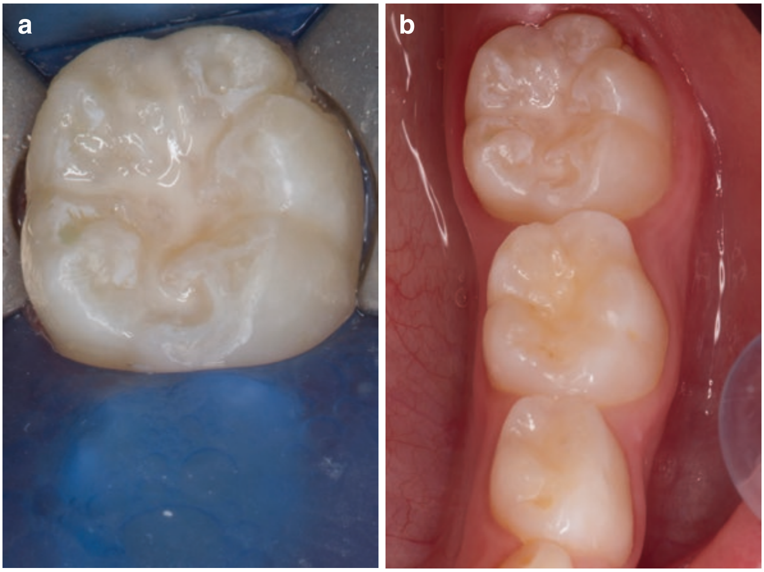

Fig. 7.12 Sealed lower first molar immediately after placement before and after the removal of the rubber dam

Fig. 7.13 Control of occlusion

Fig. 7.14 Sealed first lower molar

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Alternative Techniques for Pit and Fissure Sealings

8

Katrin Bekes

Abstract

The success of fissure sealants depends principally upon the quality of adhesion between the sealant and enamel, which correlates to their ongoing resistance to the microleakage of saliva and microorganisms at the restoration-tooth interface. In an effort to improve sealant success, various surface preparation and debridement techniques have been investigated for use on the tooth surface prior to sealant application. These different enamel treatment procedures aim to optimize both bond strength and sealant integrity leading to optimal prognosis over time. One approach comprises the application of an adhesive system as an enamel bonding layer beneath the sealant to increase the retention rate; however, this is difficult to achieve where moisture control is compromised. Another possibility is the use of lasers as a tool for pretreatment and surface conditioning in pit and fissure sealing. The aims of this chapter are to present these two alternative techniques and to discuss the current evidence.

8.1 Introduction

Pit and fissure sealants are an effective method for the prevention or control of caries on occlusal surfaces [1]. They act as a physical barrier by bonding micromechanically to the tooth, thus preventing access by cariogenic bacteria to their source of nutrients [2]. However, their preventive benefits rely directly upon the ability of the sealing material to thoroughly impregnate the pits and fissure system with the aim of good marginal integrity over time. The potential of protection will be reduced,

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lost, or even negated when part of the marginal seal between the tooth and the sealant is ineffective [3, 4]. The longer the sealant remains intact, the less likely the tooth is to develop dental caries in the pit and fissure surfaces [5]. Resin sealants are lost at a rate of 5–10% annually [6, 7]. Thereby, occlusal surfaces retain intact sealants more successfully than either the palatal surface of the maxillary molars or buccal surface of mandibular molars [8]. Factors influencing the success of sealing are the stage of eruption of the tooth, the behavior of the patient, and the technique used when placing the sealant [5, 8].

The most widely accepted enamel conditioning procedure, prior to the application of fissure sealants, is exposure to phosphoric acid which selectively erodes the hydroxyapatite rods. Practical disadvantages of phosphoric acid etching are that it is time-consuming and requires the isolation of the tooth with cotton wool or a rubber dam [9]. Consequentially, the main reason for the failure of resin-based pit and fissure sealants is the lack of proper tooth isolation and contamination of etched enamel by saliva or gingival fluid before the sealant placement [10, 11].

To enhance the longevity of pit and fissure sealants, several techniques have been developed, including the application of adhesive systems under sealants [12, 13] and pretreatment of enamel using laser [14, 15].

8.2 Adhesives

Since control of moisture in the oral cavity is difficult to achieve, a modification of the classic sealant application technique was first proposed by Hitt and Feigal in 1992 with the use of a bonding layer between the etched enamel and the sealant [13] showing an improved bond strength of etched enamel to sealant in the presence of moisture or salivary contamination. Further studies have confirmed improved results when an intermediate bonding layer is applied between enamel and sealant showing increased bond strength, reduced microleakage, and enhanced flow of resins into fissures [16–18].

8.2.1 Classification of Adhesives

The basic components of adhesive systems are acrylic resin monomers, organic solvents, initiators, inhibitors, and, sometimes, filler particles with the proportional composition—the chemistry of these ingredients differing between the different classes of adhesives [19]. Historically, dental adhesives were classified in "generations," which became rather confusing after some years. A component-based nomenclature also did not prove to be practical [20]. Currently, besides the number of application steps, adhesives can further be classified based on the underlying adhesion strategy, specifically "etch-and-rinse" or "self-etch" (Fig. 8.1) [21].

The etch-and-rinse strategy involves at least two steps and, in its most conventional form, three steps with successive application of the conditioner or acid etchant, followed by the primer or adhesion-promoting agent, and, eventually, application of the actual bonding agent or adhesive resin (i.e., fourth-generation bonding systems).

The simplified two-step version (i.e., fifth-generation bonding systems) combines the second and third step but still follows a separate "etch-and-rinse" phase [21]. Self-etch adhesives contain acidic monomers, which etch and prime the tooth simultaneously. Similarly, self-etch adhesives are available as one- or two-step systems (i.e., sixth-, seventh-, and eighth-generation adhesive systems) [22].

8.2.2 Etch-and-Rinse Versus Acid Etch

As mentioned earlier, the first study investigating the bond strength of etched enamel to sealant following the application of dentin bonding agents on contaminated enamel was published in the beginning of the 1990s [13]. Some subsequent

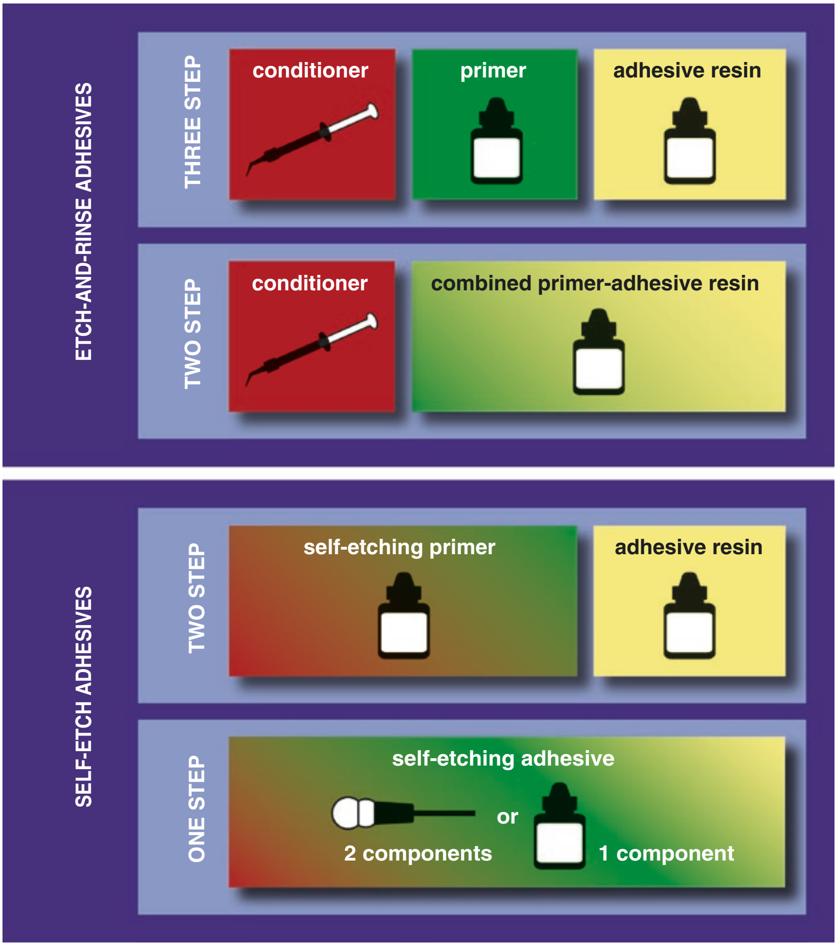

Fig. 8.1 Classification of contemporary adhesives according to Van Meerbeek et al. [21]

studies confirmed the advantages of adhesives applied under sealants to increase bond strength, reduce microleakage, and enhance the flow of resin into pits and fissures [16–18]. These investigations were based on the use of an "etch-and-rinse" adhesive system (mostly applied in the two-step technique of etching followed by adhesive application [8]).

Recently published clinical studies with current adhesive systems, based on the etch-and-rinse technology, reported inconclusive results using this approach. Pinar and colleagues described no significant sealant success using a two-step etch-and-rinse adhesive system [23]. In addition, the results of a study by Nazar et al. indicated no benefit from using a three-step etch-and-rinse adhesive system beneath the sealant in relation to sealant retention rates [24]. In contrast, Feigal and colleagues as well as Sakkas et al. showed that two- or three-step etch-and-rinse adhesive systems had a significantly positive effect on sealant retention rate [8, 25].

From the clinical perspective, it should be considered that multiple steps are required using this technique, leading to potential problems in terms of increased chairside time, patient discomfort, and risk of salivary contamination.

8.2.3 Self-Etch Versus Acid Etch

The introduction of "self-etch" adhesives in dentistry has also become of interest for use in pediatric dentistry. These bonding systems simultaneously "condition" and "prime" the dental substrate, rendering this approach to be more user-friendly (shorter application time, less steps) and less technique-sensitive (no wet bonding, simple drying) [21, 26].

A recently published systematic review and meta-analysis compared the retention rate of sealants placed on occlusal surfaces following the use of self-etch adhesive systems and traditional acid etching, with or without the application of an adhesive system [27]. As only five papers with a small sample size [28] and a high dropout [29] met the eligibility criteria and were included, the results obtained should be carefully considered.

To compound the analysis, primary molars were considered in one study [30] and permanent molars in the other four studies [28, 29, 31, 32]. As a result, a significant difference was found between both approaches, favoring the acid-etch group ($P < 0.05$), which showed lower failure rate in the retention of occlusal sealants. It was argued that higher failure rates, when using self-etch systems, could be related to their acidity which is lower than that of phosphoric acid. Their lower acidity may render these materials as effective in etching the enamel as effectively as phosphoric acid, especially sound and/or aprismatic enamel [33]. As self-etch adhesives can also be classified into "strong" (pH < 1), "intermediately strong" (pH ≈ 1.5), "mild" (pH ≈ 2), and "ultra-mild" (pH ≥ 2.5), depending upon the acid dissociation constants and the etching aggressiveness, the authors added that those studies using "strong" self-etch systems showed no differences in sealant retention [28, 30]. Considering the meta-analysis, good strength of evidence was found for all selected studies. Based on these findings, the authors concluded that sealants applied in the conventional manner, with prior acid etching, present superior retention over time relative to the occlusal sealants combined with self-etch systems.

8.2.4 Etch-and-Rinse Versus Self-Etch

Fissure sealant retention using etch-and-rinse adhesive systems or self-etching adhesive systems was recently compared in a systematic review and meta-analysis by Bagherian et al. [34]. Out of the four studies included in the review [25, 29, 31, 32], three of them were also used for the meta-analysis. The authors demonstrated that etch-and-rinse adhesives were superior to self-etch adhesives in the fissure sealant procedure (odds ratio, 14.569; 95% confidence interval, 2.616–81.131; $P = 0.002$). By using etch-and-rinse adhesive systems, the aprismatic enamel surface layer is removed by action of the phosphoric acid etching and subsequent water rinsing of the etched enamel [31]. Therefore, adhesion can be optimized via mechanical microretentive bonding of the fissure sealant, provided by the exposure of the prismatic structured enamel. In contrast, treatment with self-etching priming agents does not remove a significant amount of the prismless enamel surface layer, as no rinsing takes place after application of the primer [35, 36]. Therefore, it appears that etch-and-rinse systems are able to produce an enhanced microretentive bonding feature with the underlying prismatic structured enamel compared with self-etching systems [34].

8.2.5 Summary

Results of a systematic review and meta-analysis indicate that adhesive systems used as an enamel bonding interface below fissure sealants have a significant positive effect on retention rates and consequently are beneficial in preventing caries, which is the ultimate goal of fissure sealant therapy [34]. The smaller molecular size of adhesive components, rather than sealant components, may increase the penetration into enamel microporosities, leading to increased bond strengths. Of note, the authors recognize that there are still a limited number of clinical trials and great variability of bonding systems in both etch-and-rinse and self-etch adhesive systems. Nevertheless, when adhesive systems are used with fissure sealants, etch-and-rinse systems appear to be preferable [34].

8.3 Laser

Laser technology has been recently introduced into the dental field with the idea to replace mechanical drilling. The term *laser* is an acronym for light amplification by stimulated emission of radiation. Within a laser, an active medium is stimulated to produce photons of energy that are delivered in a beam with an exact wavelength unique to that medium [37]. In recent years, there has been significant progress in the use of lasers in dentistry. Lasers can be a useful device for dental care in children, particularly for those with dental fear, by eliminating stressors such as the sight and sensation of a drill [15].

Oral hard and soft tissues have a distinct affinity for absorbing laser energy of a specific wavelength. The wavelength of a dental laser is the determining factor of the level to which the laser energy is absorbed by the intended tissue [38]. Therefore, various types of lasers have been used in dentistry. Erbium lasers have proven to be safe and effective for the removal of tooth decay and preparation of enamel and dentin, in addition to many soft tissue and hard tissue surgical procedures [39]. Currently, two types of erbium lasers are available, each emitting a unique wavelength depending on the material present in the laser rod inside the device [39, 40]. The Er:YAG consists of erbium ions and a solid active medium of crystals of yttrium, aluminum, and garnet. These generate a wavelength of 2936 nm. The Er,Cr:YSGG contains erbium, chromium ions, and a crystal of yttrium, scandium, gallium, and garnet, emitting a wavelength of 2790 nm. Both types of erbium lasers are categorized as laser light that is converted into acoustic (mechanical) energy, in the form of a shock wave, physically disrupting the target tissue. The production of acoustic shock waves is due to the rapid, volumetric expansion occurring when water changes from liquid to gas. This expansion causes the surrounding tooth structure to explode, which is known as spallation. The water spray of the handpiece accelerates this effect by removing exploded tissue, thus transferring minimal heat to the remaining tooth [41].

The use of lasers has been suggested as a tool for pretreatment and surface conditioning in pit and fissure sealing. Early observations of enamel surfaces prepared by erbium lasers demonstrated a similar etching pattern to those of acid etching (Fig. 8.2) [42]. Laser etching is simple and has the advantage of not requiring the need for tooth isolation as well as leading to the formation of more stable and less acid-soluble compounds [43]. As the calcium/phosphorus ratio changes with the laser application, the enamel becomes more resistant to caries attack [9, 44, 45]. All these enamel-bolstering properties seem to point to enamel surface preparation as potentially mandatory prior to fissure sealant application, particularly in the case of unground primary enamel, which features an acid-resistant aprismatic superficial layer [9, 43].

The scientific evidence demonstrates the presence of conflicting results relative to the clinical effectiveness of laser etching during fissure preparation. Some studies documented that acid and laser etching cause similar results in terms of marginal adaptation and restorative microleakage performance [9, 46, 47] as well as sealant retention [14]. In contrast, some investigations support the use of acid after laser application and also showed that the laser etching did not eliminate the need for acid etching [15, 48, 49]. In all these studies, it was concluded that conventional acid etching remains the single most effective and simplest technique step in the placement of fissure sealants.

Some authors investigated laser pretreatment prior to the application of adhesive systems. Cehreli and colleagues [47] reported that the use of Er,Cr:YSGG laser

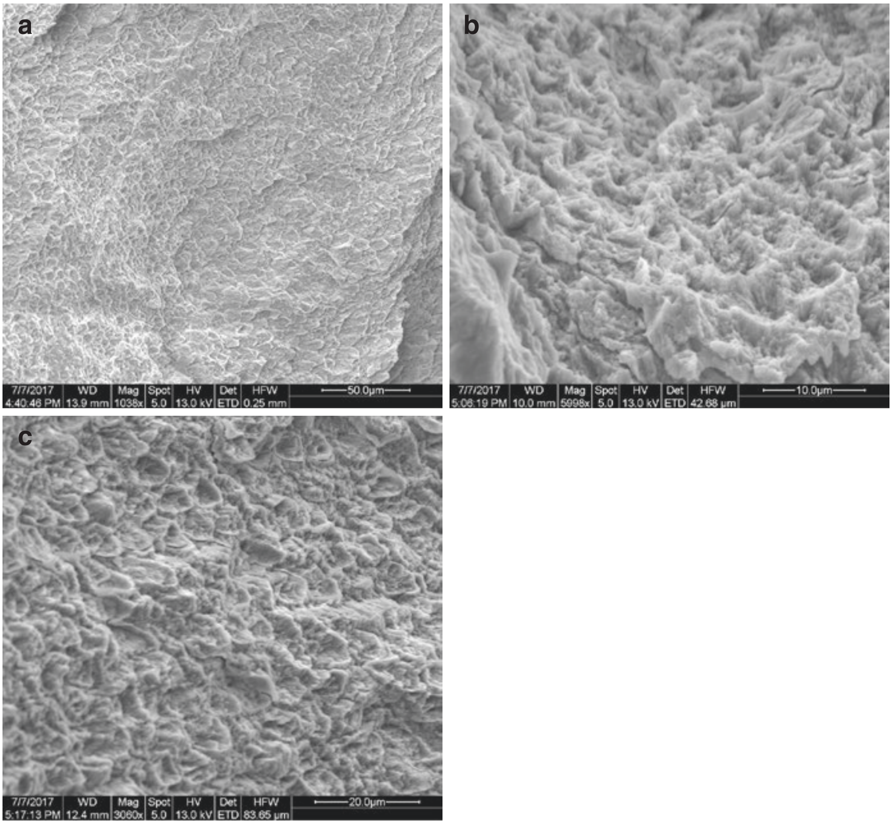

Fig. 8.2 SEM images of laser-etched enamel using an Er:YAG laser system operating at a wavelength of 2940 nm with different pulse energies and frequencies. (**a**) 200 mJ, 15 Hz; (**b**) 200 mJ, 20 Hz; and (**c**) 500 mJ, 2 Hz (Courtesy of H. Shokoohi)

prior to a bonded fissure sealant application did not improve microleakage resistance. However, laser etching in combination with the use of a self-etching adhesive provided less microleakage compared to self-etching alone. These findings were confirmed by Topaloglu-Ak et al. [50] demonstrating that laser versus no laser preparation prior to application of a total-etch adhesive system did not make a significant difference in terms of microleakage.

