Management of Deep Carious Lesions

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Removing or Controlling?

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Falk Schwendicke

Abstract

A changing understanding of the disease dental caries has initiated a paradigm shift in the management of caries and carious lesions. Instead of merely removing the symptoms of the disease (i.e., the carious lesion), the aim of any therapy is to manage the disease. Noninvasive (biofilm control, remineralization, dietary interventions) and microinvasive strategies (sealants, caries infiltration) can either prevent new lesions or inactivate existing ones, or both. Traditionally, these strategies have been used to inactivate only non-cavitated carious lesions. New evidence shows that in some cases, they can also be applied to cavitated carious lesions. More often, for cavitated lesions, invasive strategies involving the placement of a restoration are needed. As restorations have a limited lifespan, their placement should be postponed as far as possible.

1.1 Options to Control Caries and Carious Lesions

Traditionally, the disease dental caries has been seen as an infectious one, with a single or only a few bacterial species, mainly streptococci (especially *Streptococcus mutans*), being causative in the initiation of carious lesions ("specific plaque hypothesis") [1]. Alternatively, the amount of bacteria has been found decisive for carious lesion initiation, again with bacteria being at the center of the pathogenesis of dental caries ("non-specific plaque hypothesis"). Based on such understanding, dentists have strived to remove all cariogenic bacteria for more than a century in an effort to

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"cure" caries [2]. To do so, dental hard tissues, which were presumed to harbor these bacteria, had to be removed, and afterwards the removed tissues were replaced by restorative materials.

Both the understanding of the disease caries and the management of caries and carious lesions (the signs and symptoms of the disease) have changed. Current understanding is that caries is characterized by an ecologic shift within the dental biofilm, starting with a balanced population of microorganisms, only containing limited amounts of acidogenic (acid-producing) and aciduric (acid-tolerating) bacteria (like streptococci and lactobacilli). If supplied with sufficient and regular amounts of fermentable carbohydrates via the diet, this flora changes: Acidogenic bacteria gain a competitive advantage by metabolizing carbohydrates to organic acids, mainly lactic acid, and thereby decreasing the pH. This in turn displaces non-acidogenic and non-aciduric species from the biofilm. After repeated episodes of carbohydrate availability, the biofilm eventually becomes dominated by acidogenic and aciduric species and capable of substantially decreasing the pH [3]. Only then is a lasting loss of minerals from the dental hard tissues possible; under non-pathologic conditions, a minute mineral loss is compensated by mineral gain from the saliva when there is no nutrient supply. The imbalance between de- and remineralization under pathologic conditions eventually leads to a net mineral loss within the dental hard tissues, the result being a carious lesion [4].

Based on this "ecological plaque hypothesis," simply removing carious hard tissues is unsuitable for "curing" caries, as it targets the signs and symptoms of the disease (the lesion) by removing and replacing them using restorations, while the causative imbalance, driving the disease process through the dental biofilm, remains. Thus, modern therapeutic concepts for managing dental caries and carious lesions focus on the control of the caries-causing factors (via noninvasive strategies) and the imbalance of mineral gain and mineral loss (mainly via microinvasive strategies). Invasive (restorative) strategies are only used as a last resort (Fig. 1.1). These strategies are briefly presented here:

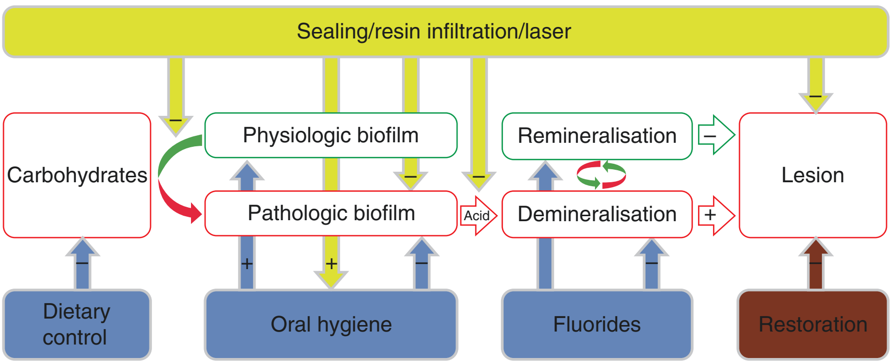

Fig. 1.1 The pathogenesis of caries and carious lesions and different management strategies, modified from [5]. Both protective (*green*) and pathogenic (*red*) factors interact in the process of caries and the associated mineral loss leading to a carious lesion. Noninvasive (*blue*), microinvasive (*yellow*), and invasive (*red*) strategies can be applied for managing the disease or its symptoms, supporting protective factors (+) and reducing pathogenic factors (−)

1.1.1 Noninvasive Strategies

Noninvasive strategies do not significantly modify or breach the surface of a tooth:

- Noninvasive strategies include the control and restriction of dietary carbohydrates. These can be attempted using both public health (education, taxing sugar/sugary food or beverages, marketing restrictions for such dietary products) and individual-level education and behavior change strategies (counseling, motivational interviewing, coaching). Providing sugar substitutes (like xylitol) also aims to reduce the intake of cariogenic dietary carbohydrates. Dietary interventions have been evaluated by a limited number of controlled clinical trials and few are of high quality [6, 7]; the evidence is thus not very strong. In theory, however, this approach is greatly attractive, not least because restricting sugar intake is directly relevant for other diseases (including obesity and diabetes mellitus)—tackling sugar intake thus fits well with the public health efforts around the so-called "common risk factor approach" to address general health problems [8–11].
- A far more common noninvasive management strategy is biofilm control. Tooth brushing, but also interdental biofilm control via interdental brushes or flossing, falls into this category. While tooth brushing has demonstrated benefits for caries prevention (not least as fluoridated toothpaste is delivered regularly) [12, 13], very few studies are available to support interdental hygiene for caries prevention [14]. For children with erupting molars, lateral brushing has been found effective. Antibacterial rinses or varnishes also fall into the category of biofilm removal; however, the evidence supporting these interventions for managing caries or caries lesions continues to be limited [15, 16].
- A third noninvasive strategy is to control mineralization, i.e., to rebalance demineralization and remineralization. Topical fluoride application via tooth brushing, rinses, or varnishes are most common, promoting remineralization, inhibiting demineralization, and possibly exerting antibacterial effects (the latter is a debated issue and might have subordinate relevance). An alternative to fluoride as agent for mineralization control is casein phosphopeptide amorphous calcium phosphate (CPP-ACP). While preclinical studies initially pointed towards its benefits, the clinical evidence remains ambiguous, and so far, the additional benefit compared with fluorides has not been convincingly demonstrated [17, 18].

All noninvasive strategies aim to prevent the development of carious lesions (via controlling the disease caries), but can also be used to control the activity of existing lesions and arrest them. It is noteworthy that this distinction between prevention (disease control) and therapy (lesion control) is an artificial one, as (1) the diagnostic differentiation between sound and carious surfaces is far from perfect and very much depends on how and with which means caries detection is performed and (2) the applied strategies do not necessarily differ [19–21]. Therefore, in this book, the term "management of caries and carious lesions" is used instead.

1.1.2 Microinvasive Strategies

Besides noninvasive strategies, microinvasive strategies are available to manage caries and carious lesions. These are called microinvasive, as they involve the loss of few micrometers of dental hard tissue for conditioning the tooth surface or for changing its surface properties:

– Resin sealants are applied after (phosphoric) acid-etching the surface, allowing micro-retentive adhesion of the placed sealants. Glass ionomer cement sealants condition the surface via their acrylic acid component and adhere to dental hard tissues via an ionic adhesion. Both install a diffusion barrier onto the tooth surface, impeding both acid diffusion into the tooth substance and mineral loss from it; they also increase the cleansability of fissured surfaces (Fig. 1.2). Sealants can thus again be placed to manage caries (preventively) [23], but also to manage carious lesions (arrest them). Traditionally, sealants were mainly applied on occlusal surfaces [24]; more recent studies have also investigated applying them proximally [25], again to prevent mineral loss and thus prevent lesion induction or progression (Fig. 1.3).
– An alternative to sealants, which are placed *onto* the tooth surface, is resin infiltration, with the diffusion barrier being installed *within* the tooth [26]. After removing the pseudo-intact surface layer of an existing carious lesion (this time using hydrochloric acid), the lesion is dried and a lowly viscous resin applied. As

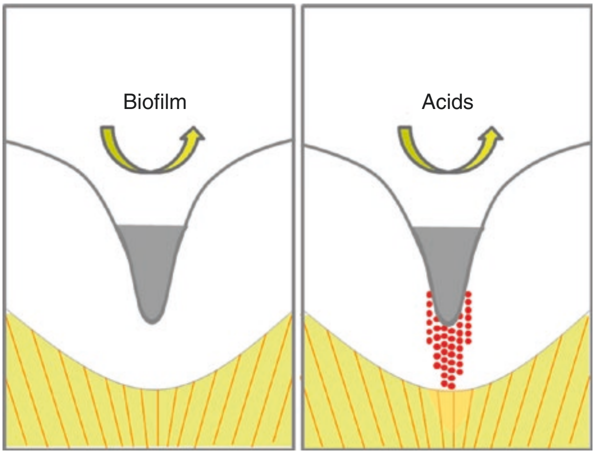

Fig. 1.2 Different mechanisms of sealing, for managing caries and carious lesions, modified from [22]. The application of fissure sealants was traditionally thought to allow more effective biofilm removal from deep and invaginated fissures which cannot be cleaned using tooth brushes (*left side*). Based on a current understanding, a second mechanism, the installation of a diffusion barrier to impede acid diffusion into the tooth and mineral loss from tooth substances seems as or even more relevant to protect sound surfaces (*right side*). The same mechanism, installation of a diffusion barrier, is also used when sealing non-cavitated carious lesions: the lesion is protected from acids and further mineral loss impossible; lesion arrest is the result

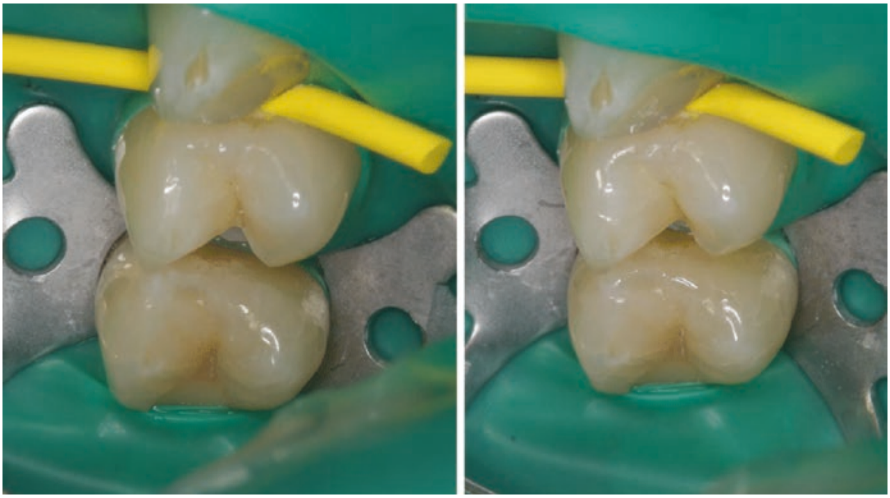

Fig. 1.3 During invasive treatment of the first upper left premolar, access could be gained for sealing a non-cavitated carious lesion on the mesial surface of the second premolar. The lesion (*left side*) is acid-etched with phosphoric acid for 30 s and adhesively sealed. The adhesive was then carefully polished using a strip (*right side*)

enamel lesions are porous, the resin infiltrates the lesion drawn by capillary forces. The resin is then light-cured and thus protected from further mineral loss, as acid diffusion into the enamel and mineral diffusion out of the enamel are impeded. Given the need for porous enamel to allow the resins to penetrate, resin infiltration cannot be performed on sound surfaces, i.e., it is only applied to manage existing carious lesions.

– A third strategy which falls into the microinvasive category is the application of laser for preventing the occurrence of carious lesions. A number of in vitro and clinical studies found laser application to enhance the enamel acid-solubility resistance [27], possibly by removing carbonate impurities [28], and also alter the surface hydrophobicity and thus reduce bacterial adhesion forces [29, 30].

In this book, we will not discuss all non- or microinvasive strategies in detail. However, resin sealants will be discussed later, as they theoretically can also be used for managing deep, cavitated carious lesions.

1.1.3 Invasive Strategies

A third category of treatments are invasive strategies: These involve the active breach of the surface of the dental hard tissue, mainly using burs or hand excavators, followed by the placement of a restoration. Invasive strategies are no longer aiming at controlling the disease, but controlling the local activity of the dental biofilm, as will be discussed in the next chapter.

1.2 When to Apply What? Guidance on Managing Non-Cavitated and Cavitated Lesions

Given the large and growing number of options available to manage caries and carious lesions, there is great need for guidance on how to choose the best strategy for each specific clinical indication. This book will not discuss the suitability of different strategies aiming to control the disease, but will focus on managing carious lesions.

For carious lesions, different lesion stages and activities might require a different management. These should follow a number of aims or principles, as recently stated in an expert consensus [31]:

- inactivation/control of the disease process
- preservation of dental hard tissue
- avoidance of initiating the cycle of re-restorations
- preservation of the tooth as long as possible

When considering carrying out one of the strategies described above, one should evaluate their outcomes against these aims or criteria. One main criterion for deciding whether to perform non-, micro- or invasive strategies is the surface integrity:

- Smooth surface coronal lesions with an intact surface are not, or only minimally, bacterially contaminated [32]; the intact enamel prevents bacterial penetration, regardless of the mineral loss in the lesion body underlying the surface layer. Such lesions are cleansable and can be successfully managed via non- or microinvasive means. Given the above aims and criteria against which management strategies should be evaluated, non- and microinvasive strategies are better suited for managing these lesions than invasive strategies, which sacrifice dental hard tissue and initiate the restorative cycle (discussed in more detail below). This means deciding between non- and microinvasive strategies. One would intuitively prefer noninvasive strategies, as no surface conditioning is needed, i.e., hard tissue is preserved, while restorations are avoided. However, noninvasive strategies usually depend on patients' adherence; their effectiveness might thus be limited unless successful behavior change has been achieved to alter the factors that led to disease initiation in the first place. In fact, a number of controlled studies have found noninvasive strategies to have a lower efficacy for arresting early carious lesions than microinvasive strategies, i.e., sealants or resin infiltration [24, 25].
- A more difficult case is occlusal lesions which radiographically extend into dentin, but do not show any surface breach, i.e., cavitation. They are theoretically cleansable and should be treatable using both non- and microinvasive means. However, given the specific anatomy of the fissure, a clinically intact surface area often communicates with the dentin underlying the thin enamel layers, mostly via micro-cavitations. Lesions which extend into the dentin on radiographs therefore often contain large amounts of bacteria [33]. Noninvasive options, like tooth brushing and fluoride application, will not be able to control these lesions any longer. As the bacteria contaminating the dentin are dependent on the supply with dietary carbohydrates to promote mineral loss and lesion progression (as discussed above), one strategy, which is increasingly applied, is sealing these

lesions: The sealant acts as a diffusion barrier again, now against carbohydrates [34], which allows even those lesions which contain bacteria to arrest (Figs. 1.4 and 1.5). We will discuss the mechanisms behind such sealing and the bacterial reaction to this environmental stress later in this book.

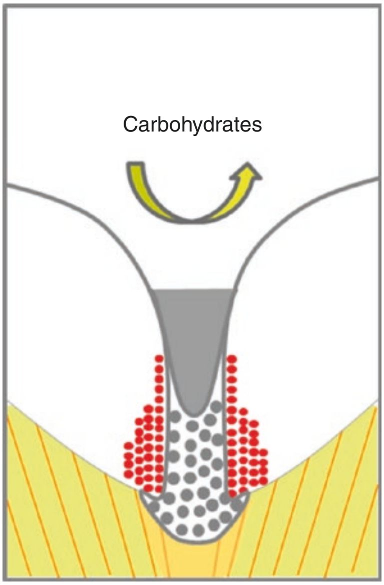

Fig. 1.4 A third mechanism of how sealing can manage carious lesions is the inhibition of the dietary carbohydrate supply of cariogenic bacteria. Such nutritional deprivation has been shown to effectively inactivate sealed bacteria and can be applied to arrest even cavitated, bacterially contaminated lesions

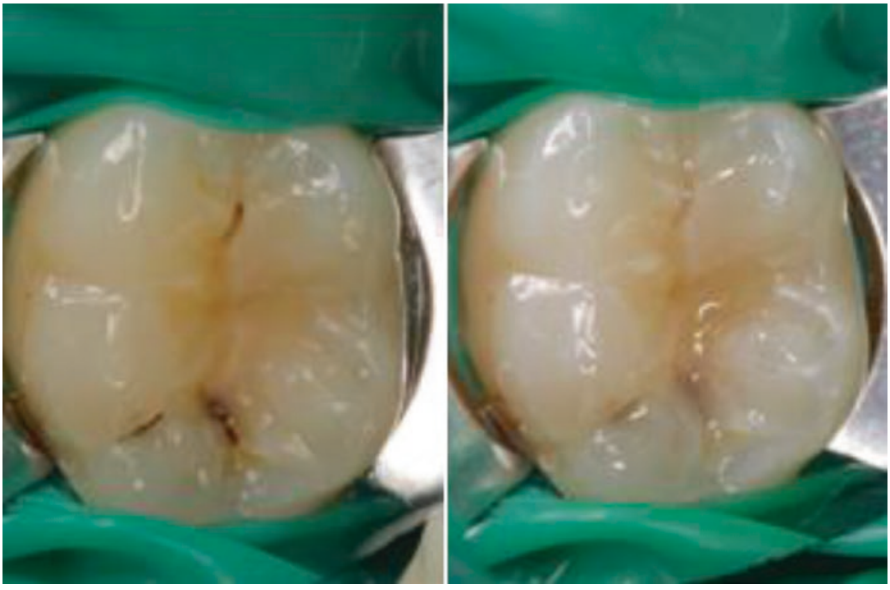

Fig. 1.5 Sealing of a micro-cavitated occlusal lesion. The distal fossa of this lower molar is affected by a micro-cavitated carious lesion, extending into dentin. Noninvasive strategies will not be sufficient to arrest this lesion. A resin sealant was placed onto the lesion, depriving sealed bacteria from nutrition and arresting the lesion. The sealant was extended onto the remaining fissures to prevent further mineral loss there

- For clearly cavitated lesions, it is not usually possible to control the lesion using only noninvasive means: Cleansability is no longer possible, the biofilm is sheltered and cannot be fully removed, and the lesion eventually progresses. It should be noted that some cavitated lesions are nevertheless cleansable, depending on their formation (Fig. 1.6). These lesions are usually inactive and do not require any further treatments (except those which might have been applied to inactivate them, like regular fluoride varnish). In some cases, non-cleansable lesions can be easily transformed into cleansable lesions by removing overhanging enamel or dentin. If dentists then encourage effective oral hygiene practices in these areas, including regular fluoridated toothpaste use and healthy dietary practices, this "non-restorative cavity control" (NRCC) approach might allow cavitated lesions to arrest and avoid invasive treatments. However, this treatment seems to be less successful than alternative strategies which will be discussed below [35]. Moreover, its application is currently restricted to primary teeth [36–38] and root surface surface lesions [39] and not widely accepted in many dental care settings. We will discuss this approach in more detail in Chap. 8.

