Preventive Measures and Minimally Invasive Restorative Procedures

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16.1   Introduction

The objectives of operative dentistry are to prevent, preserve, and maintain the sound tooth structures and to minimize the tooth structure removal required, if necessary, for restorations. The minimally invasive dentistry is part of a developmental progress, determined by the accumulation of information from the cariology that involves the knowledge of the caries disease, as well as the developing of techniques and mechanisms aiming to prevent or arrest the lesion. It is currently known that dental caries is an in part reversible disease that begins with enamel demineralization and it may, eventually, progress up to a cavitation if the risk factors are not controlled and if no preventive measures are implemented [1].

The minimally invasive dentistry involves procedures such as pit and fissure sealants, resin infiltration, and conservative composite restorations. Together with the preventive measures, as dietary advices, regular control of biofilm, and improvement of oral hygiene habits as well as the application of lowly and highly concentrated fluorides to improve remineralization and to decrease demineralization, those procedures may reduce caries development and preserve the sound tooth structure [2].

16.2   Preventive Measures

Prevention in dentistry is one of the keystones in the daily practice of each dentist. The preventive strategies are traditionally divided into primary, secondary, and tertiary preventive measures [3, 4]. The primary strategies aim to reduce the number of new cases of a disease. This is normally achieved by health-promoting strategies. For cariology such strategies include nutrition advices, oral hygiene recommendations, inhibition of demineralization by application of fluorides, and the application of fissure sealants. In the context of secondary prevention, all measures are subsumed, which aim to early detect a disease, preferably at a stage at which the disease can be reversed or even healed. The major goal is to avoid any additional coming down with the disease and to

limit the dental hard tissue loss. These measures include application of fluoride preparations to enhance the remineralization process and the infiltration of carious lesions. The tertiary prevention that includes all measures specifically treating defect oriented the sequelae of the disease aiming to prevent further damage. This includes extended fissure sealing, minimally invasive approaches as well as adequate treatment techniques, such as use of restorative materials. All measures, preventive and restorative, should be accompanied by the consideration of all factors potentially influencing the disease, such as caries activity, caries risk, nutrition habits, oral hygiene habits and devices, fluoride usage, socioeconomic status, age, etc.

The four major parts of caries prevention comprise advices regarding "nutrition," "oral hygiene" (including mechanical and chemical biofilm control), "fluorides," and also the "visits to the dentist" (including the application of fissure sealants) [5]. These parts are substantiated by the local legal framework for health promotion. Most evidence for these measures exists for fluorides, followed by oral hygiene advices and least for nutrition [6–10].

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16.2.1   Nutrition

Doubtlessly, short-chain carbohydrates, also named sugars, are one promoter of the development of caries, since no caries occurs if the bacteria in the dental plaque or biofilm have no access to metabolizable carbohydrates. After a sugar intake of even small amounts (15 mg sucrose), relevant acid production by the bacteria in the biofilm can be measured; after an intake of 500 mg sucrose, the maximum of acid production is reached.

Up to now, there is no diet completely inhibiting caries. However, it is meaningful to reduce the daily intake to a minimum, since by this measure the development can be reduced. Therefore, nutrition advices or recommendations should be given as early as possible (in kindergartens, schools) but should also be given on a regular basis during the whole lifetime by parents, dentists, and teachers and also in the later stage of life by nursing staff in care homes.

Even if we have a decline in caries in most industrialized countries, world consumption of sugars is still quite high and ranges in these countries between 12.5 kg/capita and year (China) and 71.8 kg/capita and year (Cuba) with a mean of 39.9 kg/capita and year [11]. That there is a decline in caries despite the high consumption of sugars depends most likely on the regular use of fluoride products and oral hygiene measures (see below). The WHO recommends

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reducing the sugar consumption to a maximum of 10% of the total calorie intake; if the effect of sugar consumption on caries development is considered, the WHO recommends even a maximum of 5%. Sugar includes all free mono- and disaccharides artificially added to and naturally contained in food and beverages, including juices, honey, and syrup. This means that in case of a 2000 kcal intake per day, a maximum of 10 kg/capita and year should be consumed [12]. Even the lowest consumer in the list mentioned above consumes more than allowed according to the WHO recommendations.

However, not only the absolute amount of sugar is relevant. The frequency of intake might be more important, since it has been shown that with an increase of absolute amount and intake frequency, the caries increment increases more than with the increase of absolute amount alone without increase of intake frequency [13]. This depends most likely on the asymptotic pattern of acid production after different amounts of sugar consumption.

> **The frequency of sugar intake might be more important than the absolute amount of sugar consuption alone for the caries disease.**

It is not clear which type of food is of particular cariogenicity. The content of free sugars (mono- and disaccharides) is of predominant relevance. However, also processed starch can be metabolized by the plaque bacteria. The combination between sugars and processed starch is highly cariogenic. Furthermore, several other chemical and physical factors contribute to or reduce the cariogenicity such as an increase in saliva flow, stickiness, consistency, protein, or fat content. Individual factors like the respond of the salivary gland on stimulating impacts, tooth position, and bacterial composition are also relevant. Saliva flow and tooth position determine the oral clearance rate, the time between food intake, and its elimination from the mouth.

With regard to caries, a tooth-friendly nutrition should therefore contain low amounts of free sugars, should not be sticky, and should have a consistency requiring chewing, which leads to an increase of saliva flow. The frequency of consumption at main meal or snack should be reduced to a minimum, in order to give the saliva the chance to remineralize initial carious lesions [13]. As snack milk products, fruits and vegetables can be recommended. However, one has to bear in mind that teeth can be damaged by other components than sugar in the foodstuff, such as acids, which can induce erosive tooth wear [14].

Nutrition advices should be given to everybody in terms of primary prevention. In particular, if the caries risk is high, nutrition recommendations should be an integral part of the whole concept. Nutritional habits can best be recorded with a nutrition protocol. Relevant food and beverages can easily be identified, and alternatives can be recommended. In particular in the case of young children, nutrition advices are of major importance in order to avoid the development of early childhood caries. In this context also the effect of acidic food and drinks should be pointed out.

Tip

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The cariogenicity of food and beverages can be assessed by standardized test procedures. One is the intraoral plaque pH measurement; the other is the assessment of degree of demineralization of enamel samples in the oral cavity. It is measured in the plaque how deep the pH declines after a sucrose consumption and whether the critical pH for caries is reached. A foodstuff or beverage is defined as "tooth-friendly" if the plaque pH does not sink below 5.7 within 30 min after consumption [15].

There are alternatives to sugars, which have a sweet taste but no cariogenicity. One can distinguish between caloric and non-caloric sweeteners as well as between those having volume and being a substitute for sugar and those with a very high sweetening power and without volume, which can only be used as an additive to but not as a replacement for sugar. The caloric ones are mainly the sugar alcohols mannitol, sorbitol, and xylitol. Both sorbitol and xylitol are part of plants, from which xylitol is extracted; sorbitol is mostly produced industrially by hydrogenation of glucose. Sorbitol can be metabolized by *Strep. mutans*, however, only to a small extend, and the pH decline is mild and ends at values higher than the critical pH [16]. Therefore, sorbitol is classified as non-cariogenic. There are several studies dealing with xylitol, all showing a caries-reducing effect of this sugar alcohol [17–19]. Xylitol is not metabolized in the bacteria; rather the molecule is transported inwards and later outwards the bacteria under loss of energy [16]. Several other aspects are discussed to play a role such as the reduction of *Strep. mutans* in the saliva or reduction of virulence of *Strep. mutans*, both playing a role in the reduction of cariogenicity in the oral cavity [20]. Xylitol was at the beginning only used in chewing gums and some oral hygiene products. Nowadays, a lot of xylitol containing snacks, sweets, chocolate, and other foodstuff are available, as it has been shown that xylitol is not only non-cariogenic but also a good option for patients suffering from diabetes mellitus. A side effect of sugar alcohols is that they can lead to diarrhea due to slow resorption in the bowel; however, in most cases this effect is only temporarily. Non-caloric sweeteners include cyclamate, aspartame, and erythritol. The first two molecules have a very high sweetening power. It is often discussed whether they have a health-harming effect, and some countries have already forbidden the use in particular of cyclamate. Erythritol is a non-caloric sugar alcohol with nearly the same volume as sugars but with a slightly less sweetening power. It can therefore, at least in part, be used as a substitute. First studies show that also erythritol has a beneficial effect on oral health, maybe comparable to xylitol [21]. As mentioned for other sugar alcohols, it can induce diarrhea; in addition it can provoke during consumption a cooling effect on the oral mucosa and the tongue, which is not accepted by all persons.

> Sugar alcohols, such as xylitol, erythritol, and sorbitol, are good alternatives to sugars, as they have a comparable sweetening power, are voluminous, and have a comparable taste but are not cariogenic.

16.2.2 Oral Hygiene

Oral hygiene is one of the key components of prevention. The goal of oral hygiene measures is on the one hand the mechanical removal of the plaque from the tooth surfaces and, on the other hand, the administration of active agents such as fluorides but also compounds for chemical plaque removal or modification in order to maintain oral health. Plaque removal is of major importance to avoid both caries and also periodontal disease. In this chapter only the relevance of plaque removal in the context of caries should be discussed.

As plaque is one of the key components in the development of caries, the regular and sufficient removal of the bacterial biofilm is not only meaningful but also biologically plausible. For most people oral hygiene is well integrated into the daily routine and a basic element of the personal hygiene and oral health maintenance. Different aspects in oral hygiene contribute to success of the efforts, i.e., duration, frequency, technique, systematics, and oral hygiene aids.

16.2.2.1 Duration and Frequency

While in the middle of the last century the mean brushing duration ranged between 30 and 60 s [22–24], nowadays the duration in most industrialized countries lays at 2–3 min [25, 26]. These changes to durations, which have been proven to be most effective, are a result of structured preventive programs and can be rated as one of the successes of such concepts. The recommendation to brush 2–3 min bases on the findings that the efficacy of brushing can be enhanced by approximately 55% by prolonging the brushing duration from 30 s to 180 s; as from a duration of 150 s, a maximum of enhancement is achieved [27].

It takes 24–36 h until a matured plaque has established on the tooth surfaces. Therefore, biologically seen, it would be enough to clean once per day the teeth to maintain their health. However, most people are not able to remove plaque sufficiently from all surfaces. Therefore, it is generally recommended to brush the teeth two times per day. This recommendation is supported by different studies. They have shown that with a frequency of two times per day, the risk for an increase of caries incidence and increment is lower than for a frequency smaller than two times per day; a frequency higher than two times per day has only limited additional benefit [28].

> Brushing teeth two times per day for two minutes each is effective for preventive caries. This measure is biologically plausible and he recommendation is supported by various studies.

16.2.2.2 Technique and Systematics

Several techniques have been developed for sufficient cleaning of teeth under various conditions. While during childhood easy motions are recommended such as circling on the smooth surfaces and scrubbing on the occlusal surfaces (Fones technique) [29], more complex techniques are recommended, which require more dexterity, as soon as the patients are able to perform these (usually if the patients reached the school age).

The most recommended technique is the modified Bass technique (MBT), where the toothbrush bristles have to be positioned at the gingival margin in a 45° angulation with the direction of the bristles towards the sulcus. The brush has to be moved with small jiggling motions and wiped out towards the occlusal area including a rotating movement. With these motions the plaque will be loosened at the margin and removed with the wiping [30, 31]. The MBT can be used if the periodontal structures are healthy as well as if the periodontium shows some preexisting damage. It is mostly recommended in case of intact interdental papillae and if the gingival margin ends up at the cementoenamel border.

For the Charters technique, the bristles of the brush again have to be positioned at a 45° angulation, however, this time with the bristles directed towards the occlusal surface. Small circling movements have to be done, and the bristles should be pushed with small movements into the interdental space. This technique is recommended to patients with residual pockets after periodontal therapy and with free interdental spaces.

The Stillman technique has been developed for patients with healthy periodontal tissue but showing recessions. The bristles of a soft toothbrush have to be positioned on the gingiva and wiped out towards the occlusal surface with a rotating movement (white to red technique).

Even if the MBT is named as the most recommended technique, only a few persons use this complex technique [26]. In addition, studies have shown that it is not better than the others with respect to plaque removal; rather, it has been shown that none of the mentioned techniques is superior to another [32, 33]. Therefore, it seems of secondary importance which technique is recommended, provided that the oral hard and soft tissues are not damaged during the brushing process.

More important than the technique seems to be that patients perform a systematics in order to sufficiently reach all areas. An equal brushing of all areas most likely leads to a better plaque removal, independent of the order of brushing. A sufficient systematics should be taught as early as possible [34, 35].

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16.2.2.3 **Oral Hygiene Aids**

The most commonly used tool for cleaning teeth is the toothbrush, either a manual one or a powered one. The manual toothbrush is currently the most used form of toothbrush, since it is cheap, easy to acquire, and usable independent of electricity. The manual toothbrush should have a short head (max. 2.5 cm), equipped with rounded, elastic plastic bristles, which are arranged in tufts (multi-tufted, 20–40 bristles in each tuft), and should have a length of 10–12 mm and a thickness of 0.18–0.25 mm [36]. Too hard or not rounded bristles can lead to violation of the soft tissues. There are brushes with different head designs available; however, studies have shown that the acceptance of the brush itself by the patient has more impact on the cleaning efficacy than the brush head design. The force used should not exceed 200 g (appr. 2 N) in order to avoid any damage of soft and hard tissues [37]. The brush should be changed after 4–6 weeks or in case of bending of bristles. In order to avoid unnecessary accumulation of bacteria, the toothbrush should be allowed to dry in the air. If more than one brush is used in parallel, the bristles can completely dry within 24 h. The complete drying can on the one hand reduce numbers of germs on the tooth brush head and can in addition increase the toothbrush' longevity. After each infection in the mouth-throat region brushes should also be changed to avoid any reinfection.

> **Tip**
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Powered toothbrushes can be divided into rotating-oscillating brushes, wiping brushes, sonic brushes (amplitudes: ca. 250–350 Hz), and ultrasonic brushes (amplitudes: ca. 1.5 MHz). In principle, powered toothbrushes are highly effective and could potentially be more effective than manual ones. However, systematic reviews have shown that electric toothbrushes, at least the rotating-oscillating brushes, are only marginally superior to the manual ones [38]. For the others there are not enough studies available to give final conclusions. That not a clear superiority of powered toothbrushes was found might be due to lack of good designed studies, the lack of use of a sufficient systematics [39], or the decrease of "the charm of the new" in case of an electric device after a short period. Due to the smaller brush head in case of an oscillating-rotating model, the patients have to pay attention on very systematic handling. Mostly, patients need more time with the electric device than with the manual brush. Studies have in addition shown that the force used with electric brushes is mostly lower than with the manual ones [40]; this might be an option for patients using habitually high brushing forces. (Ultra)sonic brushes are particularly technique sensitive. They should not be used with the same contact pressure as rotating-oscillating brushes or manual brushes and with different movements. These brushes work via the formation of micro-flow and hydrodynamic effects in the plaque and not by the direct removal of the plaque by the movement of the bristles [41]. The brushes have to be placed, like it was described for the modified Bass technique, in a 45° angle on the gingival margin with the bristles directing apically, however without any pressure. The brush has to be held there for some seconds, and, optimally, afterwards the brush has to be wiped out towards the occlusal surface. Using this brush with normal or high pressure leads to a reduction of efficacy. Patients have to be sufficiently taught in this special technique; used without the correct technique but with movements recommended for manual toothbrushes, the benefits of the sonic technology will not be exhausted, and the brush acts more or less like a normal manual toothbrush.

> **Powered toothbrushes are only slightly superior compared to manual toothbrushes regarding plaque removal. Sonic brushes seem to be particularly technique sensitive.**

Common to all toothbrushes is that they cannot directly reach the interdental spaces, even if there are some in vitro studies showing some effect of the sonic brushes on plaque in artificial interdental spaces [42]; the final evidence, however, is lacking. Therefore, additional aids are necessary to clean these areas, which in sum account for 30% of the whole surfaces of the teeth. Interdental cleaning aids are dental floss (waxed, unwaxed, tape, super floss, or devices with fixed dental floss), medical toothpicks or interdental sticks, interdental brushes (with metal core or metal free), and powered devices including high-velocity microdroplet devices.