In summary, there is scarce information about the use of laser pretreatment in combination with acid etching and bonding agents in dental literature. Therefore, the search continues for the most effective enamel surface preparation technique to enhance sealant integrity, performance, and retention.

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Sealing of Non-cavitated Carious Fissures

9

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Abstract

Dental caries is still a global oral health burden decreasing quality of life of affected children and adults. In addition to accepted oral prophylactic techniques fluoride therapy and regular oral hygiene visits, the positive additional benefit of sealing susceptible pits and fissures is rhetorical. Treatment strategies for occlusal but also other carious lesions have shifted more and more from an invasive procedure toward minimal invasive or even non-operative strategies. Sealing non-cavitated occlusal carious lesions is one of these strategies. This chapter is intended to discuss the various strategies of pit and fissure sealing in the management of non-cavitated occlusal carious lesions in order to arrest their progression.

9.1 Introduction

Dental caries is the most prevalent disease in the oral cavity with serious medical, social, and economic consequences for the individual patient if left untreated. Reports indicate a recent worldwide increase in caries [1–3], which is why its designation as the most important global oral health burden [4] is still applicable. Susceptibility is due to the fact that the occlusal surfaces of the teeth are primarily affected and can

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already be affected during their eruption [5], while smooth surface caries has significantly decreased due to the increased access to dietary fluoride [6, 7].

Besides general approaches for avoiding caries like regular toothbrushing with a fluoride toothpaste, avoiding the frequent intake of cariogenic food, fluoride supplements, and topical fluoride application, special approaches for pit and fissures have been considered [8–10]. These additional considerations were made since debris and microorganisms can easily be trapped in pits and fissures thereby increasing the risk of cultivating a solid biofilm with subsequent caries development. Conventional methods like the application of fluorides and mechanical plaque control seem to be less effective in these areas when compared with smooth surfaces. In order to preserve these areas that are less protected by other therapeutic approaches, sealants were developed [11]. After application of a pit and fissure sealant on the surface, a physical barrier blocking the nutrition of the biofilm is generated, and the growth of the biofilm is therefore prevented [12, 13]. The evaluation of nine randomized controlled trials showed a 76% reduction of the incidence of occlusal caries in permanent molars after a follow-up period of 2–3 years using pit and fissure sealants [14–20].

9.2 Treatment Strategies for Occlusal Caries

Despite fluoridation and other prophylactic measures, caries is still a frequently and, in many cases, rapidly occurring disease with particular distribution to occlusal surfaces. Best practice treatment strategies for not only occlusal but also smooth surface caries lesions have shifted progressively from a more invasive approach toward minimally invasive or even noninvasive strategies [21–26]. The bases for this trend reversal from G.V. Black's conservative extension for prevention to noninvasive approaches are an increased concern about saving tooth structure, an increased understanding about the effectiveness of non-operative strategies and the general decrease in the rate of caries progression [22, 26, 27]. Moreover, the placement of a restoration will critically affect the long-term prognosis of the tooth and financial commitment over the patient's lifetime [28]. Specifically, teeth with existing restorations will more likely require restoration replacements and potentially further restorative treatments over time [29].

If an open cavity is diagnosed, the option of restorative treatment is unquestionable [30]. However, at an early stage of occlusal enamel or dentin caries, the possibility of a non-cavitated lesion with a layer of intact enamel exists [31]. As long as the caries is localized to enamel only, sealing of the pits and fissures is advocated. If the caries has expanded into dentin, an invasive approach for removal of carious tissue and subsequent tooth restoration is mostly recommended [32]. However, even in cases when caries has progressed into dentin, pit and fissure sealants have been shown to be effective in arresting carious lesions when placed properly with no retention failure of the material [33].

Nevertheless, great variations in treatment philosophies and strategies of carious lesions exist all around the world [26]. For example, 70% of the dentists in Scandinavia would not choose a restorative approach until the caries progression leads to the clinical formation of a cavity and/or any radiolucency can be seen in the dentin. This means that 30% would use an operative treatment for enamel caries lesions [34]. Similar in Canada, where almost 41% of the dentists would restore and would not delay treatment under any circumstances for a lesion confined to enamel [35]. Moreover, a systematic review and meta-analysis from 2017 analyzing studies from 17 countries report that significantly more dentists would intervene restoratively on carious lesions even when less invasive therapies would be appropriate [36].

9.3 Indications for Placing a Fissure Sealing

The primary objective of introducing sealing materials in conservative dentistry was the prevention of caries. However, due to caries decline in many industrialized countries, this initial indication was revised and also partially extended [37]. Nevertheless, the original recommendation for the use of sealing materials for occlusal surfaces is still current, especially since these surfaces are most frequently affected even when caries incidence falls [38]. Interestingly only 6% of 111 pediatric departments from 13 European countries routinely implemented preventive sealing of occlusal fissures within the first year after tooth eruption. All other countries used sealing materials only when specific indications like increased caries risks indicated by the presence of active caries as well as by the fissure morphology and caries status of the respective fissures are known [37].

Other approaches of sealing fissures offer the view that teeth at any age can be sealed and that sealing is not limited to only the eruptive phase up to 1 year after full intraoral eruption. A consensus paper of the American Academy of Pediatric Dentistry Pediatric Restorative Dentistry Consensus Conference stated that sealing occlusal surfaces only within the first year after eruption is no longer state of the art since the carious event does not necessarily have to occur within the first 3 years after eruption [7]. Furthermore, incidences arise where no caries occur at all. The application of a sealing material should therefore be based on personal, tooth, and surface risk, which can change during the patient's life [7]. Figure 9.1 presents ICDAS codes and criteria for treatment of fissures with example photographs.

Furthermore, besides the use of sealing materials for primary prevention avoiding the occurrence of caries, secondary prevention in areas already affected by caries should be considered [7]. Arresting the caries and eliminating viable microorganisms under the sealing material is the purpose of this application [7]. More and more studies are presenting findings that sealing even deeper caries lesions resulted in effective attenuation of the carious process [39].

9.4 Noninvasive Treatment of Non-cavitated Pit and Fissure Caries

Occlusal caries still exhibiting a layer of intact enamel even can extend into the dentin [31]. Besides the prophylactic application of sealing materials, its use in these cases of existing caries has been considered [40]. The idea of this noninvasive intervention is to arrest caries progression which will result in the maintenance of a

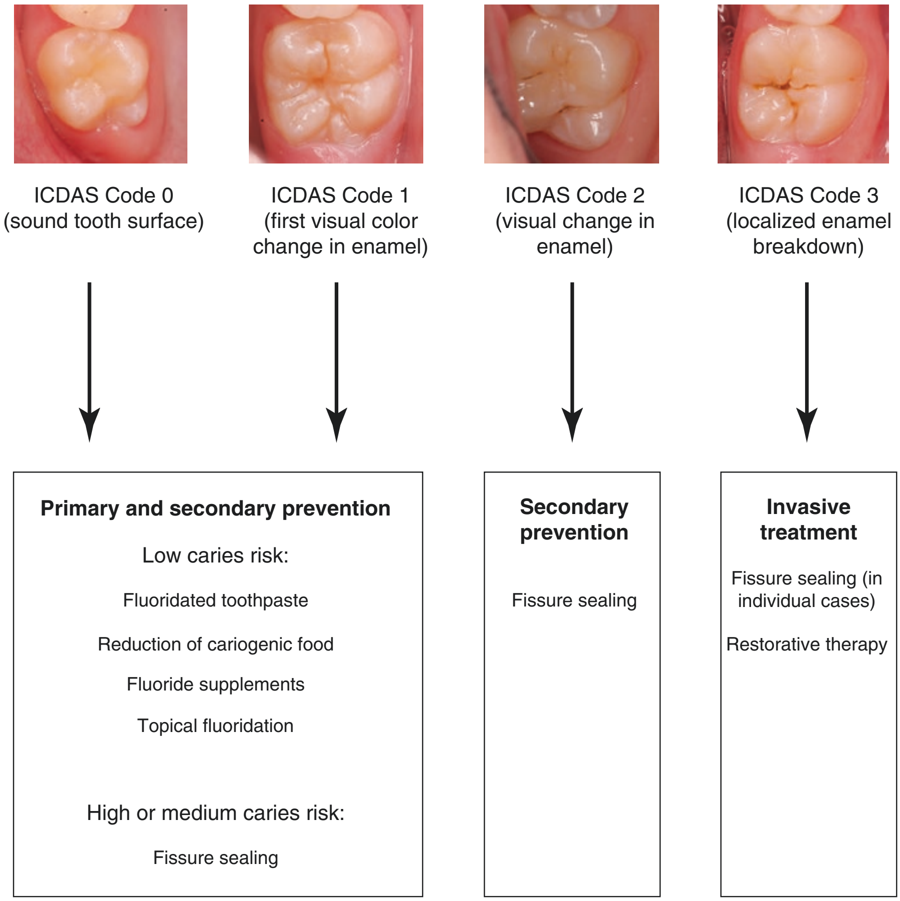

Fig. 9.1 ICDAS codes and criteria for treatment of fissures with example photographs

maximum amount of tooth structure since operative procedures are delayed and minimized [41, 42]. This procedure seems to be highly advantageous in pediatric dentistry. The sealing can be seen as a secondary preventive approach to the control of non-cavitated occlusal caries. It may replace the conventional restorative approach of removing the infectious tissue and can be performed with a shorter chair time and without the need for anesthesia.

9.4.1 Effect of Pit and Fissure Sealing to Arrest the Progression of a Non-cavitated Caries Lesion

The mechanism of action of the sealing materials in non-cavitated caries lesions is similar to the original prophylactic sealing. Since the biofilm is starved of its nutritional supply, the progression and growth of the carious lesion is inhibited. A systematic review focusing on noninvasive treatments to arrest dentin non-cavitated caries lesions was recently published [40]. De Assunção et al. included five studies that were performed on teeth with visually non-cavitated occlusal lesions with caries extension in the range between the dentinoenamel junction and middle third of dentin. They showed that four of the included clinical trials reported that fissure sealing was able to arrest the progression of carious lesions. A prerequisite for these results were, however, completely undamaged marginal sealing capability of these materials [30, 42–44]. The authors speculated that a blockade of nutritional supply that was supported by the mechanical barrier of the resin-based fissure sealant led to the lack of caries progression. The fifth included study in the review also evaluated the efficacy of a nonsurgical approach to arrest occlusal non-cavitated dentin lesions in molars [45]. However, another material was used. In contrast to the results found in the other clinical trials, the authors of this article reported that the self-etch glass ionomer sealant did not arrest caries progression. Although the treated teeth did not show any sign of caries progression on the radiographic examination, visible cavitations were observed after 12 months of follow-up. Especially in cases when the glass ionomer sealants were lost, signs of progression were detected. The authors argued that the rapid macroscopic loss of self-curing glass ionomer sealant may render fissures susceptible to biofilm adhesion and further acid attack, which led to the cavitations on occlusal enamel [45].

Another systematic review published by Schwendicke et al. compared strategies for treating pit and fissure lesions in permanent teeth using network meta-analysis [46]. The authors analyzed randomized and nonrandomized clinical trials that investigated shallow or moderately deep primary caries lesions in fissured or pitted surfaces. The risk of requiring invasive treatments or any retreatments in noninvasive, microinvasive, and minimally invasive treated lesions were compared using untreated lesions as controls. Noninvasive treatment included remineralization, antibacterial treatments, oral hygiene education, or professional oral hygiene. Caries sealing was defined as microinvasive treatment, and minimally invasive treatment was defined as restorative treatment including caries removal but aiming at preservation of sound dental hard tissues. A total of 14 studies including 1440 patients with 3551 treated lesions were included in the systematic review. The authors discovered that microinvasive and minimally invasive treated lesions require less invasive retreatments than control lesions. Nevertheless, microinvasive treatment required significantly more total retreatments like resealing than minimally or noninvasive treatments. However, due to limited study quality, the evidence was graded as low or very low by the authors.

9.4.2 Permanent Versus Primary Teeth

A positive effect on the longevity of the affected tooth by the sealing of non-cavitated lesions in permanent teeth thus appears to be affirmed by several studies. However, the question of effectiveness surrounding primary molar fissure sealant placement has yet to be answered in the literature. The application in very young children would be of utmost interest since they often lack compliance for caries removal using a bur and adhesive filling therapy. Borges et al., for example, compared the efficacy of sealing the pits and fissures using a resin-based material to that of traditional tooth restorations when treating non-cavitated dentin caries lesions in primary molars [43]. Analysis of the clinical and radiographic efficacy of the treatment showed no difference between the groups. Fissure sealing and tooth restoration were equally effective. The authors concluded that invasive procedures can be replaced with the noninvasive approach with no adverse consequences for pediatric patients. In three other studies, Borges et al. and Bakhshandeh et al. investigated noninvasive fissure sealing as a treatment to arrest caries. They found that this approach appears to be effective in both deciduous and permanent molars [30, 42, 43]. Even if the available studies show statistical significance, further clinical studies on sealing deciduous teeth are necessary. More studies are needed also with regard to the materials to be used, since an absolute dry environment in the oral cavity of children is very difficult to achieve.

9.4.3 Materials

The two most commonly used materials for sealing pits and fissures are resin-based sealants and glass ionomer sealants [7]. As already described, the included clinical trials in the review by de Assunção also used these two materials [40]. Resin-based sealants are monomers of urethane dimethacrylate (UDMA) or bisphenol A-glycidyl methacrylate (bis-GMA) that will be polymerized in the pits and fissures. Glass ionomer sealants contain of a fluoroaluminosilicate glass powder and an aqueous-based polyacrylic acid solution [7, 10]. While resin-based sealants show good durability, glass ionomer sealants feature an attractive fluoride-releasing property. Regardless, these two material classes have their respective disadvantages with regard to their use as sealing materials. Resin-based materials feature shrinkage during polymerization, which can result in debonding and microleakage around the sealing material. This in turn enables bacteria and saliva to penetrate the occlusal barrier in what is now an uncleansable cavity underneath the sealant [47, 48]. Glass ionomer cements are in danger of fracture because of the occlusal forces as well as a greater degree of wear due to decreased surface hardness [7]. A stronger attraction and accumulation of biofilms have been reported in studies featuring resin-based materials [49].

Besides all the above-mentioned advantages and disadvantages of materials used for sealing, the adhesion of the material to the tooth hard substance is most important [7, 50]. The self-curing glass ionomer cement tested by de Silveira et al. showed high failure rates that prevented it from arresting caries progression, as determined by clinical examination [45]. Resin-based fissure sealants on the other hand showed higher retention rates [30, 42–44] indicating that the application of a resin-based fissure sealant is preferable to self-curing glass ionomer cement. In studies where recurrent caries was detected, glass ionomer cements were directly compared to the performance of resin-based sealant materials. The retention of the material was about 80% for resin-based and about 3% for glass ionomer materials [51–53]. The literature also features contrary results in which glass ionomer cement showed better results for preventing caries compared to resin-based materials, however with little successful retention for both materials [54, 55]. Further studies showing no statistical differences in the caries incidence between the two sealing materials presented similar retention capacity of the two materials [56, 57].

Conclusions

Recent evidence indicates that fissure sealing seems to be effective not only in prevention of caries but also in the arresting of pre-existing occlusal carious lesions as long as no cavitations exist. Randomized controlled clinical trials with longer follow-up periods should be performed to confirm this strategy against caries and to minimize iatrogenic destruction of dental hard tissue.

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Therapeutic Fissure Sealing

10

Norbert Krämer and Roland Frankenberger

Abstract

Pits and fissures are areas being especially prone to caries in permanent teeth. Possible measures are monitoring, preventive sealing, minimally invasive preparation and sealing, and finally conventional restoration. The present chapter focuses on dental management of therapeutic fissure sealing facing the background of German and American guidelines. This also involves description and judgment of clinical procedures. Caries diagnosis on the basis of ICDAS-II allows differentiated decisions mostly resulting in sealing or minimally invasive restorations. Borderlines between initial caries with or without dentin involvement are traditionally difficult. Minimally invasive preparation is ideally managed using special rotary burs. Flowable resin composites are the materials of choice for restorations, probably with additionally applied sealant in non-prepared areas. For therapeutic fissure sealing, quality standards of adhesive dentistry have to be taken into account.

10.1 Introduction

During adolescence, occlusal pit and fissures are the predominant loci for caries formation. Fissures easily acquire and store plaque being followed by primary caries. It is well known that fluorides are supporting a caries decline of 60–80%; however, only on proximal and facial aspects of the teeth at the fissure bottom fluoride

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effects are barely measurable. This is mainly due to complex anatomy and restricted access for preventive measures. Thus, caries prevalence in fissure systems still is 60–90%. Therefore it is appealing to mechanically exclude caries-causing plaque as well as sugar as substrate. Since the introduction of the enamel etch technique, a perfect way was inaugurated to get tight seal of tooth surfaces whatsoever [1, 2].