In summary, noninvasive strategies are largely unavailable for cavitated coronal lesions (they are often able to arrest even advanced root surface lesions, though). Theoretically, sealing (a micro-invasive strategy) might be applicable for cavitated lesions, as sealing inhibits acid diffusion and also inactivates sealed bacteria by depriving them of dietary carbohydrates. Following this logic, one could seal all lesions: early, non-cavitated ones, micro-cavitated ones on occlusal surfaces, and cavitated ones. Sealing should—again theoretically—always allow lesion arrest by installing the diffusion barrier.

In reality, however, teeth are subjected not only to biological challenges like bacteria, but also to mechanical challenges like mastication. Sealants which are applied on sound or mainly sound dental hard tissues can be retained for relatively long time periods, as they are supported by the dental tissues and bond to them. However, if they are placed on carious dentin, this support is very limited, as carious

Fig. 1.6 An arrested cavitated lesion. The lesion was accessible for cleaning and shows signs of arrest (i.e., dark color, shiny, hard surface, no biofilm coverage). Note that in this patient, further lesions were present (on adjacent teeth), and the lesion was eventually restored prior to functionally rehabilitating the occlusal surfaces of the complete dentition

dentin is softer than sound dentin [40–43]. Consequently, such sealants can fracture [44, 45]. Moreover, the bond strength of sealants to carious dentin is significantly lower than that to sound dentin, which results in frequent loss of retention [46–48]. Given that lost or fractured sealants can be easily replaced, one might argue that such loss or fracture does not pose a grave problem. However, in the time between sealant fracture or loss and replacement, the lesion might be reactivated. Moreover, to replace lost sealants, dentists need the patient to attend regularly, which is not necessarily the case.

In summary, sealants are not a routine treatment option for cavitated carious lesions. More details on this topic will be given in Chap. 7 of this book. It should be noted that sealing a cavitated lesion with a mechanically more robust material might in fact be an option: The Hall Technique uses stainless steel crowns to seal cavitated lesions in primary teeth, which circumvents the problem of limited mechanical support and bond strength [49]. This topic will be covered in Chap. 8.

In conclusion, for cavitated carious lesions, non- and microinvasive strategies are usually unavailable. For such cavitated lesions, invasive (restorative) treatments are thus often needed. The aim of invasive (restorative) treatment is to recreate the surface integrity (and thereby prevent the progression of the lesion), as well as to restore form and function and aesthetics. If invasive therapies are needed for cavitated lesions, one could ask, why should they not be performed on non-cavitated lesions as well? This question will be answered in the following pages.

1.3 The Problems of Invasive Therapies

Providing dental restorations could be the perfect therapy for all lesions—regardless of their surface status—if restorations actually fulfilled all of the discussed aims: restoring form, function, and aesthetic for a lifetime. In such case, restorations would be “better than tooth tissue.” Such claims, however, are not supported by the clinical data (Table 1.1): While the annual failure rates of restorations vary widely between studies and restoration types, it is certain that statistically, all restorations have a finite average lifetime—although called permanent restorations, restorations are not “permanent”!

The failure of restorations due to fracture, secondary caries, or loss of the retention of an entire restoration would be of limited relevance (apart from lost time and cost to the patient) if it could be mended by placing the exact same restoration once more. Unfortunately, this is impossible: with every replacement, additional tooth substance needs to be sacrificed—to remove secondary carious tissue, to reshape the cavity, to remove remaining restoration parts, etc. [51]. The current evidence therefore strongly supports not completely removing partially faulty restorations, but to repair, repolish, reseal, or refurbish restorations instead, which limits the unnecessary loss of tooth tissue [52]. However, it is nevertheless likely that with every re-treatment, additional tooth substance will be lost. Restorations get larger and deeper with every cycle of treatments, which in turn eventually affects the longevity of the tooth.

Table 1.1 Annual failure rates of exemplary restoration materials placed in different cavitated lesions

Material combination	Mean (SD) annual failure rate (%)
Cervical permanent teeth	
3-step etch-rinse adhesive plus conventional composite	3.4 (2.0)
2-step etch-rinse adhesive plus conventional composite	6.7 (6.4)
2-step self-etch adhesive plus conventional composite	4.2 (4.0)
1-step self-etch adhesive plus conventional composite	5.2 (5.4)
Resin-modified glass ionomer cement	1.8 (3.1)
Load-bearing permanent teeth	
2-step etch-rinse adhesive plus conventional composite	1.1 (1.9)
2-step etch-rinse adhesive plus conventional composite	0.6 (1.6)
2-step self-etch adhesive plus conventional composite	1.2 (1.5)
2-step self-etch adhesive plus conventional composite	4.2 (3.4)
2-step etch-rinse adhesive plus bulk fill composite	1.8 (2.4)
2-step self-etch adhesive plus bulk fill composite	1.8 (1.4)
Load-bearing primary teeth	
2-step etch-rinse adhesive plus conventional composite	8.6 (9.2)
2-step self-etch adhesive plus conventional composite	0.0 (n/a)
2-step etch-rinse adhesive plus compomer	13.5 (13.1)
2-step self-etch adhesive plus compomer	7.8 (n/a)
2-step self-etch adhesive plus compomer	15.4 (n/a)
Amalgam	15.5 (18.0)
Resin-modified glass ionomer cement	5.1 (2.8)

Mean (standard deviation) rates are given, as reported in a recent systematic review [50]. As most restorative materials are not used alone, but in combination with an adhesive system, the annual failure rates of material combinations were assessed. Separate analyses for cervical and load-bearing restorations were performed; for the latter, permanent and primary teeth were assessed separately. n/a standard deviation not available

The process of repeated and escalating re-interventions on dental restorations has been termed the "death spiral of restorations" [53] or, as it eventually affects tooth survival, "the death spiral of teeth." This spiral (Fig. 1.7) is associated with repeated interventions, ever increasing treatment efforts and costs, and limited tooth survival. There are a number of ways to slow down this spiral: placing restorations which are as long-lasting, i.e., placed under near-ideal conditions by professionals with sufficient training and experience; repairing instead of replacing partially faulty restorations; lowering the risk of secondary caries by causally managing the disease caries. All these options might allow to slow down the spiral and thus retain teeth for longer, in elderly patients even lifelong. In younger patients, however, they might well be insufficient to "stretch" the death spiral over a patient's lifetime.

Avoiding entry to this spiral is therefore of absolute importance: Dentists should employ causal, noninvasive management options for avoiding caries and carious lesions wherever possible. They should strive to use sealants or other microinvasive alternatives if required to manage early carious lesions. Only as a last resort, they should provide dental restorations, knowing that they place the tooth on a path of no return.

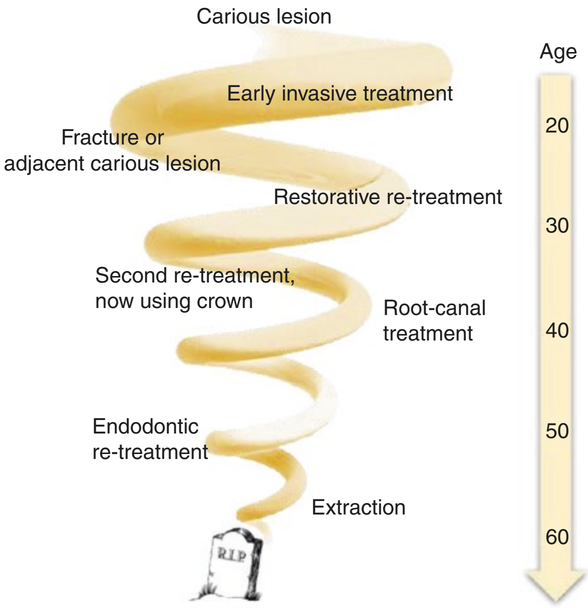

Fig. 1.7 The death spiral of the tooth. Repeated and increasingly invasive re-interventions eventually limit the lifetime of the tooth

1.4 Summary

- A changing understanding of the disease dental caries has initiated a paradigm shift in the management of caries and carious lesions. Instead of merely removing the symptoms of the disease (i.e., the carious lesion), the aim of any therapy should be to manage the disease, i.e., reduce the cariogenic activity of the dental biofilm and the resulting net mineral loss.
- Noninvasive strategies aim to control the causal factors of caries, and comprise biofilm control, dietary control, and mineralization control. They can also be applied to manage the activity of existing lesions.
- Microinvasive strategies comprise sealants or infiltration, and prevent the diffusion of acids into tooth substance as well as minerals out of the hard tissues. They prevent the initiation of carious lesions (in case of sealants) and control the activity of existing lesions (in case of both sealants and infiltration).
- Traditionally, these strategies have been used to manage caries and early, non-cavitated carious lesions. However, they can also be applied to cavitated carious lesions under certain circumstances: If cavitated carious lesions are cleansable, noninvasive strategies might well be able to control their activity. Non-cleansable lesions might be transformed into cleansable lesions in some cases. Placing a sealant is also theoretically possible for cavitated lesions, as sealed bacteria are deprived of dietary carbohydrates, which has been shown to inactivate them. The sealed lesion arrests. However, placing sealants on cavitated carious lesions has material-associated limitations. Carious dentin is softer than sound dentin and does not fully support the weak sealant against masticatory forces. Moreover,

bond strengths of dental adhesives and sealants to carious dentin are greatly reduced compared with sound dentin. Thus, sealants are currently restricted to non- or only minimally cavitated lesions. In the primary dentition, placing a preformed stainless steel crown as a sealant alternative (the Hall Technique) might be an option.

- In most cases, however, for cavitated lesions, invasive strategies involving the placement of a restoration are needed. Given the limited lifespan of restorations, however, such placement should be postponed as far as possible. If restorations are placed, the cycle of re-interventions on failing restorations could be slowed down, for example by repairing or resealing partially defective restorations, by prolonging restoration lifetimes via placing high quality restorations, by sealing over restorations, but also, essentially, by managing the cause of the dental caries; reducing the risk of secondary caries (caries adjacent to restorations).
- Given that restorations, however, still remain necessary in tomorrow's dentistry, one important question that needs to be answered is: How much carious tissue do we need to remove prior to placing a restoration? This question will be the topic of the next chapter.

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Removal Strategies for Carious Tissues in Deep Lesions

2

Falk Schwendicke and Nicola Innes

Abstract

It used to be considered preferable to remove all carious tissues with any signs of disease, regardless of the consequences, even at the expense of the hard tissue, causing stress to, or exposing, the dental pulp. However, it is now understood that this is not only unnecessary but also undesirable. Bacteria can be sealed under restorations, depriving them of nutrition and inactivating them.

In asymptomatic, vital teeth with deep lesions, strategies for conservative carious tissue removal which reduce tissue loss and pulp exposure risk have to be balanced against removing adequate tissue to maximize restoration longevity. The criterion used to guide carious dentin tissue removal is hardness, judged by tactile feedback during examination. The levels are described as: Hard, Firm, Leathery, and Soft Dentin. The four main strategies for carious tissue removal are: Non-selective Removal to Hard Dentin (now considered to be overtreatment and too destructive and not recommended); Selective Removal to Firm Dentin; Selective Removal to Soft Dentin; and Stepwise Removal.

Other strategies for managing deep carious lesions are: Non-Restorative Cavity Control where lesions are made cleansable, and Sealing-In strategies (including Fissure Sealing in permanent and primary teeth and sealing using a preformed crown in primary teeth). These strategies for managing carious tissues result in a change in the biofilm (reduced bacterial diversity, numbers, and

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cariogenic potential). The guiding principles behind removal and sealing are underpinned by a desire to preserve tissue, avoid pulp exposure, and maximize tooth longevity.

2.1 The Aim of Caries Removal

It was over 300 years ago that van Leeuwenhoek detected “animalcules” in the dental plaque of two street beggars, using his microscope to look at the scrapings from their teeth. This discovery paved the way for the idea that dental caries is a bacterial disease, discussed in the previous chapter. Following this, the concepts of dental caries pathology revolved around the idea that, as a bacterially associated disease, it was an infectious disease. This meant that carious dental tissues, enamel and dentin, were treated as “infected” and needed to be completely removed before a restoration could be placed [1], aiming to eradicate bacteria from the tooth (again, treating caries as an infectious disease). In doing this, there was no distinction between carious tissue that was bacterially contaminated (previously termed “infected”) and carious tissue that was non-contaminated but demineralized (previously termed “affected”) tissue. The aim was to remove all dental tissues with any sign of disease. This surgical excision of all tissue with any sign of disease was carried out regardless of the consequences and it was considered better to remove it all, even at the expense of unnecessary hard tissue loss, causing stress to, or exposing, the dental pulp. As a result, the restorative cycle and, with it, the “death spiral of the tooth” [2] were initiated (see Chap. 1).

The underlying aims of this historical carious tissue removal approach no longer apply [3]:

- Removing all contaminated tissue (note that this term better captures the presence of bacteria without giving the notion that caries is an infectious disease) is not necessarily required, as bacteria can be sealed under restorations, thus depriving them from their nutrition and inactivating/killing them [4].
- Removing all demineralized tissue or, specifically, demineralized dentin (which is, as discussed, softer than sound dentin and a suboptimal bond substrate) is not needed (at least not in the whole cavity). Demineralized dentin can remineralize as long as the collagen fibers are intact, and can be “healed” [5].
- Achieving additional undercuts within the cavity was advantageous when placing amalgam restorations, but is not required today when using adhesive restorative materials.

As discussed, theoretically, all carious lesions—also cavitated ones—could be sealed to arrest them. Practically, sealing cavitated carious lesions is often not possible, as the underlying soft dentin increases the risk of fracture, while the reduced bond strengths to such dentin increase the risk of retention loss. Thus, in many cases, SOME carious tissue removal is needed prior to placing a restoration. Consequently, the aim of carious tissue removal is to increase the longevity of the subsequently placed restoration by removing some or most aspects of carious dentin and enamel.

An additional aim could well be to remove most bacteria from the cavity to improve pulp outcomes. Two things, however, need to be highlighted here: Firstly, there is no strong data supporting the theory that large amounts of sealed bacteria harm the dental pulp. Secondly, the aim of removing bacteria to protect the pulp should never be superordinate to the aim of not harming the pulp during tissue removal. This immediately leads to the principles and priorities which should drive carious tissue removal.

2.2 Principles and Priorities

Based on this logic and the previously stated aim of why carious tissue is removed at all prior to placing a restoration, there are agreed guiding principles for carious tissue removal [3, 6]:

- “preserve non-demineralized and generalizable tissue;
- achieve an adequate seal by placing the peripheral restoration onto sound dentin and/or enamel, thus controlling the lesion and inactivating remaining bacteria;
- avoid discomfort/pain and dental anxiety (…)
- maintain pulpal health by preserving residual dentin (avoiding unnecessary pulpal irritation/insult) and preventing pulp exposure (…)
- maximize longevity of the restoration by removing enough soft dentin to place a durable restoration of sufficient bulk and resilience” [3].

However, the last two points conflict:

- Avoiding pulpal exposure is most relevant in deep lesions in teeth with vital, symptomless pulps. Any kind of exposure will be managed using endodontic treatments, which have either a poor prognosis (like direct capping) or are highly invasive and often shorten the lifetime prognosis of the tooth (e.g., root-canal treatment) [7–9]. It can be argued that under some circumstances direct capping of exposed pulps (under microscopic magnification using specific dressings, like mineral trioxide aggregate) will result in better outcomes than with conventional direct capping (without magnification and using calcium hydroxide based dressings) [10–13]. Similarly, alternatives for maintaining pulp vitality such as pulpotomy might be used to manage pulp exposures [14–16]. However, none of these methods has, so far, been unambiguously shown to be superior to the existing standards [17] or has entered routine clinical practice [18].

– Leaving carious dentin beneath restorations means leaving possibly soft, bacteria-containing, demineralized dentin with lower elastic modulus and reduced bonding capabilities than sound dentin. A number of *in vitro* studies show, to varying degrees, the possible detrimental effects of leaving such dentin on restoration integrity [19–21]. Also clinical studies find that very large amounts of carious dentin left under a restoration might destabilize the restoration [22–24].

In deep lesions in teeth with vital pulps, free from pathologic signs and symptoms, both aims need to be balanced against each other: in areas of deep lesions which are not at risk of pulp exposure, enough carious dentin will be removed to maximize restoration longevity, while in areas close to the pulp, pulp exposure needs to be avoided, and carious dentin should be left if possible (without compromising the restoration survival). However, the biggest problem is assessing this during carious tissue removal. How can this be done?