If dental floss is used, a piece of at least 50–70 cm will be taken and winded around the middle fingers. With the thumb and index finger, the floss will be tensioned and with small sawing movements inserted into the proximal space. Here, the floss will be moved up and down while cleaning both surfaces of the adjacent teeth. If dental bridges or blocked crowns are present, special dental floss with a stiffened end for precise insertion of the floss under the pontic is available. This floss has a fluffy part, with which the pontic can be cleaned from below. Waxed floss can be inserted easier into the interdental space, whereas unwaxed floss has a higher cleaning potential. If the interdental spaces and the contact points are very narrow, Teflon tape can be used. Even if the evidence for use of dental floss is low [43], the use of it is biologically plausible. It has been shown that the professional use of floss can lead to a significant reduction of caries increment compared to use of floss at home, where sufficient use was not guaranteed [44]. An alternative to the use of dental floss is the use of interdental brushes, which seem to be slightly superior to dental floss [43, 45, 46]. In addition, interdental brushes are often more accepted by patients due to higher comfort; however, the brushes have to be chosen according to the size of the interdental spaces. In worst case different sizes have to be used, and the patient has to identify which size fits into which space. A further

increase in comfort with a similar cleaning power can be achieved if metal-free interdental brushes, fabricated from plastic or silicone, are recommended [47]. These products do not provoke any gingiva abrasion [48]; in addition they are very small in diameter and therefore even usable at younger age with healthy periodontal conditions. Due to its conical form, they cover different sizes and reduce the individual fitting to each interdental space to a minimum. The evidence on microdroplet devices is very low. There are only few independent studies on them. It seems to be that at least under short-term conditions, these devices have an efficacy comparable to sufficiently used floss but are more comfortable in use [49].

Conclusively, the evidence for using interdental cleaning devices with respect to reduction of caries increment is low; however, their use is biologically plausible and should therefore be recommended.

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16.2.3 Fluorides

Fluoride application in caries prevention is a central measure. It has worldwide been extensively investigated, and there is a bulk of literature and knowledge on this issue. Not only its efficacy but also its toxicology was subject matter of numerous studies.

Already in the beginning of the twentieth century, it has been recognized that children in areas with high amount of fluoride in the drinking water (0.7–1 ppm) had less caries; concomitantly, they very often show non-cariously caused enamel spots (mottled teeth) [50]. Highest reductions were found for smooth surfaces followed by proximal areas; in the fissures on the occlusal surfaces, the effect was notably lower. It was hypothesized that a fluoride content in drinking water of approximately 1 ppm has a caries-protective effect. Several other epidemiologic studies have been found in the following comparable effects of fluoride in the drinking water [51].

Two modes of actions of fluoride might be relevant. The ion could either work systemically via incorporation of the fluoride into the developing dental hard tissue (systemic fluoridation) or locally by the contact between the fluoride ion and the erupted teeth in the oral cavity (local fluoridation).

Basing on the early observations from the areas with fluoride in the drinking water, it has been assumed over a long period that the systemic fluoridation plays the major role in the caries-preventive effect of fluoride. However, it has been turned out that not the systemic effect is of relevance but the local effects of the fluorides [52]. There are no indications that the preeruptively fluoridated teeth have a lower acid solubility than not preeruptively fluoridated teeth [53, 54]. Consequently, the preeruptive retention of fluoride does not

ensure that the teeth do not develop caries: persons moving away from an area with high amounts of fluoride in the drinking water are at the same risk to develop caries in the area without fluoride in the drinking water as persons never lived in fluoride-rich areas [55]. Different studies have clearly shown that an impact of a systemic fluoridation with fluoride tablets during infancy and early childhood on caries increment in permanent teeth cannot be verified [56]. The same applies for a fluoride supplementation during pregnancy [57, 58]. In fact, all systemically given fluorides in the form of drinking water, fluoride tablets, or fluoridated table salt work predominantly over the local effect during the oral ingestion of the preparation. Therefore, the administration of fluoride tablets should be accompanied by the clear instruction that the tablets have to be sucked and not to be swallowed to take advantage of the local effect. In particular those children having no access to other fluoride sources could profit from this measure; however, the overall balance of fluoride intake has to be considered. In case of regular use of fluoridated salt or fluoridated mineral or drinking water, no tablets should be used. As regularities clearly differ between various countries, no explicit dosage of fluoride supplementation or application should be given here; in this context, reference is made to the local regulations.

As it has been shown that the local fluoridation is of major efficacy, most countries nowadays prefer the local application of fluorides. Such approaches include the regular home use of toothpastes, mouth rinses, and gels or the professional application of highly concentrated preparations such as varnishes or fluids. Already in the late 1890s, first fluoride-containing oral hygiene products (rinses, toothpaste, and tooth powder) were fabricated. Mostly, hardly soluble calcium fluoride was added, making the efficacy of the compounds questionable. In the early 1960s first toothpastes with stannous fluoride or amine fluoride were marketed and comprehensively promoted. However, only in the 1990s, it has been shown that the comprehensive usage of fluoridated toothpastes but also of other fluoride sources was associated with a decline in caries prevalence [59, 60]. Later on, several systematic reviews have shown that the regular local use of fluorides is notably effective in reducing caries [9, 10, 61–65].

> **Fluorides can work systemically and locally. The systemic effects of fluorides are very low. The major share of fluoride effect in caries prevention depends on the local effect of the ion after topical application.**

16.2.3.1 Conventional Fluorides and Effect of Fluoride Ions

Several fluoride compounds are used for prevention of caries. These compounds can be divided into inorganic and organic fluorides; the inorganic ones can be subdivided into those having a monovalent ion as a counterion to the fluoride ion (conventional fluorides) and those having a polyvalent metal cation as a counterion (► see 16.2.3.2). The conventional

fluorides include sodium fluoride (NaF), sodium monofluorophosphate (NaMFP), and amine fluoride (AmF, such as dectaflur and olaflur or amine fluoride 297). While the fluorides AmF and NaF can be easily split in aqueous solutions into the ions, an intraoral enzymatic or acid-driven hydrolysis process is necessary to split the fluoride ion from the NaMFP.

Four reactions between the dental hard tissue and the fluoride can be distinguished. (1) The enamel is slightly dissolved at the surface and forms during reprecipitation CaF_2-like precipitates. (2) The enamel is slightly dissolved and forms during reprecipitation fluoridated hydroxyapatite or fluorapatite. (3) The fluoride diffuses into the enamel and specifically adsorbs to free binding places at the crystals such as OH^-, Ca^{2+}, or phosphate compounds. (4) The fluoride diffuses into the enamel and binds unspecifically in the aqueous coverage of the enamel crystals.

In particular the first mentioned mode of action, the formation of calcium fluoride (CaF_2)-like precipitates on the tooth surfaces, is of major importance. The CaF_2-like precipitates are stabilized intraorally on the tooth surfaces by phosphate groups and saliva proteins. In case of a plaque accumulation and bacteria-induced pH decline in the biofilm, parts of the CaF_2-like precipitate are dissolved releasing fluoride ions. This fluoride can diffuse into the enamel, and the modes of action 2, 3, and 4 could take place. A sufficient plaque removal with fluoridated toothpaste recovers the CaF_2-like precipitate, which again forms a reservoir for fluoride ions. The CaF_2-like layer is insofar of major importance as it can protect the underlying enamel against acid impacts. If this layer is incomplete, the underlying enamel can be dissolved, even if fluoride has been incorporated into the crystals. However, the critical pH of fluoridated enamel is decreased, which can lead to a lower solubility of the enamel itself [66].

The amount of CaF_2 formed on the tooth surface depends on the concentration of fluoride in the preparation (the higher the more), the application duration (the longer the more), the pH of the preparation (the lower the more), and the fluoride compound [67]. It has been shown that AmF leads to a higher CaF_2 formation than NaF as well as the fluorides containing polyvalent metal cations [67, 68]. All fluoride preparations lead to an enrichment of fluoride in the upper structures of enamel [69]; the penetration depth is limited and depends also on the compound used. While readily dissociating fluorides easily diffuse into the upper enamel structures, this process takes much more time in case of NaMFP, since this compound has to be split enzymatically [70], with the consequence that after NaMFP application, the fluoride uptake is lower than after the other compounds [70, 71]. In case of healthy enamel, there is a chemical balance between the saliva and the dental hard tissue, leading also to a delivery of fluoride into the environment. In case of a carious demineralization and a fluoride application, however, the fluoride uptake is much higher, leading to a permanent enrichment with fluoride ions.

> ❯ **The formation of CaF_2-like layers on the tooth surface is of major importance for caries prevention as it constitutes a fluoride reservoir from which fluoride can be released during a cariogenic acid attack. The amount of CaF_2 formed on the tooth surface depends on the concentration of fluoride in the preparation, the application duration, the pH of the preparation, and the type of fluoride compound.**

Fluoride is also retained in the dental plaque in form of ionized, ionizable (weakly bound), and bound fluoride. The bound fluoride is connected to organic components in the plaque and to the bacteria. The weakly bound fluoride is the abovementioned phosphate-stabilized fluoride. At neutral pH, only low amounts are present as ionized fluoride; in case of pH decline, bound fluoride will be set free, both from plaque, CaF_2-like precipitates, and dental hard tissue, and the absolute amount of ionized fluoride increases [72].

The basic principles of anticariogenic effect of fluorides are (1) reduction of acid solubility of the dental hard tissue and (2) inhibition of demineralization as well as promotion of remineralization. The hydroxyapatite in the dental hard tissue is not the stoichiometric form of this compound but a deficient one. Several crystals show deficits and imperfections. In these areas, fluoride can be incorporated during maturation of the teeth, in both preeruptive and Posteruptive enamel maturation. By the filling of the deficiencies with fluoride, the crystalline structure is stabilized which modifies or reduces the solubility of hydroxyapatite. Fluoride ions, however, do not only fill the deficiencies but also replaces the hydroxyl ions (conversion of hydroxyapatite into fluorapatite). This leads also to a reduced acid solubility. The replacement is limited: during preeruptive formation of hydroxyapatite, approximately 10% can be replaced. Posteruptively, the surface can also be enriched with fluoride ions by a topical application of fluoride preparations. Comparable, the interaction between the fluoride ion and the surface causes also a substitution of hydroxyl with fluoride ions. However, the depth penetration is limited.

The caries inhibition can only be partly be explained by the mentioned effect on solubility. An equally important mode of action is the impact of fluorides on de- and remineralization. The enrichment of the tooth surface by the topical application of fluorides with weakly bound fluoride (CaF_2-like precipitates) allows that during a carious pH decline, fluoride can be released into the aqueous phase. These free fluoride ions can protect the crystals of the dental hard tissue by forming fluorapatite and by reducing their solubility. During the neutralization process, the fluoride ions precipitate together with calcium ions and dissolved hydroxyapatite, forming fluorapatite and fluoridated apatite. These fluoride-enriched minerals precipitate earlier, as the solubility product of hydroxyapatite and fluorapatite differs. Therefore it can be concluded that the demineralization is reduced by the inclusion of the fluoride but also the remineralization due to the earlier precipitation [72–74]. This chemical and dynamic balance prevents, if a good oral

hygiene and less sugar consumption are present, a dissolution and destruction of the teeth. However, in case of very aggressive cariogenic demineralization, a net loss of mineral can occur resulting in the formation of white spot lesions. For the process of enrichment of the dental hard tissue with fluoride ions, concentrations of 0.1 ppm fluoride in saliva are necessary, which can be achieved by the regular application of topical fluorides.

> **The basic principles of the anticariogenic effect of fluorides are the reduction of acid solubility of the dental hard tissue and the inhibition of demineralization in combination with the promotion of remineralization.**

In addition to the effect on the tooth structure, fluoride has also an effect on the bacteria in the dental biofilm. With increasing fluoride concentration, first the metabolism of bacteria is influenced, then the bacterial growth is inhibited, and finally a bactericide effect can be reached, however, not by the concentrations found in the dental plaque. The pH in the dental plaque substantially influences the antibacterial effect of fluoride; with decreasing pH values, distinctly lower concentrations for inhibition of bacterial metabolism are necessary. However, the more acid tolerant a bacterium is, the higher is its fluoride tolerance. But luckily, in particular those bacteria metabolizing glucose could be influenced by fluoride. The fluoride can inhibit after uptake into the germ an enzyme in the glycolysis, i.e., the enolase, responsible for formation of phosphoenolpyruvate, an intermediate product in the way from glucose to lactate [75]. In addition, the glucose uptake can also be inhibited by fluoride. Two ways are possible: (1) The phosphoenolpyruvate phosphotransferase system – which is responsible for the conversion of glucose to glucose-6-phosphate, the form necessary for uptake into the bacteria – can indirectly be inhibited by the inhibition of the enolase and the lack of phosphoenolpyruvate. (2) In case of low pH in the plaque and at high concentrations of substrate, the glucose can directly be taken up into the bacteria without any transport systems driven by the pH-dependent proton gradient between the outer and the inner part of the bacterium. In case of presence of fluoride, a part of the protons will be absorbed by the fluoride, leading to hydrofluoric acid (HF), which can be directly transported into the bacteria. In the bacterium the HF dissociates intracellularly and sets H^+ ions free, which reduces the proton gradient and follows the driving force of the glucose uptake. In parallel the dissociation of HF in the bacterium decreases the intracellular pH, which in turn destroys the pH optimum of the enzymes of the glycolysis [76]. Both the reduction of glucose uptake and the reduction of enzyme activity inhibit the bacterial metabolism. Furthermore, the formation of intracellular storage carbohydrates is inhibited, as well as the synthesis of lipoteichoic acid, necessary for bacterial adherence. No impact on the degradation of intracellular storage carbohydrates as well as on synthesis of extracellular storage carbohydrates was found [73].

Over time the oral microorganisms can adapt to the fluorides (development of a type of resistance), in particular, if high fluoride concentrations are used. However, the capacity of the germs to metabolize sugars is reduced – the pH decline is milder and shorter. The benefit of a milder pH decline is that the ecological shift to more acid-tolerant and acid-producing bacteria is less pronounced [75].

> **Fluoride ions have an impact on cariogenic bacteria. They can reduce the bacterial metabolism by inhibiting the uptake of glucose into the bacteria, by inhibiting of enzymes of the glycolysis, and by inhibiting the synthesis of lipoteichoic acid, necessary for bacterial adherence.**

16.2.3.2 Fluorides with Polyvalent Metal Cations

Besides the "conventional" fluorides, also fluoride compounds containing polyvalent metal cations are available, such as stannous, titanium, and silver ions or zinc and copper ions. Titanium tetrafluoride is not approved for use in oral hygiene products and should not be described here in detail. The other ions have already been used at the end of the nineteenth and the beginning of the twentieth century in dentistry as an antibacterial agent.

Copper and zinc are able to increase the intra-bacterial production of peroxides and superoxides, inducing a damage of bacterial DNA and the inhibition of growth-relevant enzymes [77]. Furthermore, all mentioned polyvalent metal cations can react with sulfur compounds, such as thiols and proteins, disturbing the protein function and the metabolism of the bacteria. Stannous ions are able to inhibit in addition to the enolase two further enzymes of the glycolysis, the aldolase and the P-glycerin-aldehyde dehydrogenase, resulting in a lower pH decline in case of sugar intake [78–80]. It is speculated that the polyvalent metal ions also react with the lipids of the bacterial cell membrane provoking an impairment of the membrane function up to a disintegration of the whole membrane structure [81]. Often stannous ions are used in combination with amine fluoride, which can easily penetrate the bacterial membrane [82]; both compounds can reinforce each other in effect. No development of resistance of the bacteria against the polyvalent metal cations was found, which is of major importance in the context of the discussion about development of resistances due to antibiotics. In addition, the toxicological potential of these ions is very low [83]. Side effects could be a dull feeling on mucosa and dental hard tissue as well as removable staining of the dental hard tissue.

The metal cations have a high substantivity and are retained in the oral cavity over a long period. In addition to the effects on the bacterial metabolism, the metal cations, at least stannous ions, can be incorporated under acidic conditions into the upper structures of the dental hard tissue, leading to a reduced acid solubility of the dental hard tissue [84, 85]. The application of stannous in

combination with fluoride [68] as well as of silver ions in the form of silver diamine fluoride leads to a higher formation of CaF_2-like precipitates on the tooth surfaces, potentially promoting the anticariogenic effect. However, the additional effect of polyvalent metal cations to fluoride on reduction of caries increment is negligible in case of a normal caries risk. If special care, however, is necessary (manual or mental disabilities, dry mouth, root caries, early childhood caries), the application of these fluoride compounds appears meaningful. In particular silver diamine fluoride and stannous in combination with fluoride could be a good option [86–90].