10.2 Definition

Whereas the classic preventive pit and fissure sealing is defined as microinvasive sealing of caries-free or stained fissures, therapeutic pit and fissure sealings always involve some minimal cutting action in order to definitely exclude dentin caries. The access has to be just as wide as a dental probe needs to explore the dentin beneath. In the case of dentin caries, it is first excavated and then restored. When no or almost no dentin caries is found and therefore enlargement of the microcavity is unnecessary, immediate adhesive seal is the best choice.

The therapeutic pit and fissure sealing is therefore also regarded as so-called preventive pit and fissure sealing. It is therefore the primary solution of small minimally carious lesions and represents the first step of a minimally invasive restorative concept, i.e., preventive resin restoration. It is the counterpart to the traditional extension-for-prevention strategy because huge occlusal boxes are strictly avoided [3].

10.3 Diagnosis and Therapy Decision

Caries diagnosis in pit and fissures is a major clinical challenge. This is even more true with suboptimal morphology and food impaction but also with stained areas as well as pre-existing pit and fissure sealings having to be reevaluated after certain years of clinical service. Prior to any clinical diagnosis, teeth have to be thoroughly cleaned, e.g., with brushes and polishing pastes or ideally using air-polishing devices.

Based on reports of the Ekstrand group [4, 5], the International Caries Detection and Assessment System was developed (actual version: ICDAS-2) [6]. Using this system, different stages of caries progression among non-cavitated lesions are classified, allowing for an appropriate therapy afterward [7]. For the indication "therapeutic fissure sealing," the respective codes are 2–5, because with higher numbers dentin caries is highly probable. Chapter 5 is referring more intensively to ICDAS.

As second opinion in occlusal diagnosis, laser fluorescence is meanwhile widely established (DiagnoDent, Kavo, Biberach, Germany). Laser penetration depth into enamel was measured to be ca. 1 mm, so also hidden caries may be detected [8]. Bitewing radiographs may also be considered, primarily when they already exist anyway or when they are legally justified [9]. However, the interpretation of occlusal defects using bitewing radiographs is almost impossible, also beginning dentin caries is barely detectable [10]. Figure 10.1 displays the flowchart for diagnostic and therapeutic clinical reasoning.

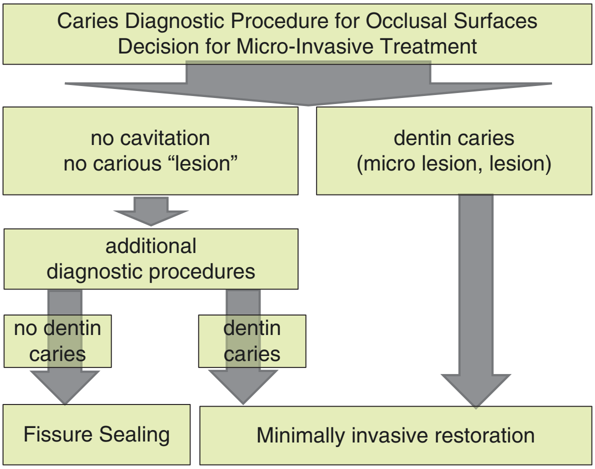

Fig. 10.1 Diagnostic diagram

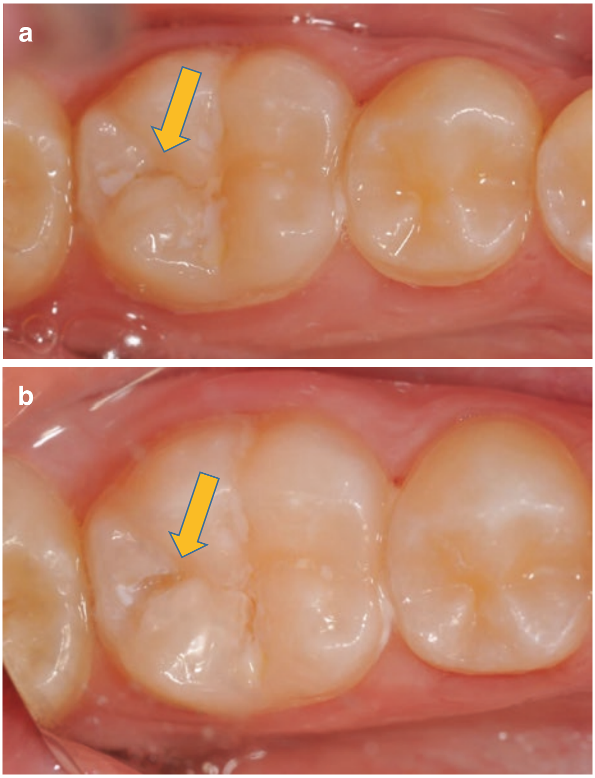

Fig. 10.2 (**a**) Insufficient sealing of the first molar with possible dentin caries (arrow). (**b**) Prepared fissure with removed insufficient sealing. No hidden caries detected (arrow)

Figure 10.2 shows the challenge of caries diagnosis beneath an insufficient PFS (Fig. 10.3a). In such a case, the defect part of the pre-existing PFS has to be removed in order to allow for dentin caries detection (Fig. 10.3b).

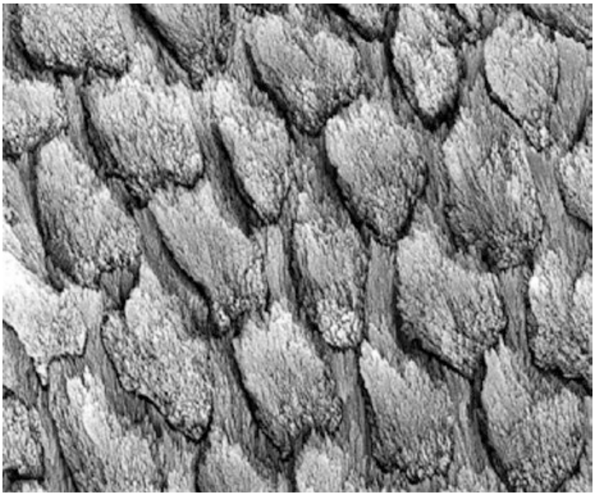

Fig. 10.3 Etch pattern (beveled enamel after 15 s etching with phosphoric acid, SEM, 1:3000)

10.4 Materials for Therapeutic Fissure Sealing (TFS)

Appropriate materials for TFS are based on an adhesive, minimally invasive restorative concept. Prior to intervention it should be considered whether it is a single measure or being combined with larger restorative operations. Manufacturers today tend to offer a wide range of products being adjusted to one another (i.e., adhesive, sealing, flowable composite, sculptable composite). In contrast to prophylactic PFS, TFS always involves opened dentin (Fig. 10.4). Therefore, phosphoric acid etching alone is not enough for overall pretreatment. Additionally it has to be taken into account that in a TFS also occlusal load comes into play, so classical low-filled sealing materials fall short from a material science view [3].

10.4.1 Adhesives

Resin-based materials such as composites or compomers do not adhere to enamel and dentin by themselves, meaning that marginal gaps would be the consequence [1]. Once formed, gaps would even get worse by factors like different coefficients of thermal expansion and mechanical load and fatigue [11, 12]. Secondary caries is one major reason for failure of resin-based materials [13]. The stringent integration of adhesion concepts led to a minimally invasive breakthrough for clinical use of resin-based biomaterials [14]. Today, adhesive dentistry is based on minimum loss of tooth hard tissue—preventive resin restorations are the classical way to do so.

Adhesion physically means any “bonding of different substrates in tight contact.” In most of these cases, a solid adhesive substrate and a more liquid phase interact [15]. Both superficial roughness and certain porosities cause microretentive adhesion, with adhesive and substrate being able to chemically bond, i.e., ion binding,

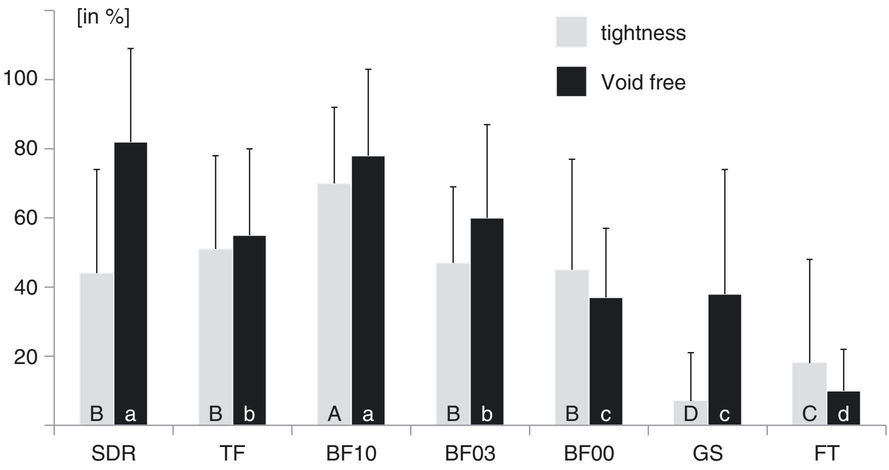

Fig. 10.4 Results for tightness and homogeneity of different flowables shows Fig. 10.4 (SDR, Dentsply Sirona), TF (Tetric EvoFlow, IvoclarVivadent), BF (BeautiFlow 10, 03, 00; Shofu), GS (GrandioSo Flow, Voco), FT (Fuji Triage; GC Europe). Same letters in columns represent no significant difference between groups (Mann-Whitney test; $p < 0.05$)

covalent binding, hydrogen bridges, and van der Waals forces [14]. Micromorphological reports in dentistry have shown that the resin-enamel and resin-dentin bond are of a micromechanical nature with chemical interactions having been scarcely reported [14, 16].

First of all, tight contacts (0.1 nm) are needed; however, adhering bodies do not provide this. Thus, liquid phases are designed to fill non-tight spaces involving a certain amount of wettability. The adhesion substrate should have high surface energy, whereas the adhesive should be characterized by low viscosity. Moreover, surface roughness considerably helps to increase surface areas.

The basis of any chemical bonding is when two atoms use identical electrons, e.g., via hydrogen bridges; however, like in any chemical binding, distances should go below 0.7 nm. When natural or formed irregularities of bonded surfaces are filled with the adhesive, micromechanical interlocking works—it is of a primarily mechanical nature and influenced of rheological circumstances.

10.4.2 Enamel Bonding

10.4.2.1 Etch-and-Rinse

The breakthrough paper of dental adhesion was published in 1955 with the introduction of the enamel etch technique by Dr. Michael Buonocore [2, 17–21].

Facing clinical success, i.e., gap- and stain-free margins and/or durable retention, adhesion to phosphoric acid-etched enamel is estimated to be effective. Phosphoric acid etching (the so-called etch-and-rinse protocol) forms an ideal surface morphology (Fig. 10.3) for micromechanical adhesion. Caused by different solubility of enamel prisms in their center and periphery, an irregular rough structure is created and afterward filled by adhesives which are light-cured. This kind of adhesion is capable of counteracting polymerization shrinkage of resin-based materials under clinical load [15, 16].

Enamel consists of 98% wt. inorganic hydroxyapatite. Its crystallites are arranged to prisms with varying acid solubility. The so-called prismless enamel is found in outer and non-worn layers (e.g., also in pits and fissures). For these special areas, etching time should be >30 s. Phosphoric acid removes 10 μm enamel with 50 μm roughness, the so-called enamel etch pattern [16, 22]. It provides high surface energy allowing good wettability of etched enamel. Respective phosphoric acid products are mainly offered as 35–40% gel and applied for 15–60 s followed by rinsing with water and/or air-water spray to remove both acid and dissolved inorganic material. An optimum etching roughness regarding depth and regular structure is achieved when prims are cut rectangularly. When prims are cut longitudinally like in basal proximal box margins, the adhesive effect is only ca. 50%. The clinical need for enamel bevels, especially in posterior teeth, is controversially discussed since decades because, although several in vitro reports showed a positive effect, there is no clinical proof for this paradigm to the date. Also H3PO4 concentration is important with 30–40% being the most effective concentration. Concentrations >40% dissolve less calcium, and concentrations <27% are characterized by less soluble precipitates. The ideal numbers are 37% concentration and a 30 s application time. The final enamel bond is guaranteed by functional adhesives based on bis-GMA. Resin tags guarantee micromechanical interlocking. Another way micromechanical interlocking is guaranteed is by intercrystallite retention.

10.4.2.2 Etch-and-Dry

The so-called self-etch adhesives (i.e., etch-and-dry) were primarily developed for gentle dentin conditioning; however, they are routinely used for enamel bonding as well. Regarding market surveys, etch-and-dry adhesives are the by far most popular products worldwide. Etch-and-dry adhesives contain acidic primers or acidic monomer mixtures providing pH values between <1 and >2 and are also classified according to their acidity (Table 10.1).

Etching effects of etch-and-dry adhesives are less pronounced than with phosphoric acid etching. Both efficacy and durability of enamel bonds generated by etch-and-dry adhesives are controversially discussed. Our own in vitro results have been always worse for etch-and-dry adhesives compared to etch-and-rinse adhesives. Several papers demonstrated that the effect of etch-and-dry adhesives in enamel was enhanced by selective phosphoric acid etching of enamel. The other way round, phosphoric acid etching compromises the success of classical etch-and-dry adhesives on dentin.

10.4.3 Dentin Bonding

Compared to relatively easy achievable enamel bonds, it took a considerably longer to gain success in dentin bonding. Dentin is a hydrophilic tubular substrate. Therefore, it is difficult to bond hydrophobic resins to hydrophilic dentin surfaces.

Table 10.1 pH values of self-etching primers and universal adhesives

Strong	Adper Prompt L-Pop (3M Espe)
Moderate	AQ-Bond (Morita)
(pH ±1.5)	Bond Force (Tokuyama)
	Clearfil SE Bond (Kuraray)
	Clearfil Protect Bond (Kuraray)
	Clearfil Tri-S Bond (Kuraray)
	G-Bond Plus (GC)
	Hybrid Bond (Morita)
	iBond GI (Kulzer)
	One Coat SE Bond (Coltène)
	Unifill Bond (GC)
	Xeno V (Dentsply)
	Peak Universal Adhesive (Ultradent))
Mild	Contax (DMG)
(pH ±2)	Futurabond U (Voco)
	iBond Self Etch (Kulzer)
	Optibond Solo Plus SE (Kerr)
	One-up Bond F (Tokuyama)
	Revolcin One (Merz)
	Prime&Bond Elect (Dentsply)
	Scotchbond Universal (3M Espe)
Ultra-mild	All-Bond Universal (Bisco)
(pH >3)	Adhese Universal (Vivadent)
	Prime&Bond active (Dentsply)

Moreover, after rotary dentin preparation, a smear layer corroborates clean contact to underlying dentin.

For the etch-and-rinse technique, colored 35–40% phosphoric acid gels are used. The acid penetrates along the dentinal tubules that have been opened by the acid. Intertubular dentin is demineralized to 3–10 μm, average irreversible dentin loss is 10 μm, and overall penetration is 20 μm, i.e., altogether 30 μm [23, 24].

The duration of phosphoric acid etching leads to varying demineralization depths which are also dependent on acid agitation during application. Deeper areas of non-coated collagen fibrils are especially prone to biodegradation processes. Prolonged etching therefore may reduce dentin bonding performance [25, 26]. Finally, with a thorough rinse step for 15 s, the etch-and-rinse approach is finished. Consequently, the collagen network has to be penetrated by monomers. However, in order to visually control the effect of enamel etching, the cavity margins have to be dried, however causing overdrying of adjacent dentin surfaces with collagen collapse and probably less monomer penetration. “Wet bonding” is the logical consequence because wet or moist dentin after phosphoric acid etching avoids collagen collapses [27]. It is mandatory to discuss wet bonding facing the background of different solvents being incorporated in primers or self-priming adhesives. These solvents act as carriers for amphiphilic molecules for dentin wetting. The original actual term wet bonding however results from studies using exclusively acetone-based adhesives (e.g., All-Bond 2, Bisco or Prime&Bond NT, Dentsply). With acetone as solvent, moist dentin is a fundamental prerequisite on dentin after phosphoric acid etching. This is the reason why ethanol- and acetone-based primers or priming adhesives fail to work on dry dentin. Incomplete interfibrillar monomer penetration causes remaining unfilled areas in deeper areas of the demineralized dentin matrix. This is referred to as "nanoleakage" [12, 15, 28, 29]. Water-based adhesive systems are less prone to the described wet bonding problem (Adper Scotchbond Multi-Purpose, 3M Espe); the same is true for water-/alcohol-based adhesives (OptiBond FL, Kerr), because the contained water guarantees for rehydration even in the absence of rewetting [15, 30, 31].

In contrast to the etch-and-rinse technique, main advantage of etch-and-dry adhesives is that the previously mentioned incomplete penetration of demineralized areas should actually not occur [29]. By making primers acidic, they are able to superficially demineralize enamel and dentin without prior etching with phosphoric acid. There are dentin conditioning primers and enamel/dentin conditioning agents. Acidic power is terminated by the amount of dissolved hydroxyapatite, solvent evaporation, and finally the light-curing process.

10.4.4 Universal Adhesives

Most recent developments are so-called universal adhesives. The actual idea behind these adhesives is to combine universal primers (e.g., Clearfil Ceramic Primer, Monobond Plus) with primers for conditioned enamel and dentin surfaces.

The second—and the by far clinically most important—innovative aspect of these actually etch-and-dry universal adhesives is the ability to act as etch-and-rinse bonding, even on dried or moist dentin surfaces. It has been shown that classical etch-and-dry adhesives bond better to pre-etched enamel. But especially in small cavities like TFS, it cannot be totally avoided that phosphoric acid is also applied to dentin. First clinical data as well as in vitro evaluations show rather promising results. Today, in most of the universal adhesives, MDP is incorporated, which was shown to be effective in reducing aging effects primarily in the etch-and-dry mode, which was attributed to nanolayering as well as chemical bonding to calcium in dentin [32]. However, most recent studies are also indicating that universal adhesives are also prone to hydrolytic degradation, primarily when used as etch-and-rinse adhesives. So also here, the combination of selective enamel etching and using the universal adhesive in self-etch mode is recommended [33].