2.3 Assessing Carious Tissue Removal

A large number of studies have described carious tissue removal strategies for managing cavitated lesions. These studies have used a vast range of terms to assess and describe what was removed, what was left, and how exactly this was done. A number of issues should be clarified:

- Firstly, it is important to remember that the clinical appearances of carious tissues both during initial inspection (including radiographic assessment) and during removal do not always correlate with histologic findings (yielded from assessment of removed teeth, for example). There are a number of histologic terms, for example, which can be used to describe layers of carious dentin, and theoretically, one could relate carious tissue removal to these layers. However, as can be seen in the cross-sectional image of a tooth, it is obvious that these layers do not have clear-cut boundaries, but merge into each other, often gradually (Fig. 2.1). The resulting clinical appearance (for color or hardness characteristics, for example), also, therefore, appears as a gradient (Fig. 2.2), too: clinicians cannot clearly distinguish bacteria-containing from demineralized dentin, for example.
- Secondly, it is also important to note that no study so far has found it relevant to remove or leave carious dentin of a specific quality or a specific layer. Instead, the principles above should be adhered to, as these are based on clinical evidence. Thus, in summary, carious tissue removal strategies should not pretend to remove specific carious tissues or layers; giving them names like "complete" or "incomplete" excavation is therefore not helpful. For example, it remains unclear what "completely" or "incompletely" removed actually means (bacteria? soft

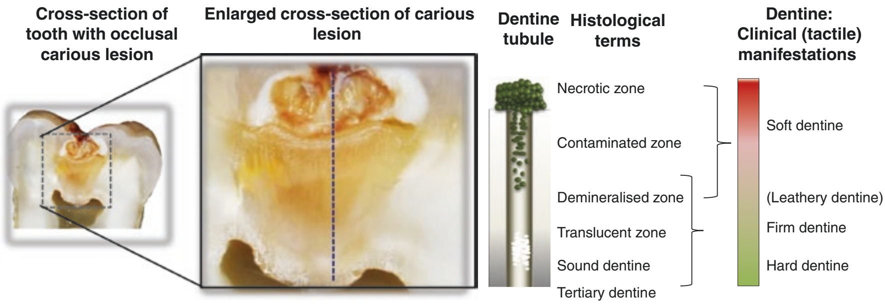

Fig. 2.1 Diagrammatic representation of the cross section of a carious lesion (after Ogawa et al. 1983 [25])

Fig. 2.2 Lower primary molar showing a gradient of color from *black* through *dark brown* to *light brown*, *golden yellow*, and *white*

dentin? discolored dentin? hydrolytically degraded dentin?). Moreover, it is very unlikely that any removal will be perfectly "complete" or "incomplete" (regardless of which criterion is chosen), as—again—the gradual changes between different dentin qualities will make it very hard for a clinician to be able to gauge accurately what exactly was removed or left (at least with most current means for assessing carious tissue removal). It might therefore be best not to describe carious tissue removal in terms of what one aims to do (completely or incompletely remove carious dentin), but how one aims to perform the removal (until soft dentin is removed, etc.). This is the approach that will be taken in this book.

One criterion, which has been consistently used in both daily practice and dental research, is the hardness of the removed or retained dentin [26]. In this book, hardness will be one major aspect to assess and describe carious tissue removal, which is why, although in some ways subjective, we will now describe what is meant when talking about soft, leathery, firm, and hard dentin [6]:

- Soft dentin: “Soft dentin will deform when a hard instrument is pressed onto it, and can be easily scooped up (e.g., with a sharp hand excavator) with little force being required.”
- Leathery dentin: “Although the dentin does not deform when an instrument is pressed onto it, leathery dentin can still be easily lifted without much force being required.” The hardness of leathery dentin is between that of soft and firm dentin.
- Firm dentin: “Firm dentin is physically resistant to hand excavation and some pressure needs to be exerted through an instrument to lift it.”
- Hard dentin: “A pushing force needs to be used with a hard instrument to engage the dentin and only a sharp cutting edge or a bur will lift it. A scratchy sound or ‘cri dentinaire’ can be heard when a straight probe is taken across the dentin.”

The hardness criterion has been validated against clinical outcomes in several studies [27]. Hardness is assessed using probes, or via tactile feedback during excavation. Hardness of the dentin correlates with the residual bacterial numbers within the dentin [28], with dentin softening preceding bacterial invasion [25, 29, 30]. Removing bacteria is not the focus of managing deep carious lesions, which is why this aspect is not central when judging an assessment strategy. However, carious tissue removal until only hard dentin remains has been found detrimental with regard to maintaining pulp vitality in teeth with deep carious lesions [27].

A range of other criteria for assessing the removed and retained dentin have been described, including moisture, color, dye stainability, etc. Most have been validated *in vitro*, often against the description “removal of bacteria” (which, as previously discussed, was historically relevant but does not seem to be central these days, at least when considering clinical outcomes for pulp vitality). More important, most methods have not been validated clinically and have not (yet) been found truly beneficial for patients. Instead, some of them, like stainability via caries detector dyes (see below), have been found harmful when dealing with deep lesions [27]. Thus, we will only briefly summarize the available evidence on further criteria:

- Moisture is associated with bacterial numbers, with moist or wet dentin harboring more bacteria than dry dentin, but so far there are no studies evaluating what the clinical impact might be of leaving or removing all moist dentin [27].

Although moisture often correlates with hardness, it is subjective and more difficult to assess (at least by tools currently available in the dental surgery), and it is therefore recommended that moisture is not the focus, but that hardness is instead assessed for evaluating carious tissue removal.

– In the past, color has been recommended as an indicator for carious lesion activity and the need to remove tissue. However, color is associated with a wide range of factors, among them the (past) presence of bacteria (bacterial by-products stain the dentin), but also the incorporation of external stains (for example, from existing amalgam restorations—Fig. 2.3—and foodstuffs). It is often the case that inactive lesions can be highly stained (dark, brown) (Fig. 2.4), but they can also be pale (Fig. 2.5). Removing such hard dentin, whether it is light or dark is, of course, not required and should be avoided. Therefore, color is not a good indicator of activity and instead of color, hardness should be assessed.

Fig. 2.3 Dark staining from an adjacent amalgam restoration, within a cavity that has been opened. The dentin is hard

Fig. 2.4 Dark and light carious dentin lesions. The dark lesions are hard to touch and arrested but the light lesions are soft and still active

Fig. 2.5 A *golden* colored lesion that is very hard to touch and inactive

– A method to determine the degree of bacterial contamination during carious tissue removal is Fluorescence Aided Caries Excavation (FACE). Because dentin, which has not been bacterially invaded, displays strong green autofluorescence in contrast to bacterially contaminated dentin, which exhibits red autofluorescence caused by bacterial by-products (porphyrins) [31], FACE can distinguish both types of dentin by using a violet light for excitation and a highpass filter to allow visual assessment of whether the tissue is bacterially invaded (red fluorescence) or not (green fluorescence) [32]. This is possible without the need for fluorescent dyes because it is based on tissue autofluorescence. FACE can be carried out using either SiroInspect (Sirona, Wals, Austria) or Fluoresce HD (Lares Research, Chico, CA, USA). Using FACE, the dentist can see which areas are heavily contaminated and which are not (Fig. 2.6). It is then up to the dentist to decide which areas need removal, while FACE might make removal more efficient as repeated probing of the dentin to measure hardness is not needed [33]. However, and most important, when treating deep carious lesions near to the pulp, removal of bacteria is not central, while maintaining pulp integrity is. FACE should be used with such considerations in mind; using it appropriately might allow to be efficient while selectively removing carious tissue. Because it is a relatively new method, long-term clinical investigations are still lacking and should be performed in the future [27].
– Caries detector dyes have been used for staining carious dentin, the idea being selective uptake of dye molecules into bacterially degraded dentin, but not non-degraded demineralized or sound dentin. Clinically, this highly selective stainability has not been demonstrated, mainly as no clear-cut border exists between different dentin layers as has been described above [34–38]. Instead, a color gradient of dye stain can be found in most cavities; in some instances, reactionary (tertiary) dentin is stained (as its structure is different from that of primary or secondary dentin), which could lead to removal of this non-carious dentin. Clinical studies have found the use of caries detector dyes to lead to more pulp

exposures and complications, which is why this assessment method is not recommended for deep lesions (at least not when using it to remove all stained dentin) [27].

In summary, the most common and versatile criterion for assessing and describing carious tissue removal is hardness of the dentin remaining in the cavity (or, vice versa, hardness of the removed dentin). Using these terms for describing differently hard dentin layers, one can deduce four main strategies for carious tissue removal which have been established in the last decades.

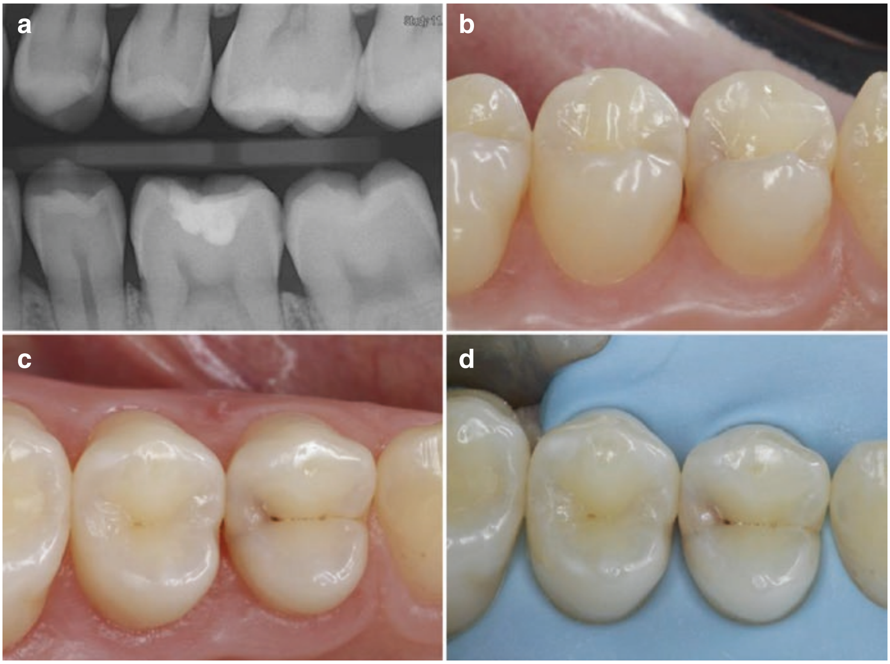

Fig. 2.6 (**a**) Bitewing radiograph showing a moderately deep carious lesion (middle third of dentin) in an upper left premolar (tooth 24) with high likelihood of a cavitated interproximal enamel surface. Tooth 24 showing clinical signs (dark and opaque appearance with distinct interproximal enamel breakdown) of a deep distal caries (**b**–**d**). Access cavity showing carious dentin under normal (**e**) and fluorescence light conditions using Fluorescence Aided Caries excavation with SIROInspect (**f**), where red autofluorescing, heavily contaminated dentin areas can clearly be distinguished from *yellow* to *green* fluorescing dentin which is not heavily invaded by bacteria. Situation after complete removal of *red* fluorescing dentin in the periphery, while some slightly *red* fluorescing dentin at the pulpal wall was left behind in order to avoid pulp exposure (**g** and **h**). Complete minimally invasive adhesive preparation (**i**) with matrix (**j**) in place (here: Palodent, Dentsply-Sirona; (**k**) Selective enamel etching with 37% phosphoric acid gel and application of an adhesive (here: Scotchbond Universal, 3 M–Espe, **l**). Application of consecutive increments of a nano-hybrid composite (here: Filtek Supreme XTE, 3 M–Espe, **m**–**p**). Completed restoration after removal of the rubberdam (**q**–**r**). Courtesy of Prof. Wolfgang Buchalla, Regensburg

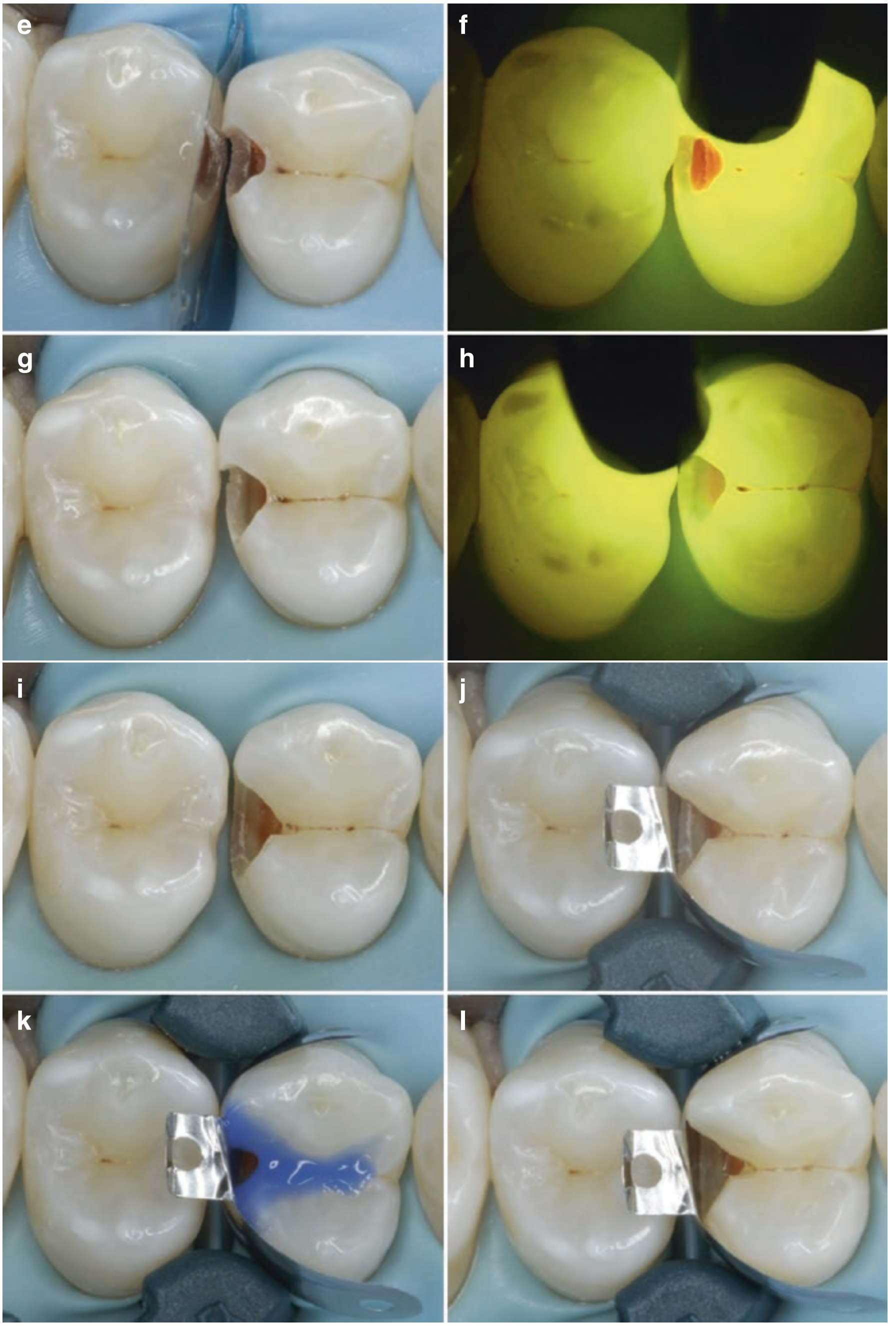

Fig. 2.6 (continued)

Fig. 2.6 (continued)

2.4 Removal Strategies

As these four main removal strategies will be discussed in detail in the next chapters, we will only briefly present an overview over these strategies here (Fig. 2.7):

Fig. 2.7 Removal strategies. (**a**) For deep carious lesions in teeth with sensible pulps, four strategies are available. (**b**) Non-selective removal to hard or firm dentin, which is not recommended for deep lesions, was the historically recommended approach. All softened and moist or even discolored dentin was completely removed from all of the cavity. (**c**) In stepwise removal, in the first step soft dentin is left in proximity to the pulp, and sealed temporarily. In the periphery, hard dentin is left, supporting the restoration and allowing a tight seal. The soft dentin is removed after 6 or more months (*dashed line*), until only firm dentin remains in the pulpo-proximal areas. (**d**) In selective removal to soft dentin, soft dentin is left in proximity to the pulp to avoid pulp exposure; hard dentin is left peripherally. (**e**) No Removal, involving non-restorative cavity management, fissure sealing, or—as shown—the Hall Technique

2.4.1 Non-Selective Removal to Hard Dentin

Non-selective Removal to Hard Dentin (formerly also known as "complete removal") aims to remove soft dentin, stopping the removal only when hard dentin (similar to healthy dentin) is reached. This is aimed for in all areas of the cavity: as the same criterion (the same endpoint) of carious tissue removal is used both peripherally and pulpally, it is termed non-selective (compare with selective removal, see below) [6].

Non-selective Removal to Hard Dentin includes the removal of demineralized dentin, which is in conflict with modern aims and the guidelines stated above. It is overtreatment and not necessary. Moreover, in deep carious lesions with vital painless pulps, such removal bears significant risks for the pulp [26, 39]. While this approach was the standard in the past, it is now considered overtreatment and not recommended any longer, especially when dealing with deep lesions in teeth with vital pulps [3]. It is not only not necessary, but also not desirable.

2.4.2 Selective Removal to Firm Dentin

In Selective Removal, not one but several different criteria (endpoints) are used to assess carious tissue removal in the periphery of the cavity and in proximity to the pulp. As described above, one guiding principle during carious tissue removal is to create an environment which allows the best adhesive seal for a restoration. This aim can be achieved when there is sound enamel and hard dentin at the periphery of the cavity. This approach also serves another guiding principle, maximizing restoration longevity. In the pulpal area of a cavity, however, another criterion (endpoint) is used, with firm dentin being left [6]. Although removable, this firm dentin is physically resistant to hand excavation and requires effort to remove it.