> Fluoride compounds containing polyvalent metal cations, especially stannous and silver ions, could be a good option in particular if the caries risk is high. The cations lead to higher retention of CaF_2-like material on the surface, a change of acid solubility of the dental hard tissue (stannous ions), and a more pronounce impact on bacterial metabolism than the fluoride ions alone.

16.2.3.3 Efficacy of Fluoridated Preparations and Toxicology

As mentioned above, several systematic reviews show that fluoride is of notable efficacy in preventing caries [9, 10, 61–65]. The effect of preeruptive fluoridation by systemic administration of fluorides is considered to be small; the topical effect of both highly and lowly concentrated fluoride mainly contributes to the anticariogenic effect [91]. The effect of fluorides is highest on smooth free surfaces than on proximal surfaces and lowest on occlusal surfaces (in pit and fissures). Here other preventive measures, in particular in case of high caries risk, are more meaningful, such as pit and fissure sealing (see below).

> The effect of fluorides is highest on smooth free surfaces than on proximal surfaces and lowest on occlusal surfaces (in pit and fissures).

The efficacy of fluorides depends on the concentration and on the form of delivery as well as on the lifetime duration of fluoridation and on individual caries risk.

Systemic fluoridation can achieve a caries-reducing efficacy. However, one has to bear in mind that these measures mainly work via the direct topical contact between the fluoride ion and the dental hard tissue. Drinking water fluoridation and salt fluoridation is comparably effective with caries reduction in the range of 50–60%. The results for fluoride tablets are less homogenous; they have an effect in the range of 28–61% of caries reduction.

Toothpaste plays the major role in fluoride delivery. It has been shown that toothpastes, with a fluoride content in the range between 1000 ppm and 2800 ppm, show an increase in efficacy with an increase in concentration with a more or less linear dose-response relationship. However, in most countries, toothpastes with a concentration higher than 1500 ppm

(in some countries even higher than 1000 ppm fluoride) are not available as an over-the-counter product (for details please take the local regularities into account). Toothpastes show in various studies quite different efficacies, in particular if used as a conventional fluoride preparation for daily oral hygiene under unsupervised conditions. The caries-inhibiting effect most likely does not exceed 20%. In some countries fluoride toothpastes with very high concentrations (5000 ppm) are available but only on prescription for adults. These products are indicated for therapy of root caries in order to prevent the development of new lesions and to reduce the progression of existing lesions. They could also be significant in case of high caries risk (xerostomia, manual disabilities, etc.). Beneficial effects of mouth rinses are mostly masked by the regular use of fluoride toothpastes if the patient has a normal to low caries risk. In case of high caries risk, the benefit of this measure might be found. According to systematic reviews, mouth rinses with a fluoride content between 250 and 500 ppm can achieve 20–45% caries reduction. Fluoride gels and fluids with concentrations up to 1.25% show a very high variation in efficacy (3–48%). This is mainly due to the fact that they are used at home only weekly or even more seldom. The professional tray application two to four times per year shows a more constant efficacy with a caries reduction between 20% and 40%. The effect of varnishes is given with 20–75% caries reduction [9, 10, 61–65].

There is a bulk of knowledge on the toxicology of fluorides from the dental literature but also from research on osteoporosis. The used dosages in dentistry can be all classified as safe, and it is well-known that fluoride in oral hygiene products and prophylaxis products is not toxic for human being if used as intended. For sure, overdosages are possible, if the preparations are misused. One has to distinguish between acute and chronic overdosage. Signs of an acute overdosage are typical signs of poisoning such as nausea, vomiting, and stomachache. Additionally, symptoms like sweating, headache, and increased saliva flow can occur followed by spasms and tetany. Fluoride has direct impact on the calcium-potassium equilibrium. The calcium level will decrease if the potassium level increases. Potassium has a direct impact on heart activity. As a consequence, arrhythmia, low blood pressure, and reduction of breathing frequency including a respiratory acidosis can occur; finally the patient can die. As an antidote emesis should be induced, if there is no aspiration hazard, or calcium-rich preparations ($CaCl_2$, Ca-gluconate or milk) should be given in order to complex the fluoride ions [92]. In addition, the patient should be hospitalized.

The acute lethal dose of fluoride ranges between 32 and 64 mg/kg body weight (certainly toxic dose, CTD). This range is determined by the effect that different fluoride compounds, the individual resorption velocity, and the pH of the compounds impact the toxicity. But also below this, threshold poisoning effect can occur, which can be extremely deadly. In particular infants are at risk for probable toxic effects. The probably toxic dose (PTD) is 5 mg fluoride/kg

body weight. If a child has ingested this amount of fluoride, medical measures should be arranged [93]. This dose can be reached in case of infant with 10 kg body weight by 100 fluoride tablets with 0.5 mg, 50 liters of fluoridated mineral water with 1 ppm, 156 g fluoridated table salt, 100 g (= 67 ml) of a 500 ppm fluoride toothpaste (approximately 1.25 tubes), or 50 g (= 33.5 ml) of a 1000 ppm fluoride toothpaste (approximately 0.5 tubes). Therefore, infants should not have access to fluoride products, and oral hygiene should be performed with supervision [93], preferably after meals as the resorption of fluoride is much higher if the stomach is empty than after a meal. Higher concentrated gels (1.25% fluoride) should be applied in children with individual trays [94]. Highly dosed fluoride preparations should only be applied by professionals. Preparations which prevent any unnecessary swallowing of fluoride should be preferred, for example, varnishes, which harden in case of contact with saliva. If such preparations are used, no toxic relevant increase in plasma levels in (pre-) school children were found [95]. Chronic fluoride exposure with more than 1.5 mg/day can induce during enamel formation dental fluorosis [96]. In particular, if several fluoride sources are combined, the risk for fluorosis increases, such as tablets, salts, and/or drinking water.

> **The used dosages in dentistry can be classified all as safe, and it is well-known that fluoride in oral hygiene products, supplements, and prophylaxis products is not toxic for the human being if used as intended.**

16.2.4 Additional Caries Preventive Strategies

16.2.4.1 Chewing Gums

Different clinical studies have shown that regular chewing of sugar-free chewing gum can have an impact on oral health [97]. It increases the saliva flow during the chewing process and also the pH of the saliva. In addition, the plaque formation and concentration of mutans streptococci and lactobacilli in saliva can possibly be reduced. Studies on children investigating the effect of supervised chewing of sugar-free chewing gum several times per day have shown that the caries progression and the caries increment can be reduced by this intervention. It seems that chewing gums containing the sugar alcohol xylitol (for mode of action, see [16]) are of particular effectiveness [98]. As there is some evidence on the positive effect of chewing gums, the recommendation of its use up to three to five times per day should be included into the preventive concept. It should be chewed in particular after meals in order to increase the saliva flow and saliva pH to enhance the clearance and the neutralization of acids from the metabolism of plaque bacteria [99].

16.2.4.2 Chlorhexidine

Chlorhexidine (CHX) is a positively charged molecule, which has at lower concentrations bacteriostatic and at higher concentrations bactericide properties [100]. It binds intraorally to the pellicle as well as to the bacterial cell membrane, and the integrity of which can be disturbed by this compound [101]. The efficacy spectrum of CHX is broad; in particular *Strep. mutans* reacts very sensitively [102]. CHX can provoke some local side effects such as staining of teeth and restorations, changes in taste, increased formation of tartar, and desquamation of the oral mucosa [103]. CHX has a very good substantivity and is potent in reducing the intraoral plaque level [103]. Due to its potential side effects, it is not intended to use CHX permanently; however, it is suitable in phases of high caries risk, such as during eruption of teeth, when a fissure sealing is not yet possible due to inadequate moisture control and shows efficacy comparable to fluoride varnishes [104]. In these cases varnishes with at least 1% CHX should be used [97]. If there is a high caries activity, a short-term CHX therapy could be applied. During a period of 14 days, 1% CHX gel could be applied with a tray to decrease the absolute number of bacteria [102]. In two clinical studies, the caries-reducing effect of CHX application has been shown [105, 106]. There is some evidence that the application of CHX varnish during orthodontic treatment around brackets can reduce caries increment [107]. Some other studies give indications that also in case of root caries, a beneficial effect by CHX application can be achieved [108]. However, the evidence for these recommendations is not very high.

16.2.4.3 Probiotics

The definition of probiotics is "live microorganisms intended to provide health benefits when consumed" [109]. Such approaches have been used since several decades for the health of the gut. The idea beyond the application of probiotics in the context of caries is to reduce the virulence of the bacterial flora in the oral cavity. It is important that the ingested bacteria have no harmful impact, for example, if they recombine with other bacteria leading to an increase of pathogenicity. The goal is to incorporate probiotics into the biofilm and to replace more pathogenic bacteria by formation of specific cellular mediators, inhibition of bacterial growth, competitive displacement, or modulation of the immune system [110, 111]. The effect depends on what germ is used. Some positive effect has been shown for lactobacillus species (*L. rhamnosus*, *L. reuteri*) in the context of root caries. Furthermore *L. reuteri* seems to have a positive effect on periodontal status. However, even if there are some studies showing a beneficial effect, the evidence is still low. In addition, one has to keep in mind that there is only an effect of the probiotics expectable while they are regularly (preferably daily) ingested. Few days after termination of use, there are no probiotics detectable in the oral cavity [112, 113]. Some cautionary voices argue that by incorporating lactobacilli species into the oral cavity, the number of acid-producing bacteria could potentially be increased with the potential effect of an increase of caries risk. However, there is no evidence for this statement.

16.2.4.4 Ammonia-Forming Agents

Urea and arginine can both be metabolized in the oral cavity by specific bacteria, such as *S. sanguis* or *S. mitis*. In addition, both molecules can be split by enzymes from the saliva, i.e., arginine deiminase or urease. During this biochemical conversion, ammonia is released from the molecules, which has an alkaline pH [114, 115]. The increase of pH by this process leads to a faster neutralization of cariogenic acids, and the pathological shift to a higher occurrence of aciduric and acidogenic bacteria can be avoided [116]. According to the current level of knowledge, both compounds arginine and urea have no harmful side effects.

There are some oral hygiene products and chewing gums containing urea; however, the evidence on their efficacy is low. Urea-containing chewing gums have no additional effect compared to other sugar-free chewing gums [114, 115].

Arginine is split by the complex arginine deiminase system, which occurs in both the saliva and specific bacteria. Interestingly, in the biofilm from caries-free surfaces, the level of this enzyme system is higher than in the biofilm from carious surfaces. The same applies for the level of ammonia and of the arginine deiminase system in the saliva – caries-free individuals show higher concentrations than persons suffering from caries. Arginine is used in toothpastes in a complex with insoluble calcium compounds in order to increase the availability of calcium and the remineralization potential. It is used in combination with NaMFP due to the calcium-rich formulation in avoidance of reactions between calcium and fluoride in the preparation. Both modes of actions – of fluoride and of arginine – are independent, and both compounds do not inhibit each other. There are some studies showing a benefit of arginine in stopping caries progression and in remineralization of carious lesions [117–120]. In particular for patients with high caries risk, arginine-containing products might be of interest.

16.2.4.5 CPP-ACP, Bioactive Glass, Hydroxyapatite

Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) is a synthetic colloidal complex derived from milk. It is well-known that milk can be anticariogenic despite its high content of sugar [121]. Different mechanisms might be relevant. Milk is supersaturated with respect to various calcium phosphate compounds, being part of the dental hard tissue [122]. Therefore, in the presence of these compounds, the acid solubility of the dental hard tissue (enamel) is reduced, and remineralization processes are facilitated [123]. The pH decline after milk consumption is relatively low, which is in addition in parts buffered by the metabolism of protein compounds to alkaline end products (e.g., [124]). One of the milk proteins that is of particular importance is the casein [125, 126]. It has been shown that this protein can bind to hydroxyapatite and can influence bacterial adherence and metabolism [127, 128]. On its own it cannot inhibit completely demineralization; however, it has been shown that smaller fragments in combination with phosphate (CPP, patented as Recaldent™) are more effective than the casein itself [121]. In addition it has less allergenic potential [129] and affects to a lesser extent the taste than casein. The CPP can stabilize calcium and phosphate in solutions forming amorphous calcium phosphate (ACP); both compounds form the colloidal complex. The complex is so small that it can diffuse through the enlarged pores of an initial carious lesion. As ACP is a metastable compound, the CPP acts as a carrier for calcium and phosphate in order to increase the concentrations of these ions in the carious lesion to promote the remineralization process.

Several products with CPP-ACP are available, such as chewing gums, toothpastes, mouth rinses, and prophylaxis pastes, with and without fluoride additives. There are indications in the literature that it has remineralizing potential; however, the study situation is not fully clear. In particular, there is no evidence that this compound is better than the standard fluoride. There is also no clear evidence whether the combination between fluoride and CPP-ACP shows any benefit in comparison to fluoride alone; however, it shows better remineralization potential than CPP-ACP alone [130]. The use of a CPP-ACP in chewing gums seems to have no or only little beneficial effect [131]. In case of dental erosion, such preparations fall short of expectation if used as an oral hygiene product [132]; as an additive to acidic drinks, it can reduce their erosivity [133].

Another calcium phosphate compound is the bioactive glass, which has been used as remineralizing agent. Even if there are some in vitro studies showing promising results, the evidence on the efficacy of such preparations is very small, as controlled randomized clinical studies are lacking [134].

Other preparations contain artificial hydroxyapatite, which should fill submicron defects with the calcium phosphate particles in terms of a biomimetic approach. These particles can be used at a microscale and at a nanoscale. While minor effect was shown under in vitro conditions for the microparticles, the nanoparticles show some effect [135]. The evidence for these compounds for the clinical use is very low, as comprehensive clinical studies are lacking. In none of the very few studies dealing with this approach, superiority to the conventional concept using fluorides was found.

Conclusively, none of the calcium and phosphate preparations without fluoride has been investigated under clinical conditions in a dimension that allows them to be recommended as an alternative to fluoride in caries prevention.

❯ **None of the calcium and phosphate preparations without fluoride has been investigated under clinical conditions in a dimension that allows them to be recommended as an alternative to fluoride in caries prevention.**

16.2.4.6 Ozone

Ozone is a natural molecule which contains three oxygen atoms and has antimicrobial activity against bacteria, fungi, and virus [136]. The ozone therapy on carious lesions

involves the application of the ozone gas over the tooth's surface aiming its decontamination [137]. The ozone gas can be produced from oxygen in the environment air (low-dosage principle) or from pure oxygen supplied by an oxygen bottle (high-dosage principle). The application of ozone is usually performed through a handpiece, which has a disposable silicone cup tip, with diameter in a dimension (usually 3–10 mm), which can be firmly attached to the selected area of the tooth. It directs the ozone and prevents the escape of the gas into the mouth. After the application, the ozone gas is suctioned off and again converted into oxygen by a neutralizer.

The intention of the use of ozone is to arrest caries progression, due to a reduction of the cariogenic bacteria by oxidation processes, aiming to prevent or delay the need for a restoration [138]. However, the ozone therapy did not meet all expectations and can only be classified as an additional option for controlling dental caries. The conventional strategies, such as the dietary advice, oral hygiene instruction, and use of fluorides, are still the primary strategies for caries control [138].

The ozone therapy could potentially be used for disinfection of fissures prior to fissure sealant application or as a noninvasive initial caries lesion treatment. In cavitated lesions it can be used to decontaminate the remaining infected dentin after tooth preparation. The high-dosage ozone application works with pressure. In this case the gas can penetrate into the smallest pit and fissures to reduce or maybe inactivate the bacteria [137]. However, the ozone acts on contact; therefore, any lesions that do not allow the access of the equipment tip or the surface sealing with the silicon tip cannot be treated. These include proximal lesions, hidden caries, or lesions difficult to access. Thus, ozone is mainly used on the occlusal and free-smooth surfaces.