10.4.5 Biodegradation

It is well known that matrix metalloproteinases are capable of dissolving hybrid layer collagen over time [28, 34–36]. Although there is some evidence that chlorhexidine may be able to counteract or at least slow down this process, there is still no fundament for a clear clinical advice in favor of any MMP-inhibiting action during dentin bonding.

10.4.6 Restorative Materials

The TFS restoration is carried out with totally bonded low-viscosity resin-based composites. Compared to sculptable high-viscosity composites, flowables exhibit lower filler contents of 40–55% vol or 55–70% wt meaning 10–25% less filler volume compared to high-viscosity materials [37]. The consequently lower wear resistance affects material properties in a way that previously only non-stress-bearing areas have been described as indications for flowables [38]. Also higher shrinkage upon polymerization [39–41], water uptake [42, 43], and compromised mechanical data such as wear [44] and flexural strength [38, 45] were recorded.

However, its low viscosity makes flowables attractive for microinvasive restorations such as TFS [46]. Rheological measures do not always correlate with filler content [47]. Own studies revealed differences in sealing ability of extended fissures and marginal quality [48]. All sealants showed imperfections and voids (Figs. 10.4 and 10.5). But also here, optimized viscosity and reduced shrinkage cause considerably better results in vitro. In this study, three different viscosities of a flowable composite (F00 = 67.3 wt.%; F03 = 66.8 wt.%; F10 = 53.8%) were investigated with BF10 having been the lowest.

Since 2010, flowable resin composites were also offered as so-called bulk-fill materials. Compared to classical flowables with polymerization shrinkage up to 6%, polymerization shrinkage and its stress were significantly reduced [49]. Our studies revealed no difference between SDR and conventional flowables regarding

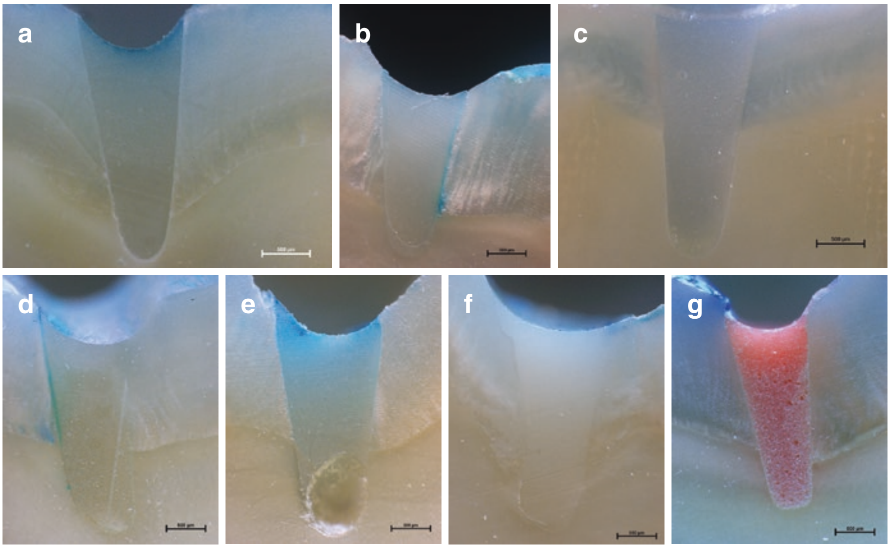

Fig. 10.5 Macroscopic view of tightness and homogeneity ((**a**) TF, (**b**) GS, (**c**) SDR, (**d**) BF00, (**e**) BF03, (**f**) BF10, and (**g**) FT). In contrast to prophylactic PFS, TFS always involves opened dentin visible in all figures

homogeneity and tightness (Figs. 10.4 and 10.5c). Other bulk-fill flowables have been described regarding polymerization stress or depth of polymerization; however, for TFS data are not available [50].

For the use of resin composites, appropriate isolation of the field is mandatory. However, it is often required to intervene when teeth are not yet fully erupted (Fig. 10.6). Glass ionomer cements (GIC) are used for both prophylactic and extended PFS [1, 51]. Beneficial aspects of GIC are chemical binding to tooth hard tissues, good biocompatibility, chemical cure, and neglectable polymerization stress and thermal expansion [51]. For PFS, a low-viscosity GIC is available since several years (Fuji Triage, GC). In our studies, it showed a sufficient and tight seal, however, with a higher incidence of voids (Figs. 10.4 and 10.5g) [48]. In vitro, marginal adaptation was promising [52]. Mechanical parameters (flexural strength, flexural fatigue) are inferior compared to resin-based materials such as composites or resin-modified GIC [53]. Due to high fluoride release, a caries-inhibiting effect on cavity margins is expected [54, 55].

Recent so-called “smart” and “bioactive” materials release not only fluoride but also calcium and phosphate ions. In a biofilm model, positive marginal effects have been reported (Fig. 10.7). Mechanical parameters are available, leading to limited indication spectra [53].

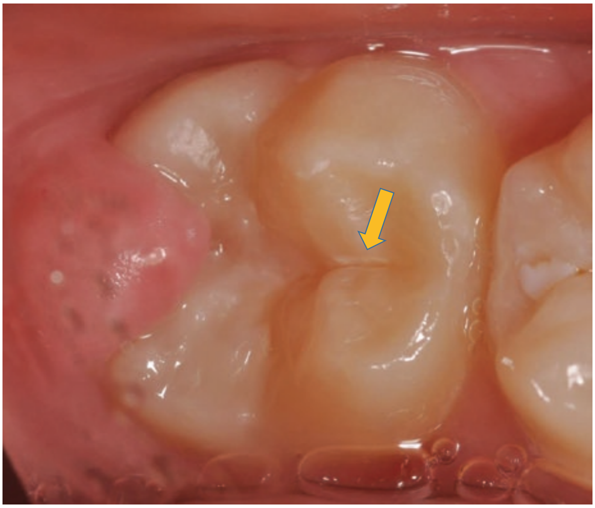

Fig. 10.6 The second molar in not fully erupted. In the mesial part, white-opaque areas are already detected at the entrance of the fissure (arrow). A minimally invasive restoration is strongly advised

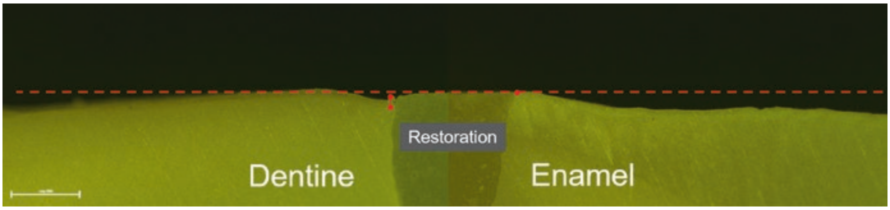

Fig. 10.7 Fluorescence microscope evaluation of ACTIVA BioACTIVE under 4× magnification after biological loading in a biofilm artificial mouth. The individual parameter measured in dentin (left) is demineralization (red). The red dotted line does not correspond to the tooth surface due to the natural tooth morphology. This is not perceived as substance loss

10.5 Step-By-Step Procedure

The according procedures are displayed in Figs. 10.8 and 10.9. After cleaning and visual inspection, diagnostic criteria are applied in order to decide whether we intervene or monitor.

10.5.1 Preparation

Any invasive measure in the occlusal area is primarily carried out to support diagnosis. When dentin caries is probable beneath a good-looking fissure, an absolute minimum intervention strategy is followed to allow for probing of the dentin (Fig. 10.2). Careful extension is furthermore beneficial because it was reported to lead to higher retention rates [56, 57]. Compared to non-prep prophylactic PFS, extended PFS exhibited less marginal imperfections and less leakage [58, 59].

When an active lesion is detected, invasive preparation is necessary. Then, quite substantial progression into dentin is possible beneath a sound-looking fissure.

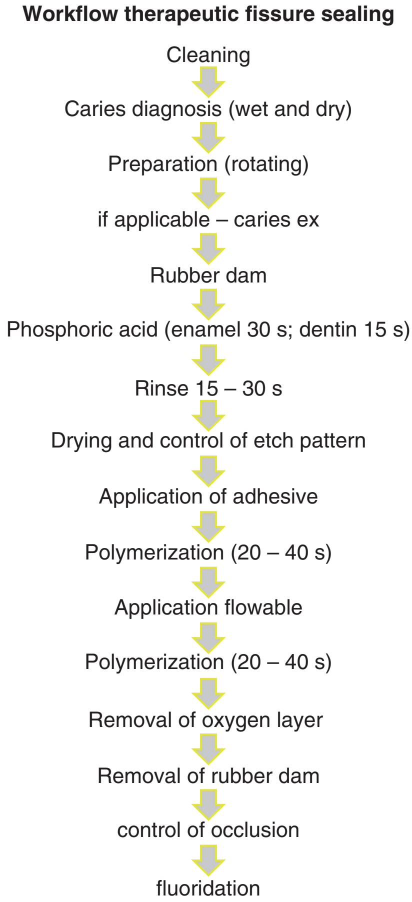

Fig. 10.8 Workflow therapeutic fissure sealing

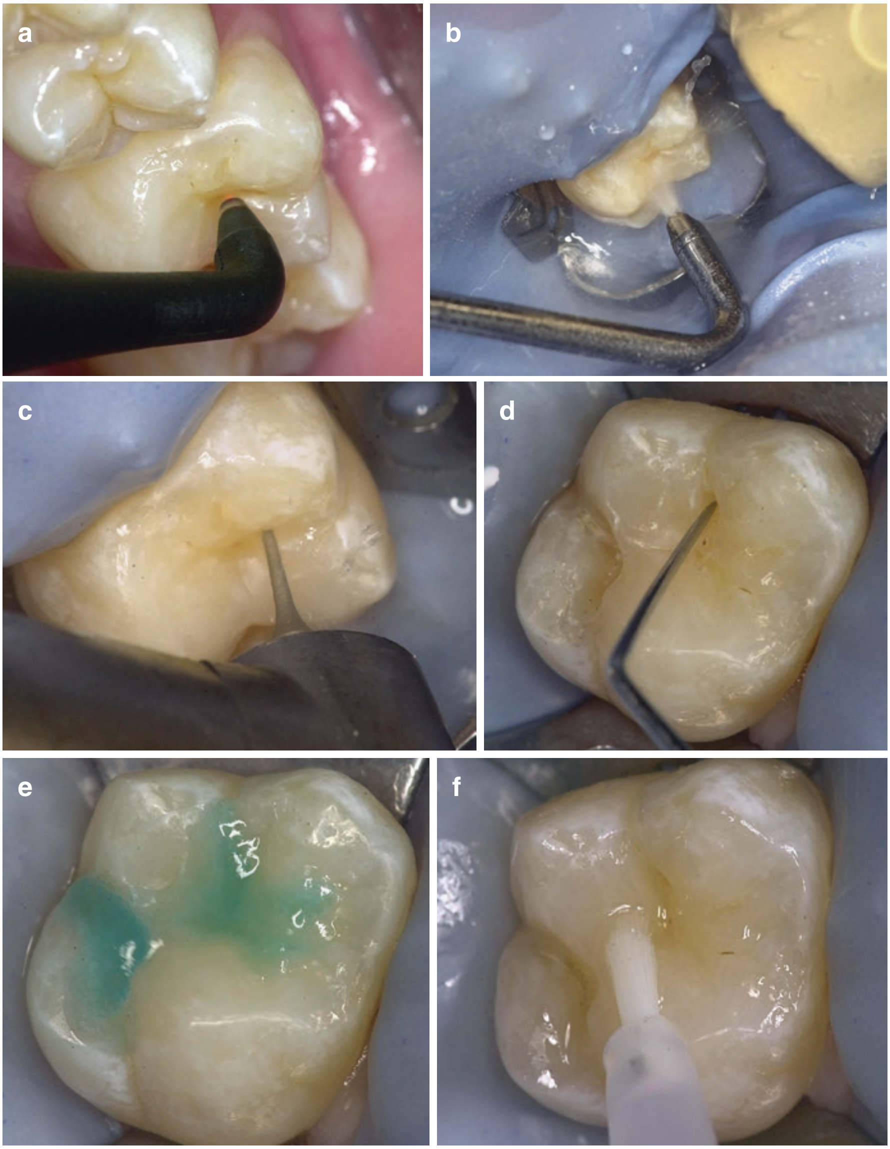

Fig. 10.9 Technical procedure minimally invasive fissure enlargement and restoration: Additional diagnostics with laser fluorescence (Diagnodent) (**a**), isolation with rubber dam and renewed cleaning (air polishing) (**b**), fissure enlargement with a diamond-coated rotary instrument (**c**), checking for complete caries removal (**d**), etching with phosphoric acid (enamel 30 s, dentin 15 s) (**e**), application of dentin adhesive (**f**), checking for complete polymerization (**g**), application of flowable composite (**h**). Extended fissure restoration after check of occlusion. By courtesy of the Deutscher Ärzteverlag

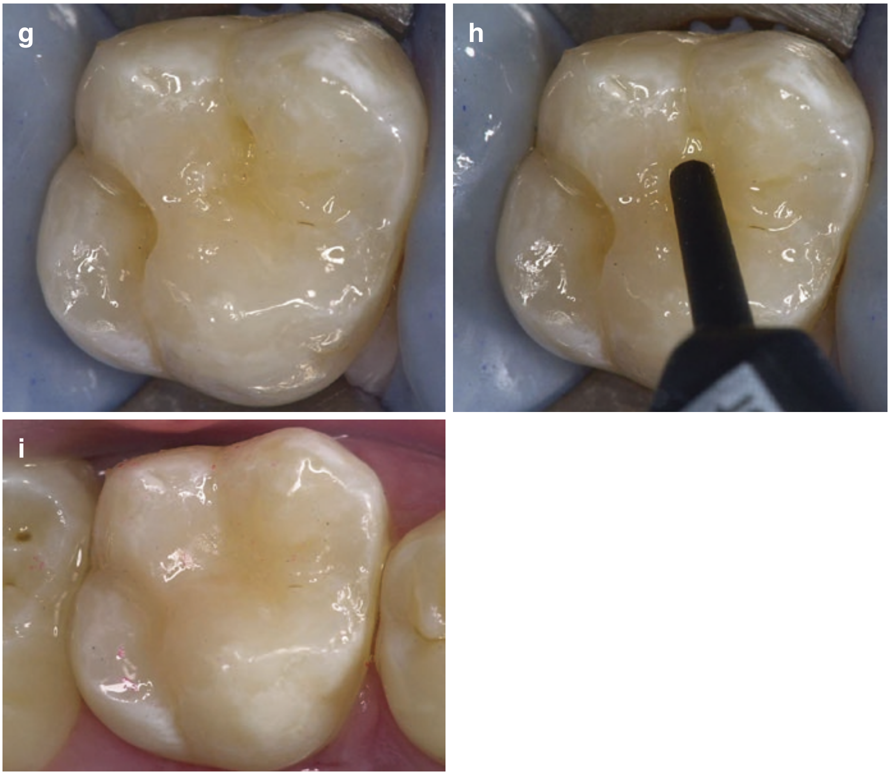

Fig. 10.9 (continued)

However, a 100% extension of all fissures is not mandatory [60]. Leaving occlusal contacts in enamel furthermore enhances the prognosis and guarantees for a maximum tooth stability [61–64].

10.5.1.1 Preparation Techniques

Rotary preparation. Rotary preparation is still the gold standard in PFS [65]. Utilized rotary instruments should have the same shape as the dental probe for a minimum reduced enamel. Both diamond and tungsten burs are applicable [66, 67]. Diamond burs suffer more from wear than tungsten burs. Derived from our results, we conclude that preventive preparations prior to PFS may be most exactly performed with rotary burs of minimum diameters such as De Craene or Fissurotomy. Both small diameters and exact guidance mediated by the fissure line are advantageous. Therefore, rotary burs are still recommended as preparation mode of choice for preparations prior to minimally invasive PFS [65].

In air abrasion in 1951, SS White Company (Lakewood, USA) marketed the "Airdent air abrasion unit" which was the first commercially available sandblaster [68]. Basic principle is air pressure being transformed to kinetic energy ($E_{kin} = ½ mv^2$) [69, 70]. It is therefore also regarded to as "kinetic cavity preparation (KCP)." Aluminum oxide particles (27 µm or 50 µm) abrade enamel very efficient because harder surfaces are abraded more effective because the particles barely loose speed [71]. So, enamel is normally removed quicker than with burs [72]. The amount of removed enamel is also dependent of pressure, distance, grit size, and application time [73]. Using higher pressure [74, 75], less distance [76], and prolonged exposure time [75], substance loss increases. A distance of 1 mm at an angle of 90° is estimated as optimum [70]. Data relating to the correlation of grit size and effect are not clear [74]. Also nozzle size has been discussed to have some influence [73].

Beside substance loss, air abrasion also causes roughening of the surface. This led to the assumption that air abrasion could replace enamel etching [72]. However, the majority of studies showed that this is not true [77–81]. So after air abrasion, an additional etching step is absolutely mandatory. Also a beneficial effect for marginal adaptation was discussed sometimes, but, compared to PPFS, this was not confirmed [82, 83]. The influence of grit size is unclear; von Fraunhofer found no significant effect on marginal leakage [77]; Fu and Hannig detected tighter seal with 50 μm compared to 27 μm [84].

For pediatric dentistry, air abrasion was primarily interesting from the psychological point of view because unpleasant bur noises can be avoided [70, 72, 85].

The main indication of air abrasion is the TPFS [86]. Our group investigated the effect of different air abrasion devices. Regarding cavity width and depth, rotary burs and PrepStar (having the thinnest nozzle of 0.4 mm and the highest pressure with 6 bars) showed significantly less substance loss than all other devices [65]. Facing overall costs, rotary burs may have the better cost-effectiveness.