This approach is recommended for shallow or moderately deep lesions, but not deep lesions (i.e. those extending beyond the pulpal third or quarter of the dentin radiographically) in teeth with vital pulps, as even removal to firm dentin risks pulp exposure and harm. The reason for it often being required for shallow or moderately deep lesions is that the cavity depth needs to be sufficient to allow enough sound enamel and dentin around the periphery for good quality bonding and a complete peripheral seal to be achieved.

2.4.3 Selective Removal to Soft Dentin

Selective Removal to Soft Dentin is recommended for deep carious lesions in teeth with vital painless pulps. Here, in the pulpal area of a cavity, avoiding pulp exposure and maintaining remaining dentin thickness are prioritized. Consequently, it is expected that leathery or, if needed, soft carious dentin will remain in the pulpal aspect of the cavity, serving the guiding principle of maintaining pulp vitality. A sharp excavator or a probe can be used to check the remaining carious dentin, which will deform and can be lifted up under little force [6]. In the periphery, achieving a good seal and maximizing restoration survival are prioritized, with peripheral enamel and dentin again being hard at the end of the removal process (Fig. 2.8).

Selective Removal to Soft Dentin has been convincingly shown to reduce the risk of pulpal exposure compared with Non-Selective Removal to Hard or Selective Removal to Firm Dentin [26, 27, 39]. Note that this removal technique has been previously known as partial or incomplete removal.

2.4.4 Stepwise Removal

Stepwise removal is carious tissue removal in two steps (visits) [40–42], essentially combining Selective Removal to Soft Dentin in the first step and, 6–12 months later, Selective Removal to Firm Dentin in the second step, with the carious dentin being sealed beneath a temporary restoration in-between. In the first step, demineralized soft dentin is left pulpally, aiming to avoid pulp exposure and irritation, while peripherally, carious tooth tissue is removed until only hard dentin is left, allowing a complete peripheral seal. For the temporary restoration, a restorative material should be chosen that will be durable for at least 12 months or (better) longer, as patients might not return before that, with lost temporary restorations being one major risk for stepwise excavated teeth [43]. It is also helpful for the material to be easily differentiated from tooth substance to avoid tooth removal accidentally when removing the temporary restoration during the second stage of the stepwise process. In the 6–12 months period between steps, sealed bacteria are deprived of dietary carbohydrates, with significantly reduced bacterial numbers in the carious dentin being found at the second step stage [41]. Furthermore, the remaining carious dentin is remineralized within this sealing period (with minerals obtained either from restorative materials, as described in Chaps. 3 and 5, or from the pulp), and reactionary (tertiary) dentin development is stimulated. All these mechanisms help to reduce the risk of pulp exposure in the second step (as less dentin needs to be removed and

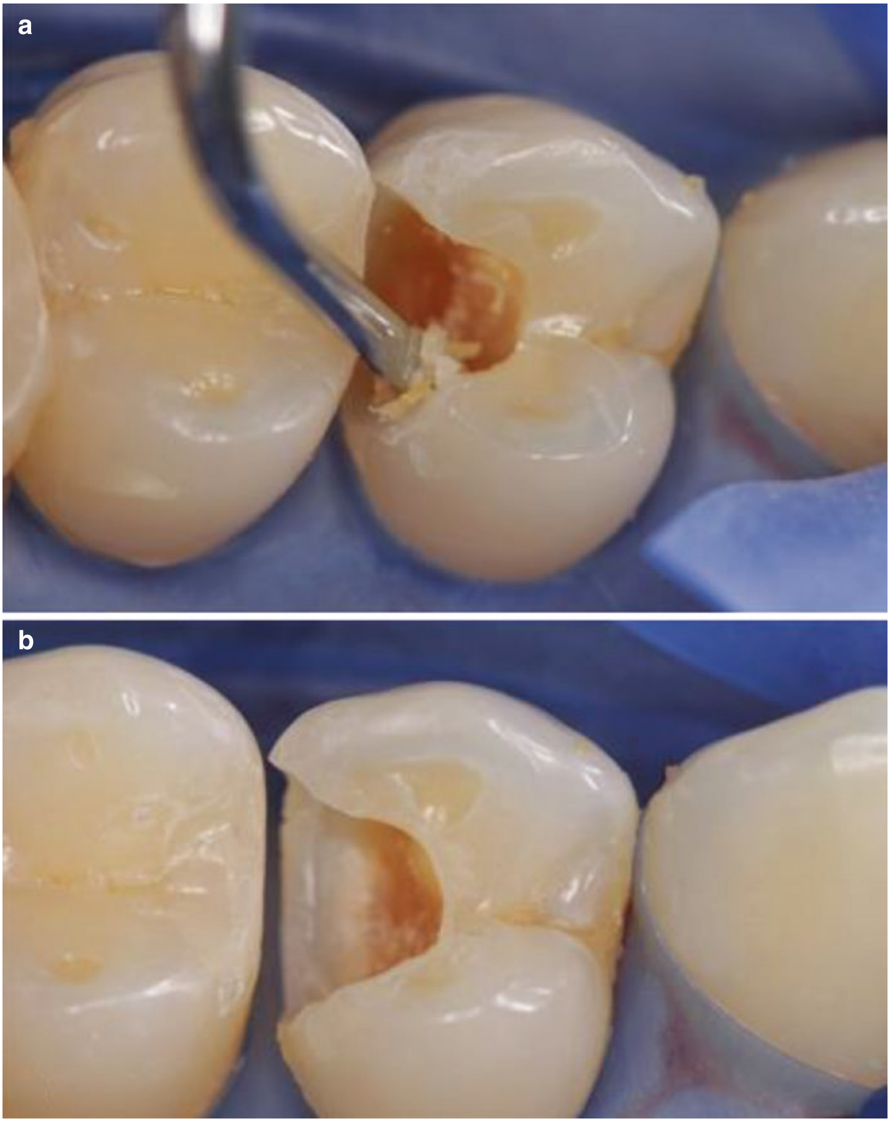

Fig. 2.8 Selective removal to soft dentin. A deep lesion in a tooth with a sensible tooth is treated. (**a**) In the periphery, only hard dentin, similar to sound one, and sound enamel is left. In the periphery, very soft dentin is spooned out with a hand excavator; (**b**) the remaining dentin is leathery, moist and discolored, and sealed under the restoration

the residual dentin thickness above the pulp is higher). After 6–12 months, the temporary restoration is removed and Selective Removal to Firm Dentin carried out until only firm dentin remains also pulpally. Note that this technique has previously been also known as “two-step excavation.”

Stepwise removal has been shown to have higher risks of pulp exposure and, from the evidence so far, there seem to be equivalent restorative outcomes when compared with Selective Removal to Soft Dentin. It also adds costs, time, and discomfort to the patient without any tangible benefit [26, 43, 44]. This implies that there needs to be good justification for stepwise removal to be carried out. Such justification will be given in the next chapter.

2.5 Other Strategies for Managing Dental Carious Lesions

Having discussed the different strategies involving removal of the carious lesion to a greater or lesser extent and the situations where these might be applied, we now move on to summarize strategies for carious dentin where there is no active tissue removal carried out by the clinician.

2.5.1 Sealing in Strategies

There are currently only two situations where the carious lesion is not removed at all but only sealed into the tooth; fissure sealing over carious lesions and the Hall Technique for primary molar teeth.

2.5.2 Fissure Sealing

The first studies in this direction did not perform fissure sealing, but used "ultraconservative caries removal and sealing" with a restorative material. The landmark study investigated carious lesions extending up to halfway into dentin, i.e. does not directly relate to our discussion on management of the deep carious lesion [45]. The study looked at sealing in all of the carious lesion in permanent teeth using bonded and sealed composite restorations placed directly over frank cavitated lesions. These were compared with sealed conservative amalgam restorations and conventional unsealed amalgam restorations. The main aim of the study was to look at the materials; restoration longevity but also other outcomes such as pulpal pain were recorded. At 10 years (54% follow-up), both types of sealed restorations showed better clinical performance and longevity compared with the unsealed amalgam group. The authors also noted that, over the 10 years of the study, the bonded and sealed composite restorations arrested the clinical progress of these lesions. However, this is the only study on ultraconservative carious lesion management and did not include deep lesions. Although perhaps leading to the conclusion that further investigation is merited, the evidence does not support it being recommended as a standard part of practice and is not directly relevant to deep lesions.

Nowadays, fissure sealing over carious lesions can be used for both permanent and primary teeth but is limited to cases where the enamel surface is relatively intact. However, although there is a growing body of research to support it [46], the research still lacks the level of detail to be able to give certainty to how deep or how extensive a lesion can be before fissure sealing is not adequate to provide a long-lasting solution [47]. The problems with fissure sealing extensive lesions are likely to be twofold.

Firstly, fissure sealant materials are low filled resins and do not have structural strength to withstand force. If a piece of cured sealant material is taken between the fingers, it can be snapped very easily. On the top of a sound tooth, this does not matter (although sealants do wear and break) because the material is placed on tooth structure that will support it. However, in the case of a deep lesion, even where there is very little cavitation visible (usually because the breach in enamel is at the base of a fissure and cannot be seen), the dentinal lesion has demineralized the dentin. While healthy dentin has around 70% mineralization, after being affected by the acids from the biofilm this is greatly reduced. This weakening is compounded by the proteolytic enzymes that are also travelling down the dentinal tubules and denaturing the collagen. Secondly, formerly moist and soft carious tissue becomes hard and dry while being sealed. This shrinkage and drying has not been quantified (stepwise removal studies have investigated it) but it is likely to have the effect of leaving the sealant on a base that is not sound; sealants placed under such conditions might not be strong enough to withstand masticatory forces (see Chap. 1).

Taken together, the underlying weakened dentin (caused by the carious lesion) and the possible sealed lesion drying and shrinking (when it is successfully sealed), means that placing a fissure sealant over a weak structure and then subjecting it to biting forces could result in a "trampoline" type of effect on the tooth and fracturing of the enamel. The sealant, while working well to seal the lesion, may not rebuild much of the tooth structural strength once it has been compromised.

2.5.3 The Hall Technique

The Hall Technique is a method for managing carious lesions in primary molars by sealing them in under preformed metal crowns (Fig. 2.9). The crowns are designed for primary teeth but have traditionally been used following "complete" caries removal (and often a pulp therapy) and after the teeth have been prepared for the crown. With the Hall Technique, after determining clinically and radiographically that the lesion has not irreversibly damaged the dental pulp, there is no carious tissue removal at all. The correct size of crown is chosen and simply pushed over the tooth to seal the lesion and the whole coronal tooth structure under the crown. Data on the Hall Technique has been published over the last 10 years with robust evidence from several randomized control trials. These have found the Hall Technique superior to comparator treatments, with success rates (no pain or infection) of 99% (UK study) [48] and 100% (Germany) [49] at 1 year, 98% and 93% over 2 years (UK and Germany), and 97% over 5 years (UK) [50]. The Hall Technique is now regarded as one of several biological management options for carious lesions in primary molars.

Fig. 2.9 Three crowns placed, using the Hall Technique, on upper primary molars. The teeth have not been prepared and no carious tissue was removed. The correct size of the crowns to fit over the teeth was chosen, the crown filled with glass ionomer cement, pushed over the teeth and held, by the child biting until the cement set

2.5.4 Atraumatic Restorative Treatment (ART)

This is a specific technique for carious lesion management using hand instruments only to remove carious tissue. Excavation is carried out to firm dentin in shallow lesions and to soft dentin in deep lesions. The cavity is restored and then the pits and fissures are sealed with an adhesive material such as a resin fissure sealant or high viscosity glass ionomer cement.

2.5.5 Non-Restorative Cavity Control (NRCC)

Non-restorative cavity control is a method for managing carious lesions by making them cleansable, where a decision has been made not to restore them (Fig. 2.10). The decision may have been made because the tooth is not restorable or because there is no clinical need to restore the lesion based on the principles and priorities stated before. The technique is generally limited to primary teeth or to root surface caries although it may have an application in groups with very high caries rates where there is a need to stage treatment through a stabilization phase.

Each tooth is judged on its own merits as to whether this is a suitable treatment option. However, more importantly, there are a number of additional conditions that have to be satisfied for NRCC to be successful including willingness and ability of the patient or the parent/carer to accept responsibility and their role in ensuring the success of the procedure.

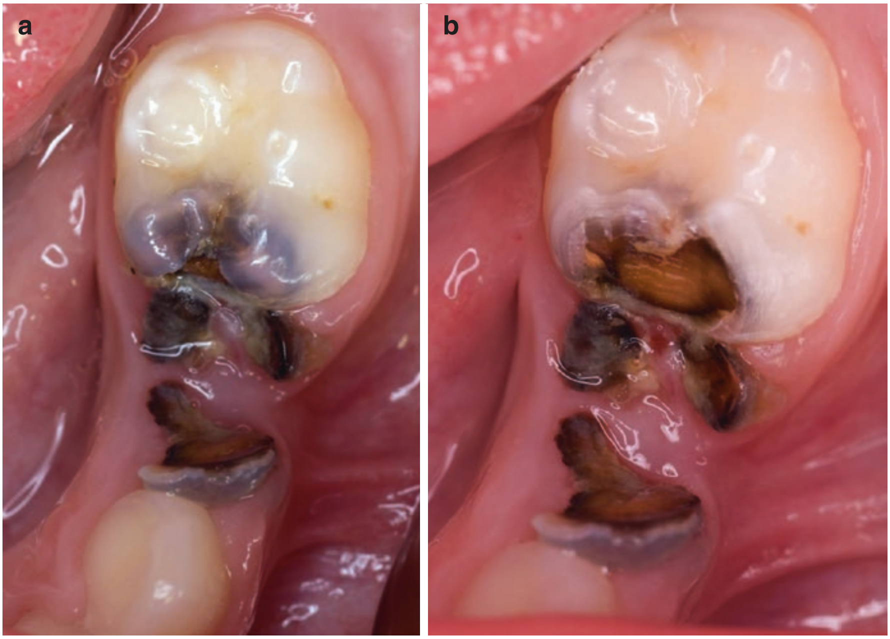

Fig. 2.10 (**a**) Lower second primary molar before the lesion is opened up using an air rotor with a diamond bur to remove enamel and some carious dentin. (**b**) After the lesion has been opened to expose the lesion to the oral environment transforming it from a sheltered highly cariogenic environment to a cleansable lesion. The parents were shown how to clean the lesions, and fluoride varnish was applied to them every 3 months to encourage remineralization. More information, also regarding to the managment of the retained carious roots, are given in Chap. 8

The cavities are made accessible to a toothbrush or adjunctive cleansing device. There may or may not be regular application of a fluoride-based substance such as fluoride varnish or silver diamine fluoride to the cavity and sometimes a layer of resin-modified glass ionomer cement-lining is placed (after removing the biofilm with a prophy brush and toothpaste). Lesions are monitored over time for progression, and there is intensive communication (using a theory-based approach such as motivational interviewing or coaching) and action planning to motivate the patient or their parent/carer to clean.

There has been very little high quality research into NRCC [49, 51]. The technique is still commonly misunderstood as a "do nothing" treatment but is actually very much the opposite. It requires twice daily maintenance, and not by the clinician; their responsibility is to hand over care of the lesion to the patient or parent/carer. This can be more challenging than carrying out technically difficult dentistry. We discuss it more in Chap. 8.

2.6 Summary

- The hardness of the retained or removed dentin can be used for describing and assessing carious tissue removal.
- Non-selective Removal to Hard Dentin is overtreatment, removes unnecessary tissue, and increases the risk of pulp exposure.
- For deep carious lesions in teeth with vital, painless pulps, three of the four strategies presented, namely Selective Removal to Soft Dentin, Stepwise Removal, or Sealing, can be carried out. These are presented in more detail in the subsequent chapters of this book.
- Strategies for conservative carious tissue removal have to be balanced against removing adequate tissue to maximize restoration longevity.

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Deep Carious Lesions: Understanding and Challenges

3

Lars Bjørndal

Abstract

In this chapter, focus is extended on the local cariogenic environment within deep stages of carious lesions. When examining various stages of deep lesions in many patients, a systematic pattern of clinical signs are exposed, that quite often are specifically related to changes of the local cariogenic environment, e.g., the undermined enamel has been broken down. When following the same carious lesion over time, a number of clinical variables can be taken into account, in particularly when carious dentin is clinically detectable, to assess lesion activity. The intra-lesion dentin characteristics over time comparing an active "closed" lesion environment (yellow/light-brown, soft and wet carious dentin) versus a slowly progressing "open" lesion environment (darker, harder and drier dentin) reflect the basic mechanism that modulates lesion activity in untreated lesions. This know-how is used as a concept during the intervention for deep carious lesions. In short, the treatment and control of deep lesions are inspired from the events taken place during natural deep caries progression and show that activity can be monitored using well-known dentin variables.

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3.1 Background and Aims

The previous chapters of this book have dealt with the general aspects of the pathology of caries, carious lesions, and the management of both. The remaining chapters of this book will deal specifically with deep carious lesions. This chapter will therefore expand on the specifics of deep lesions—what is different in such lesions compared with other lesions, what are the challenges, and based on what biologic principles should dentists approach such lesions?

In many Western countries a decline of the speed of lesion progression is noted [1, 2], resulting in more and more carious lesions that can be managed non- or micro-invasively (see previous chapters). So are deep lesions still relevant? The answer to that question is unambiguously yes! That is, as untreated cavitated carious lesions are the most frequent disease affecting mankind [3], burdening billions of individuals with pain, limited masticatory functions and impaired aesthetics. In addition, it is known that a significant percentage of untreated lesion which has penetrated less than half into the dentin may develop to much deeper stages of penetration already within a year or so [4], hence presenting potential complications for the subjacent pulp. Deep cavitated carious lesions are the main cause for performing endodontic interventions [5] and loosing teeth [3].