There is good in vitro evidence of the prophylactic application of ozone as antimicrobial treatment prior the acid etching and placement of sealants and restorations. Positive results have been obtained without interference on enamel physical properties or adhesive restorative materials [139]. However, there is only limited information from clinical studies, which are in addition in part contradictory. According to manufacturer's recommendations, the noninvasive treatment of the incipient occlusal caries lesions should be possible. This involves the application of the ozone directly over the lesion for 20–120 s, followed by the application of a remineralizing solution that contains fluoride, calcium, zinc, and phosphate to increase remineralization of the disinfected area. They also recommend the use of a fluoridated toothpaste and mouthwash, as well oral hygiene instructions. The ozone application should be repeated after 3 and 6 months. Even though the first studies have shown some effects on arresting caries and preventive treatment, the use of ozone still requires further studies [140]. Reinfection of the disinfected surface can rapidly occur in the oral cavity if no sufficient sealing of the surface is performed.

16.2.4.7 Further Approaches

For a long time, caries has been classified as an infectious disease. Therefore, it has been considered to develop a vaccine against *Strep. mutans*. As several bacteria contribute to the development of dental caries, this strategy appears not promising [141]. In addition, the resident flora in the oral cavity is part of the immune system and cannot be eliminated at all. It has also been proposed to avoid any transfer of caries pathogenic germs from caries active parents to the newborn baby; however, this recommendation appears just as little meaningful. More reasonable is an increase of preventive measures and restoration of frank cavities in caries active parents. Such strategies are called primary-primary prevention. Some studies give indications that the chewing of xylitol-containing chewing gums by the parents during the first time of life of the children can reduce the caries incidence in children, most likely due to the *Strep. mutans*-reducing effects mentioned above [142]; however the evidence for this measure is based only on a single study.

Another possibility to reduce the biofilm on tooth surfaces could potentially be the photodynamic therapy. This approach is regularly used in dermatology for skin tumor therapy. The intention is to reduce pathogens by application of light in combination with a photosensitizer. This molecule will be incorporated into the bacterial cell membrane and activated by impact of light with a specific wavelength, depending on the sensitizer used. From the molecule oxygen will be split off in the form of radicals, which should destroy the bacterial membrane. This approach is in particular used in areas difficult to reach, such as subgingival regions, what is of interest for periodontal treatments; however, in case of supragingival biofilm in the context of caries, its relevance is questionable. Furthermore, it is not clear how deep the sensitizer can penetrate into a matured biofilm and to what extent the biofilm can be destroyed. In the context of caries, there is no evidence for its efficacy [143].

Some other strategies for caries prevention have been discussed, such as the use of plant extracts, antimicrobial peptides, enzymes, biopolymers, metaphosphates, quaternary ammonium salts, or flavonoids [110, 144]. There is weak to no evidence from clinical studies on anticariogenic efficacy of these compounds, even if a reduction of bacteria can be achieved. However, a reduction of bacteria does not necessarily mean that a compound is caries inhibiting. It has also considered to modify the communication between bacteria in the biofilm (anti-quorum sensing), though without any evidence at this moment.

16.3 Pit and Fissures Sealants

Pits and fissures are more susceptible for development of caries than the other surfaces due to their morphology. The occlusal surface of the posterior teeth presents develop-
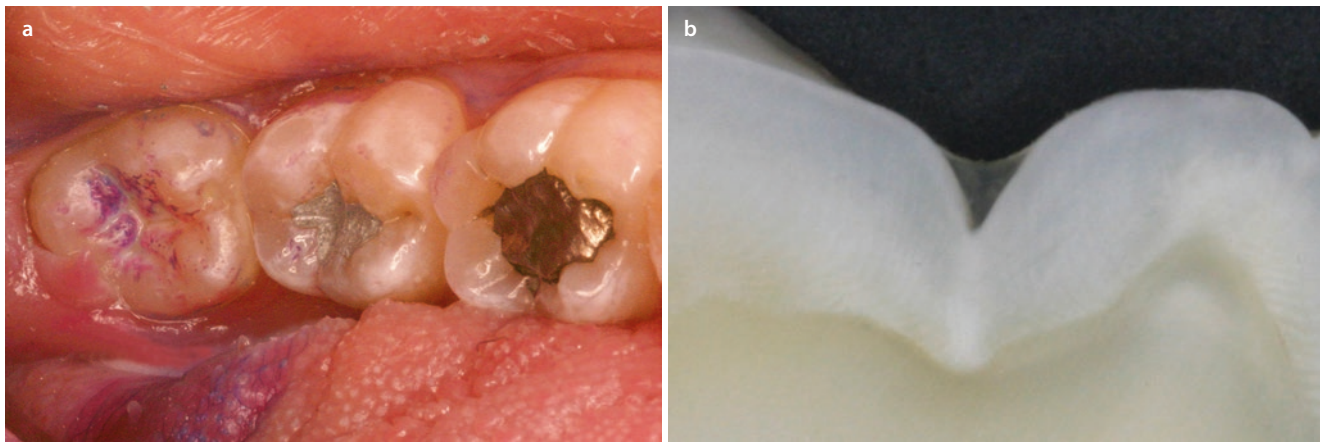
□ Fig. 16.1 **a** Occlusal surface of molars with biofilm deposits; **b** mesiodistal cross section of a molar with a sealant applied on the occlusal groove

mental grooves separating the cusp slopes, which is called a fissure. In some areas of the grooves' bottom, there is no enamel coalescence from one cusp slope to the other, creating a direct path between the oral environment and the dentin [145]. A pit is a located and small coalescence fault on the tooth's surface. It is generally found on the intersection of two fissures or at the end of a developmental groove. The irregular anatomy of the grooves, pit, and fissures favors food and plaque retention, being an area at high risk for developing dental caries. Even if the occlusal surfaces constitute only 12.5% of all tooth surfaces, approximately 50% of all caries lesions in school children occur at these surfaces. Regarding the distribution on the posterior teeth, most frequently caries lesion development occurs at the occlusal surfaces of the first and second molars, corresponding to about 90% of all lesions present on children and teenagers (□ Fig. 16.1a) [146].

It can be distinguished between different types of fissures: flat and wide, slit-shaped, or ampoule-shaped; in particular the latter two shapes cannot be sufficiently cleaned. As a consequence bacterial biofilm, food leftovers, and cell debris can be retained in these areas. The neutralizing and remineralizing potential of the saliva and also the topical effect of fluoridation measures are also reduced in these areas, resulting in a higher risk for the development of caries. Therefore, materials were developed to be applied into the grooves, closely sealing the pits and fissures, reducing its irregularities, and smoothing the surface. Those materials create a physical barrier between the occlusal surface and oral environment, hampering the deposition of bacteria and its nutrients, as well as the progression of caries lesions (□ Fig. 16.1b) [147, 148].

During many years, it was generally accepted that the best way to maintain the molars sound is applying sealants right after the eruption. However, with the reduction of caries prevalence in the industrialized countries, resulting from the progressive increase of the knowledge about the caries dis-

ease etiology and prevention, the caries risk assessment has become evident for sealant indication [149]. Many occlusal surfaces remained sound during the entire patient's life without any sealant. This way, the indiscriminate use of sealants is nothing more than a modern version of the classic concept of "extension for prevention." This means that sealing all occlusal surfaces to hinder the caries development is considered nowadays as unacceptable and may be considered an overtreatment, since by using other preventive measures caries risk can be decreased and the disease can be controlled [150]. Therefore, monitoring of the etiological determinant factors of caries disease is of major importance, as well as the correct and sufficient preventive use of fluorides.

The operatory approach of the occlusal sites varies according to its health and anatomical conditions, as well as the patient's risk of developing caries lesions. The latter one is the most important factor to be considered when sealants are indicated. Among the clinical parameters that are available to evaluate the caries risk, the previous caries experience seems to be the most accurate criteria [149]. Other factors that indicate caries susceptibility are the retentive macro-morphology of the occlusal surface (□ Fig. 16.2a, b), frequent sugar intake, inadequate exposure to fluoride, and poor oral hygiene [151]. In addition, people with hypomineralized teeth, fixed orthodontic appliances, general health problems, manual disabilities, and xerostomia, the use of medication that reduces salivary flow or the frequent intake of medication with high sugar levels is potentially considered a high risk [147, 149].

Based on that, occlusal surface sealing is, in general, indicated for patients at high caries risk and/or presenting teeth with active occlusal incipient lesion, which show progression during the treatment (□ Fig. 3.5g, h). In addition, it can be used in patients who are not responding to a treatment based on the control of the disease [149]. It can also be recommended, in case of high caries risk, to apply fissure sealant on deciduous molars or at the palatal pits of incisors or canines.
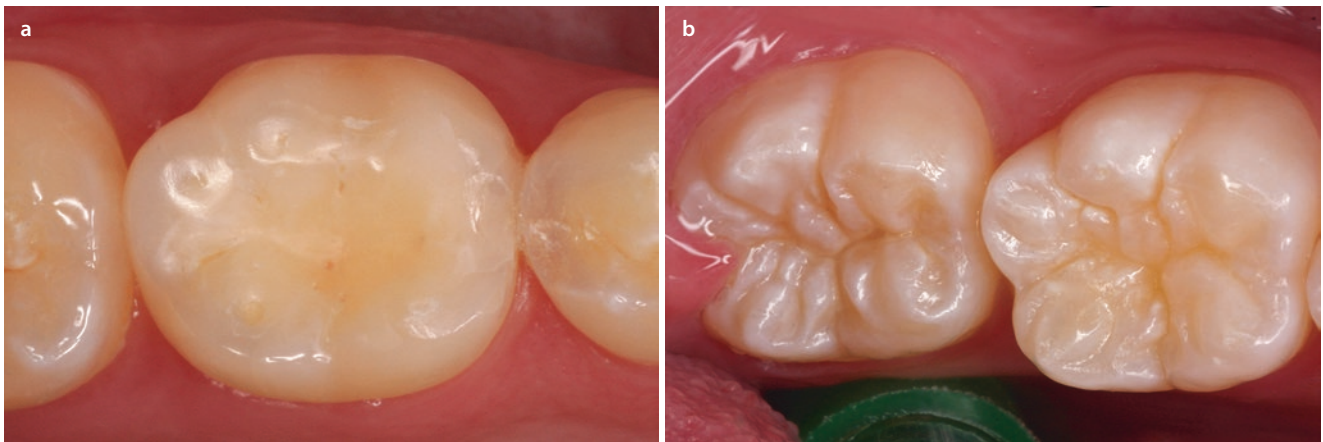
■ **Fig. 16.2** **a** Posterior teeth with a smooth occlusal morphology and with shallow grooves; **b** molars presenting irregular morphology, with deep grooves favoring the biofilm deposition

> ▶ **The indiscriminate use of sealants is unacceptable and may be considered an overtreatment. Its indication must be done only after the caries risk assessment. It is recommended for patients at high caries risk and/or presenting teeth with active occlusal incipient lesion. Fissure sealing should always be accompanied by other preventive measures, i.e., nutrition recommendations, oral hygiene education, and fluoride application.**

The patient's caries risk has to be periodically evaluated, since it can change with time. In particular during the period necessary for the eruption of molar teeth (12–18 months), the risk for developing occlusal caries is high due to the lack of chewing friction and natural cleaning mechanisms, as well as due to difficulties to sufficiently reach the occlusal area with mechanical oral hygiene devices. Immediately after eruption the enamel does not have its maximum degree of mineralization. During a period of approximately 2 years after eruption, the enamel undergoes a secondary mineralization process (Post-eruptive enamel maturation), in which minerals, such as calcium, magnesium, and phosphate, from the saliva are incorporated into the dental hard tissue. This complementation of the mineralization is supported by the application of fluorides. These processes result in a reduction of the enamel permeability, which can decrease the caries risk [152, 153]. However, this does not necessarily mean that the matured tooth will be caries-free during the whole life span.

All in all, the sealants indication has to be based on the caries risk assessment in different periods of patient's life, because the tooth can be at low risk immediately after eruption, but due to changes in patient's behavior or habits at high risk at a later stage of one's life, and vice versa [146]. To achieve the maximum benefits of the sealants, these materials should be applied only to those teeth judged as high caries risk [146, 154].

Sealants are considered a valuable and low-cost preventive measure, and it is an adequate strategy for caries prevention, if correctly indicated and made [155]. However, it has to be ideally used in combination with patient education, effective personal oral hygiene, rational use of fluorides, and regular dental visits [146]. As fissure sealants are normally applied during age of childhood, the parents have to be informed about necessary preventive measures and the need of regular controls of sealants in the dental practice.

> **Tip**
>
> As fissure sealants are normally applied during age of childhood, the parents have to be informed about necessary preventive measures and the need of regular controls of sealants in the dental practice.

Sealants can also be applied over active incipient lesions on the occlusal surface since it has been shown to be effective in inhibiting the progression of demineralization confined to enamel [156–158]. However, enamel demineralization can be associated with the presence of dentin lesions, in particular if the fissure is very deep and close to the dentin enamel junction. If there is no visible cavitation, such dentin lesions can be sealed. Studies have shown that it can significantly reduce the number of viable bacteria inside the lesion and lead to caries arrestment [159–161]. In fact, there is a trend towards noninvasive approaches, aiming the prevention, arrestment, or management of caries. Following this, sealants can be used both as a preventive measure in at-risk teeth and as a therapeutic measure when applied over an incipient non-cavitated caries lesion [156, 162]. In case of cavitation, however, an invasive treatment is not avoidable. In such cases a minimally invasive procedures should be performed in order to avoid any unnecessary substance loss.

If one decides in favor of sealing a non-cavitated lesion, the material used for the sealing is of major importance, since a tight closure of all parts of the fissure is a prerequisite. Resin-based material is recommended [163–165]; glass ionomers should not be used as a tight sealing cannot be ensured

[166]. The sealing of carious deciduous molars is also possible and not worse in comparison to invasive measures [167]. In all cases of sealing carious lesions, a periodic evaluation is essential, both in relation to lesion progression and to sealant integrity and retention. A total or partial loss of the sealant applied over a dentin lesion will open again the entrance for bacteria and for the substrate for the bacteria in the resting carious lesion, favoring the activation of the caries process [154, 168]. One has to keep in mind that sealants placed over dentin lesions, even in combination with adhesive systems, present more micro-leakage and less retention than sealants in sound fissures. Carious fissures are often surrounded by demineralized enamel, which presents reduced adhesive properties adversely affecting the proper adaptation of the sealant in the fissure [169].

Except for a proven allergy, there are no absolute contraindications for a fissure sealant. The presence of a cavitation into dentin, an inadequate moisture control, and deciduous teeth, which will exfoliate soon, can be judged as a relative contraindication.

> **Non-cavitated dentin caries lesion can be sealed and arrested. However, periodic evaluation is essential, both in relation to lesion progression and to sealant integrity and retention.**

16.3.1 Type of Sealants

Different materials can be used as a sealant. Mostly resin-based sealants are recommended, either as unfilled resin formulations or flowable composites. Glass ionomer cements (GIC) are also a possibility; however, this material is in some countries' guidelines classified as a material to be used only as an interim solution.