Oscillating preparation. Oscillating instruments have been first introduced in the 1960s [87, 88]. Compared to low-frequency systems (e.g., EVA Prepcontrol, KaVo) that were originally designed for finishing and polishing, high-frequency systems are capable of preparation of at least small cavities [89]. The corresponding tips are oscillating in a range between 6.5 kHz (Airscaler, e.g., Sonicflex, KaVo) and 32 kHz (e.g., Piezo Master 600, EMS, Nyon, Switzerland). The air scaler is energized via the turbine account; the energy is coming from air pressure [87]. Beside longitudinal waves, also transversal motions are possible (60–1000 μm). In contact to the tooth, the free amplitude is reduced depending on the distance. Diamond-coated tips (25–70 μm grit size) are used for TPFS; the shape of the cavity is primarily determined by tip shape [89]. This so-called sono-abrasive preparation is carried out with water cooling (15–30 mL/min). Caused by the swinging motion, the tips are quite well water coated which guarantees a good cooling effect [90]. Meanwhile, also special tips are available—the SONICflex seal instrument was especially designed for TPFS. However, caused by the amplitude, cavities were shown to be still wider than after rotary treatment. Nevertheless, adhesive performance was not affected [65, 91]. Finally these instruments reveal the fastest wear of diamond particles over time.

10.5.2 Procedure of Therapeutic Pit and Fissure Sealing (TPFS)

TPFS have to be performed under proper isolation [92, 93]. As already mentioned, not fully erupted teeth cannot be isolated by rubber dam. Alternatives (Isolite, Isolite Systems) have been anecdotically reported so to the date no clear recommendations are possible [94, 95].

Then teeth are cleaned, ideally with air polishing (e.g., Prophyflex, KaVo) which achieves a good plaque removal for better initial diagnosis [96]. Also falsified results have been reported after highly frequent use of air polishing [97].

The fissure is then rinsed and thoroughly dried. Phosphoric acid is used for 30 s in enamel and for 15 s in dentin; selective etching, however, is difficult. After rinsing for 30 s, acid and dissolved enamel is removed. The etching effect is now visualized by the frosty appearance of the enamel. Saliva contamination has to be avoided.

The adhesive is applied according to the manufacturer's recommendations and light-cured for 10–20 s [98]). Flowable composites are applied with a cannula. For elimination of voids and homogeneous distribution, a periodontal probe (PCP-12) is ideal. Should it unintentionally happen that too much flowable composite has been applied, it should be sucked with a foam pellet before light curing.

After visual control of material homogeneity, the resin composite is light-cured for 20–40 s. Should a void or underfilled areas occur, just some more material is applied on the still present oxygen-inhibited layer [99]. Some authors recommend to remove the oxygen-inhibited layer prior to rubber dam removal [100] in order to minimize monomer uptake by the patient. Occlusion control is actually not necessary because only the very deep areas of the fissure should be filled, not interacting with any occlusion. Should still some areas interfere with the occlusion, they can be easily removed and polished. Finally, the tooth is touched with a fluoride varnish (Fig. 10.9a–i).

When field isolation is impossible but the restoration of the fissure urgent, GIC is an alternative (Fig. 10.10), especially for non-fully erupted molars [101]. Low-viscosity GIC is clearly better than high-viscous GIC [102, 103].

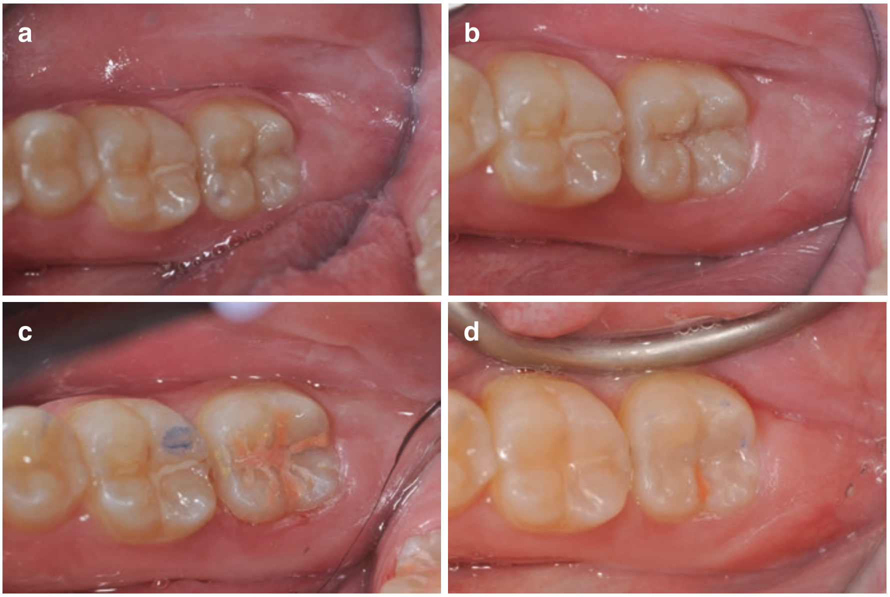

Fig. 10.10 (**a**) Second molar during eruption with hardly impossible rubber dam application. (**b**) In order to exclude dentin caries, the fissure is extended. (**c**) Consequently, the fissure is sealed with glass ionomer cement (Fuji Triage, GC Europe). (**d**) After 2 years, the sealing was covered with a flowable resin composite. Lingually, the still intact GIC is visible

10.6 Control and Repair

During recalls (every 3–6 months according to caries risk classifications), the PFS is always monitored. When staining, crevices, or probable margins occur, it has to be taken into account that the PFS has failed. In such a case, the PFS is removed with burs or hand instruments. Intact parts can be left in place—the same rules like in every resin composite repair apply. Also remaining GIC can be left, just etched and sealed.

10.7 Clinical Significance

Adhesive PFS are an effective measure to inhibit the caries process and to stop demineralization progression. This supports a further caries decline in occlusal aspects of molars. On the other hand, it is extremely important to state that insufficient PFS are supporting caries progression. Therefore it is mandatory to stick to a meticulous bonding and application protocol as well as a stringent recall system every 6 months. Clinical trials report annual failure rates of 5–10%.

On the material sector, resin-based light-cured low-viscosity sealants have prevailed. GIC and compomers have worse outcome. So after 24 months, 80% of GIC sealings were lost [10]. Finally, PFS can be only successful with a clear recall concept. Defects occur more often in the first 6 months of clinical service, so the first control has to be carried out after 6 months at latest [10].

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Retention of Fissure Sealants

11

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Abstract

Sealant retention is a commonly used outcome measure for sealant materials, for example, in clinical trials. Retention rates are also used to inform practitioners about the clinical performance of a sealant material and thereby guiding them in the decision for the preferable sealant. However, the association between sealant retention and the prevention or management of carious lesions is questionable. In this chapter, we will discuss why this is and present data as to the retention of different sealants materials. Moreover, factors that may influence sealant retention will be discussed in depth, and clinical recommendations to improve retention will be given.

11.1 Sealant Retention and Clinical Efficacy

Sealants are placed on pits and fissures that are susceptible to carious lesion development and/or progression, in order to create a physical barrier. This barrier stops the ingress of food and microorganisms into the fissures but also (and possibly mainly) the diffusion of organic acids into the tooth tissues. This barrier thus serves three purposes: (1) making the surface easier to clean, (2) avoiding mineral loss from the tooth tissue, and (3) inhibiting bacterial carbohydrate nutrition and thus metabolism, thereby inactivating bacteria. Thus, it seems reasonable that the clinical efficacy (preventing and managing caries lesions) of a sealant is strongly correlated with its ability to cover all pits and fissures in the

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long term; retention rates of sealants should thus predict the clinical efficacy of a sealant material [1]. Many clinical studies use retention rate as their primary outcome in order to assess the performance of a sealant. However, doubts exist as to the validity of retention as a surrogate measure for the clinical efficacy of a sealant material.

The assessment of sealants was originally evaluated in clinical trials which compared the occurrence (or prevention) of carious lesions in sealed and non-sealed teeth (often within the same mouth in a split-mouth design). Due to favorable outcomes of sealants, the use of a no-sealant control became ethically unacceptable. Consequently, later studies compared different sealant materials and/or techniques instead of comparing sealed versus non-sealed teeth [2, 3]. As early trials found non-sealed teeth at high risk for lesion occurrence compared to sealed teeth, it was assumed that sealed teeth with complete or partially sealant loss were at the same (or even higher [4]) risk for lesion development as never-sealed teeth. Regression analyses of fissure sealant trials have supported this theory, showing a positive association between retention rate and lesion occurrence [5]. It was further argued that sealants can only be effective when they are present on the tooth, and therefore it was claimed that the effectiveness of a sealant is a direct function of its retention [1, 6–8]. Therefore, retention rate of the sealant was broadly accepted as a valid surrogate measure for their clinical efficacy [3, 9].

According to the *Prentice* criteria, valid surrogate endpoints need to (1) reliably predict the true clinical endpoint of a disease and (2) need to be independent from the applied treatment [10]. For sealant retention (as a surrogate for carious lesion prevention), this means (1) sealant retention should be directly associated with the occurrence of lesions and (2) this association should hold true regardless of the applied sealant material (e.g., the association between sealant retention and lesion occurrence should be the same for different sealant materials) [3]. In two systematic reviews, *Mickenautsch* and *Yengopal* assessed if the surrogate endpoint "sealant retention" fulfills these criteria and is thus valid [3, 9]: One review assessed the association between sealant retention as a predictive outcome for lesion occurrence when resin-based fissure sealants were placed in permanent molars for a minimum follow-up of 24 months. It was found that the retention rate, as a predictor for lesion occurrence, was not more accurate than random estimates. The authors concluded that retention rate is not a valid predictor for lesion development but also found that complete retention remains a beneficial clinical factor for a sealant material [9]. The second review assessed if the association between sealant retention and lesion occurrence was the same for different sealant materials. Data from clinical trials and systematic reviews reporting on retention rate and lesion occurrence in permanent molars sealed with resin-based or glass-ionomer cement sealants were included. The risk of complete retention loss was contrasted with the risk of lesion occurrence. Significant differences in the ratios of retention and lesion occurrence values were found between resin-based sealants (mean/SD ratio was 9.64/24.58) and glass-ionomer cement sealants (13.68/13.72). This indicates that the association between retention loss and lesion occurrence was not independent from the used material. In summary, sealant retention does not fulfill the Prentice criteria as a valid surrogate endpoint, while additional regression analyses revealed a significant association between sealant retention and lesion occurrence for resin-based sealants, but not for glass-ionomer cement-based sealants. Interestingly, even after complete loss of glass-ionomer sealants lost, they still provided a carious lesion-preventive effect [3].

As a clinical guide, complete retention of a sealant material may nevertheless contribute to its carious lesion-preventive effect. However, this might not be the only preventive factor. Other known and unknown factors acting independently of the retention rate may contribute to the preventive effect. Therefore, the judgment on the clinical efficacy of a particular sealant material should not only be based on its ability to retain on the tooth surface but also (and possibly mainly) on its ability to prevent carious lesion (and arrest existing ones).

11.2 Caries Risk of Teeth with Lost Sealants

As discussed in previous chapters, fissure sealing is a highly effective treatment for the prevention of carious lesions. However, concerns exist that teeth with lost sealant material may be at a higher risk for new lesions compared with never-sealed teeth. For partially lost sealants, areas next to remaining sealant material might be less cleanable and therefore could represent a predilection site for new lesion development. Another explanation might be that the previously modified tooth surface (e.g., by acid etching) could bear a higher risk compared to a non-modified surface. Particularly for patients where regular inspections of sealed teeth cannot be ensured, these concerns can act as a barrier for providing fissure sealants.

Griffin and *colleagues* assessed the risk of lesion occurrence in formerly sealed teeth by analyzing data from different systematic reviews [4]. The authors compared the lesion incidence in molars of children (aged 5–14 years) where partial or full retention loss occurred, with the lesion incidence of molars that never had been sealed. To allow for comparisons between formerly sealed and never-sealed teeth included studies needed to have used a split-mouth design, where sealed and non-sealed teeth were compared within the same mouth. For all included studies, either UV-light-polymerized or auto-polymerized resin-based sealants were used. After 1 year, the risk of lesion development in teeth with lost sealant versus never-sealed teeth was not different (relative risk, 0.99; 95% CI, 0.82–1.22). After a period of up to 4 years, the caries risk of formerly sealed teeth was even slightly (albeit significantly) lower compared to never-sealed teeth (0.94; 0.90–0.98). It was further found that partially retained sealants could offer some protection against new lesions [11]. The authors concluded that after retention loss of a sealant, teeth do not have an increased risk of developing carious lesions and suggested that sealants should also be provided if indicated even if it cannot be assured that children can attend to regular checkups [4].

For glass-ionomer cement sealants, clinical observations indicate that they still offer some protection even if they got visually completely lost [3]. Using microscopic evaluations of replica of teeth with lost glass-ionomer sealants, it could be shown that in many cases, sealant material remained in place [12]. Due to their brittle nature and their chemical bonding to the tooth surface, glass ionomers tend to fracture cohesively within the sealant layer leaving the tooth surface still covered with a thin layer of glass-ionomer cement. The carious lesion-protective effect of this residual layer might emanate from its diffusion barrier effect but also from its release of fluoride [3, 13, 14].

In summary, teeth with lost sealants may not be at a higher risk for carious lesion development, most likely the opposite. It seems unreasonable to refuse the placement of sealants in less cooperative patients who may not return regularly as a result of fearing retention loss of the sealant in the meantime.

11.3 Retention Rates of Fissure Sealants

11.3.1 Sealant Material Classes

A variety of different sealant materials are commercially available of which two material classes—resin-based sealants and glass-ionomer sealants—are most relevant today (see Chap. 2). Resin-based sealants, which are commonly based on urethane dimethyl (UDMA) or bisphenol A-glycidyl methacrylate (BISGMA) monomers, can either be polymerized by chemical activated initiation (autopolymerization) or photopolymerized by use of visible or UV light [15]. Resin-based sealant materials bond by micromechanical retention to the tooth. To create such a bonding, the tooth surface has to be pretreated (commonly by acid etching). Resin-based materials have advantageous mechanical properties compared to glass-ionomer cements. However, their hydrophobic nature and the more technique-sensitive application are a disadvantage of this material class. Less commonly used modifications of the resins are polyacid-modified resins (or compomers) where properties from resins and glass ionomers (fluoride release, adhesive properties) are being combined [15].

The other predominant sealant materials are glass-ionomer cements. Curing of glass ionomers occurs chemically by an acid-base reaction between a fluoroaluminosilicate glass powder and a polyacrylic acid solution. Due to their ability to chemically bond to the tooth structure, it is not necessary to create a micro-retentive tooth surface (e.g., by acid etching) prior application. Glass-ionomer cements are less susceptible to moisture contamination than resin-based sealants, but their mechanical properties are inferior compared to resin-based materials. However, due to their lower technique sensitivity compared to resin-based materials, they are often used in patients that are less cooperative during treatment. Resin-modified glass-ionomer cements are modifications of glass-ionomer cements. Curing of these materials can be initiated by application of light.

The different sealant material classes vary in their properties (e.g., fracture resistance, bond strength to the tooth structure) and their application technique (e.g., tooth surface pretreatment, contamination control, curing mode). All of these factors might have an influence on the retention of the sealant.

11.3.2 Retention Rates of Different Sealant Materials

In a systematic review, Kühnisch and colleagues [1] meta-analyzed the retention rates for different sealant material classes. Data from the included 23 studies revealed that calculated retention rates of resin-based sealants after 2 years were higher (all were in the range of 84% (auto-polymerizing sealants) to 78% (light-polymerizing sealants)) compared to compomer- and glass-ionomer-based sealants (Table 11.1) with one exception; retention rate for UV-light-polymerizing sealants was considerably lower (51%) compared to the other resin-based sealants. However, it should be noted that UV-light-polymerizing sealants represent the first generation of sealant materials (all of the studies on this sealant class were published between 1971 and 1986) and are no longer available today. For compomer-based sealants, the calculated retention rate after 2 years was as low as for UV-light-polymerizing sealants (52%), and for glass ionomer the 2-year retention rate was lowest (12%) among all included material classes.

After 5 years the study found that light-polymerizing sealants (84%), auto-polymerizing sealants (65%), and fluoride-releasing resin-based sealants (70%) performed best regarding retention rate, whereas glass-ionomer-based sealants (5%), compomer-based sealants (4%), and UV-polymerizing sealants (19%) performed inferior. The authors concluded that glass-ionomer cement- and compomer-based sealants were associated with a considerably lower retention rate than resin-based sealants and did not recommend the use of glass-ionomer cement or compomer-based use in clinical practice [1].