The deep carious lesion often obtains a peculiar role of "sitting between two chairs," because dentists often aim for either saving the pulp by all means or, assuming irreversible pulp inflammation, removing it by performing endodontic treatment. It is the aim of this chapter to discuss aspects of treatment selection for well-defined deep lesions. We will base this discussion on the answers to one question: What do we know about the deep lesion pathology and the response pattern of the subjacent pulp tissue?

3.2 Understanding Deep Lesions

The pathogenesis of dental caries is currently based on the concept of the ecological plaque hypothesis [6]. As introduced in Chap. 1, the hypothesis highlights the interplay between the environment surrounding the lesion and its importance for both the growth (quantity) and the actual composition of the cariogenic microbiota in the biofilm and the lesion.

The relevance of the ecological plaque hypothesis can be well demonstrated when assessing the changes in the dental ecosystem in so-called "closed lesions" compared to "open (cavitated) lesions," with carious dentin being soft light yellow and wet in the first stage; while after the breakdown of the undermined enamel (Fig. 3.1a–c), the environment within the lesion markedly changes, leading to different clinical appearances of the carious dentin. Similar signs of environment change can be seen during when carious lesions are sealed as briefly discussed in the previous chapter, with soft, moist and yellow dentin being transformed into dark, hard and drier dentin after a sealing period (Fig. 3.1d–f). A third example of "natural" lesion arrest following breakdown of undermined enamel can often be shown in an upper front teeth (Fig. 3.2), as has also been demonstrated in Chap. 1.

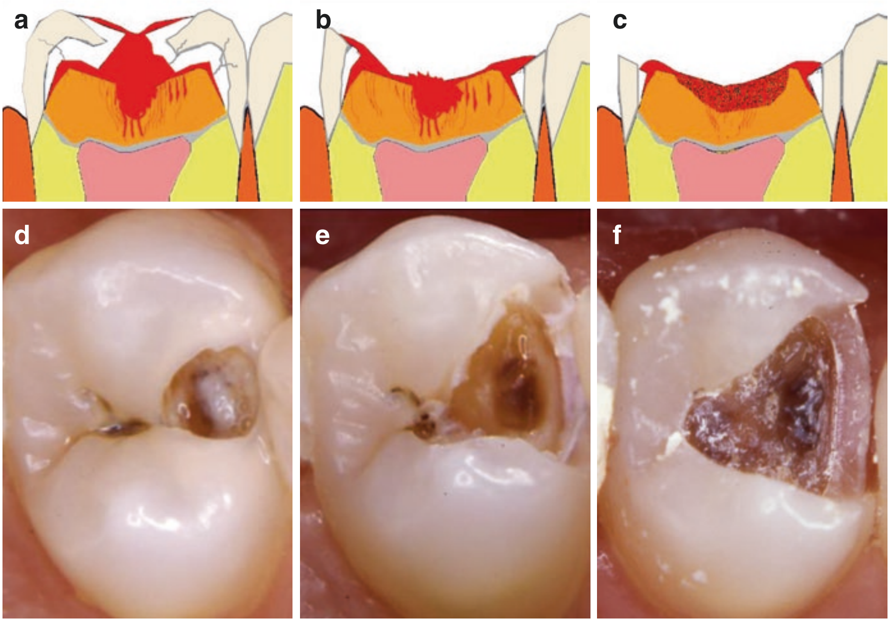

Fig. 3.1 Principle illustration of a so-called "closed" lesion environment defining an active cariogenic environment (**a**), during mastication undermined enamel breaks off (**b**); and the growth condition for the biofilm has changed markedly converting the environment into a slower progressing ecosystem (**c**) (**a**–**c** modified from [7]). The clinical demonstration of this concept can of course only be shown during an active intervention (**d**–**f**). A close cariogenic environment is noted, the undermined enamel can be seen surrounding the cavity, as a whitish change in translucency (**d**). In this principle demonstration only the enamel is removed exposing the yellow, soft and wet carious dentin (**e**). After a time interval including the removal of a temporary filling, the carious dentin has changed into a darker, harder and drier clinical appearance (**f**)

Fig. 3.2 Clinical examples of natural arrested/slowly progressing lesions. The ongoing breakdown of the undermined enamel makes it difficult for a biofilm to grow fast. However, along the borderlines of the lesion the biofilm can still be covered/protected, whereby further breakdown of the enamel eventually will take place if no intervention occurs

3.3 The Pathology of Deep Lesions

Before going into detail concerning the clinical assessment of carious tissue removal, an update of lesion histopathology and the pulp is presented.

The pulp reacts to a cariogenic stimulus at a very early stage. Already in case of superficial enamel demineralization (i.e., outer 1/3 of the enamel layer), studies on undemineralized tooth sections have shown that the odontoblast cell size is reduced and a less distinct cell-free zone within the sub-odontoblastic region is formed (Fig. 3.3). Notably, these very early signs of pulpal response are beyond any clinical signs of pulp inflammation, because at these early stages of lesion progression there is no dentin demineralization or any bacterial contamination of the dentin [8]. In contrast, what can be expected is the formation of a higher level of mineral within the intratubular environment of the dentinal tubules. The so-called translucent or hypermineralized dentin is in fact the first histological visible zone in the dentin in relation to a carious lesion and presumably established as a result of the described cellular reaction at the odontoblast cell level. This reaction can be compared with the physiological age-related process that takes place in the odontoblast–dentin pulp

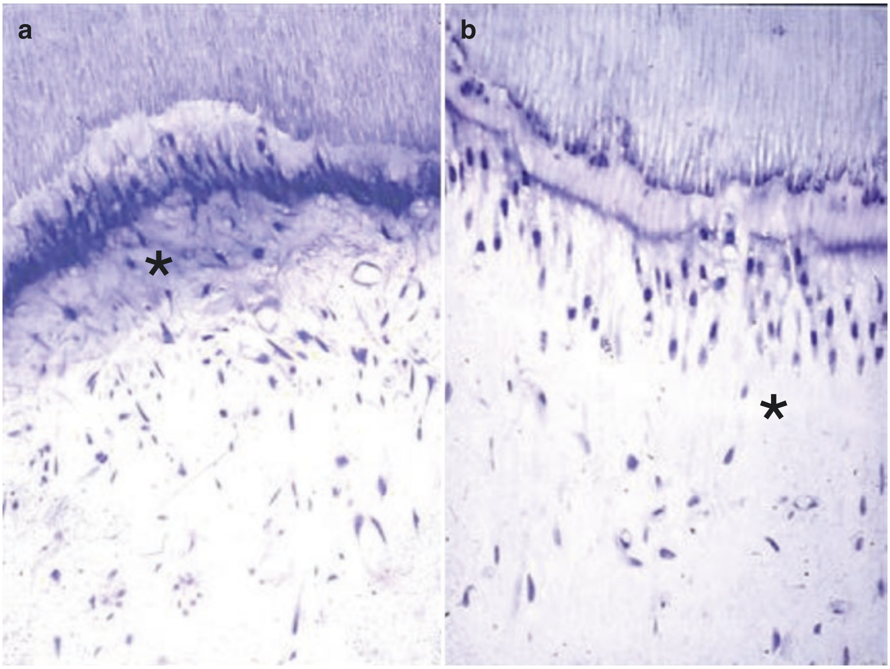

Fig. 3.3 Subjacent an enamel lesion, a reduction of the odontoblasts is an early sign to the cariogenic stimuli transversing the dentin, combined with an indistinct cell-free zone (**a**, *asterisk*), compared with the well-defined sub-odontoblastic region in an unaffected control site (**b**, *asterisk*). Modified from [8]

complex [9], which is also known to lead to a markedly reduced permeability due to intratubular mineral deposition [10]. This permeability-reducing process as a reaction to initial carious lesions may trigger the unset of programmed cell death as well [11]. Eventually, when the demineralization reaches the enamel–dentin junction (EDJ), the dentin becomes affected, with the zone of hypermineralized dentin being the first area of mineral loss within the dentin (Fig. 3.4).

As long as the enamel lesion is without any surface cavitation, microorganisms remain at the surface enamel. The higher porosity created by demineralization (at the enamel rod level) does not create a space sufficiently wide for bacteria to penetrate along the demineralized rods. An actual bacterial penetration needs a structural breakdown of the demineralized enamel. This breakdown usually occurs when the dentin is affected by demineralization. When enamel cavitation is exposing the demineralized dentin it spreads laterally along the EDJ undermining sound enamel. However, when the enamel lesion is without cavitation, the extent of dentin demineralization along the EDJ is guided by the size of the enamel lesion [12–15]. From a histopathological viewpoint, this explains why it is possible to arrest enamel-dentin lesions prior dentin exposure by controlling the surface biofilm activity

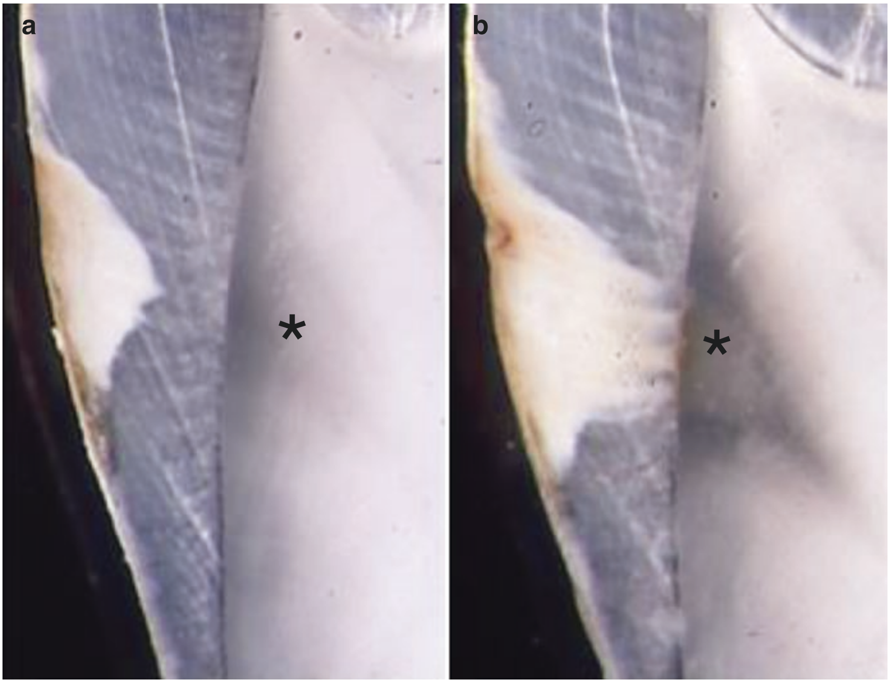

Fig. 3.4 Before initial dentin demineralization occurs, the dentin has responded with enhanced intratubular sclerosis resembling the physiological alterations taking place during aging. Here visualized by the darker translucent zone (**a**, *asterisk*). When the enamel lesion eventually is reaching the EDJ, it is not unaffected dentin (**b**, *asterisk*). Modified from [12]

(Chaps. 1 and 2) [16]. If the surface biofilm is removed, the described reaction of the pulp tissues is reduced and eventually reversed.

However, as soon as the dentin becomes exposed due to enamel breakdown, there is dentin invasion with microorganisms. Typically in the central lesion area, the lesion is oldest and most advanced. Concomitantly, with the bacterial invasion, the mineral loss from the demineralized dentin has reached a level that has changed the texture of the dentin. In other words, the dentin structure starts to collapse and shrink, creating a slit/gap along the EDJ (Fig. 3.5). This gap allows improved growth conditions of the biofilm and sooner or later a new frontier of the lesion will establish along the EDJ. The lateral spread along the EDJ can be clearly shown in the clinic and can be described as a retrograde demineralization (Fig. 3.5). This represents a relatively late stage of lesion progression because it is created only after a cavity has formed. Detailed observations along the EDJ have shown a very systematic structural relationship between lateral demineralization and the presence of microorganisms along the EDJ [17]. It needs highlighting that

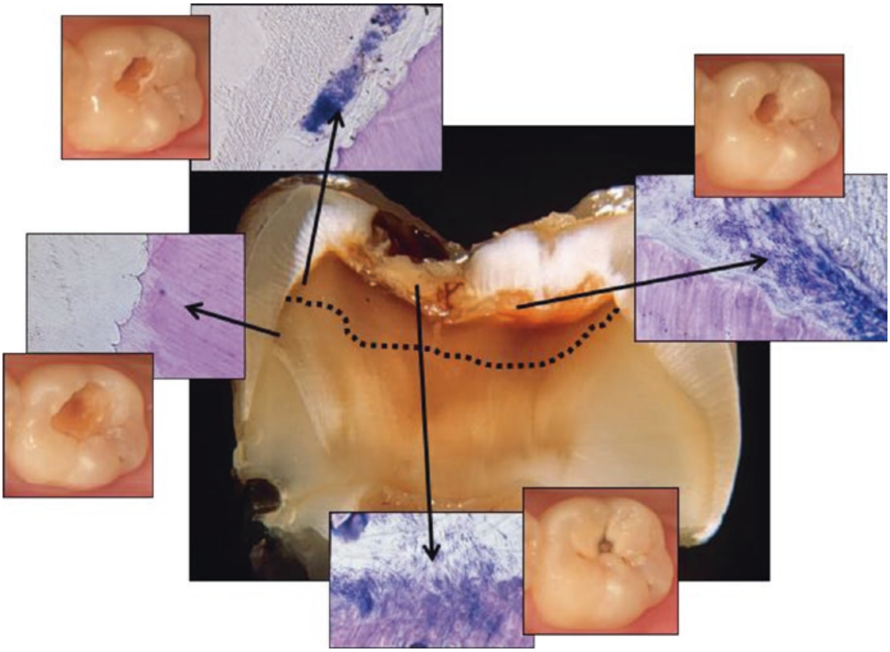

Fig. 3.5 The microbial profile along the EDJ in a cavitated lesion. Corresponding to the retrograde enamel demineralization bacteria are present along the gap of the EDJ. In the outermost peripheral site only demineralized dentin discoloration is noted without bacteria along the EDJ. Clinical example of an opening of a lesion along the EDJ corresponding to the histological sites. The *dotted line* indicates the possible border between the affected and infected zones of carious dentin, but not being possible to detect clinically. Modified from [17]

while the dentin demineralization extends beyond the border of the retrograde enamel demineralization, these demineralized areas (which are in great distance from the oldest central lesion parts) do not harbor microorganisms (Fig. 3.5).

The carious dentin, as described, can now be discriminated into an outer contaminated zone (being necrotic, decomposed, and non-remineralizable and containing bacteria) and an inner demineralized (vital, remineralizable, and bacteria-free) dentin (Fig. 3.5 dotted line). While it is clear that even if one aims to remove all bacteria (which, as discussed in Chap. 2, is not in line with the current understanding of caries and not required to manage carious lesions), demineralized and not decontaminated dentin (which can be remineralized, thus restituting its hardness) can be left behind and does not need to be removed. However, clinically it is difficult to determine the exact border between the contaminated and non-contaminated demineralized dentin.

3.4 Effects of Sealing: Histopathological and Microbiological Data

Importantly, it may be clinically irrelevant to determine the exact border between contaminated and non-contaminated layers: As long as the dentin is sealed tightly, isolating the lesion from acids (preventing further mineral loss) and from carbohydrates (depriving bacteria from their nutrition and killing them), it may not matter greatly if this sealed dentin was contaminated or not. Numerous studies have shown that sealed carious dentin seems to arrest (that is, it does not progress with regard to further mineral loss or bacteria growth) regardless of its contamination status. But what exactly happens when carious dentin (contaminated or not) is sealed?

3.4.1 Along the EDJ

Along the EDJ it was shown and confirmed that the most lateral stained demineralized dentin appeared to be without bacteria or low numbers of bacteria, as described above, questioning the previous held belief that all discolored dentin especially along the EDJ needed removal [18, 19].

3.4.2 Deeper Stages of Carious Lesions

In relation to deeper stages of dentinal lesion progression, it has also been shown that the level of bacterial growth is markedly reduced when the lesion was sealed; moreover, the complexity of the bacterial microflora was reduced [20]. The reduction of cultivable microorganism is also correlated with a clinically detectable

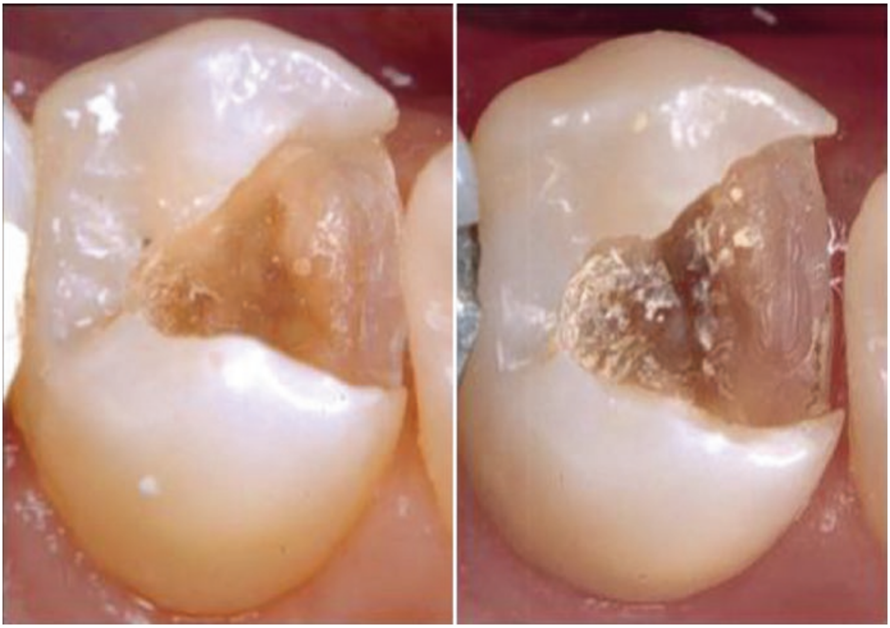

Fig. 3.6 Changes before and after a treatment interval during a stepwise removal of carious tissue. At 1. stage a selective removal to soft dentin is carried out with a nonselective approach in the peripheral part of the cavity left. After a treatment interval and removal of a temporary restoration, the same site is exposing a darker, harder and drier lesion site. Modified from [21]

change of the retained dentin [21]. The dentin left behind was initially yellow, soft, and wet, and now turned darker, harder, and drier, as discussed (Fig. 3.6).