16.3.1.1 Resin-Based Sealants

These sealants are based on fluid resins associated or not with filler particles. They contain traditional monomers, such as BisGMA and UDMA, which are diluted with low molecular weight molecules, such as TEGDMA, to obtain a proper viscosity for clinical use. In addition, some products also have white pigments such as titanium dioxide, to differentiate the sealant from enamel, aiming to facilitate the application and its later control during the clinical examination (■ Fig. 16.3a, b). Clear sealants, however, allow controlling the underlying fissure system. There is also a sealant available with a thermochromic pigment. This pigment is transparent at the oral temperature, but at temperatures below 31 °C, induced by the use of air or water stream, it becomes bluish, which should facilitate the identification of the sealant in the fissure system (■ Fig. 16.3c, d). To facilitate the application of the sealant,
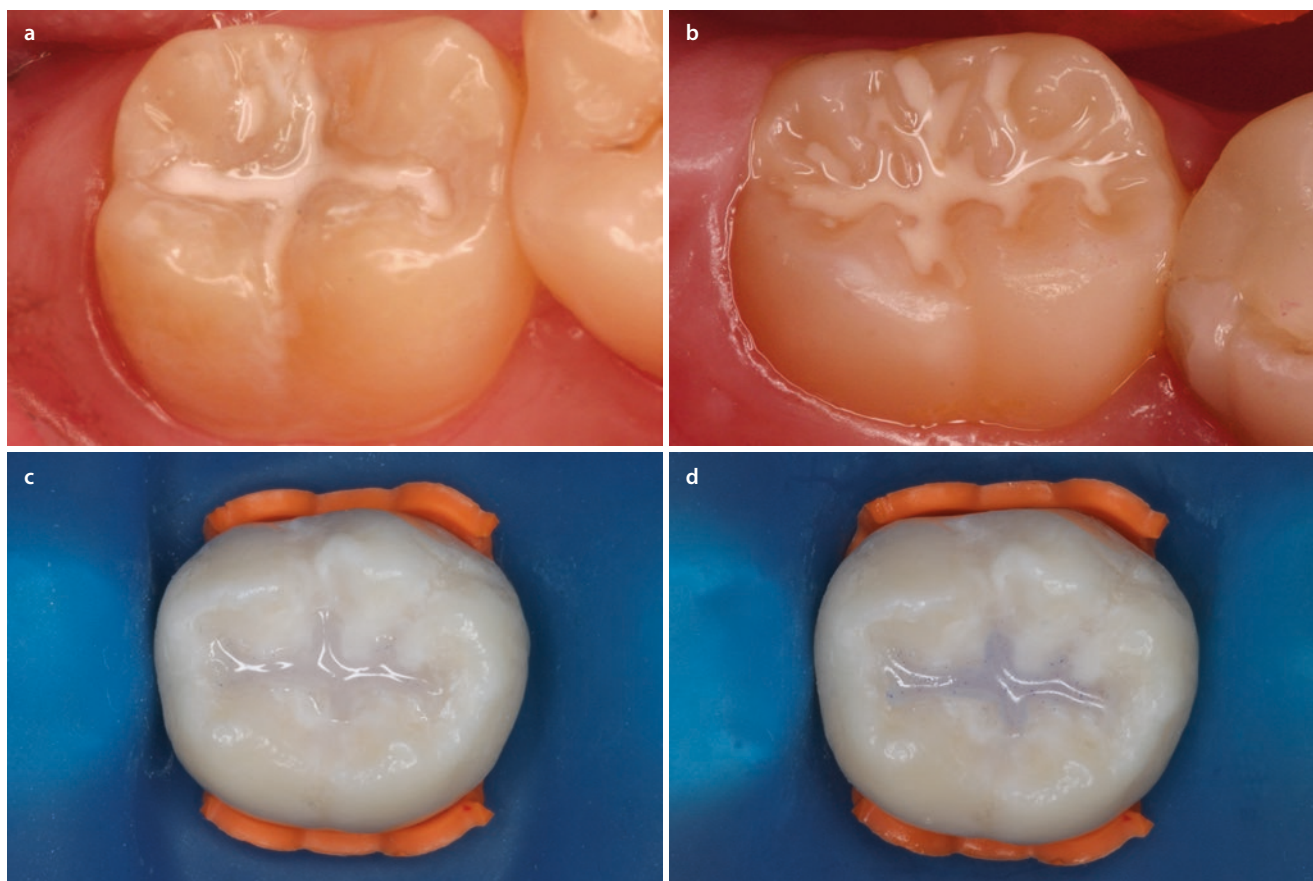
■ **Fig. 16.3**   **a**, **b** Sealants with white pigment applied on the molars occlusal surface; **c** sealants with thermochromic pigment after the polymerization; **d** bluish aspect of the sealant with a thermochromic pigment after receiving a water spray (Defense Chroma-Angelus)

companies developed materials which change the color from the non-cured (other color than white or clear) to the cured condition.

Resin-based sealants are normally light-curing, but chemically curing materials are also available, both presenting comparable retention rates in long-term evaluations [170, 171]. Some preparations contain fluoride; however, studies have shown that fluoride release by the resin-based sealants is minimal and there is no advantage over the sealants without fluoride. Thus, it seems to be more of a marketing strategy than a real clinical benefit [154, 172, 173].

The addition of filler particles to the sealants aims to improve surface hardness and reduce wear. Although they present improved mechanical properties, they are more viscous, and consequently, the penetration into the etched fissures is more difficult. As the layer thickness is higher after application, they mostly require occlusal adjustment after application [149]. However, there is no evidence for superiority of filled over unfilled sealants in relation to retention rates and caries prevention [147, 174].

> **Tip**
>
> There is no evidence for superiority of filled over unfilled sealants in relation to retention rates and caries prevention. The same holds true for the presence or not of fluoride in the composition and the use of light- or chemical-curing materials.

The sealant application technique, which will be exemplarily presented, does not require the use of an adhesive system after the acid etching step, as it is possible to get similar retention rates with or without an application of a bonding agent, in particular if the moisture management is excellent [175]. Thus, adequate isolation is an essential part of the technique, and the use of rubber dam is strongly recommended. Sometimes it is not possible to use rubber dam, and the cotton rolls isolation has to be performed. Studies have shown than when properly done, results similar to rubber dam can be achieved by cotton rolls isolation. However, if this cannot be ensured, such is the case in partially erupted teeth, glass ionomer cement as sealant should be used instead of resin-based materials (for details see below). Salivary contamination during sealant placement is the most common cause of failure of the technique [154, 176, 177].

Most problems associated with retention loss of a sealant do not occur when it is totally lost. That exposes the fissures system to the oral environment, allowing mechanical removal of the biofilm and contact with saliva and fluoridated oral hygiene products. However, in case of a partial loss and insufficient retention of the remaining sealant, the areas below the partially retained material will hardly come into contact with saliva and fluorides, which can increase the risk for caries development. Furthermore, in particular if dyed sealants are used, the visual diagnosis is impaired [150].

The outer surface of enamel is prismless (◘ Fig. 6.1d), which shows smaller porosities after acid etching and impairs the retention of the fissure sealant. Besides, the solubility of prismless enamel is smaller than of prismatic enamel. A minimum etching time of 30 s is required. A reduced etching time leads in most studies to a more heterogeneous retention behavior. It is important to highlight that the acid etching has to reach a larger area than the sealant will cover. The material should never be applied beyond the etched enamel because no bonding would be obtained. After etching and rinsing and drying, the surface should have a chalky/frosty-white appearance as a result of the acid-induced demineralization. The application of self-etching adhesives before sealant application could be used as an alternative to phosphoric acid etching before sealant application; however, the retention rates do not reach those after conventional acid etching [178]. The same applies for laser or air abrasion conditioning [179]. The latter three methods (self-conditioning, laser, air abrasion) cannot be recommended without reservations.

To maximize the longevity, the retention, and the durability of the sealants, the application has to follow a standardized protocol:

- Proper isolation of teeth, preferably with rubber dam (◘ Fig. 16.4a).
- Cleaning of tooth surface with pumice and prophylaxis brush or with sodium bicarbonate Prophy-Jet to remove the biofilm and debris from the occlusal surface, that adversely affects the adequate enamel etching (◘ Fig. 16.4b). The surface can also be cleaned with the patient's toothbrush without toothpaste [180]. Oily or fluoridated prophylaxis pastes have to be avoided since they may hinder the enamel acid etching.
- Thoroughly rinsing with air/water spray and drying with airstream.
- A dental probe should gently be passed through the bottom of the grooves to remove pumice residues and debris.
- Etching of the surface with 35–37% phosphoric acid gel for at least 30 s (◘ Fig. 16.4c).
- Thorough rinsing with air/water spray until complete removal of the acid for at least 20 s (◘ Fig. 16.4d).
- Drying of the surface with airstream (◘ Fig. 16.4e).
- Applying of the sealant using a dental probe or the applicator tip provided by the manufacturer, directing it towards the center of the pits and grooves and taking care not to incorporate bubbles into the sealant material (◘ Fig. 16.4f).
- Note: If it is a self-curing sealant, it is presented in two bottles. One drop of each bottle has to be dispensed, mixed, and applied to tooth surface. The curing time is about 3 min. If it is a light-curing material, the sealant has to be applied directly to the tooth surface and then light-cured for 20–40 s according to manufacturer's instructions (◘ Fig. 16.4g).
- Evaluating of the entire surface of the sealant with a dental probe to ensure its integrity and to verify the

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homogeneity of the material and the absence of bubbles as well as whether the sealant covers the entire extension of pits and fissures (Fig. 16.4h, i). If necessary, the sealant can be reapplied if no contamination with saliva has happened. If contamination was the case, the acid etching procedure including rinsing and drying has to be repeated before applying additional material.

- Removal of rubber dam and evaluation of the occlusion using an occlusion foil.
- If there is any occlusal interference, the occlusion has to be adjusted using a fine-grain diamond point, a multi-bladed finishing bur, or an Arkansas stone.
- If it is recommended in the respective home country, application of a highly concentrated fluoride preparation (varnish or fluid).
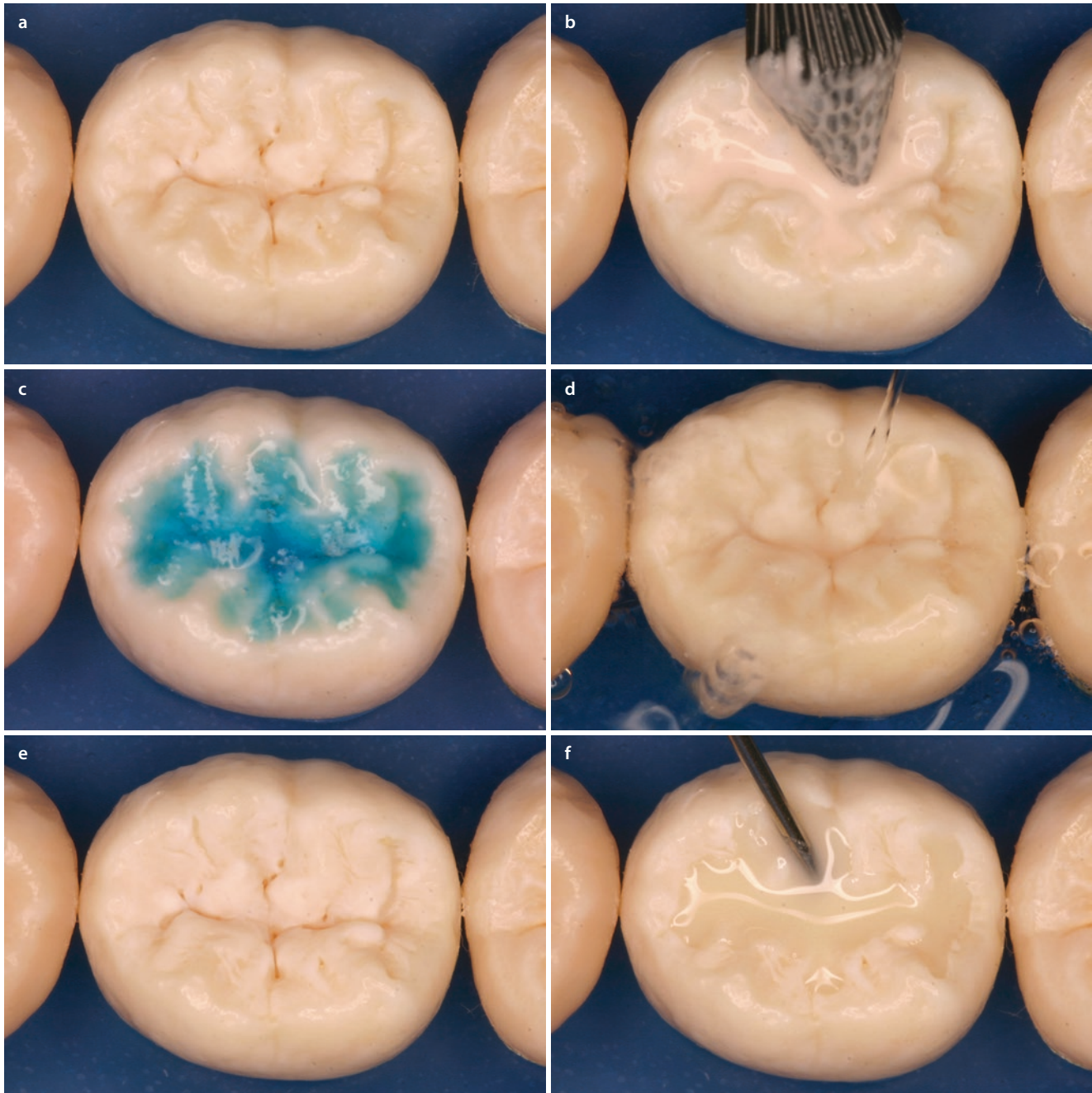
Fig. 16.4 Light-curing resinous sealant application technique. **a** Teeth after rubber dam isolation; **b** prophylaxis with pumice and water; **c** phosphoric acid etching; **d** rinsing; **e** opaque aspect of the etched enamel; **f** application of the sealant using the tip of an exploratory probe; **g** light-curing; **h** evaluating the sealed surface using the probe tip; **i** final aspect before evaluating the occlusal contacts
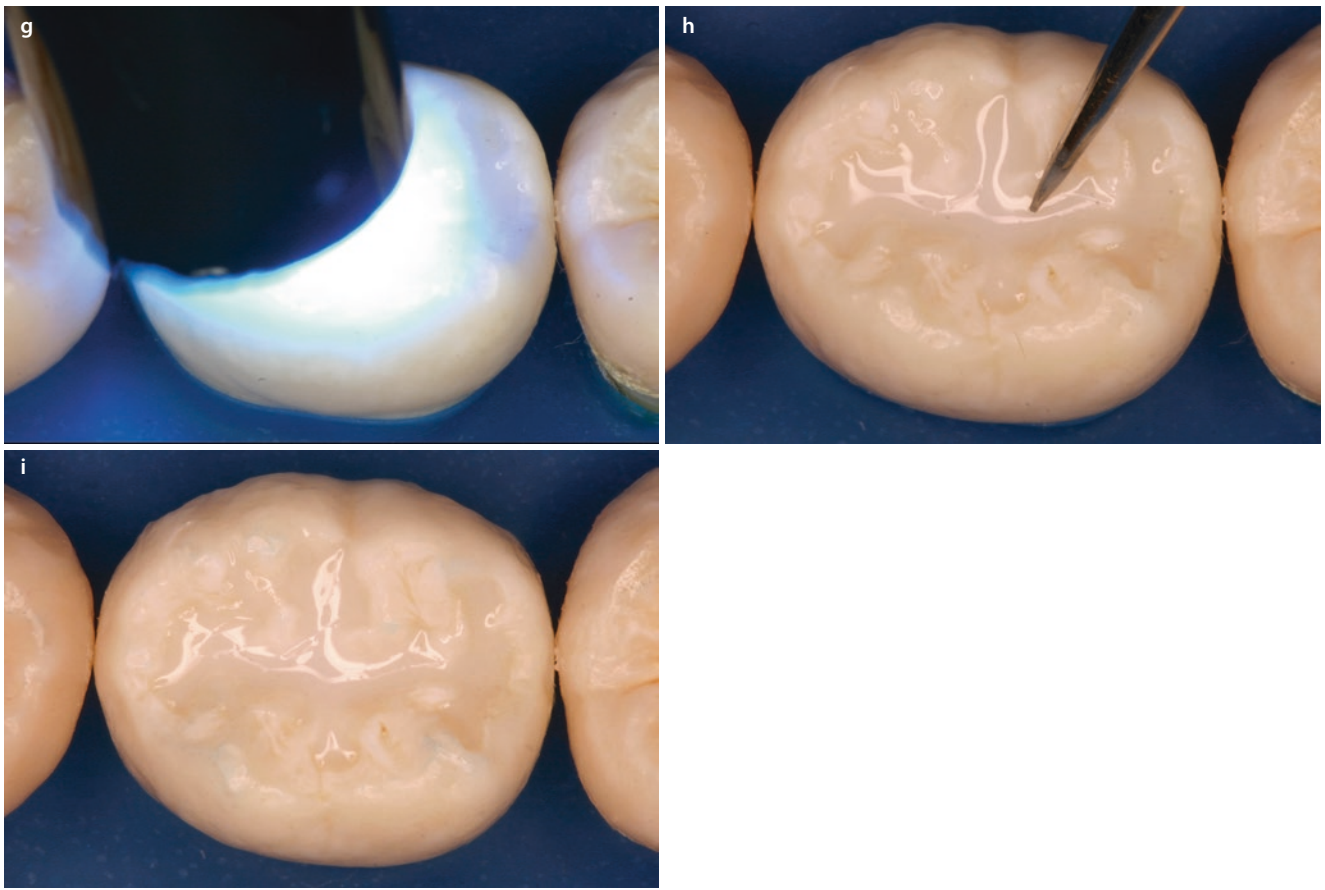
Fig. 16.4 (continued)

16.3.1.2 Flowable Composite Resins

Flowable composites, especially those with very low viscosity, can be used as pit and fissure sealants. They present good wetting properties and adequate wear and fracture resistance [145]. Clinically, the results of flowable composites, if used with an adhesive system, are comparable to those obtained with unfilled resin-based sealants [181–184]. The use of an adhesive system after etching is a prerequisite in case of the usage of a flowable composite for occlusal sealing. Except for this additional step, the application technique is similar to the application of resin-based sealants. There is no need to use the primer of the adhesive system, if a three-step adhesive system is used (etching, primer, and adhesive), since only enamel is involved; it is of major importance that in this case the etched enamel is completely dry, to avoid any contact between water and the hydrophobic bonding material. For enamel bonding, the use of etch and rinse systems is always the preferred choice, to achieve a stable and effective bonding [185]. Self-etching adhesive does not lead to a sufficient etching patter, in particular in the prismless enamel, since the pH value of the self-etching primer is higher. As a consequence, its application results in the formation of shorter resin tags compared to the etch and rinse systems. All in all, the self-etching approach results in lower bonding performance and a poor sealant retention [186, 187]. Thus, the use of self-etching adhesive systems is not recommended. After polymerization, the finishing and polishing steps are performed as in case of any regular composite restoration.