In another systematic review [15], retention rates of different sealant materials were meta-analyzed. Four sealant material categories were assessed: resin-based sealants, glass-ionomer sealants, resin-modified glass-ionomer sealants, and polyacid-modified resin-based sealants (i.e., compomer sealants). Odds ratios and 95% confidence intervals were assessed for the outcomes of the comparisons that have been performed within the included trials, allowing for direct

Table 11.1 Retention rates of different sealant material classes, estimated via meta-analysis (from [1])

Material	% retention rates (95% CI) of sealants over different observation intervals		
	2 years	3 years	5 years
UV-light-polymerizing resin-based sealants	51.1 (37.6–64.0)	38.6 (26.0–52.7)	19.3 (7.9–39.9)
Auto-polymerizing resin-based sealants	84.0 (79.8–87.5)	78.8 (75.3–82.9)	64.7 (57.1–73.1
Light-polymerizing resin-based sealants	77.8 (64.3–88.9)	80.4 (63.6–89.8)	83.8 (54.9–94.7)
Fluoride-releasing resin-based sealants	81.1 (45.8–97.8)	75.3 (59.4–88.8)	69.9 (51.5–86.5)
Compomer-based sealants	52.0 (18.8–94.9)	17.9 (8.2–58.0)	3.8 (0.2–31.8)
Glass-ionomer cement-based sealants	12.3 (7.6–19.0)	8.8 (4.3–13.7)	5.2 (1.3–15.5)

Table 11.2 Risk of sealant retention loss (expressed as odds ratios (OR) and 95% confidence intervals (95% CI)) of different sealant materials (from Ref. [15])

Comparisons	Observation period (years)	Indication (*n* studies)	Comparison OR (95%CI)
GIC vs RB	2–3	Carious or deep fissures (1)	2.50 (2.00–3.11)
		Sound fissures (9)	5.62 (1.26–25.07)
		Total	5.06 (1.81–14.13)
	4–7	Sound and carious fissures (1)	0.56 (0.18–1.76)
		Sound fissure (1)	7.97 (2.19–29.01)
		Total	2.00 (0.15–27.95)
GIC vs RMGIC	2–3	Not reported (1)	3.21 (1.87–5.51)
RMGIC vs PMR	2–3	Sound fissures (1)	1.17 (0.52 – 2.66)
PMR vs RB	2–3	Sound fissures (2)	0.87 (0.12 – 6.21)

GIC glass-ionomer cement-based sealant, *RB* resin-basesd sealant, *RMGIC* resin-modified glass-ionomer sealant, *PMR* polyacid-modified resin-based sealant

Table 11.3 Comparison of risk of carious lesion development (expressed as odds ratios (OR) and 95% confidence intervals (95% CI)) of different sealant materials (from Ref. [15])

Comparisons	Observation period (years)	Comparison OR (95%CI)
GIC vs RB	2–3	0.71 (0.32–1.57)
	4–7	0.37 (0.14–1.00)
GIC vs RMGIC	2–3	1.41 (0.65–3.07)
RMGIC vs PMR	2–3	0.44 (0.11–1.82)
PMR vs RB	2–3	1.01 (0.48–2.14)

GIC glass-ionomer cement-based sealant, *RB* resin-basesd sealant, *RMGIC* resin-modified glass-ionomer sealant, *PMR* polyacid-modified resin-based sealant

comparisons of the different material classes (Table 11.2). After a time interval of 2–3 years, glass-ionomer sealants had a fivefold increased risk of retention loss compared to resin-based sealants, which was statistically significant. After 4–7 years, participants who received glass-ionomer sealants had a (nonsignificant) twofold increased risk of retention loss compared to resin-based sealants. (Conventional) glass-ionomer sealants also had a statistically significant threefold increased risk of retention loss compared to resin-modified glass-ionomer sealants. Risk of retention loss was not statistically different between resin-modified glass-ionomer sealants and polyacid-modified resin-based sealants. Nonsignificant differences were also found for the comparison between polyacid-modified resin-based sealants and resin-based sealants. This review thus confirmed the inferiority of glass ionomers compared to resin-based sealants regarding their retention rate. However, in the same systematic review, the risk of carious lesion development in teeth sealed with the different material classes was also assessed (Table 11.3). No significant differences could be found between the sealant materials, indicating that retention rate may not be a good surrogate for the clinical efficacy of sealants, as discussed above.

11.4 Factors Influencing Sealant Retention

A number of factors have been found to impact on sealant retention. These will be discussed here in depth.

11.4.1 Where to Place Sealants: On Sound or Carious Enamel?

One of the main barriers for dentists to place a sealant is the fear of sealing carious enamel or dentin. While, as discussed in the previous chapters, sealing (at least early) carious lesions is a highly effective and safe therapy for arresting them, the difference in sealing substrate (sound versus demineralized enamel) might have a significant impact on the retention of the sealant (lowering it). We will follow this question and compare the retention rate of (mainly resin based) sealants on these different hard tissues.

As described above, the retention rates of sealants have been analyzed systematically, with annual rates of retention loss ranging between 8% (for auto-polymerizing resin sealants) to 40% (for glass-ionomer cement sealants). Light-polymerizing sealants, compomer sealants, and UV-light-polymerizing sealants range somewhat in between (with annual retention loss rates being 12–25%). For light-polymerizing sealants, these retention loss rates seem to be higher in the first years after sealant placement, with only few sealants being lost after 3–5 years [1]. One can now compare these rates with those yielded by studies sealing enamel carious lesions, as meta-analyzed recently [16]. Note that this meta-analysis could not always ascertain why a sealant was replaced, but we can conservatively assume that partial or total retention loss was the reason. Table 11.4 displays the annual retention loss rates of sealants in these different studies (which span a publication period of 36 years). The mean annual retention loss rate (as sample-sized weighted rate) was

Table 11.4 Annual sealant loss rates (ASLR, in %)

Study	Lost sealants[a]	Total sealants	Follow-up (months)	ASLR (%)
Going (1976)	12	41	24	15
Gibson (1980)	15	58	30	10
Mertz-Fairhurst (1986)	0	14	21	0
Frencken (1996)	139	314	36	15
Mertz-Fairhurst (1998)	37	85	120	4
Florio (2001)	10	29	12	34
Hamilton (2002)	3	113	24	1
Bahshandeh (2012)	7	49	33	5
Borges (2010)	0	26	12	0
da Silveria (2012)	16	27	12	59
Liu (2012)	132	256	24	26
Total	371	1012	32	15

[a]Presumed all failures which were mended not invasively were retention loss. References can be found in the original review [16]

15% (standard deviation, 18%). It should be noted that, as many studies were from the early times of fissure sealing, UV-light-polymerized sealants had been used (some studies even used glass-ionomer sealants). Thus, it is difficult to compare this compound rate with that from different specific materials placed on sound enamel. However, one can state that the pooled retention rate of sealants placed on carious enamel is not significantly lower than that yielded for sealants placed on sound enamel, even when comparing it against the "best" material class on sound enamel (auto-polymerizing sealants). What should additionally be noted is the large range of annual sealant loss rates, something which might be due to a range of further factors impacting on sealant retention.

11.4.2 Prior to Placing the Sealant: Pretreating the Surface or Not?

A major question when placing a sealant is: Do I need to pretreat the enamel, and how can this be done both effectively and efficiently? It is thought that cleaning the surface, for example, increases the access of any conditioner (acid etchant, etc., see below) to the enamel rods as well as the penetration of the sealant material into the pit or fissure, which eventually could translate into better retention. A range of pretreatments have been investigated, for example, chemical and mechanical cleaning using acids, brushing with pumice and brushes or rubber cups, toothbrushing but also air abrasion using alumina oxide, laser treatment (to roughen and disinfect the surface but also recrystallize it), and enameloplasty, i.e., invasive removal of superficial enamel layers (see Chaps. 7 and 8). A recent systematic review has investigated this issue in depth [17].

All studies included in this review used hydrophobic resin-based sealants (i.e., glass-ionomer sealants had not been tested). Two meta-analyses had been performed, one using data from eight studies comparing any kind of surface treatment followed by acid etching versus only acid etching and one on four studies comparing pretreatment without acid etching (i.e., pretreatment as etching substitute) versus acid-etching only of the surface prior sealant treatment. The authors found the retention to be 3.3 (95% CI: 1.8–6.0) times more likely after surface pretreatment than no such pretreatment. No significant difference was found when comparing mechanical versus chemical (acid etching) pretreatment (the odds of retention was 1.5; 95% CI: 0.5–2.9) times.

A number of aspects can be discussed here. First, cleaning with a rubber cup prior to acid etching, but not necessarily cleaning with a bristle brush alone, has been found to improve retention. This is in contrast with another systematic review, which found that cleaning using toothbrushes does not seem to be inferior to cleaning with pumice or prophylaxis paste [18]. The latter might be as some (older) studies used unsuitable prophylactic pastes (containing oils), which could negatively distort findings toward such pastes. However, it might also be difficult to remove pumice or pastes from the fissures, which could explain a possible disadvantage of this technique. Given that use of toothbrushes seems easy and cheap to perform, it might be recommendable from a pragmatic point of view [19]. However, the uncertainty around any such recommendation should be noted.

Mechanical preparation with a bur (a so-called enameloplasty) prior to etching has also been found to increase retention; explanations for this finding range from removal of debris, widening of fissure, increase of the surface energy, and removal of prismless enamel [20]. It is clear, however, that such process involves loss of significant parts of the enamel and in case of sealant loss exposes a fissure which is wider, more plaque retentive and possibly at higher risk of carious lesion development than a fissure which was not prepared invasively. Given that, as discussed above, retention of sealants is not a perfect surrogate for lesion prevention, one should be cautiously weighing both these aspects against each other. We do not advocate invasive preparation of the fissure.

Air abrasion has been found to significantly enhance retention of sealants [20], again possibly due to removal of debris and better sealant penetration into the fissures but also due to removal of the prismless enamel surface and enamel roughening. Similarly, laser application (in the single study included, a carbon dioxide laser was used) might improve retention of sealants [20]. It is further argued that such treatment might have an antibacterial effect; the relevance of which needs to be put into the context of the effect of sealing itself on any residual sealed bacteria and their viability.

As described, the review also found that performing such pretreatments results in similar retention rates as acid etching, which could call for not performing etching but only pretreatments. However, both the efforts needed for pretreatment (cleaning or preparing the surface is time intensive, application of the laser or air abrasion generates additional costs for devices and materials) and the possible side effects (as discussed, mechanically pretreated surfaces might be at higher risk for carious lesions) should be considered. Thus, there is currently no argument to make against acid etching (replacing it by bur, laser or air abrasion). As the authors of the review conclude: “Acid etching before sealant application is favorable because it roughens the surface without destroying the anatomy of the pits and fissures” [17].

11.4.3 A Separate Step: Using an Adhesive or Not?

Given that most sealants are un- or lowly filled resins, their polymerization shrinkage is high. Together with the disadvantageous formation of to-be-sealed fissures (a cavity with a high configuration factor), shrinkage forces might be overproportionally high during polymerization. Such shrinkage, in turn, could lead to debonding from the enamel surface, which eventually would allow leakage and possible induction or progression of carious lesions.

It has been hypothesized that using a low-elastic modulus intermediate material like an adhesive (see Chap. 8), which additionally might increase retention by better penetrating the fissure and the exposed acid-etched conditioned surface, could reduce the risk of debonding and leakage. The comparison of using an adhesive after acid etching and prior to placing the sealant versus not using such adhesive has been the focus of a recent systematic review [21]. Overall, 12 studies were included, with mixed levels of quality. These were also meta-analyzed and found that using an adhesive increased the chance of sealant retention by more than three times (OR, 3.3 (95% CI, 1.3–8.4)). The authors further compared which adhesive system might be better suited to be used prior to placing the sealant; etch-and-rinse adhesives (where an acid is used for conditioning, as discussed above; this could still be regarded as the standard but comes with a multistep process of etching, rinsing, and placing the adhesive) versus self-etch adhesives (these combine all these steps, decreasing the time needed for treatment and reducing the risk of handling failure). The authors also submitted this comparison to meta-analysis and found the chance of sealant retention to be 14 times (95% CI, 2.6–81) more likely when using etch-and-rinse versus self-etch adhesives.

The authors conclude that using an adhesive after acid etching improves retention, while using self-etch adhesives and thus omitting the etching step is rather disadvantageous. These findings—acid etching being the strategy of choice for enamel bonding, followed by placement of an adhesive—are in line with findings from the general field of restorative adhesive dentistry [22]. The authors, however, could not make clear recommendations as to which etch-and-rinse adhesives (3- or 2-step etch-and-rinse; or water- versus ethanol- versus acetone-solved adhesives) could be most recommendable. In general, however, it can be stated that enamel should be etched prior to placing a sealant. This ensures removal of prismless enamel, reliable and sufficient surface roughening, an increase of the surface energy, and thus good penetration of the resin afterward. Afterward, an adhesive system could be placed if retention is of utmost importance or any other factors possibly compromising sealant retention are present. Such use of a separate adhesive and the resulting possibly higher retention rate should be balanced against the additional efforts and, indirectly, costs coming with it.

11.4.4 Who Should Place Sealants: Dentists or Dental Care Professionals?

Given their proven clinical efficacy, dental sealants would, ideally, be placed on large populations in general dental care but also schools, etc. (in fact, school-based sealant programs, etc., exist all over the world). Moreover, the steps needed for sealing pits and surfaces are relatively non-complex. Consequently, dental care professionals (also termed dental auxiliaries) might be suited to placing sealants, with significant cost savings but also an impact on the availability in settings which are not regularly visited by dentists (like schools). A recent Cochrane review has assessed this issue, comparing retention rates of sealants placed by dentists versus dental auxiliaries [23].

The authors included 4 studies (with 6 auxiliaries and 4 dentists on a total of 1023 participants who received sealants). Three studies found, after a median observation period of 12 months, no significant difference in retention rates between the two groups, while one study (48 months follow-up) found higher retention rates in dentists (29%) versus auxiliaries (9%). There was no consistent definition of what an auxiliary is, and generally, the low number of providers makes any conclusions very hard (it could be that the four dentists were excellent performers, while the six auxiliaries were not, or vice versa; the risk of finding any differences by chance and thus coming to erroneous conclusions is thus very high).

In many settings, it is unlikely that dentists will place any sealants, while provision of sealants by auxiliaries could increase the access to this preventive therapy especially for the neediest (those with low income, who don't attend the dentist regularly and rely on setting approaches, etc.). Thus, one could cautiously conclude that the lack of evidence toward dentists being the better performers allows to recommend sealing by dental auxiliaries in such settings.

11.4.5 How to Place Sealants: Four Handed or Not?

For placing sealants, the handling is crucial, as (a) most sealant materials need to be placed under stringent contamination/moisture control and (b) sealant placement is usually performed in children, where treatment times need to be short. Thus, it is a matter of debate if placement of sealants should be performed four handed or if it is also possible (and would save significant resources) to have sealants placed by only one professional. Sealant retention after four- versus two-handed placement was the focus of a recent systematic review [19].

Eleven studies were included. Retention rates were found to vary significantly between studies both when annualized but also over the different observational periods. Pooled sealant retention rates in studies using four-handed placement were 90% after 1 year, 83% after 2 years, and also 83% after 3 years. These were significantly higher than those from studies using two-handed placement (85% after 1 year, 72 and 68% after 2 and 3 years). The authors concluded that retention rates were significantly higher when sealants are placed four versus two handed; the mean difference was 9%. It is noteworthy that this review found dentists to be the poorer performers for sealant placement (which supports the conclusion made for the former question).

11.5 Recommendations for Sealant Application

- Judgment on the performance of a sealant material should not solely be based on its retention rate.
- Lack of willingness to attend regular recalls is no argument against placement of sealants as teeth with lost sealant material are not at a higher caries risk.
- Sealants can be safely applied on sound enamel and also enamel carious lesions. Placing sealants on enamel carious lesions does not seem associated with significantly decreased retention.
- The tooth surface should be cleaned with a toothbrush and water, or cups/brushes, and pumice/pastes. Given current evidence being inconclusive, a pragmatic

approach might be chosen here. Cleaning increases sealant retention but also ensures correct diagnosis of the fissure or pit status.

- Invasive (mechanical, air abrasion, laser) preparation of the enamel is not necessarily recommended prior to placing sealant: While it might increase sealant retention in some cases, there is insufficient evidence to show that it also increases the preventive effect of sealants. In contrast, in case of sealant loss, prepared (opened, widened, significantly roughened) surfaces could be at higher risk for carious lesion development.
- Acid etching is a crucial conditioning step and should not be omitted, but performed carefully, as it ensures surface roughening, removal of prismless enamel, and penetration of the sealant into the micro-retentive surface.
- An adhesive can be used after acid etching to increase retention. It cannot replace acid etching.
- Sealants can be applied by both dentists and dental care professionals. While current evidence does not necessarily see dental care professionals to be superior to dentists with regards to sealant retention rates, it also does not support the opposites (dentists being more successful).
- A four-handed technique should be used for placement of sealants, as this increases retention.

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Decision, Risk, and Health Economic Analyses of Fissure Sealings

12

Falk Schwendicke

Abstract

The decision to seal or not to seal a fissure is subject to a range of influencing factors. In this chapter, these factors as well as the uncertainty around them are described, and methods to transparently and explicitly make the best decision under different situations are outlined. Such methods involve decision analysis, but also risk assessment and health economic evaluations. These methods are not readily available to clinicians in most cases, but are increasingly built into decision aids. More importantly, the underlying concept of consciously weighing different parameters against each other and comprehensively and systematically approaching a decision problem can be applied in daily life.

12.1 The Need for Decisions and Aspects to Consider

Clinical decision-making is a difficult endeavor: nearly all decisions are complex, with the need to consider the patients' expectations, risks, options, but also the effectiveness, applicability, reliability, and costs of possible treatment options. Decision-making generally aims to make the best available decision, build on the best "available evidence" [1]. It is obvious that in most circumstances, this best available evidence will have gaps, will be ambiguous, will be weakened by sparsity of data or low validity of trials, etc. This should not mean we cannot make decisions; it just means we need to be aware of these factors and lay them out clearly either implicitly or explicitly. Decision-making in general has as much to do with known aspects as with uncertainty.

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Uncertainty usually applies to all factors guiding decisions: We don't perfectly know the patient's expectations, for example, and will sometimes only learn after a made decision that his expectations did not fit to our expectation. We also don't a priori know the patient's risk profile. With regard to caries, caries detection, and caries management, for example, knowing the risk profile greatly improves our knowledge base for making the best decision. In patients with low risks (low prevalence of carious lesions, low risk of developing new lesions), the likelihood of finding a lesion or correctly predicting a tooth surface at risk for caries is significantly different from those in high-risk patients [2]. Risk assessment will be followed by a diagnostic test, like visual or radiographic assessment of tooth surfaces for carious lesions. Considering the mentioned risk aspects and based on the results of the test, we will then make a diagnostic decision ("surface A is carious"). This decision then turns into a benefit or a harm for the patient via the treatment decision made: does it make sense to seal this presumably sound or carious surface, and is it needed or overtreatment and wasted money? Do we need to restore it instead of sealing it? Would a fluoride varnish suffice to arrest the presumed lesion? Overall, the described decision pathway is marred with uncertainties: expectations, risk assessment, diagnostic decisions, and the effectiveness of the eventually applied treatment are all uncertain.