3.5 Summary

Deep cavitated carious lesions remain a major oral health burden, leading to pain, impairment, endodontic treatment, and tooth loss. In most cases, deep lesions are clinically "closed ecosystems" harboring a cariogenic biofilm which is sheltered from removal; deep lesions are usually non-cleansable. Histologically, a zonal structure can be shown; however, and as discussed in the previous chapters, these zones are not clear-cut and cannot exactly be determined clinically. Dentists usually do not know if the dentin remaining in a cavity is bacterially contaminated or only demineralized, but non-contaminated. However, as deep lesions are sealed, one can observe changes in the lesion activity using clinically detectable variable, such as color and surface of the dentin; these changes can be further supported by evaluated bacterial numbers within the dentin [21]. Thus, sealing deep lesions allows to arrest them regardless of what exact kind of dentin is left—contaminated or non-contaminated.

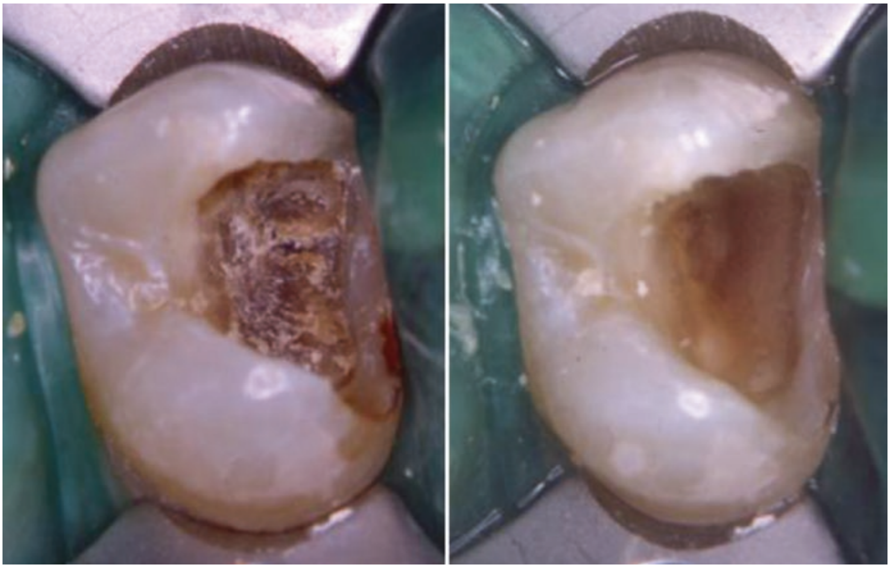

Fig. 3.7 When a relatively large part of carious dentin is left behind a restoration, it will shrink and it can be speculated whether the base of the cavity will be stable for a permanent restoration. In this specific case, the temporary filling has just been removed reflecting the status of the retained carious dentin (*left*). The mechanical properties of the retained carious dentin may be one of the main concerns, when discussing whether or not to do a re-entry in deep lesion. In this case, the re-entry was suggested to be beneficial for the final restoration. The cavity is shown during the completion of selective removal to firm dentin (*right*)

As discussed, the major reason of why sealing alone is usually insufficient for managing deep lesions is thus mechanical, not biological: The placed restoration is unlikely to be long-lasting if all the underlying dentin is carious, that is soft and unsuitable for adhesive materials to bond to (Fig. 3.7).

Thus, for most deep lesions, carious tissue removal is required. We have already outlined the four main strategies for carious tissue removal. Only three of them are recommended for deep lesions. As substantial parts of the above outlined knowledge have been gained in studies on stepwise carious tissue removal, and as this strategy has been around for over 70 years and is accepted standard in many countries, we will discuss it in more detail in the next chapter.

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Stepwise Carious Tissue Removal

4

Lars Bjørndal

Abstract

For deep lesions (defined as those lesions radiographically penetrating into the pulpal third or quarter of the dentin) in teeth with vital pulps, selective removal to soft dentin and stepwise carious tissue removal are two recommended options, while nonselective or selective removal to firm dentin often result in pulp exposure. The therapy of such exposures using direct capping has a poor prognosis, while initiating root canal treatment for exposed vital pulps is more successful, but nevertheless reduces the survival of teeth. We discuss the histologic basis for performing stepwise removal and describe the clinical procedure.

4.1 Aims

In this chapter, we will define for which teeth stepwise carious tissue removal is recommendable, and for which not. A discussion of advantages and disadvantages of stepwise removal will be performed, including the pulpal and restorative issues during this specific treatment. Moreover, the applicability and feasibility of stepwise removal will be presented in the light of the available clinical evidence. Finally, state-of-the-art recommendations on the clinical handling of deep carious lesion in adults will be given.

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4.2 Selection Criteria for Selecting Stepwise Removal

It is well known that with deeper lesions, a more established pulp inflammation is likely. However, a proper objective monitoring of the inflammation status is not yet possible [1]. Instead, and as shown later in the protocol for stepwise carious removal, a collection of subjective data from the patient as well as an objective and a paraclinical examination is best suited to assess the pulp condition, leading to a clinical diagnosis.

One important prerequisite for the selection of the stepwise caries removal protocol is the notion of the actual penetration depth of the carious lesion. A deep carious lesion is defined as being into the pulpal third or quarter of the dentin when examined on a radiograph [2]. Concomitantly, a clear radiodense zone is separating the carious dentin and the pulp.

In case the demineralized dentin penetrates the entire thickness of the dentin, it is defined at being extremely deep [2]. Such lesions are essentially reaching the pulp, and with any kind of therapy aimed at maintaining pulp vitality being at significantly higher risk of failure [3], because bacteria have penetrated through the (tertiary) dentin into the pulp chamber. These extremely deep carious lesions are usually associated with irreversible damage to the pulp and should not be selected for stepwise carious removal or any other of the described strategies of tissue removal aiming to maintain pulp vitality. Instead, such teeth should be submitted to endodontic therapy.

4.3 Current State of Evidence

Stepwise removal in adults in well-defined (not extremely) deep carious lesions is supported by robust evidence [4, 5]. Based on recent randomized clinical trials providing up to 5-year follow-up data stepwise removal has a significantly higher proportion of pulps with preserved vitality without apical radiolucency versus nonselective removal of deep carious lesions in adult teeth. However, doubts remain as if to prefer stepwise over selective removal to soft dentin, as discussed in Chap. 2, with a number of systematic reviews [6–9] highlighting this uncertainty.

4.4 Protocol for Stepwise Removal

As discussed in Chap. 2, the main aim of carious tissue removal is to allow longevity of restorations. This, longevity, however, needs to be balanced against maintenance of pulp vitality. For deep lesions in vital teeth, pulp vitality should generally be prioritized over restoration longevity. Stepwise removal aims to maintain pulp vitality, but also to ensure restoration longevity. The following steps should be taken when performing stepwise removal.

Pretreatment data should be collected, including the following information:

I. Subjective evaluation of the region containing the carious lesion, by questioning the patient on the area in focus, intensity, duration, stimulus, relief, and spontaneity: No signs of "irreversible pulpitis" should be present, which in clinical terms means no unbearable pain and no disturbed night sleep.
II. Objective examination of extra- and intraoral on soft and hard tissues. The pulp should react normal on pulp testing, without lingering or persistent prolonged pain following thermal testing. There should be no signs of swelling, palpation, percussion, or mobility (mobility due to periodontal bone loss excluded).
III. Radiographic examination. As described, the depth of the carious lesion is in the pulpal 1/3 or 1/4, and there is a well-defined radiodense zone between the pulp and the carious dentin. If the lesion is extremely deep (extending the entire thickness of the dentin), the case should not be submitted to stepwise removal, but root canal treatment, as the pulp is very likely to be irreversibly damaged. For stepwise removal, there should also not be any translucency around the apex of the tooth, that is there should be no signs of an apical periodontitis.

In case a tooth is decided to be eligible for stepwise removal, the following treatment steps should be undertaken:

Stepwise removal—first stage (Fig. 4.1)

I. Peripheral removal to hard dentin for optimizing the cavity for restoration, as discussed in Chap. 2.
II. In the pulpal (central) areas of the cavity, selective removal to soft dentin should be performed. That is, as much of the superficial soft as possible should be performed so a temporary restoration can be placed without removing leathery or even firm dentin to avoid pulp exposure.

Fig. 4.1 Clinical demonstration of the stage 1 of stepwise removal to soft dentin. In the periphery, only hard dentin remains, while pulpally, soft and discolored dentin is left (**a**). A principal drawing shows that the dimension of the temporary restoration should be sufficient for this restoration to last. Using a contrast coloring for the temporary restoration may allow easier removal in the second step (**b**). (Permission given for the use of Fig. 4.1a [10])

III. A calcium hydroxide containing base material and a temporary restoration are placed. Note that the temporary material needs to be expected to remain intact for several months or, optimally, minimum a year, as patients might not return earlier for the second step. Zinc-oxide eugenol materials or other short-lasting cement restorations are thus not recommended. Glass-ionomer cement materials might, however, be suitable.

Stepwise removal—second stage (Fig. 4.2):

IV. After 3–9 months, the tooth is scheduled for the second step. The longer the interval, the better. Within this period the retained carious dentin has changed color towards a darker appearance which most often is clinically visible, reflecting lesion arrest. Concomitantly, the dentin may have shrunk, thus creating a gap between the restoration and the retained carious dentin (Fig. 4.2b). Tertiary dentin has most probably developed, bacteria have been inactivated, and the lesion remineralized and hardened. Intervals shorter than 3 months are not recommended, as this is usually insufficient for the described alterations in the sealed dentin to occur, which may increase risk of pulp exposure in the second step.

V. The temporary material and the base are removed.

VI. Selective removal to firm dentin is carried out using hand excavators.

VII. A definitive restoration is placed, usually employing adhesive materials.

Practically, a number of questions around this protocol remain. For example, how should one best perform carious tissue removal in the first step, should dentists use a specific base material, are there recommendations towards the final restoration material, when are more than two treatment steps recommended? A practice-based study performed two decades ago provided some answers. First, it did not

Fig. 4.2 Demonstration of the clinical changes of the retained carious dentin following sealing for 6 months. The temporary restoration was removed and the sealed dentin is now darker and drier. Upon probing, the surface texture is also harder than at first stage (**a**). A principal drawing of the scenario just before the removal of the contrast colored temporary restoration. A squared zone (*arrows*) indicates the area with potential shrinkage of the arrested carious dentin (**b**). When removing the contrast colored temporary restoration, the chance of pulp exposure is reduced (**c**). (Permission given for the use of Fig. 4.2a [10])

significantly affect the treatment outcome if hand excavators or burs were used in the first step, nor did it matter which burs. It seems that the criterion of leaving soft dentin behind is applicable with various instruments. The different base and restoration materials used in this study also had no significant impact. Last, one does not seem to gain a benefit by using more than two treatment steps, which given the effort of each step clearly speaks towards performing two, not more steps [11].

4.5 The Benefits of Stepwise Removal

One of the advantages of using a stepwise removal is that clinically the dentist is able to confirm lesion arrest (darker, harder dentin remaining after the 3–9 months interval). Moreover, the final restoration is supported by firm, not soft carious dentin in the pulpal aspects of the cavity, thus increasing the mechanical support of the restoration and optimizing the substrate for adhesive restorations. Compared with nonselective removal or selective removal to firm dentin, stepwise removal significantly reduces the risk of exposure and the risk of pulp complications like pain and apical pathology [5]. As discussed, pulp exposure treatment using current concepts (direct capping, partial pulpotomy) has very limited success rates, which is why avoiding pulp exposure seems adamant. Thus, stepwise removal can be unequivocally supported when compared to more invasive strategies like nonselective or selective removal to firm dentin.

In terms of disadvantages, the temporary restoration placed during stepwise removal may fail, which as discussed might lead to reactivation of lesions and subsequent pulp complications [12]. As discussed, the choice of the restoration material is thus important. In the second treatment step, pulp exposures might occur (they are very unlikely in the first step). The risk of such exposures has been reported to be 10–15% [4, 6, 11, 13]. This risk and the efforts needed to perform the two-step process are the reason why doubts towards the need and benefits of the second treatment step have been emerging recently [14]. Especially in primary teeth, the second step is a big disadvantage, which is why stepwise removal is not recommended here any longer (selective removal to soft dentin or alternative concepts like the Hall Technique should be chosen instead, see Chaps. 5 and 8). But what about adults and permanent teeth—are there arguments to support stepwise removal against selective removal to soft dentin (i.e., performing only the first step, omitting the second)?

First, the evidence supporting stepwise removal has been gained on truly deep carious lesions, i.e., those extending into the pulpal 1/3 or 1/4 of the dentin. Most studies supporting selective removal to soft dentin in permanent teeth have investigated lesions extending not deeper than half or 2/3 into dentin, i.e., not deep lesions, meaning that there is currently only weak evidence supporting this strategy for truly and well-defined deep lesions in permanent teeth and adults [6, 9].

Second and as mentioned, restorations placed after selective removal to soft dentin are supported by soft dentin in the pulpal aspects, which could compromise the restoration longevity because the retained carious dentin dries out and shrinks when sealed off (Fig. 4.2), especially when large amounts of soft dentin remain. In

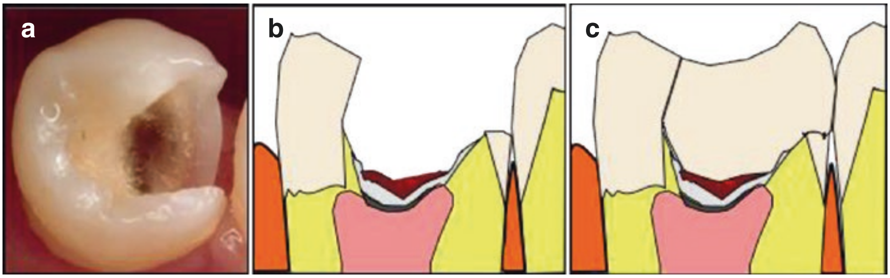

Fig. 4.3 Demonstration of the stage 2 stepwise carious tissue removal (**a**). Compared with Fig. 4.2, it is clear that only limited additional dentin was removed. Only firm dentin is left (**b**). The cavity is now prepared for a long-lasting adhesive restoration (**c**). (Permission given for the use of Fig. 4.3a [10])

stepwise removal, the restoration will be placed on hard, mechanically supporting dentin instead. No studies, however, showed this to translate into better restoration survival. There are some indications that in occlusal cavities, both stepwise and selective removal to soft dentin might perform similar, while in proximal lesions, the soft dentin remaining after selective carious tissue removal could be detrimental [15, 16] (Fig. 4.3).

4.6 Summary

- Stepwise removal is recommended for well-defined deep lesions in adults, being defined as radiographically extending into the pulpal third or quarter of the dentin but showing a radiodense zone between the lesion and the pulp.
- Moreover, pulps in teeth eligible for stepwise removal should show the clinical ability to heal (reversible pulpitis, i.e., only short-term pain or pain on provocation) or be clinically non-symptomatic.
- Teeth with lesions radiographically extending into the pulp are usually not eligible for stepwise removal; oftentimes, such teeth show signs of irreversible pulpitis (permanent and unbearable pain). For these teeth, maintaining pulp vitality is difficult, which is why endodontic therapy is recommended (at least at present; this recommendation might need to be revised in the future).
- Long-term clinical randomized data shows that deep lesion can be successfully treated with stepwise removal. Stepwise removal is superior to nonselective or selective removal to firm dentin.
- There is more ambiguity around the decision between stepwise and selective removal to soft dentin. In primary teeth, stepwise removal is not recommended any longer, as the need for a second step comes with unclear benefits, but obvious burdens for the child. In adults and permanent teeth, stepwise removal remains a valid and recommendable option for managing teeth with deep lesions and vital pulps.

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Selective Removal of Carious Dentin

5

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Abstract

In adult patients where dental cavities are a cause of pain with ongoing active carious lesions, plaque biofilm stagnation, poor aesthetics and/or structural/functional problems, restorative intervention will need to be considered. In order to preserve tooth structure and pulp sensibility long term, carious tissue removal should be adapted accordingly, employing a minimally invasive (MI) approach, aiming to avoid harm to the tooth and the pulp. The extent of carious tissue removal will depend on lesion-pulp proximity/pulp sensibility, the extent/restorability of remaining supragingival tooth structure, the patient's caries susceptibility and operative factors (e.g. moisture control, access). In deep lesions, selective removal to soft dentin is recommended, avoiding pulp exposure and sealing the remaining (residual) carious dentin beneath an adhesive restoration. Modern removal technologies including air-abrasion, chemomechanical agents and rotary plastic burs can assist selective caries removal. Avoiding pulp exposure, having healthy enamel/dentin margins at the cavity periphery and by using adhesive restorative biomaterials, the operator can, if handling all with care,

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optimise the histological substrate coupled with the applied chemistry of the material, form a durable peripheral seal and bond to aid retention of the restoration as well as arresting the lesion without pulpal harm. Achieving a smooth tooth-restoration interface clinically to aid the co-operative, motivated patient in plaque biofilm agitation/removal is an essential prerequisite to prevent/manage the disease caries and to avoid carious lesions adjacent to the restoration margins. These procedures coupled with patient-focused supportive caries management consultations enable the tooth-restoration complex to attain its maximal survival rate in the functioning oral environment.