16.3.1.3 Glass Ionomer Cement

The use of GIC to seal pit and fissures is a controversial topic in the literature. Some authors believe that they are not adequate for occlusal sealing, because they show high wear and low fracture resistance, as well as poor retention rates [145, 154, 188]. However, other studies showed success rates with regard to occlusal caries prevention similar to the resin-based ones [189]. Two reasons for this effect have been discussed. On the one hand, even when the sealants apparently are lost, residual material remains in the bottom of the fissures and still protects against caries lesions. On the other hand, they can act as a fluoride reservoir, reducing the caries progression [147, 190, 191]. The latter aspect is often subject for a discussion, since it is not clear whether the fluoride effect is measurable in case of the regular use of fluoride containing oral hygiene products.

GICs are generally used in terms of a temporary treatment, in particular in situations where sealants are indicated, but adequate isolation cannot be achieved. Typical clinical situations are partially erupted teeth with active white spot lesions and/or patients with high caries risk and
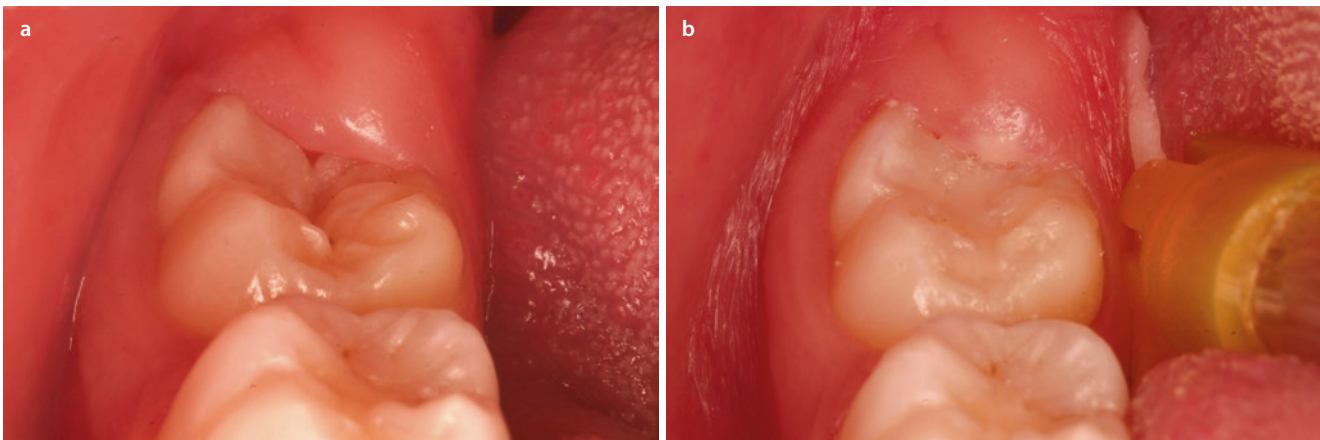
Fig. 16.5 Mandibular second molar erupting into the oral cavity. **a** Initial clinical situation; **b** immediately after the application of the GIC as pit and fissure sealant
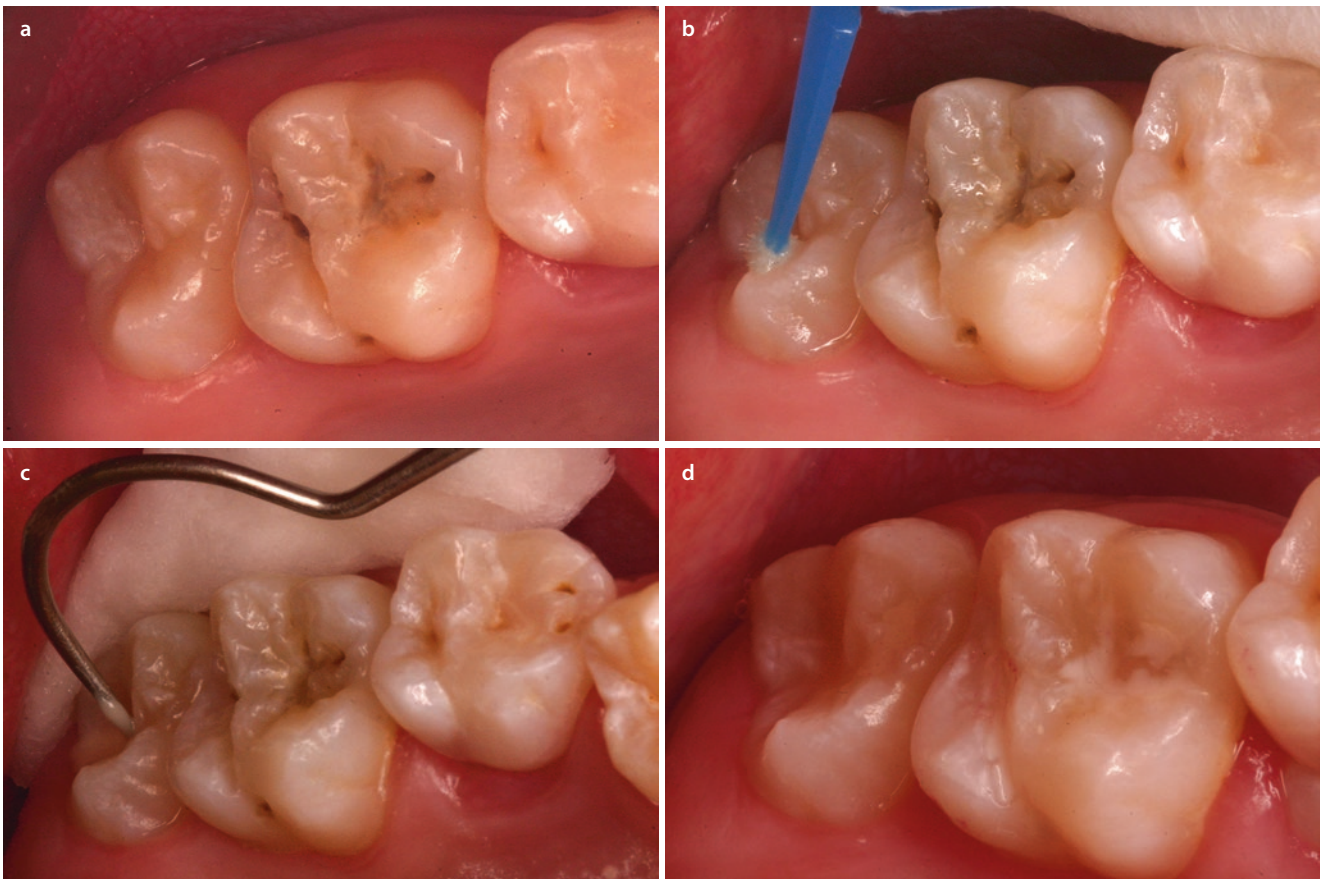
Fig. 16.6 Application technique of the GIC used as sealant. **a** Initial case – maxillary second molar erupting in the mouth of a caries high risk patient; **b** application of polyacrylic acid after the prophylaxis; **c** application of the GIC with the tip of an exploratory probe; **d** case after 6 months, showing the retention of the GIC on the pit and fissures. The first molar also received the same treatment

previous history of caries lesions (Fig. 16.5a, b) [152, 192, 193]. Even if they can be used in cases where an adequate isolation cannot be guaranteed, GICs are technique sensitive against desiccation on the one hand and high amounts of saliva in the fissures on the other hand. Moisture control is therefore also for GIC sealants an important factor. Besides conventional GICs, the resin-modified glass iono-

mer cements (RMGIC) can be used. They have to be light-cured but are less sensible to desiccation and water absorption and have better physical properties and retention rates to enamel [152, 194].

The application of the conventional GIC as pit and fissure sealant should be performed according to the following protocol (Fig. 16.6a–d):

- Cleaning of the tooth surface with pumice and prophylaxis brush or with sodium bicarbonate Prophy-Jet or the patient's toothbrush without toothpaste.
- Thoroughly rinsing with air/water spray and drying with airstream.
- A dental probe should gently be passed through the bottom of the grooves to remove pumice residues and additional debris.
- Isolation of the teeth using cotton rolls.
- Application of the polyacrylic acid conditioner to enamel, according to manufacturer's instructions (◘ Fig. 16.6b).
- Note: The surface energy is increased by applying the conditioner, which enhances the wettability and penetration of the GIC into the grooves.
- Thoroughly rinsing with air/water spray to remove the acid, for at least 20 s, avoiding saliva contamination.
- Change of cotton rolls.
- Note: This step is critical because unexpected saliva contamination of the surface will negatively influence the adhesion of the GIC to the tooth.
- Gentle drying of the tooth surface with airstream. An absolute drying of the tooth surface has to be avoided.
- Note: The enamel surface will not show the frosty-white appearance observed after the phosphoric acid etching.
- GIC will be mixed from two components. The mixture should be homogeneous, fluid, and shiny; if manual mixing is performed, the incorporation of air bubbles by strong mixing procedures has to be avoided. Application of the cement using the tip of the dental probe or the application syringe, directing it into the pit and fissures, with care (avoid air bubbles; ◘ Fig. 16.6c). Pressure can be applied with a petroleum jelly-coated index finger to improve the penetration of the material into the pit and fissures [195]. During the initial setting reaction, which takes about 5 min, the surface should not be touched; any saliva contamination has to be avoided.
- Protect the surface with cavity varnish or bonding agent to avoid syneresis and imbibition processes until the final hardening, which would adversely affect the materials' physical properties.
- Checking for bubbles and whether the GIC is correctly applied to all pit and fissures.
- Removal of the cotton rolls and evaluating of occlusion with articulating paper.
- If there is excess, manual shaping instruments should be used to remove it.
- Application of a coating (fluid resin) to protect the surface.

If a resin-modified GIC is used, a tooth conditioner or a specific primer has to be applied following the manufacturer's instructions. Afterwards, the material is placed over the fissures and light-cured. It is usually not necessary to protect the surface of this material, since the resin component avoids desiccation and water absorption. Finishing and occlusion adjustment steps are similar to the conventional sealant technique presented above.

16.3.2 Longevity of the Sealants and Effect on Incidence of Caries

The longevity of the sealants has been proven by clinical studies, which have shown that the retention of the sealant is the most important factor for occlusal caries prevention, since it blocks the bacteria and/or its nutrients [196–198]. The survival rate of the resin-based sealants according to a systematic review study was up to 90% after 1 year, 80–93% after 2 years, 41–87% after 3 years, 70% after 4 years, and 39% after 9 years [199]. A reduction of the sealant retention is observed over the time. Therefore, periodic visits to the dentist are important so that the sealant margins and integrity can be re-evaluated. If there is any fracture or loss (◘ Fig. 16.7a–d), it should be repaired or replaced if necessary, in particular when the patient still presents high caries risk or when the sealant was applied on teeth with enamel demineralization. Regarding the effect of fissure sealants on caries incidence, it was reported that sealed permanent molars presented up to 73–84% less caries lesions after 2 years compared to the non-sealed molars [199].

> ❯ A reduction of the sealant retention is observed over time. Therefore, periodic visits to the dentist are important.

16.3.3 Extended Fissure Sealant and Conservative Composite Restorations

In 1977, when the extension for prevention principles was still the state of the art for the invasive therapy of dental caries, Simonsen and Stallard wrote the first reports about minimally invasive or conservative preparations. They used No.1/4 round burs to widen those pit and fissures affected by incipient carious lesions (selective enameloplasty of the fissures), which was followed by sealing with self-cure composite dissolved in fluid resin (extended fissure sealant) [200]. Later, the term "preventive resin restorations" was given to small composite restorations, which were made after conservative preparations of small lesions that extend up to the dentin. The preparation was defect oriented, and only the caries-affected area was prepared. The small restoration was associated with a sealant application on the adjacent pit and fissures [201]. Today this kind of procedure is called a "conservative composite restoration" and still includes the same steps: small preparation with minimum removal of tooth structure, restoration with composite material, and sealing of the pit and fissure on the healthy adjacent fissure system, in particular if there is a high risk for new caries lesion develop-
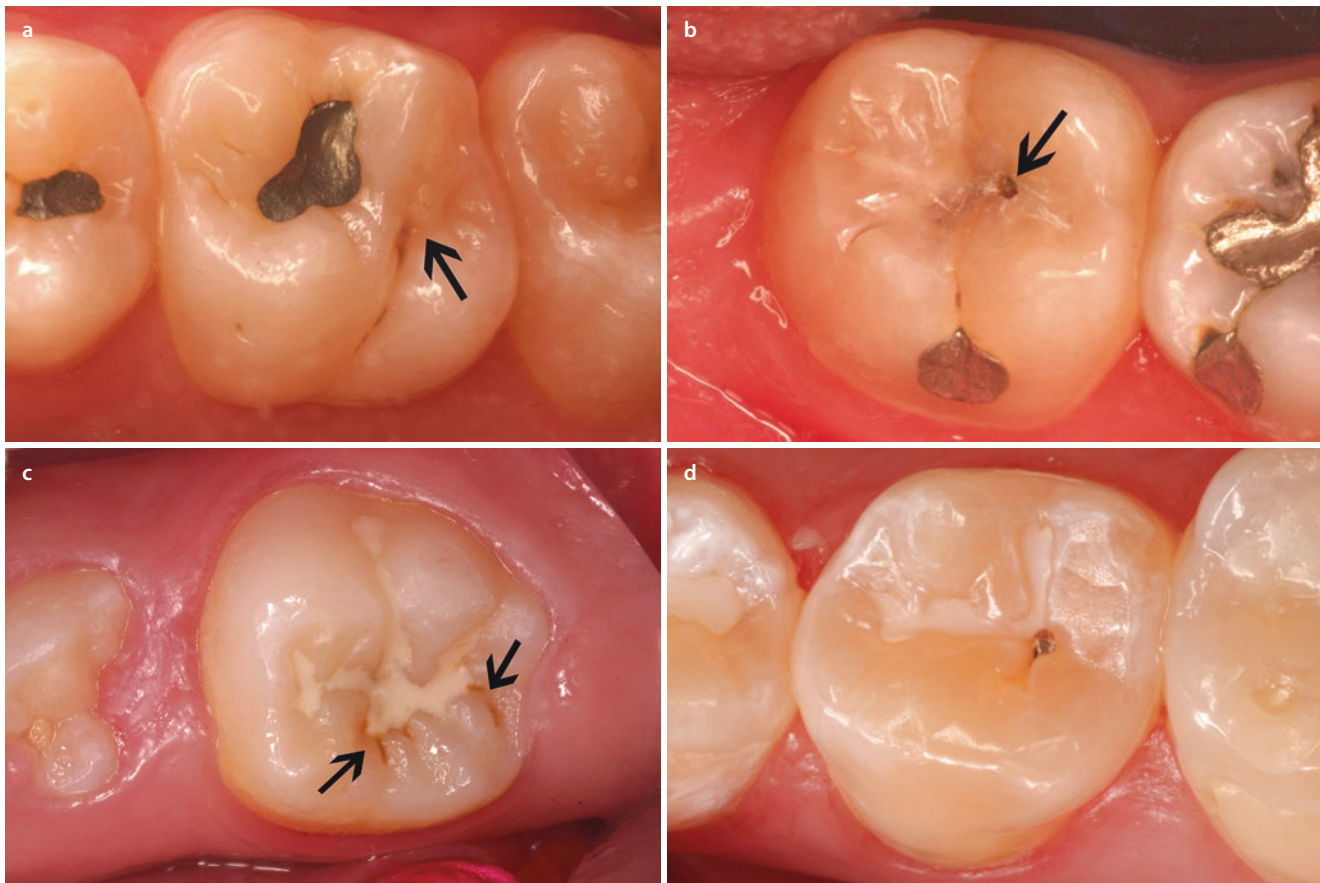
Fig. 16.7 **a** Partially retained sealant on the distal groove of the occlusal surface of the maxillary first molar; **b** fractured sealant on the mandibular second molar, with presence of a carious lesion; **c** partially retained sealant on the mandibular first molar; **d** fracture of sealant of the mandibular second premolar, with presence of carious lesion

ment in this area [145]. Instead of the combination of regular composites with sealants, a flowable composite can be used both for restoring the prepared cavity and for sealing the occlusal pit and fissures [202].