However, decision-making with regard to caries and sealing is even more complex, as there are further aspects to consider:

1. One central question is: what comes next? If applying sealants, dentists can usually repeat the therapy (in case a sealant is lost, and this is detected early on). If instead one decides to immediately place a restoration, retreatments are very different. In case of restoration failure, the next decision to be made is how to replace or repair the restoration (entering the so-called restorative cycle). It cannot be overstated how central the consideration of this "death spiral of the tooth" (Fig. 12.1) is and how important the consideration of the long-term consequences of initial decision are.
2. A lot of decisions made are guided by one perspective—that of the clinician. We look at outcomes like sealant retention or avoided carious lesions, etc. However, there are a range of other perspectives which are as or even more important to the decision-making. For example, patient-centered outcomes of any decision should be considered. This is an aspect which is currently undervalued in dental science, but highly relevant: patients might not agree with researchers, but also their clinician as to what is relevant, and might prioritize other aspects (aesthetics over costs, longevity over treatment discomfort), which will lead to different decisions. Weighing the different perspectives against each other is a factor which further complicates decision-making.
3. The applicability and the costs emanating from a decision should be considered. Not all treatments are easy to perform, and this applicability might be different in different patients. Similarly, costs are relevant to payers regardless if these are patients or public payers; costs for the same treatment might also differ between patients (as efforts differ, but also as risk profiles differ, leading to different

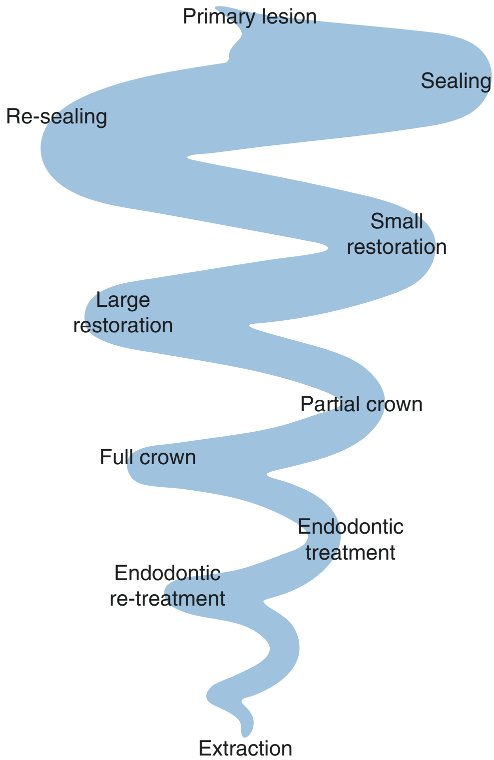

Fig. 12.1 The "death spiral," also known as restorative cycle [57, 58]. Sealing is an intermediate step, allowing to postpone or completely avoid the placement of restorations

follow-up treatments). Again, integrating these into decision-making is not an easy endeavor, as we will see below.

In summary, decision-making in dentistry (and most other things in life!) is complex, as a range of factors need considering. To assist decision-making and to facilitate better decision-making, a number of analytical methods are available. These will be discussed next.

12.2 Decision Analysis

Most decisions in daily life are made instantly, considering a number of aspects which come to mind in that second [3]. They involve a weighing of the importance of each aspect as well as an extrapolation of what the decision will mean for the future. However, daily decisions are usually not (1) comprehensive and (2) explicit, as they are made based on readily available information and not transparently. Decision analysis aims to overcome these aspects, allowing for the — described — best available decision to be made.

While a number of methods are available, it is characteristic for medical decision-making analysis that (1) the information used is collected systematically, aiming to inform the analysis with the most robust available data (which means that researchers often aim to collect systematic review data, or data from large controlled or observational studies, or representative epidemiologic data, etc.). Moreover, they aim to make the decision analytic process transparent, with each step being explicitly outlined, each information and weighing is given and known, and the result of the decision replicable and thus also justifiable.

It is clear that given the efforts needed, such analyses will only be performed for decision problems with greater relevance, and if so, the findings need to be applicable in the daily setting. The latter, however, is one of the difficulties with such analyses: implementing them in (clinical) practice is not straightforward and requires completely different methods than those applied when designing and conducting the decision analysis. Such methods involve various implementation strategies, for example, educational and dissemination efforts, regulation or monetary incentives, and many more. Further details on this "last mile" of research are beyond the scope of this book chapter.

Usually, decision analysis involves some kind of decision model, which lays out the decision problems (transparently) and assigns probabilities to different events, both negative ones (like retention loss of a sealant) and positive ones (sealant avoids caries increment). These probabilities are drawn from the literature as described (from systematic reviews and meta-analyses, large controlled trials, or large observational studies). As discussed, the decisions supported by such models are usually more complex and involve a number of comparators or chains of events (which cannot be assessed easily without such models), for example, caries detection → probability of detecting a carious lesion correctly (or not) → placing a sealant (or not) → sealant averts caries increment (or not). Such scenario could be compared with fluoride varnish application and no intervention with regard to the chance of averting caries increment. This exemplary case can be assessed using a simple decision tree, depicting the different chain of events and the associated probabilities (Fig. 12.2). Using a so-called rollback, one can then assign the overall probabilities of the final events and thus decide which initial option is most likely to yield optimal results. Such simple trees assume the used probabilities to be constant with time. Moreover, they do not allow to model long-term events.

With regard to dental caries, such models therefore have limited applicability, as many decisions have consequences over long periods (like years or decades). Within such periods, probabilities (like the probability of a patient experiencing caries increment) typically change [4]. Moreover, they are affected by previous events (an occlusal surface which had experienced caries increment and has been filled is unlikely to experience caries again and will also not be sealed) [5]. Thus, more complex models are needed. Such models need a memory function (to allow reflecting that previous events have an implication in the future) and additionally should allow for probabilities to change with time (patient's age, retention time of sealant). A typical model having these properties is a Markov model [6]. For example, such model has been used to assess how placing occlusal sealants, occlusal restorations, or providing fluoride varnish on occlusal surfaces affects the long-term retention of teeth [7, 8]. The model incorporates the sequels of averting caries increment (or

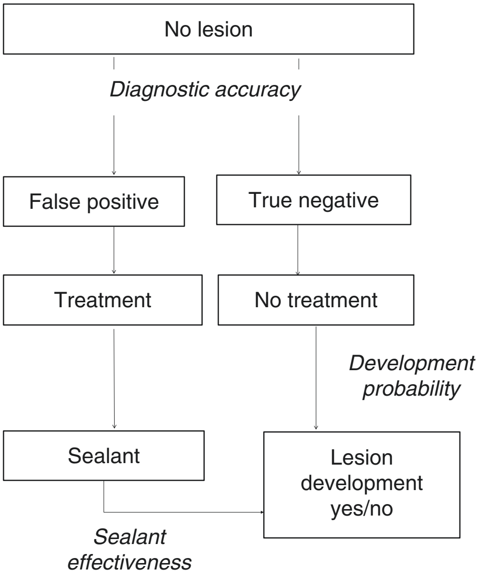

Fig. 12.2 Simple decision tree. By knowing the diagnostic accuracy of a detection method and the prevalence of carious lesions in a population (or the specific patient's caries risk), one can estimate the number of false positive or true negative detections for sound surfaces (or, not depicted, vice versa for carious surfaces). For positive detections, a treatment, in this case a sealant, is applied, with a certain preventive effectiveness. Knowing this effectiveness and knowing the probability of lesion development in unsealed surfaces then allow to estimate the overall preventive fraction of carious lesions. Based on such assessment, one can, for example, decide which diagnostic method is best to apply in a population and if sealing (or no sealing) or alternative treatment methods (like fluoride varnish) yield the most likely best results with regard to avoided carious lesions. Note that this is only one outcome of many (as discussed, the patient's preferences, the costs emanating from decisions as well as the long-term sequels should be considered, too)

not), placing restorations (or not), avoiding re-restorations (or not), losing pulp vitality, and many more. The used decision model is thus very complex, and prone to more uncertainty (as events in the future are more uncertain to be correctly predicted), but allows to assess long-term outcomes like tooth retention (averted caries increment has only limited impact on patients if they place similar preferences on a restored versus a non-restored tooth) and lifetime costs (avoiding carious lesions early allows to avoid costly prosthetic interventions, for example; this will be discussed later on).

In any such model, analysts can (and oftentimes should) assess one, but also more outcomes. Such outcomes can be caries increment, likelihood of re-intervention, costs, pain, number of visits needed, etc. These outcomes are all related to the different perspectives of different decision stakeholders (clinicians, patients, payers, etc.), as has been discussed above. One major question, which has so far not been answered in detail in dentistry, is how to relate these outcomes to each other. While a range of methods exists to weigh health benefits and costs against each other (see below), it is more difficult to weigh averted caries increment against the number of dental visits needed per year or the aesthetic impact of placing an amalgam filling in case caries occurs. A number of survey instruments have been designed to elucidate possible weightings of preferences (while it is clear that such preferences will differ widely depending on the group surveyed). So-called multi-criteria decision analysis methods [9, 10] then allow decisions to be built not only on both the probabilities of events (like the need for placing a restoration on an occlusal surface at age 16 if the surface is sealed at age 8) but also the preference weights for such events. So far, no such analysis has been performed in dentistry.

12.3 Caries Risk Assessment

One main driver of many decisions made in caries management in dental practice is caries risk [11]. Caries risk assessment plays an increasing role in daily decision-making, as the epidemiology of dental caries is increasingly complex. A range of factors have driven this pathway to complexity. First, caries experience has been decreasing in many countries and groups (e.g., the average 12-year-old German has only 10% the caries experience compared with 1979) (Fig. 12.3) (see Chap. 1). Second, this caries experience is heavily polarized, with a small group of (high-risk) patients having the majority of carious lesions (Fig. 12.4). Third, people live significantly longer now than in the past, with teeth being retained for much longer, too. This coincides with caries onset occurring later. The result is that the risk of experiencing caries is postponed, with older and not only younger individuals being at risk for dental caries (Fig. 12.5). This so-called morbidity compression is relevant when considering decision-making in different age groups [12].

As a result, identifying individuals or groups at risk for caries nowadays is more difficult than in the 1960s or 1970s. Caries risk assessment assists making the best decisions in this regard. That is relevant, as decisions made in the low-risk group (e.g., not to seal an occlusal surface, assuming this surface to be very unlikely to experience caries) might not yield the best results in the high-risk

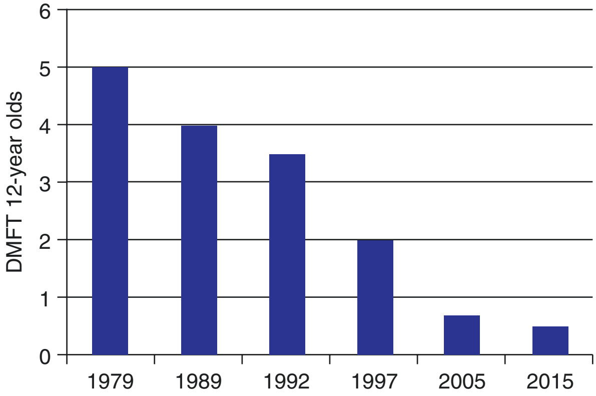

Fig. 12.3 Caries experience changes with time. For 12-year old Germans, caries experience (DMFT) has been decreasing significantly [26]

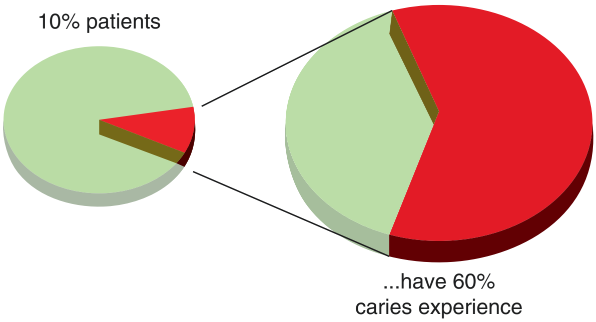

Fig. 12.4 Polarization of caries experience. Dental caries is unequally distributed, with few high-risk patients having the majority of carious, filled, or missing surfaces or teeth

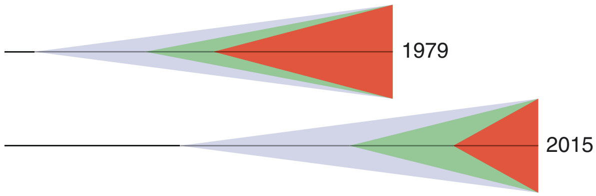

Fig. 12.5 Caries (blue), but also periodontal disease (green), occur later nowadays than in the past. This also leads to tooth loss occurring later (red). However, as life experience is significantly longer, the morbidity is compressed in higher ages [12]. This has consequences for decision-making

group and vice versa. We will use the chance to briefly touch what risk assessment comprises and how valuable risk assessment tools for caries are at present.

First, we need to define the terms used in the risk literature.

1. Risk is defined as the probability of an individual developing new disease. In the specific context of sealants, that would mean new caries lesions. Risk is usually evaluated on the patient level: does this patient have the risk for developing one or more new lesions?
2. The prognosis of a disease then comprises the probability that it will progress, regress, or arrest. In the specific context of sealants, that would mean that the existing caries lesion will progress, regress, or arrest (e.g., will an existing lesion progress if untreated, warranting some intervention like therapeutic sealant, or not?). The prognosis is oftentimes evaluated on surface or site level. For caries and carious lesions, the prognosis is usually called "lesion activity" [13–15].

For clinicians, it is relevant to assess both risk and prognosis, as knowing risk and prognosis will oftentimes lead to better decision-making. A number of parameters [16] are typically available to estimate risk and prognosis (Fig. 12.6):

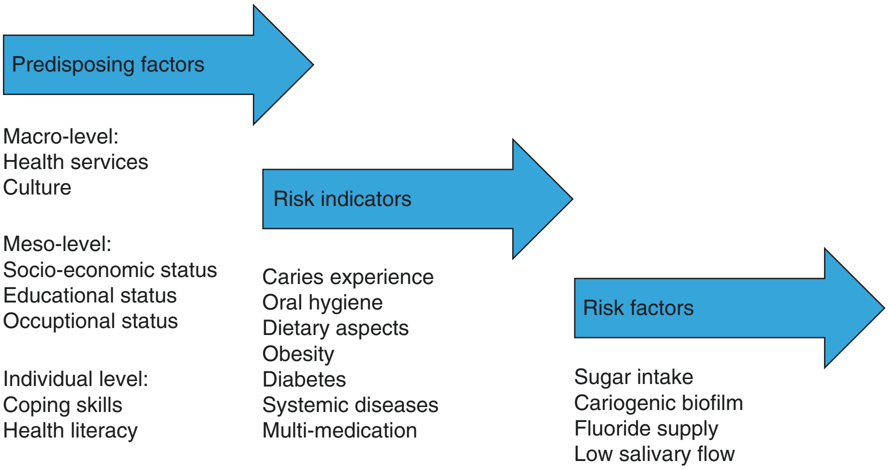

Fig. 12.6 A range of parameters can be used to assess caries risk. These range from distal (left) predisposing factors to true risk factors (right). Modified according to [16]

1. True (or proximal) risk factors are factors that are directly (causally) related to the disease outcome (both positively and negatively). For caries, such factors would, for example, be frequent consumption of fermentable sugars (negatively) or fluoride intake (positively).
2. Risk indicators (or markers) are factors that are associated with the disease outcome, but do not have a direct causal relationship. That can be, for example, caries experience (having had high caries experience in the past is a good predictor of future caries increment, but of course having had lesions in the past does not "cause" future lesions).
3. Risk determinants (or predisposing, distal factors) are assessed on a wider level, a typical example being socioeconomic status. Caries is greatly associated with social determinants (individuals from lower income, educational or occupational status have a higher caries risk and a poorer prognosis) [17–21]. Of course, being poor or not well educate itself does not "cause" caries, but serves as indicator of health-related resources like financial or physical means and health behaviors, like tooth brushing or health services utilization [22].

Similar discriminations can be made for prognostic factors (lesion activity is largely assessed via evaluating prognostic indicator like lesion surface roughness, color, or gingival bleeding: all these parameters are not causally related with the disease, but allow inferences as to how likely the lesion will progress, regress, or arrest) [15, 23–25]. From a clinician's point, it is of limited relevance if factors are causally or not causally related, which is why we will use the term risk factors for both causal and non-causal parameters in the following.

A number of studies have been performed to assess caries risk (patient level) or lesion activity (site/surface level). For caries risk, a number of parameters have been found to be associated with the risk of developing of new lesions:

– Caries experience, as discussed. Caries experience needs to be related to the patient's age, as obviously having three carious, missing or filled teeth at age 12 indicates a very high caries experience (the average in Germany, e.g., would be 0.5 DMFT), while at age 65, this is extremely low caries experience (the average German aged 65 would have 18 DMFT) [26].
– Dietary factors, mainly the frequency and consistency of fermentable cariogenic carbohydrates (sugars like sucrose), have been found to be associated with caries risk. Assessing dietary factors is not straightforward, as a number of factors bias patients' dietary reports [27–31].
– Oral hygiene habits are associated with caries risk, mainly tooth brushing and (to a more limited effect) interdental hygiene. Tooth brushing is central with regard to delivering fluoridated toothpaste [32].
– Topical fluoride application (toothpaste, gel) or systemic fluoride intake (salt, tables, which have both topical and systemic effects) has been found to be associated with caries risk [33–35].
– The flow of saliva plays a direct role and can be used to assess caries risk. Note, however, that flow rates vary widely, and only very low flow rates (<0.1 ml/min) have been found to truly be associated with high caries risk. For risk assessment purposes, evaluating if the mouth is "very dry" or normally moist is likely to suffice for discriminating high from low risk [36, 37].
– Parameters like the number of salivary mutans streptococci and lactobacilli or saliva buffering capacity can be evaluated using commercial test kits. The value of these parameters for caries risk assessment is, however, limited [38].
– A number of wider factors like socioeconomic status or psychosocial factors like sense of coherence are associated with caries risk, but are seldom assessed in practice.