5.1 Introduction

In all aspects of dentistry, the clinicians must always justify their management decisions to the patient, as well as morally and ethically to themselves. These must be communicated effectively to the patient and documented judiciously in handwritten or electronic patient records. As discussed in Chap. 1, there are a number of reasons for placing a restoration in a tooth:

- Eradicating hard-to-clean plaque biofilm stagnation sites; creating easily cleansable tooth-restoration surfaces that encourage the patient's optimal oral hygiene procedures to disturb and remove any stagnating plaque biofilm (that is, allowing caries management).
- Helping to alleviate acute, reversible pulpitic pain.
- Re-creating structural and functional integrity of the tooth within the existing dental arch.
- Optimising compromised aesthetics.

As outlined in the previous chapters, the operative placement of a restoration has, in the past, been governed by the traditional rationale of excising all diseased, bacterially contaminated tissues. This outdated concept has now been shown to be unnecessarily overly destructive when considering the preservation of viable tooth structure. Instead, the removal of carious tissue should be adapted to the specific carious lesion and the associated challenges and priorities it presents with. A number of factors need to be considered to achieve success clinically when using such contemporary caries removal strategies:

1. The varying histology of the dental hard tissue substrate being treated (enamel, dentin, pulp)
2. Chemistry of adhesive bioactive/bio-interactive materials used to restore the tooth
3. Practical invasive operative technologies and techniques available to remove carious tissues minimally and selectively as well as those skill sets to manage the oral environment e.g. moisture control, instrument access, etc.

An appreciation of these related factors will enable the oral healthcare practitioner embrace the *contemporary* oral physician's biological approach to carious tissue removal as opposed to the *traditional* dental surgeon's mechanistic efforts of preparing cavities of a predetermined shape, governed primarily by the properties of the chosen restorative material as opposed to the actual histopathology of the disease process and retention of tooth substance [1, 2]. The underlying tenets of this strategy are to preserve pulp sensibility, tooth structure and ultimately increase the overall clinical longevity of the functional tooth-restoration complex.

5.2 How Much Caries Should Be Removed/Excavated?

As described in the previous chapters, carious dentin has been subdivided descriptively into two histopathological zones throughout the lesion depth:

1. the more peripheral *contaminated* (caries-infected) zone, closest to the enamel–dentin junction (EDJ), irreversibly damaged, necrotic and softened by long-standing heavy bacterial contamination, proteolytic denaturation of collagen and acid demineralisation of its inorganic component.
2. the deeper-lying *demineralised* (caries-affected*)* zone, reversibly damaged by virtue of the caries process, but with the potential to undergo biological repair by the dentin-pulp complex, under the correct conditions. This zone also suffers from bacterial contamination but to a significantly lesser extent than the overlying contaminated dentin and the collagen is not completely denatured and is therefore repairable [1, 3–5].

The soft, wet necrotic nature of contaminated dentin means it is a substantially inferior chemical and physical substrate for adhesion, seal formation and physical restoration support, whereas the deeper, more leathery/firm, potentially repairable demineralised dentin has been shown to exhibit adhesive bonding potential [6–10].

However, as described in Chap. 3, delineating these layers within a lesion clinically is a subjective process at present. Contaminated dentin is moist, sticky and soft to a sharp dental explorer whereas demineralised dentin is more leathery/tacky ("scratchy and sticky") in nature and ultimately blends into the hard, scratchy consistency of the deeper underlying sound dentin (where present) [1, 11]. Propylene glycol-based caries indicator dyes were developed to act as a clinical visual marker for that carious dentin requiring removal, but many conflicting studies exist regarding their efficacy in this regard [12]. Recent research developments include more specific indicators highlighting the sulphur-containing bacterial products indicative of the increased bacterial load present in contaminated dentin or using hydrazine-based covalent esterification interactions specific to carious dentin, but these have yet to be validated in vivo (as described in Chap. 2).

The answer to how much carious dentin needs to be removed therefore cannot be answered by histology and bacterial presence alone. Instead, the specific tooth/lesion, oral cavity, patient and the dentist co-variables have to be considered.

5.2.1 Lesion Depth

Lesion-pulp proximity affects the level of protection afforded to the vital pulp by the remaining dentin thickness and its quality. It has long been appreciated that the extent of advancement of the lesion is linked directly to the severity of the pathological caries process. Traditional approaches to carious tissue removal have relied on the erroneous belief that it is critical to remove all traces of contaminated tissue within the cavity depth as this harbours significant levels of active bacteria, which if residing close to the pulp, will affect it adversely whilst at the same time, perpetuating the disease process. As discussed, traditional recommendations of the past have advocated risking pulp sensibility by such cavity over-preparation leading to unnecessary and ultimately fatal, vital pulp exposures. These were then managed using calcium hydroxide-based direct pulp capping procedures. Published clinical studies and systematic reviews with meta-analyses have shown that this practice leads to a significant increase in risk of loss of pulp viability in the medium/longer term [13–16].

As described in the overview in Chap. 2, contemporary removal strategies thus aim to conserve demineralised dentin close to the pulp in deeper lesions, so minimising (or actually negating) the risk of unnecessary pulp exposure. However, it is accepted that leaving SOME contaminated dentin within a deep cavity adjacent to the still vital pulp is unproblematic, as remaining bacteria will be sealed and killed once the restoration is placed. Therefore, the contemporary rationale behind minimally invasive operative caries management concepts is not based on removing all bacteria, but on creating conditions which allow both the pulp and the restoration to survive long term. The use of suitable adhesive materials (e.g. glass ionomer "lining" cements beneath deep amalgam restorations, or calcium silicate cements) with antibacterial properties as well as having the ability to bond and seal chemically to the remaining dentin affords a potential seal so permitting arrest of the caries process and tissue rejuvenation via the regenerative response of the dentin-pulp complex [1, 4, 6, 7, 11, 17, 18]. Carious tissue removal from shallower cavities is less problematic. Indeed, the emphasis here moves away from pulp viability, as greater concern now needs to be given to the properties of the chosen restorative material as opposed to managing the pathological/biological process per se. Due to the inherent limitations of alloplastic restorative biomaterials, they all gain their optimal mechanical properties beyond a certain inherent thickness/bulk. Materials also need adequate mechanical support from the underlying retained tooth structure. Therefore a balance has to be achieved between tissue preservation/management of the biological processes and the mechanical needs and properties of modern man-made materials used to repair teeth. In shallow cavitated lesions the priority will be directed towards maximising restoration survival whereas for deeper lesions, maximising pulp survival [11].

5.2.2 Extent of Viable, Restorable Tooth Structure

The functional and aesthetic restorability of the tooth must always be assessed primarily when considering operative intervention. A minimally invasive approach removing mainly contaminated dentin will conserve significantly more tooth structure that can be used to help retain and support the definitive sealed restoration. The optimal restorative material is natural tooth substance and smaller cavities are easier to manage for both the dentist and the patient. A reduced surface area of exposed restoration with its margins in cleansable, oral hygiene aid-accessible areas will increase the patient's ability to regularly disturb and remove the plaque biofilm, so reducing the risk of carious lesions developing adjacent to the restoration.

5.2.3 Pulp Sensibility

As described in the previous two chapters, sensibility of the pulp must be assessed at the outset from the clinical signs and symptoms and other suitable investigations (a combination of electrical, thermal and radiographic). Signs and symptoms of an acute, reversible pulpitis can resolve if the caries process is arrested using a sealed restoration aiding effective plaque biofilm control measures by the patient, so tipping the histopathological balance away from the bacteria and toxins, in favour of the healing dentin-pulp complex and its acute inflammatory mediators [4, 14, 17, 19].

5.2.4 Patient's Caries Susceptibility

It cannot be stressed enough that, although this book's focus is on managing deep, cavitated carious lesions, prevention of caries via non-invasive management strategies applied by the oral healthcare team and carried out by the patient is paramount to successful long-term oral health management. These non-operative prevention regimes should be linked to the caries susceptibility/risk assessment of the individual patient as a motivated co-operative patient has a greater potential to be converted to, and maintained at, a low caries risk state. If these regimes are in place and are being adhered to by the patient, any kind of restorations placed have a good chance of medium/long term success [15, 16, 20, 21]. If, however, the caries susceptibility is continually high in less motivated patients, then adhesive restorations may show a reduced long-term survival rate [22]. However, it must be appreciated that *all* restorations placed in such an "unsuitable" high risk oral environment will always be compromised to a significant clinical degree. Remember, the restorative procedure itself does not cure dental caries!

5.2.5 Clinical Factors

Practical operative considerations in restoration placement must play a part in deciding whether selective removal to soft dentin is a feasible option. These may include:

- ability to control moisture contamination adequately, allowing a tight seal of the remaining carious dentin (ideally, with rubber dam isolation)
- appreciation of the final position of the cavity-restoration margin (supra- or subgingival; in occlusion or not; easily cleansable by the patient)
- appropriate handling of adhesive restorative materials by all members of the oral healthcare team (e.g. ensuring that dental adhesive bottle lids are replaced promptly after dispensing to ensure minimal evaporation of any solvent carrier; appropriate ratios of powder: liquid hand-mixed when required, etc).
- operator having the necessary skills/knowledge/technology to perform the procedures optimally

Prospective long-term randomised controlled clinical trials have assessed the validity and efficacy of minimally invasive selective caries removal in terms of restoration longevity and pulp status [13, 20, 21, 23]. Systematic analysis of the results has concluded that as long as there is a suitable patient-oral healthcare team-care approach to maintaining oral health, with regular recall/maintenance consultations with the patient, adhesive sealed restorations placed in ultra-conservative cavity preparations can last well in the functioning oral cavity [15–17, 19, 24]. The issue of the necessity of pulp capping using a separate “lining” or “base” material has been reviewed in the literature. If using modern adhesive restorative materials, the clinical need of a separate layer of indirect pulp protection (lining or base) has been shown to be unnecessary (apart perhaps from the scenario where the pulp may be protected with a thin layer of GIC or calcium silicate cement beneath a large restoration with direct pulp proximity) [18]. When dealing with hopefully ever rarer incidences of small, vital direct pulp exposures, setting calcium hydroxide or bioactive calcium silicate cements are advocated to cover the exposure site itself. These materials themselves need protection from further chemically aggressive adhesive procedures (e.g. acid etch) to follow, afforded by a layer of glass ionomer cement [17]. Current advances and limitations in contemporary adhesive dental biomaterials science will be discussed in Chap. 6.

In summary, it is clear there is no fixed “formula” to calculate objectively how much carious dentin to remove in deep lesions spreading close to the pulp. Schwendicke et al. [11] have offered practical guidelines to the practitioner, showing the variations in the level of tissue removal that can/should be achieved in different clinical scenarios. Considering the multiple linked factors discussed above, an example of deep carious dentin removal has been given in Figs. 5.1, 5.2, 5.3 and 5.4. In a scenario where the pulp is still viable clinically, exposure should be prevented by removing the contaminated soft dentin and retaining the demineralised leathery dentin overlying the pulp. Radiographic analysis will help with this

Fig. 5.1 Cavitated occlusal lesion UR7 with demineralised, unsupported peripheral enamel (*frosty white appearance*) and visible soft *contaminated* (caries-infected) dentin (*dark brown*). Symptoms were those of an early reversible pulpitis and the pulp was vital to electric pulp testing and ethyl chloride

Fig. 5.2 Radiograph of UR7 showing demineralisation extending into the inner third of dentin towards the pulp. The pulp chamber is clearly visible with a potential bridge of dentin between it and the advancing lesion (see Chap. 3: a well-defined deep lesion). There is no proximal cavitation

decision as depth of lesion penetration can be crudely assessed pre-operatively. If there is concern that this level of excavation may still risk pulp exposure, then retention of some soft contaminated infected dentin may be acceptable, as shown in Fig. 5.3. It is imperative that the cavity periphery finishes on sound enamel and/or sound dentin. Again, in situations where further tissue removal to reach these sound levels of tissue will lead to excessive tissue loss and compromise of other clinical factors (mentioned above), then at least either sound enamel or sound dentin must still be achieved to allow sufficient tooth-restoration sealing to occur.

Fig. 5.3 The flakes of soft dentin have been removed carefully avoiding unnecessary exposure of the pulp, using a spoon excavator gently as a curette. The dentin adjacent to the enamel–dentin junction is both scratchy and slight sticky to a dental probe (leathery), indicating it is still *demineralised* (caries-affected) histologically. The peripheral enamel margin is hard and sound, so providing the optimal tissue for adhesive sealing with a good surface area for bonding

Fig. 5.4 The final conventional resin composite restoration has been placed (having been placed in angled 2 mm increments) and finished to reduce plaque biofilm adherence in the oral cavity

5.3 How to Selectively Remove Carious Tissue

As we have described why and how much carious dentin is removed when dealing with deep lesions using selective removal to soft dentin, we will now deal with how such removal can be performed. As can be seen from Table 5.1, there are several

Table 5.1 Tooth-cutting/carious tissue removal technologies, the substrates acted upon and their mechanism of action

Mechanism	Substrate affected	Tooth-cutting technology
Mechanical, rotary	Sound or carious enamel and dentin	SS, CS, diamond, TC and plastic burs[a]
Mechanical, non-rotary	Sound or carious enamel and dentin	Hand instruments (excavators, chisels), air-abrasion[b], air-polishing[c], ultrasonics, sono-abrasion
Chemomechanical	Carious dentin	Caridex™, Carisolv™ gel (amino acid-based), Papacarie® gel (papain-based), pepsin-based solutions/gels
Photo-ablation	Sound or carious enamel and dentin	Lasers
Others	Bacteria	Photo-active disinfection (PAD), ozone

SS stainless steel, *CS* carbon steel, *TC* tungsten carbide
[a]Works only on carious dentin
[b]Alumina powder, non-selective; bioactive glass powder, selective for carious enamel
[c]Sodium bicarbonate used for stain removal (from [1])

clinical technologies available for removing carious dentin and preparing teeth. Most are not self-selective and involve active discriminatory input from the operator [1, 9, 25, 26]. Dentists and therapists are highly trained at using dental burs in slow-speed or air-turbine handpieces as well as hand excavators, and although not self-selective, a careful operator with appropriate knowledge, understanding and skills can effectively use these instruments for selective removal to soft dentin (Figs. 5.1, 5.2, 5.3 and 5.4).

Slow-speed polymer burs have an intrinsic hardness similar to contaminated dentin, and have been shown to be reasonably self-limiting as they tend to blunt as they attempt to cut the harder deeper dentin layers. Research is ongoing into impregnating burs with ions/particles. Such a dental "bio-bur" could act both as a selective removal instrument for the irreversibly damaged, necrotic tissue and as a carrier to direct bio-active/interactive healing chemistry to the tissues most at need.

Ultrasonic and sonic instrumentation use the principle of probe tip oscillation and irrigant micro-cavitation to "chip away" hard dental tissues. Lasers transfer high energy into the tooth through water causing photo-ablation of hard tissues. Great control is required by the operator in order to harness this energy effectively and the effects on the remaining enamel, dentin and pulp continue to be investigated in terms of residual damage, strength and bonding/sealing capabilities. A systematic review has concluded that laser carious tissue removal is not yet a viable general dental practice option for effective selective removal of dentin [27].

Chemomechanical agents (see later) may also be used in combination with more abrasive, as opposed to cutting, hand instruments, manufactured from medical-grade plastics or stainless steel, to help maximise the overall self-limiting nature of the technique towards contaminated dentin excavation. Other chemically based cavity disinfection methods include photo-activated disinfection (PAD) where tolonium chloride is introduced into the cavity, absorbed by the residual bacteria in the cavity walls and then this chemical is activated using light of a specific wavelength causing cell lysis and death, and ozone treatment of caries (gaseous ozone infused into lesions causing bacterial death). These latter technologies and other cavity disinfection protocols using chlorhexidine, diode laser application, acidulated phosphate fluoride gels, natural extracts of aloe vera and Brazilian Propolis, to name but four, currently suffer from a paucity of clinical research evidence to validate them for routine clinical use [28].

5.3.1 Air-Abrasion

At the time of publication, air-abrasion is a seven-decade-old dental operative technique used for the removal of enamel and dentin during cavity preparation that predates the air-turbine handpiece [29, 30]. Air-abrasion units are capable of minimally invasive tooth preparation using aluminium oxide (α-alumina) [26, 31, 32]. However, dentists are accustomed to the parameters of resistance, tactile feedback and an appreciation of finite cutting depth when using rotary tooth-cutting techniques, all of which the end-cutting alumina air-abrasive jet lacks. This makes the use of alumina air-abrasion highly operator-sensitive and requires careful education of clinicians to realise its potential for minimally invasive preparation and the prevention of cavity over-preparation [33]. Studies have been published which characterise the efficacy of alumina air-abrasion and its cutting characteristics on both sound and carious enamel and dentin and collectively these show the technique to be efficient if specific operating parameters (e.g. air pressure, powder flow rate and reservoir volume, nozzle diameter and working distance) are regulated judiciously by the operator [34–37]. Clinical studies have indicated good patient acceptance of the technology, in terms of the lack of vibration, no heat generation and the reduced need for local analgesia [38, 39].

An important clinical use of air-abrasion is obtaining suitable enamel access in minimally invasive restorations. Meticulous cleaning of the occlusal surface prior to visual examination using a rotary brush or air-polishing is essential for carious lesion detection, followed by the use of a small size dental bur or alumina air-abrasion for the removal of the carious, demineralised enamel [40, 41]. The microscopically roughened enamel surface created by alumina air-abrasion is devoid of weakened prisms and is therefore better adapted for adhesive bonding. However, lack of substrate selectivity and no self-limiting operator feedback when using these operative technologies can result in significant cavity over-preparation. Innovation has resulted in the development of a water-shrouded air-abrasion system which helps reduce the dust contamination within the dental surgery. With regard to abrasive powder development, there is a commercially available bioactive glass powder (Bioglass 45S5, Sylc™) capable of removing extrinsic dental stain, desensitising exposed dentin and exhibiting an intrinsic selectivity towards carious, demineralised enamel and resin composite restorations [42–45]. This powder has also been shown to have the ability to remineralise incipient enamel white spot lesions in vitro, so offering the exciting potential in the future for further non-destructive management of the earliest signs of disease [46, 47]. Research is ongoing into development of a self-selective air-abrasive powder for contaminated dentin. Other powders including sodium bicarbonate and glycine derivatives have been used in conjunction with air-polishing units for stain removal and potential pain relief of dentin hypersensitivity.