The conservative composite restoration technique includes the following steps:

- The preparation has to involve only the carious tissue, using an ultraconservative diamond point, a small diameter round diamond point, or a very small tapered carbide bur, in high-speed handpiece, to allow access to the underneath carious dentin (◘ Fig. 16.8a, b).
- The caries-infected dentin is removed using a round carbide bur, with diameter compatible to the cavity size, in the low-speed handpiece. Attention has to be directed to the dentin, to maintain the caries-affected demineralized but not infected dentin, capable of remineralization, according to what is described in ▶ Chap. 6 (◘ Fig. 16.8c–e). The rubber dam is placed, and the surface is cleaned using pumice and prophylaxis brush or sodium bicarbonate Prophy-Jet (◘ Fig. 16.8f). After that, the tooth is thoroughly rinsed and dried with air.
- Etching is performed with 37% phosphoric acid for 15 s in dentin and for 30 s in enamel margins and the entire fissure system adjacent to the cavity (◘ Fig. 16.8g).

Surface is thoroughly rinsed for at least 20 s until the entire acid has been removed. Afterwards the area will be gently dried.

- The adhesive system is applied according to the manufacturers' instructions (◘ Fig. 16.8h).
- Afterwards, the composite is placed (◘ Fig. 16.8i). Both conventional and flowable composite resins can be used. If the depth of the preparation is more than 2 mm, the incremental technique has to be used, and light-curing will be performed on each increment for 20 s.
- As a final step of filling, the sealant is applied on the entire adjacent pit and fissure system, according the procedure described above (◘ Fig. 16.8j). If flowable composite is used, it can be placed both into the prepared cavity and on the grooves.
- The surface has to be evaluated for voids or bubbles.
- The rubber dam is removed, and the occlusion has to be evaluated using articulating paper (◘ Fig. 16.8k). If an adjustment is necessary, fine-grain diamond points, a multibladed finishing bur, or an Arkansas stones can be used to remove it. Finally, polishing has to be performed with abrasive rubber points or polishing pastes with felt points or polishing brushes (◘ Fig. 16.8l).

16.4 Enamel Caries Infiltration

Every dentist regularly comes across incipient enamel carious lesions or white spot lesions in the daily clinical practice. They are characterized by the presence of a pseudo-intact mineralized surface (superficial zone) followed by a demineralized subsurface lesion, also called as lesion body, as described in ▶ Chap. 3 (◘ Fig. 3.4a–d). If a progression of the mineral loss is not stopped by adequate preventive measures,

enamel prisms collapse, the pseudo-intact surface layer will be destroyed, and a cavitation process begins.

The treatment of proximal caries lesions generally involves two approaches: the noninvasive (preventive) and the invasive (restorative) treatment. When there is no enamel cavitation, noninvasive remineralizing measures involving fluoridation associated to dietary control and oral hygiene counseling represent the first option [203, 204]. However, this approach is not always successful, as it requires compliance and change of
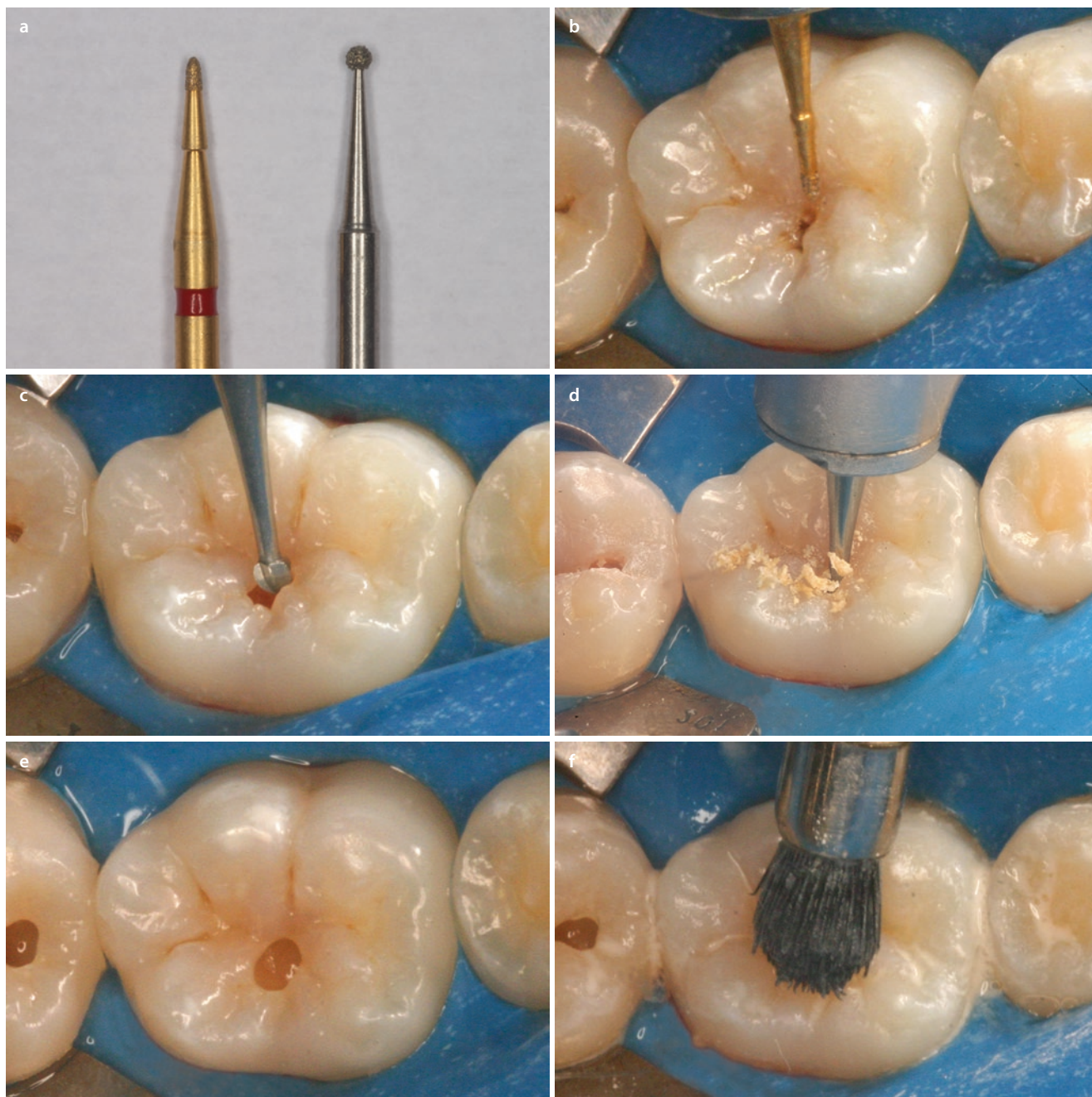
◘ **Fig. 16.8** Conservative composite restoration technique. **a** Ultraconservative diamond point (on the left) and round diamond point (on the right); **b** minimum tissue removal to access the carious lesion; **c, d** removal of the caries-infected dentin; **e** conservative preparation completed; **f** prophylaxis with pumice and brush; **g** acid etching; **h** adhesive system application on enamel and dentin; **i** composite resin application into the preparation; **j** occlusal surface with composite restoration and sealant on the adjacent grooves; **k** evaluation of the occlusal contacts; **l** final aspect of the conservative composite restoration

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◘ Fig. 16.8 (continued)

patient's habits. Many patients do not follow the recommendations and give up the treatment prematurely. As a consequence, the lesion can progress, in particular if a high caries risk exists. Cavitation can be the result, requiring an invasive treatment including tooth preparation and restoration. Especially in case of proximal lesions, the preparation of the access cavity is associated with the loss of large amounts of healthy dental tissue [205].

The caries infiltration technique, using very low-viscous resin material, is a new alternative approach in minimally invasive dentistry. As it is not associated with any preparatory measures, it could also be classified as microinvasive.

Different from the pit and fissure sealants that cover the enamel surface with a resin barrier to avoid carious demineralization, this technique aims to fill the pores within the carious lesion with liquid resin material, by penetration of this material into the lesion body, in order to reinforce its weakened structure. This makes the lesion on the one hand more stable against mechanical impacts, in order to avoid the breakdown of the surface layer, and, on the other hand, the dental structure becomes more acid resistant. Both mechanisms should lead to an arrest of its progression to a cavitation stage. Resin infiltration technique represents an intermediate treatment between the prevention and restora-

tion [205, 206]. This procedure, however, does not supersede the well-established preventive strategies. Like any dental treatment, it has to be performed in combination with educational procedures, such as oral hygiene and diet counseling, as well as fluoride application aiming the prevention and control of the caries disease.

> **Different from the pit and fissure sealants that cover the enamel surface with a resin barrier to avoid carious demineralization, the resin infiltration technique aims to fill the pores within the carious lesion with liquid resin material, by penetration of this material into the lesion body, in order to reinforce its weakened structure.**

The infiltration of a carious lesion is not a trivial process, as the superficial layer of the incipient carious lesion is characterized by precipitation of minerals from saliva on the enamel surface and low porosity, blocking the penetration of the resin into the lesion body. Thus, to allow the resin penetration, the superficial zone has to be removed through an erosive procedure using a strong acid. Different acids were tested; however, the sole one able to sufficiently remove the surface layer is 15% hydrochloric acid, applied for 2 min, followed by rinsing with water. To allow the infiltration of the hydrophobic monomers into the lesion, the etched surface has to be thoroughly dried. For this reason, after drying with airstream, absolute ethanol is applied and has to be dried completely in order to remove the remaining water. This procedure improves the low-viscosity resin (infiltrant) penetration, driven by capillary forces, into the lesion body [207].

The infiltration technique is indicated only to those lesions without cavitation implying that no bacterial contamination within the lesion body has happened. The indication for using it on smooth surfaces of free access can be easily made. However, in the proximal area, the clinical diagnosis of cavitation is quite complex. ⬛ Figure 16.9 shows a scheme of the different depths of carious lesions in the proximal area according to the

radiographic image with the respective treatment option. When nothing is seen, the score E0 is applied. The enamel layer is divided into outer (E1) and inner halves (E2), while dentin between the dentin enamel junction and the pulp is divided into three thirds (outer, D1; middle, D2; and, inner, D3) [208]. Studies comparing the radiographic images with the actual presence of cavitation showed that E1 lesions never had cavitation, while E2 is cavitated in 10–19.3% of the cases [209, 210]. However, 32% D1 lesions were cavitated, while 72% of lesions extending into the inner 2/3 (D2 and D3) of the dentin also showed cavitation [211]. In addition, some studies observed that when the radiolucency reaches the inner third of dentin (D3), cavitation was present in 100% of the cases [209, 210]. The resin infiltration technique is indicated for caries lesions in the proximal region with radiographic image up to external third of the dentin (D1), expecting that more than 2/3 of the cases are free of cavitation [211]. However, some studies showed a high prevalence of cavitation even in D1 lesions [212, 213]. This way, regular radiographic examination is recommended on cases where the infiltration technique has been performed, mainly on situation where the radiolucency reaches the dentin. The best way to have a more predictable evaluation of presence of cavitation is to perform a temporary elective tooth separation, followed by impression with a silicone material [214], as described on ▶ Chap. 3. In each case when a cavitation is present, this technique is not indicated, and a restoration is required, since at that stage, bacterial penetration into the lesion has already occurred.

> **Infiltration technique can be used only in case of non-cavitated lesions. The deeper a proximal lesion is, the higher the probability that a cavitation is present. In case of cavitation, an infiltration is not indicated, and a restoration has to be placed.**

To allow the resin application in the proximal lesion, a small tooth separation is required using wedges in the proximal space. Then, a special applicator device, a foil matrix delivery

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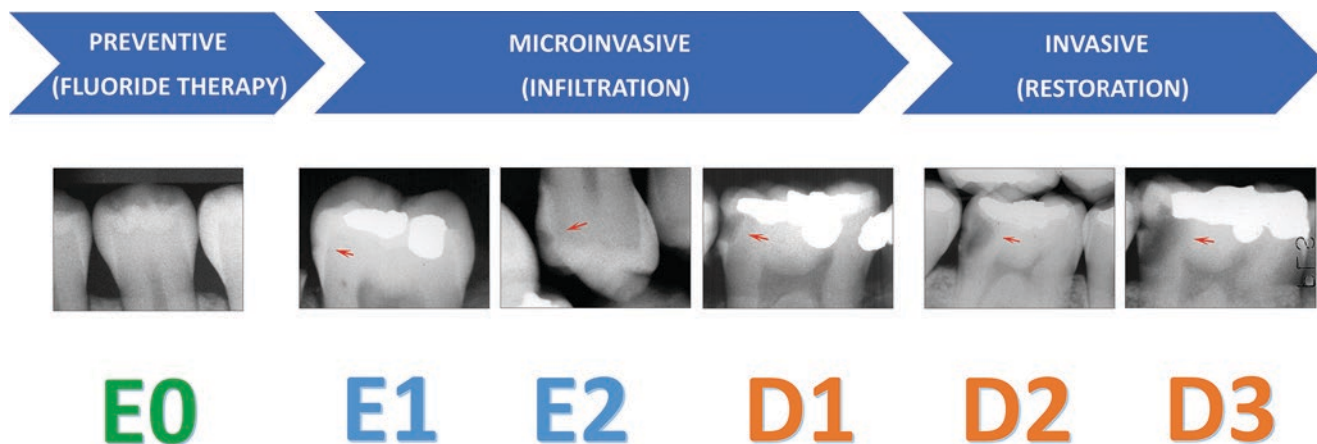
⬛ **Fig. 16.9** Different depths of carious lesions according to the radiographic image and the treatment indications. E0, no lesion; E1, outer enamel; E2, inner enamel; D1, outer third of dentin; D2, middle third of dentin; D3, inner third of dentin
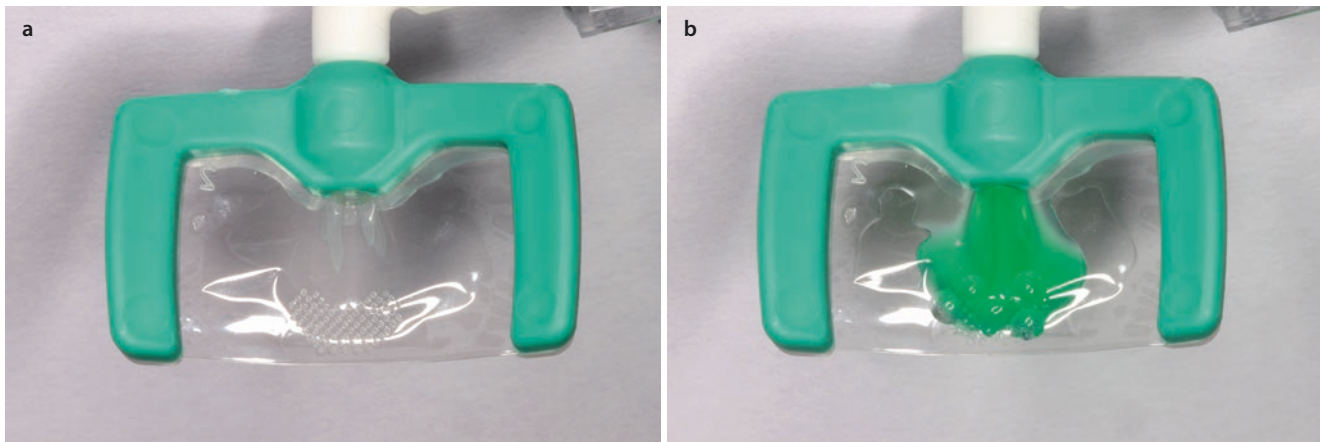
■ **Fig. 16.10** **a** Proximal tip foil matrix delivery system with micro-perforations in only one of the sides; **b** hydrochloric acid gel passing through the perforations of the matrix

system that contains micro-perforations, has to be put into the proximal space. The perforations point towards one of the sides. This allows the product application only to the affected proximal region, protecting the sound adjacent surface (■ Fig. 16.10a, b).