Some of the parameters can be evaluated very easily (the DMFT is automatically calculated by many practice software applications); others (like mutans streptococci numbers) are more difficult and expensive to assess and should only be considered in specific cases. If assessing only few factors, it is recommendable to evaluate caries experience, fluoride intake, and dietary parameters, as these explain a large part of caries risk. If assessing more factors, weighing them is again an issue. Most risk assessment systems use explicit or implicit weighing factors. There are a number of software tools which allow to estimate the caries risk (weighing is performed automatically). This can be used to determine intervals for re-evaluating patients during supportive preventive therapy, but also to motivate the patient, who can follow possible changes in his/her caries risk over time [39, 40].

For lesion activity (disease prognosis), fewer systems are available; the most common ones assess one or more of the following parameters [15, 23, 24, 41–45]:

– Surface status, with cavitated lesions being likely to progress, as biofilms cannot be removed.
– Lesion texture, with rough surfaces indicating ongoing mineral loss (higher probability of lesion progression), while smooth and shiny surfaces indicate a high surface mineralization (higher probability of lesion arrest).

- Lesion color, with chalky white lesions indicating ongoing mineral loss, and brown or black lesions indicating lesion arrest.
- Surface status, texture, and color have originally been proposed to assess the activity of root surface lesions and are not always easily assessed on pits and fissures.
- Further aspects which are often assessed are biofilm being present (lesions covered by plaque are more likely active) and gingival bleeding (indicating the presence of biofilm in the past days). For pits and fissures, the presence of biofilms is a good indicator for lesion activity [46].

In summary, a large number of parameters are at the hand of clinicians to assess the probability of new lesions developing or existing ones progressing. It should, however, be noted that the studies yielding such probabilities have their limitations. First, clinicians should interpret any given parameters in relation to the overall absolute risk: in many industrialized countries, the risk of developing new caries lesions is low; an average German child, for example, has an annual caries increment of <0.1 carious, missing or filled permanent teeth between age 6 and 12 years. Even a twofold increase would mean that less than one in five children will have any caries increment per year. Clinicians should thus be careful when interpreting statistically significant increases in risks and compare them against clinical relevance. Moreover, many risk or prognosis studies are built on small populations, with the risk or prognostic model fitting well to this particular but no other populations. Only seldom are risk or prognostic models validated in other populations (admittedly, this is gaining attention in dental research).

12.4 Health Economic Evaluations

As discussed, healthcare is usually provided within a system where all care generates costs. These costs are either covered by an insurer or the patient itself. From both perspectives, it is relevant to consider costs when making decisions. Moreover, besides only considering costs for the initial treatment (which is a complex endeavor in some cases), decision-makers might want to assess the benefits of the treatment and weigh costs and benefits against each other. Last, decision-makers might want to use the described decision analytic tools, but also information regarding risks, to extrapolate what implications a treatment will have long term both with regard to health benefits or complications and costs (generated for treating these complications).

Four different types of health-economic analyses can be distinguished, usually categorized according to the measured health outcome [47]:

- Cost of disease studies do not assess any health benefit, but only the costs treatment. Costs can be assessed from a range of perspectives, the widest being the societal perspective. This is the most relevant for decision-makers interested in what a decision means in terms of gains and losses for the whole society. Costs

under this perspective include direct costs (incurring for diagnostic and treatment, e.g., for staff, materials, drugs) and indirect costs (incurring for transportation, etc.), but also so-called opportunity costs. The latter are costs for lost opportunities either due to the disease itself, like productivity losses at work due to pain or sickness, or due to the treatment received, like costs for time off work or school. Other perspectives are narrower, for example, a healthcare payer's perspective would only look at costs occurring to the payer, ignoring opportunity costs in many circumstances. One should also note that even direct medical costs might differ between perspectives, as payers oftentimes pay for medical services based on fee items, which are assumed to arbitrarily cover the costs of staff and materials.
- Cost-effectiveness studies assess the effectiveness of a treatment (with effectiveness being defined as a clinically measurable outcome) and weigh effectiveness against the treatment costs. Effectiveness parameters could be retention time of a sealant or avoided caries increment, determined, for example, via cohort studies or randomized trials.
- Cost-utility studies investigate the utility of a treatment, which is oftentimes measured as quality- or disability-adjusted life. They involve the subjective positive (retained tooth) or negative (untreated carious lesion) values placed by patients onto a certain health state. It should be noted that determining utilities is not always easy and not fully established in dentistry (what is the value patients place on a sound versus a filled tooth or a retained versus a replaced tooth?).
- Cost-benefit studies transform effectiveness or utility, i.e., the health outcome, into a monetary value. This is advantageous, as treatments for various disease can be measured on the same scale (something which partially applies to utility as well), and costs and outcomes are easily weighed against each other on the same scale. However, these studies are ambiguously discussed at present and have only very sparsely been applied in dentistry so far.

In general, health economic analyses can be using one of two ways or both ways combined: the first way involves conducting a primary data collection, for example, as part of a clinical study. This has the advantage that costs can be determined in depth, for example, staff costs (staff hours factorized them with the costs per hour for different staff) and materials costs (costs for sealant material factorized with amount of sealant used). This so-called micro-costing allows very detailed and realistic cost estimation. It is also well suited to collect data on indirect and opportunity costs. Clinical trials have further advantages, like being able to collect efficacy or effectiveness data in the same setting as the cost data (mixing cost data from one source, like a university clinic, with effectiveness data from another source, like a dental practice, has obvious limitations and might lead to erroneous conclusions as to the true cost-effectiveness of a treatment in both settings).

The second way uses mathematical models. Modeling studies aim to simulate the natural path of (sealed) teeth or patients (children with sealants) throughout their lifetime. Teeth or patients are initially placed in a certain health state (e.g., a sealed, sound surface) and can move from one to another health status (e.g., from sound to carious, from intact to lost sealant). The probability of every move ("translation") is based on data obtained from other studies, oftentimes systematic reviews or large cohort study (compare this with the subchapter on decision models; health economic models are only a subgroup of such models). For each translation, a treatment (e.g., sealing, resealing, restoration) is assumed to be provided, and costs are generated. These costs are estimated based on various data sources, like previous clinical studies (which might have used micro-costing) or fee item catalogs. Note that it is more difficult to realistically determine indirect and opportunity costs, and usually modeling studies need to make certain assumptions in this regard.

Modeling studies make use of the best available data and combine these in a way which allows to follow teeth or patients in longer sequences of events (sealed sound tooth → lost sealant and carious surface → restoration → replaced restoration → extracted tooth → implant, etc.). Their advantage compared with original studies is that they are less costly, allow to assess the long-term sequels of initial decisions (clinical studies will not be able to estimate the lifetime costs or averted expenses following the placement of a sealant), and also easily compare a larger range of therapies (like no treatment, sealing using a resin, sealing using a cement, sodium fluoride varnish, silver diamine fluoride varnish, fluoride rinse).

All modeling studies can only be as valid as the input data; moreover, modeling studies usually require a number of assumptions to be made both in the construction of the model as well as the parameters used for modeling. Thus, all modeling studies are subject to uncertainty. This uncertainty can be evaluated, for example, using univariate sensitivity analyses. Such analyses vary one aspect of the study, for example, a structural component of the model (like the simulated sequence of events, this is called structural uncertainty), an input parameter (like the costs for a sealant, this is called parameter uncertainty), or the individual profile of a patient (like gender, lifetime, and caries risk, this is called heterogeneity). Moreover, many models are analyzed via more advanced mathematical simulations, which allow to introduce the uncertainty of many variables at the same time (which is why this is called joint probability sensitivity analysis). This is done via simulating a number of patients (e.g., 1000), with transition probabilities (or other uncertain parameters) being randomly sampled from a certain range of each parameter (like the costs of a sealant in different dental practices in the USA). The sampling is repeated for a series of times (e.g., 1000), allowing to estimate both the per-patient and per-population variance. This allows to quantify the overall uncertainty of the findings and to conclude as to their robustness. As described early on in this chapter, uncertainty is something we need to accept when making decisions. Moreover, uncertainty might not even be problematic: the findings from a study might be robust despite great uncertainty being present (as long as, e.g., sealant is always both more effective and less costly, it might be of limited interested if the effectiveness advantage is two, three, or four averted carious lesions per patient, with 100, 200, or 500 Euro being saved). If uncertainty, however, affects the ranking of strategies (sealing being more effective, but more or less costly than not sealing depending on the data input), the decisions to be made will be uncertain, too. It is thus relevant to highlight and quantify this uncertainty.

The following subchapter will discuss the body of evidence on the economics of sealants.

12.5 Economical Evaluation of Sealants

In the following, results from a number of studies on the economics of sealants will be summarized. These need to be further discriminated between sealant of sound surfaces (preventive sealant) and sealant of carious surfaces (therapeutic sealants). Moreover, it greatly matters where sealants are provided and by whom: sealant application in a community setting, for example, a school, by a dental nurse generates completely different costs compared with sealants being provided by a dentist in office.

A recent systematic review summarized a range of studies on preventive sealant application in schools [48]. The costs for sealants were based on the costs for used resources, i.e., labor, supplies, and equipment. The main findings were:

- Labor was the main cost driver, accounting for around 2/3 of the total costs. The resulting mean labor costs were 54 US dollars per child (with a mean of 3.2 teeth being sealed). One should note that costs were recalculated from the specific setting the study was conducted in (like Chile or China) into US dollar, accounting for the different value money has in different countries (something termed purchase power) and also for the year of study conducted (the values cited here apply to US dollar in 2014). Having a hygienist instead of a dentist screening children and placing sealants reduced labor costs by approximately a fifth.
- The second large cost block was consumable supplies, mainly for infection control (disinfection/sterilization of instruments). Mean costs were around 7 USD.
- Costs for capital equipment (i.e., costs for the use of the dental chair, etc.) were low, at around 2.50 USD. Travelling expenses were around 1.60 and other costs at around 1.00.
- Total costs per child were around 79 USD or 26 USD per tooth.

It should be noted that if sealing is performed in a dental office, such costs will differ. There are not much data on the exact costs generated by in-office sealing; however, a range of studies assessed what fees are charged by dentists for providing sealants (these fees, after all, are the true costs occurring to payers). For Germany, for example, costs per sealant have been estimated to range between 6 and 12 Euro per tooth depending on the patient—which is below the US costs even when considering purchase power and exchange rates [8]. On the other hand, sealants in the US dental office are more expensive, with the average per tooth fee for a sealant having been reported as 51 USD [48]—which is significantly more than the costs generated in schools.

As discussed, most health economic assessments cover not only costs but also the gains realized by a treatment. The health benefits of sealants has been evaluated by a large range of studies, which have been discussed elsewhere in this book. These benefits are oftentimes reported as prevented fraction of carious/missing/filled surfaces or teeth (DMFS/DMFT). Cost-effectiveness studies can now estimate the costs per, for example, averted carious surface. One can also assess the subjective benefit of patients when sealing and relate subjective health gains against sealant costs. However, as outlined briefly above, the sealant itself might be of limited subjective value to a patient, and the same applies to averted fillings, etc. (the impact on the quality of life will be limited). Only when assessing the sequels of the treatment (like pain for untreated caries or tooth loss), a considerable impact on quality of life might be expected [49].

Assessing the sequels of a decision is always something to consider. For dental caries, these sequels might be even more important both from a clinical but also a health economic perspective than the initially occurring events. That gets clearer when comparing the economics, let's say for most pharmacotherapies, with those from caries: in pharmacotherapy, a treatment will usually improve health, but not necessarily save money long term (oftentimes the opposite: sick people might live longer when provided with a certain drug, which increases the risk for competing diseases to occur, which further increase costs). For caries, however, this is not necessarily the case. By avoiding carious lesions to develop, one also avoids restorative treatments (which are costly) and also the sequels of restorative treatment (like repeated and escalating re-treatments, involving eventually crowns, endodontic therapy, bridges, or implants; Fig. 12.1). These sequels are usually more expensive than the relatively cheap initial therapy (compare the costs of sealing, even repeatedly, against the costs of a crown). Thus, sealing might eventually even compensate the initial costs by savings later in life [2, 7, 50, 51].

The described review on sealants placed in a school setting consequently estimated not only the sealant costs but also the costs for dental treatments which one would avoid if placing a sealant. In addition, opportunity costs were estimated (like parents being off work as they need to visit the dentist with their child). The total averted cost per patient was around 10 USD. That, however, does not say much, as it is relevant what these costs were:

1. Per tooth
2. Per year of follow-up

The more teeth were sealed and the longer the evaluation period, the higher the averted costs will be! In this sense, sealing studies in which only one molar was sealed and where children were monitored only over 1 or 2 years will record only minimal averted costs. As a result, the initial treatment costs will be relatively high and the averted costs low; sealants will have low cost-effectiveness in such studies. Studies sealing all molars and monitoring children over 10 years, in contrast, will be better suited to capture the sequels of averting caries, with averted costs being much higher; sealants will thus have more favorable cost-effectiveness. In the described review, annual averted costs per tooth were around 6 USD. Considering that the costs for placing a sealant were 26 USD, this means that after 4–5 years, the averted costs will be as high as the initial spending for sealants. Afterward, the sealing might even save money.

For therapeutic sealant application, a far smaller number of studies have been conducted. These have often used a model and assessed the long-term consequences of sealing carious lesions. Two studies have further combined the issue of sealing lesions with detecting them [7, 8], as briefly touched in Fig. 12.2. Such studies are of interest, as dentists might not always be 100% correct in their assessment of a surface being sound or not: the accuracy of such detection, i.e., the chance of true or false positive or negative evaluations largely depends on how the detection is performed, i.e., visually, radiographically, using laser fluorescence-based methods, etc. The cited studies showed that for suspected early lesions, it is important to avoid invasive treatment, as the risk of false positive detections is high. Instead, these lesions should be sealed, as therapeutic sealants are effective for arresting such lesions (see Chap. 10), but also save to apply on possibly non-carious sound surfaces [7, 8], with an advantageous cost-effectiveness especially in high-risk populations.

As described several times above, in most economic analyses, costs can be weighed against health gains (only in cost-benefit analyses are the health benefits translated into a monetary scale, and one can compare money spent for treatment against money "gained" for health). When comparing two strategies (like sealing versus not sealing), this results in one of the two following scenarios:

1. One treatment is less costly and more effective. Sealants have been shown to be highly effective and are likely to fall into this category when compared with not sealing, especially in high-risk populations and when follow-up costs are considered as well [52]. In such case, there is no decision problem—sealing can be recommended both from a health and a cost side.
2. One treatment is more costly, but also more effective. This is also a possible scenario for sealants, especially in short-term studies. In such case, one can estimate the additional costs (e.g., for sealants against not providing sealants) per gained health benefit (averted carious surface when sealing versus not sealing). Such ratio is termed incremental cost-effectiveness or cost-utility ratio (ICER, ICUR), for example, Euro per averted DMFT. Payers can now decide if they accept these additional costs per effectiveness or utility gain or not.

The concept of accepting additional costs for health gains has further consequences. Depending on a decision-maker's so-called willingness to pay, one can estimate the so-called net monetary benefit [53, 54]: by accepting additional costs per health gain, payers indirectly give an estimation of how they value health, allowing to translate the health gains into money values (similar to what is done in health benefit studies). The concept of net monetary benefit (NMB) is applied in the next subchapter.

12.6 The Value of Information

As discussed all cost-effectiveness considerations are affected by uncertainty stemming from imperfect input information, like diagnostic validities, therapeutic efficacies, the efficacy of follow-up treatments (like restoration), or the exact costs occurring in a specific setting or patient. Value of information (VOI) analyses aim to quantify the costs and effectiveness losses stemming from this uncertainty, also termed “expected value of perfect information (EVPI)” [55]. Besides EVPI (which assesses the savings from completely eliminating the uncertainty of all parameters), the expected value of partial perfect information (i.e., perfect information on particular parameters) can be measured. EVPI can be used to estimate if there is the need for further studies, to weigh the costs and benefits of further studies against each other and to identify those parameters which should be prioritized for future studies, as they promise the greatest information gain, leading to the highest costs reductions and/or greatest health gains due to better (more informed) decisions.

EVPI is calculated from the net monetary benefit as $NMB_{perfect\ information} - NMB_{imperfect\ information}$, i.e., it depends on the decision-maker’s willingness to pay. For decision-makers willing to not spend any money, the less costly option is usually preferable; there is not a great decision problem, and the EVPI is low. For decision-makers willing to invest high amounts of money, such cost considerations might be irrelevant, too, as they would rather decide based on clinical efficacies and health gains; again, the EVPI is low. In contrast, for payers with a willingness to pay in between these extremes, the EVPI can be considerable.

The available studies employing VOI analysis indicate that for cariology, uncertainty regarding risk assessment might be more relevant than uncertainties associated with the efficacy or effectiveness of treatments. More specifically, for fissure sealants, the uncertainty around sealant efficacy seems less relevant than the uncertainty as to who would benefit the most [56]. In the only available study, which modelled a population of publicly insured children receiving primary molar sealants or strategies, the “always seal” strategy was more costly; additional mean costs per child per restoration or extraction averted ranged between $15 and $44. In this study, widespread sealing would likely be beneficial on a whole-population level, but waste money in a lot of cases (who would not benefit from sealing as their risk of lesion development was low). The EVPI for a projected population of 8 million children at risk was calculated as ranging between $96 million and $530 million, i.e., having perfect information (mainly to identify the subgroups who would benefit the most for sealing) would save large amounts of money.

This high value of perfect information is greatly associated with the discussed issues of dental epidemiology, mainly the decline in risks and the subsequent polarization: only few patients are likely to benefit the most from pit and fissure sealants, while for a large number of patients, these benefits are limited or absent. In this case, spending money elsewhere (e.g., for additional programs for those neediest) might be the better (and also fairer).

Conclusions

Decision-making is marred by uncertainty. Moreover, most decisions have a range of aspects to consider and both short- and long-term consequences. We have outlined the parameters which are relevant to decision-making with regard to fissure sealing and have described a range of methods which are applicable to assess the consequences emanating from made decisions. It can be recommended to consider outcomes relevant to patients, clinicians, and other stakeholders in such decision-making and to integrate a range of parameters into the decision process. A transparent and explicit decision-making can help to choose the best available option and to justify this choice. Quantifying the uncertainty around a decision is advisable both on a clinical and a wider setting.

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