The treatment protocol for proximal surfaces includes the following steps (■ Fig. 16.11a–o):

- Making of bitewing radiography for lesion diagnosis (■ Fig. 16.11a, b)
- Cleaning of the teeth with prophylaxis paste and brush and of the proximal surfaces with dental floss
- Isolation of teeth with rubber dam in order to avoid any harm by use of the strong hydrochloric acid
- Separation of teeth using a wedge, which allows the placement of the delivery device into the proximal region (■ Fig. 16.11c)
- Connection of the applicator with the hydrochloric acid syringe, insertion of foil matrix between the teeth, and application of the acid for 2 min (■ Fig. 16.11d, e)
- Removal of the applicator and rinsing with water for at least 30 s; drying with air (■ Fig. 16.11f)
- Connection of a new applicator with the ethanol syringe, placement of it into the interproximal space, application of the ethanol onto the lesion and incubation for 30 s; drying with air (■ Fig. 16.11g)
- Connection of a new applicator with the infiltrant syringe, placement into the proximal space, application of the infiltrant, and incubation for 3 min. Removal of the applicator and of any excess of the infiltrant with dental floss. Light-curing of the infiltrant for 40 s from all sides (occlusal, buccal, and lingual) (■ Fig. 16.11h–k)
- Rerunning of the last step, incubation for 1 min, and light-curing from all sides for 40 s (■ Fig. 16.11l)
- Polishing with fine grit polishing strips (■ Fig. 16.11m, n)

One has to bear in mind that the infiltrant is not radiopaque; therefore, a radiographic observation of the infiltrant penetration into the lesion is not possible (■ Fig. 16.11o). This is even more important if the patient changes the dentist.

Furthermore, any follow-up can only be done indirectly via the estimation whether there is a lesion progression on periodically made bitewing radiographs. It is very important for monitoring that the radiographs have always the same direction. A recent systematic review revealed that proximal caries lesion progression was less likely to occur in permanent teeth being infiltrated with resin material as compared to noninvasive methods, provided that oral hygiene instructions and measures were performed [215, 216]. The evidence is at this moment moderate to low, due to lack of high number of studies. However, further newer studies not included in the review show also quite positive results, in particular in patients with high risk [217].

A second indication of the infiltration technique is the color masking of initial carious lesions on smooth surfaces. If an initial carious lesion occurs, the teeth get a whitish or chalky appearance (white spot lesion). The whitish color is due to the increase of the intercrystalline spaces of the demineralized enamel and creation of a high porous area, which changes its the refractive index (RI). While the sound enamel has a RI of 1.65, the lesion pores will be filled with water, which has a RI of 1.33, or air (RI of 1.00). In this case, the light waves reach multiples interfaces between the fluid and the mineral phase, with different refractive indices. At each interface the light is deviated and reflected, becoming imprisoned in an "optical maze" that is over-luminous and therefore perceived as white [218, 219]. The infiltrant has a refractive index of 1.475, closer to sound enamel, resulting in a masking effect of the white spot lesion, if deeply penetrated into the micropores, and in an improvement of the esthetics [220–222].

Typically, white spot lesions on the smooth surfaces occur due to inadequate oral hygiene, e.g., during an orthodontic treatment with brackets. The brackets are biofilm retention sites; however, white spots can also occur without orthodontic treatment in case of insufficient general oral hygiene. Usually, oral hygiene education and the application of fluorides are recommended to enhance remineralization of white spot lesions. However, this procedure is not successful in

Fig. 16.11   Resin infiltration protocol for incipient proximal caries lesion. **a** Initial case without clinical evidence of cavitation; **b** radiographic image suggesting enamel carious lesion on distal surface of maxillary first premolar; **c** rubber dam isolation and tooth separation with the plastic wedge; **d** placement of the proximal-tip foil matrix applicator in the proximal region, with the perforations directed to the affected tooth surface; **e** application of the hydrochloric acid; **f** rinsing and drying; **g** application of ethanol; **h** application of the infiltrant resin; **i**–**k** light-curing from occlusal, buccal, and lingual sides; **l** reapplication of the infiltrant resin, followed by light-curing; **m** polishing with fine-grain abrasive strip; **n** final case; **o** absence of radiographic evidence of the infiltrant resin, since the material is not radiopaque
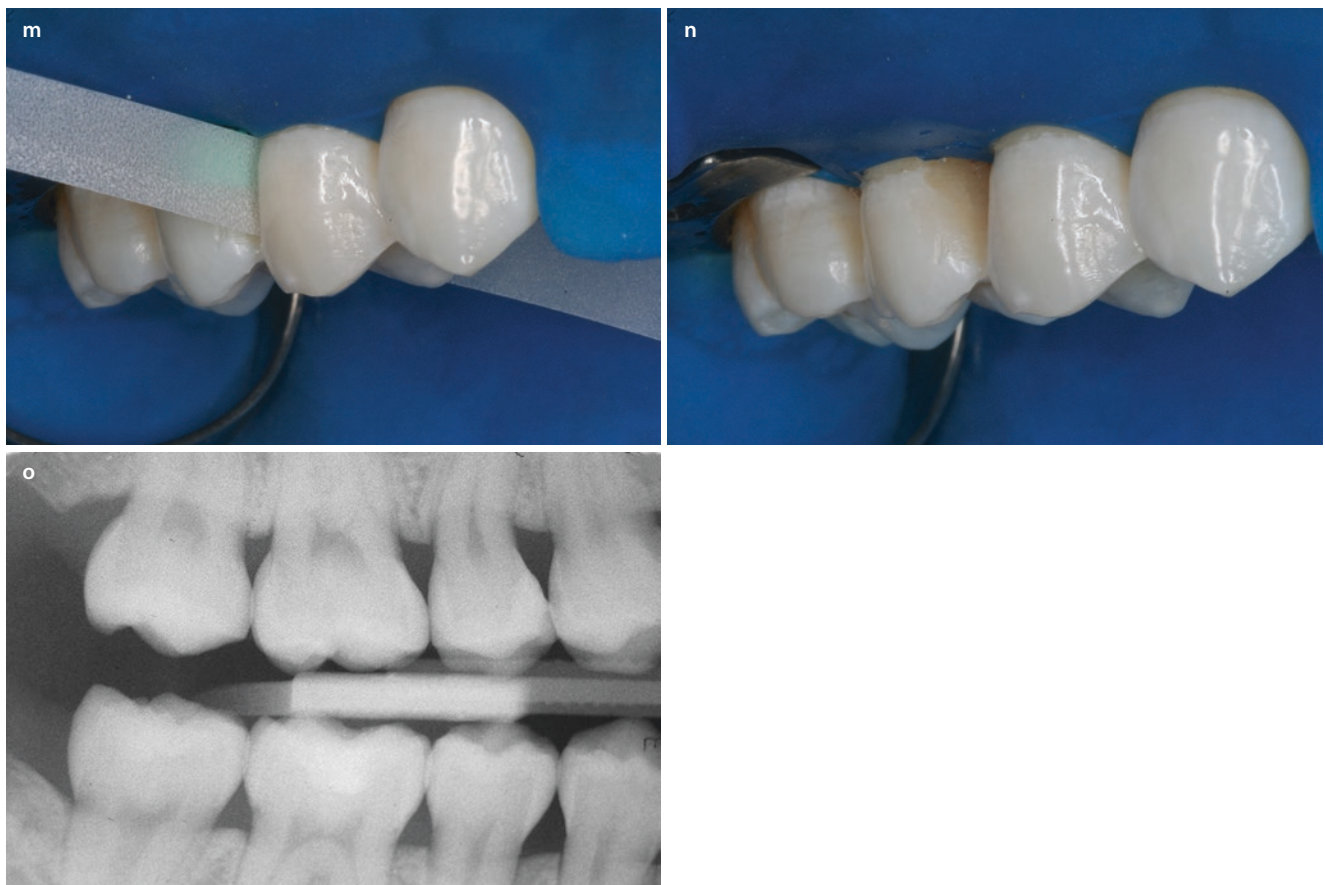
16
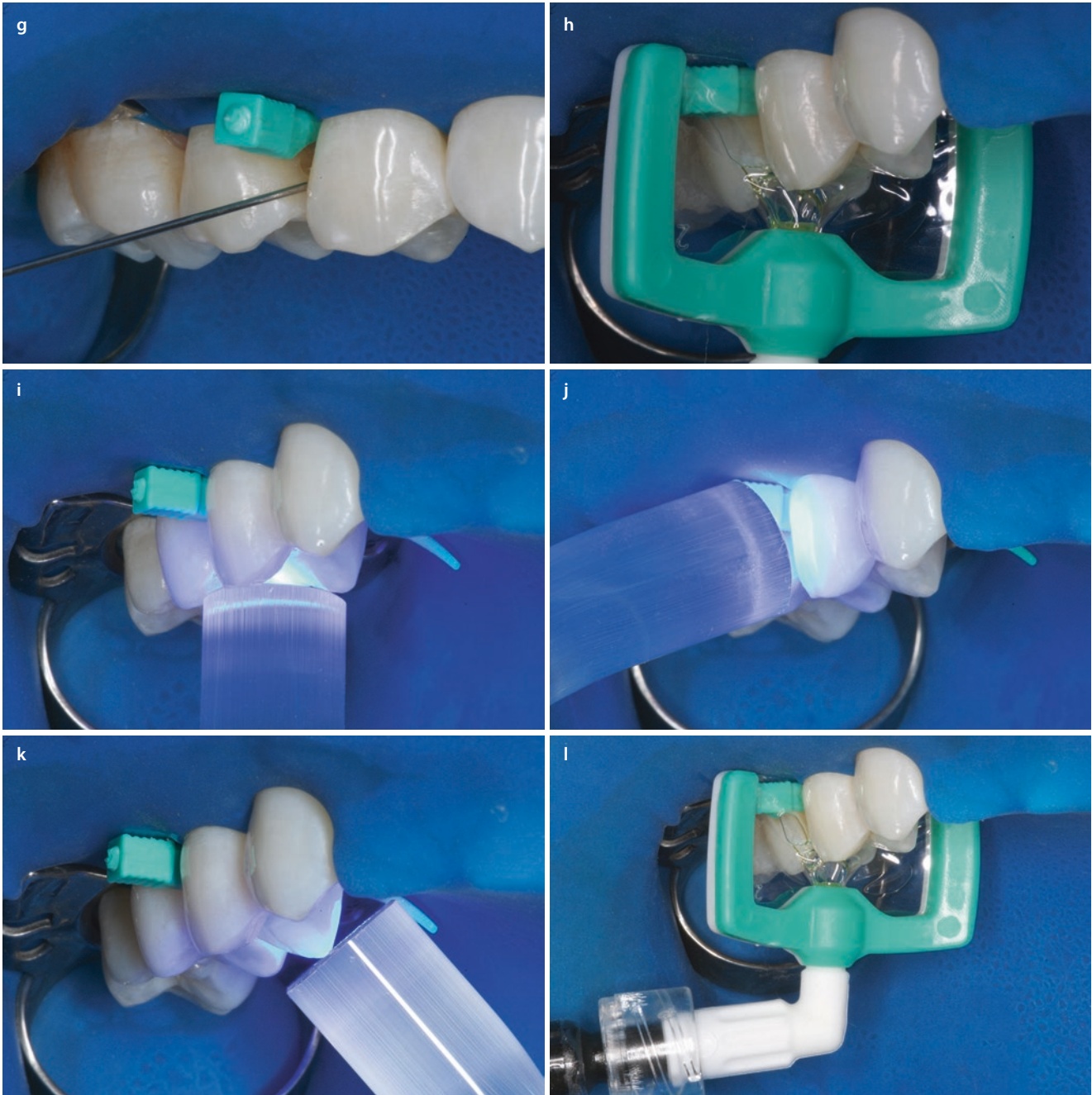
Fig. 16.11 (continued)

■ **Fig. 16.11**   (continued)

all cases and is dependent on the patients' compliance. The infiltration technique is a possible alternative. However, in cases of inactive but still visible lesions, in which the surface layer is thick and the lesion is in parts remineralized, the success is often limited, most likely due to an incomplete infiltration of the lesion. This is the case if the surface of the white spot has a glossy instead of a frosty appearance or shows even a discoloration.

The technique for application is comparable to that of proximal lesions except for the application device. Isolation of the teeth is, as mentioned for the proximal lesions, a prerequisite. Both a conventional rubber dam and a liquid dam are possible, depending on the extension of the lesion. The patient should be informed about potential changes in color and about the possibility of failure.

■ Figure 16.12a–i shows a clinical case of infiltration of white spot lesions as a sequela of bad hygine during orthodontic treatment (■ Fig. 16.12a). The following steps have been performed: isolation of the teeth using a light-curing liquid dam, application of the hydrochloric acid for 2 min (■ Fig. 16.12b), and rinsing for 20 s (■ Fig. 16.12c). The step was followed by air-drying, ethanol application, and drying for 30 s each (■ Fig. 16.12d, e). Afterwards, the infiltrant was

applied for 3 min (■ Fig. 16.12e). Excess was removed, and the infiltred surfaces were light-cured for 40 s. The infiltrant application was repeated for 1 min and light-cured again for 40 s (■ Fig. 16.12f). Finally, the surfaces were polished with abrasive discs to remove any excess and create a smooth surface. After these procedures, it was observed that the white spot lesions' masking was effective (■ Fig. 16.12g–i)

Due to histological structural similarities between carious white spot lesions and fluorotic enamel, the infiltration procedure can also be used in such cases. First clinical studies showed good results [223], and it appears to be a promising strategy [224]. In case of other hypomineralization such as in case of molar incisor hypomineralization (MIH), the results are less promising, mainly due to differences in histological structure.

> **Tip**
>
> Besides arresting proximal caries lesion, the resin infiltration can promote a color-masking effect of carious white spot lesions and fluorotic enamel, on labial surface of anterior teeth, resulting in esthetic improvement.

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■ **Fig. 16.12**   **a** Initial situation showing white spot lesions; **b** isolation with light-curing gingival barrier and application of the etching gel; **c** rinsed teeth after etching with wet surface; **d** dried teeth, showing the frosty-white appearance of the enamel; **e** application of ethanol using a smooth surface tip; **f** application of the infiltrant resin; **g** aspect immediately after the infiltrant application; **h** final result

◘ Fig. 16.12   (continued)

Conclusion

In modern preventive dentistry, micro- and minimally invasive strategies are the key components, superseding the traditional dentistry, which was based on the restorative-surgical model. The reestablishment of the shape, function, and esthetics of the lost tooth structures has been forced back, and approaches that emphasize health promotion and disease prevention, representing a great advance in direction to the oral health maintenance, are paramount. Contemporary preventive strategies comprise caries risk identification, prevention of development and progression of incipient lesion, remineralization of initial lesions, sealing of fissures to avoid biofilm accumulation in the retentive occlusal area, minimally invasive (conservative) preparation for fillings, and repair of the defective restorations instead of its replacement. To reach this goal, the dentist must be proficient in the etiology, pathogenesis, and development of caries as a disease, as well as in the early diagnosis of carious lesions. That will allow the implementation of reasonable individual-based preventive and minimally invasive strategies, together with measures that reduce or eliminate the causes of the caries disease, reducing their recurrence with the goal to optimally preserve the dental structures.

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