5.3.2 Chemomechanical Carious Tissue Removal

Chemomechanical solutions (including hypochlorite, chloramines, enzymatic pepsin and papain) have been investigated clinically regarding their ability to help further breakdown of collagen in already softened carious dentin in the hope of developing a more self-limiting technique of removing contaminated dentin alone [25, 48]. After the development and subsequent demise of the Caridex™ system in the 1970s, chemomechanical caries removal techniques were resurgent with the commercialisation of Carisolv™ gel in the late 1990s. This hypochlorite/amino acid-based gel system is used with special non-cutting hand instruments offering greater tactile sensitivity to the operator, so permitting selective dentin removal [1]. Studies indicated good patient acceptance of this technique even if these methods can clinically take up to 5 min longer to perform than equivalent rotary instruments [9, 39, 48]. An example of carious tissue using chemomechanical Carisolv™ gel and hand instrumentation is given in Figs. 5.5, 5.6, 5.7 and 5.8.

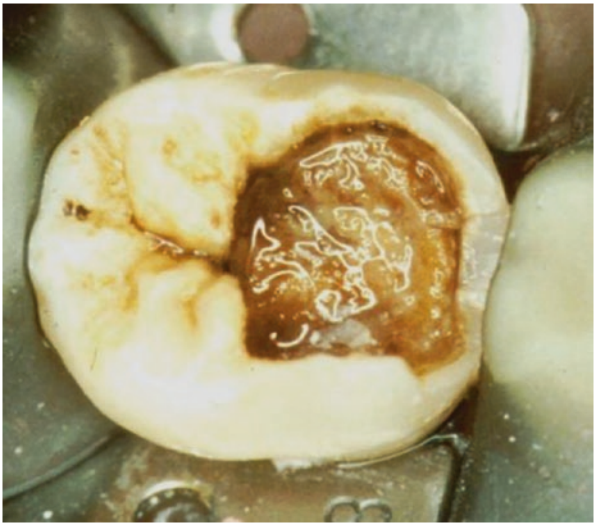

Fig. 5.5 Cavitated occlusal caries with soft dentin evident in a mandibular molar tooth

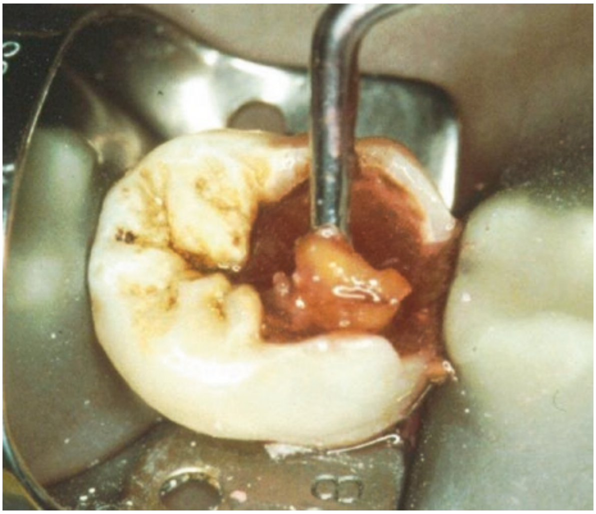

Fig. 5.6 Slightly viscous Carisolv™ gel introduced into the cavity using the mace-tip hand instrument, left for 20–30 s prior to excavation and then gently abraded using the proprietary hand instrument. The contaminated dentin "emulsifies" out into the gel

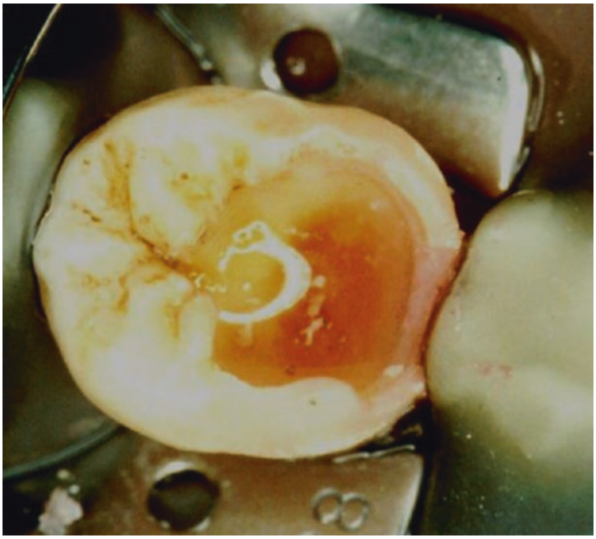

Fig. 5.7 As soft contaminated dentin is removed, subsequent applications of Carisolv™ gel appear less cloudy after hand instrument abrasion as there is less dentin to remove. This technique offers an element of selective tissue removal, retaining demineralised dentin at the cavity base

Developments in chemomechanical technology include the laboratory development of pepsin-based gels using specially designed nylon brushes and plastic disposable hand instruments to abrade the softened dentin as well as papain-based systems (see Table 5.1).

Fig. 5.8 The final prepared cavity. Leathery demineralised dentin is retained over the pulpal aspect of the cavity. The peripheral margins in the case have purposely been excavated and now resemble sound dentin/enamel to aid the restorative peripheral seal

Conclusion

The clinical and scientific evidence-base for selective carious tissue removal in appropriate patients and cavitated lesions now exists. In cavitated lesions which are not deep, the extent of removal is governed by the mechanical properties of the restorative biomaterial to maximise the longevity of the tooth-restoration complex. In deep lesions closer to the pulp, the emphasis in more minimally invasive selective removal shifts towards maximising the longevity of the pulp and tooth. In both scenarios, due consideration must be given to conserve as much coronal tooth tissue as possible. The complete removal of grossly softened contaminated dentin is recommended in most situations (except perhaps in a very deep lesion overlying the pulp where its vitality assessment still leans towards a reversible, acute inflammatory response and an adequate clinical seal can be achieved at the periphery of the cavity). Peripheral removal should extend to sound dentin where an inadequate quantity and quality of enamel remains. It is at this tooth-restoration interface that the peripheral seal is achieved and is critical to prevent further histopathological progress of the disease. The seal can be obtained using adhesive dental biomaterials which penetrate micro-/nano-mechanically into the mineral and collagenous components of enamel and dentin, respectively. With judicious use of contemporary adhesives with their bactericidal/static and insulating properties, there is no need clinically for a separate lining/base layer to “protect” the pulp. A thorough understanding of the chemistry of the materials and how they relate to the histology of the tissues is necessary to ensure the best prognosis of a sealed, adhesive restoration. Patient co-operation is required and their long-term behaviour and expectations need to be managed appropriately by the oral healthcare team to ensure the longevity of the functional tooth-restoration complex.

Acknowledgements Figures 5.1, 5.2, 5.3 and 5.4 have been reproduced with publisher's permission from Chap. 9—A large carious lesion. In: Odell EW, editor. Clinical problem solving in dentistry. 3rd ed. Churchill Livingstone: Elsevier; 2010.

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Restorative Challenges and How to Overcome Them

6

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Abstract

Restoration of deep carious lesions may be challenging in clinical practice. Many generations of dentists have been trained to remove all weakened carious dentin. This may, however, easily lead to pulp exposure and subsequent endodontic treatment. Especially this type of treatment may weaken a tooth, and it has been documented that endodontically treated teeth are more prone to fracture.

New insights in the pathology of caries and the importance of a well-sealing restoration have led to changing treatment concepts. Selective carious tissue removal allows to avoid pulp exposure, but may also compromise the longevity of the restoration, mainly because of mechanical and adhesive reasons. Moreover, residual carious dentin is challenging with regard to radiographic diagnosis. In this chapter, these restorative challenges and possible solutions are discussed.

6.1 Introduction

Even though it becomes increasingly clear that a restoration is not necessary to stop the caries process in or on a tooth, placing restorations (sometimes also referred to as "fill-and-drill" practices) still occupies a central part within general dental practices [1]. Currently, it is indeed no longer assumed that restorations can cure or halt the disease "caries," as they rather only treat the local symptoms of the disease. There are ample examples where an active carious lesion is halted without a restoration when the (de-remineralization) equilibrium can be turned again in favor of

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remineralization. Typical examples are arrested root lesions [2], or lesions in primary teeth treated arrested using non-restorative cavity control (as described in Chap. 2) [3]. By removing the biofilm from the tooth, further demineralization by the acidic metabolites produced by cariogenic species will no longer take place, and under the best circumstances, a process of partial remineralization will take place [4].

However, when removal of the biofilm is difficult to achieve, a restoration will be useful to stop the carious lesion from progressing. For example, approximal lesions with cavitation will benefit from the placement of a restoration, as plaque control in such a cavity is practically impossible. Besides facilitating plaque control, restorations will also restore the chewing function, mechanical strength, and anatomy of teeth, so as to prevent undesired tooth movement or outgrowth, and they can improve the esthetics. Last, especially in deep cavities, where the pulp has not yet been able to deposit tertiary or reparative dentin, a restoration will also protect the pulp [1].

Nevertheless, in spite of these advantages of restorations, it is also known that the reparative cycle of subsequent restorations can be very destructive for the tooth and may eventually lead to premature extraction [1]. This process has been referred to as the “death spiral” or “the process of dental countdown”. The reason for this would be the fact that every subsequent restoration will be more invasive than the previous one. (Re)placement of restorations may indeed result in additional sacrifice of sound tooth tissue, which may lead to further weakening of the tooth [5, 6]. Several studies have quantified the weakening effect of restorative treatment by evaluating the effect of cavity size and design. From a biomechanical point of view, a mesial-occlusal-distal cavity will lead to more cuspal deflection upon loading than only two-surfaced cavities [7, 8]. Most detrimental for the intrinsic strength of a tooth is an endodontic access preparation, which entails removal of the coronal pulp roof, which provides resistance both in the mesiodistal and bucco-palatal/lingual plane [9, 10]. Cusp fractures therefore often occur in endodontically treated teeth [10]. Research showed that this is not due to a difference between non-vital versus vital dentin, but rather due to the weakening of the tooth associated with tissue loss and lack of pulpal proprioception [9].

Even though it is logical that placing a restoration in a tooth should, at best, not result in additional loss of tooth structure, sacrificing healthy tooth tissue has long been the standard in operative and restorative dentistry. There were several reasons for this. First, with conventional restorations, both direct and indirect, tooth preparation and the amount of removed tooth tissue were dictated by the material properties. To obtain sufficient strength for non-adhesive restorations like amalgam fillings, sufficient bulk was required [11]. Second, the concept of “extension for prevention” prescribed to extent the preparation margins in healthy and easily accessible areas. Third, amalgam, which was standardly used to restore cavities until two decades ago, required macro-mechanical retention of the restoration material, again at the expense of sound tooth tissue.

With the advent of adhesive restorations and facilitated by the described changing understanding of the pathogenesis of caries and carious lesions, a paradigm shift in restorative dentistry occurred. Together with the increased awareness of the importance of sufficient healthy tooth tissue to prolong the oral lifetime of teeth, adhesive techniques allow minimal preparation [12]. No additional sacrifice of healthy tooth tissue is required to place adhesive restorations, which additionally also helps to avoid the placement of intra-canal endodontic posts for retaining the restoration. Adhesive dentistry thus assists preserving tooth tissue and pulp vitality.

Even though the "dental countdown" cannot completely be avoided, it can be delayed/stretched by (a) reducing the loss of healthy tissues as far as possible and (b) avoiding the need of repetitive restorations by ensuring placed restorations to be of the highest possible quality to guarantee good durability. Just as important will be the causal treatment of the caries process in the patient. Even though recent research more and more points to some restorative material factors that may contribute to the development of secondary caries, it is also clear that secondary caries will only develop in those persons with general risk factors for caries [13].

6.2 Restorative Challenges in Deep Lesions

Restoring deep dentin carious lesions may hold several challenges: First, the proximity to the pulp is associated with high risks of pulpal trauma through either the carious lesion itself or by the application of the restorative material [14]. Dentin near the pulp is characterized by the presence of many dentinal tubules per surface area, which are typically also wider and thus more patent than in dentin far away from the pulp. Especially in deep lesions without sclerotic dentin, which may be the case in rapidly progressing carious lesions and in young patients, the pulp may be connected with the restorative material through the dentinal tubules. As the bacterial metabolites in a dentinal carious lesion may already lead to a (subclinical) pulpitis, it is therefore important that the restorative treatment does not induce further damage to the pulp (Fig. 6.1). Secondly, dealing with deep lesions signifies that a certain part of the tooth is affected by the carious process,

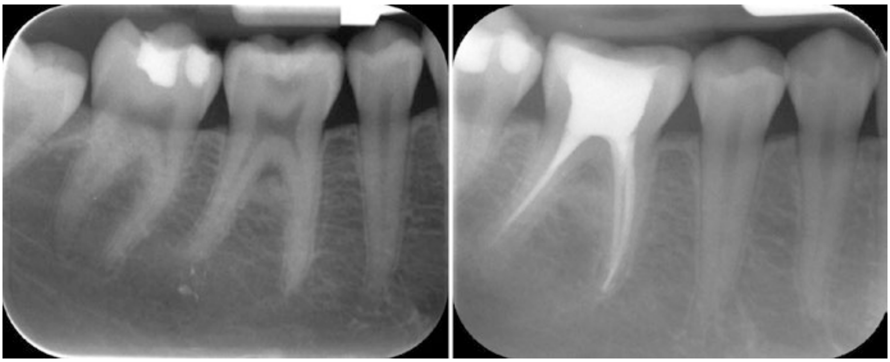

Fig. 6.1 Treatment of an occlusal carious lesion in tooth 46 resulted in unintentional exposure of the mesial pulp horn, after which a root canal treatment was carried out. Selective caries removal might have avoided the endodontic treatment, which entails a large endodontic access cavity and subsequent weakening of the tooth

which may, in itself, result in weakening of the tooth. It is therefore important that the restorative procedure should not result in additional weakening and removal of sound tooth tissue. As described above, parts of the tooth that provide strength should be saved if possible (such as the marginal ridge, etc.). Most importantly, trying to avoid the need for pulpectomy and an endodontic access will avoid undermining the strength of the tooth. In deep carious lesions, selective removal to soft dentin may thus be beneficial for the mechanical properties and eventually the lifetime of a tooth [14]. Generally, it can be stated that these challenges can be dealt with by choosing an adhesive restorative material that allows a minimally invasive procedure. Usually, a direct restorative procedure is preferred, as indirect restorations typically require non-retentive preparations and thus additional tooth structure loss can be avoided.

The function of a restoration will be threefold:

1. Aiding plaque control, by providing a new, more easily cleansable surface. Even though a restoration will stop further progression of the carious lesion, it will not halt the caries process. Moreover, when the biofilm on the restoration will be left undisturbed due to inadequate oral hygiene habits, the risk of secondary caries is high [2].
2. Protecting the pulp by stopping the carious lesion near the pulp. It is clear that the biocompatibility of the restoration is important to avoid additional chemical trauma of the pulp.
3. Restoring the function, anatomy, and esthetics of the tooth. Whereas esthetics will be important in the visible teeth (maxillary incisors, canines, and premolars), restoring the anatomy may prevent overeruption of affected teeth and/or the antagonistic tooth, and/or mesial tipping or drifting of adjacent teeth [15].

Following these functions, the main requirements for an adequate restoration can be stated as follows:

- The restoration should seal the lesion. Restorations may leak through gaps at the margins, or fractures. When such leakage takes place, both cariogenic bacteria and nutrients may diffuse underneath the restoration and result in secondary caries. In the case of selective removal, the carious lesion may start to progress again [13, 16]. There is, however, some evidence that certain gap sizes are required for such leakage to allow lesion reactivation [17–19]. To allow sufficient seal, the cavity margins should end in sound dentin and enamel, as (1) carious enamel and dentin is typically more permeable, and (2) reliable adhesion can only be achieved on sound tooth tissue (as will be discussed below).
- The restoration should be as durable as possible to avoid premature failure and future repetitive replacements. The durability of a restoration will depend on [1] the mechanical strength of the restorative biomaterial, [2] the remaining tooth structure, and [3] restorative factors that may prevent secondary caries, such as sealing ability, surface smoothness, buffering ability, and absence of defective margins that promote plaque accumulation [13].

6.2.1 The Sealing Capacity of a Restoration Is More Important Than the Removal of Carious Dentin

Earlier generations of dentists were taught that all carious dentin, both demineralized and contaminated, should be removed and that all bacteria in the cavity should be eliminated to achieve successful and durable restorations [2]. It was believed that residual cariogenic bacteria underneath a restoration may continue to live and multiply, and could cause lesion progression, pulpal irritation, and postoperative pain. When histological research revealed that mainly the contaminated dentin is invaded by bacteria, leaving demineralized (but bacteria-free) dentin and removing contaminated dentin in conjunction with the use of a disinfectant became the gold-standard cavity preparation procedure. The rationale for this was that the contaminated dentin should be removed to eliminate the cariogenic bacteria in the cavity. This concept was thus still stooled on the belief that residual bacteria underneath a restoration can lead to clinical failure due to secondary caries or pulpitis [20]. However, further research showed that even while removing all contaminated and demineralized dentin, it is virtually impossible to eradicate all bacteria in a cavity, in spite of several dentin disinfecting techniques [2]. This, however, is not surprising, considering the non-sterile procedure for preparing cavities [20]. Moreover, even the dentinal tubules in unaffected dentin may harbor oral bacteria. This knowledge seems to contradict the fact that restorations have been a quite successful treatment for many years, unless we question the premise that residual bacteria underneath a restoration always lead to complications and failing of the restoration.

As outlined, this premise has long been overcome; studies on stepwise [21, 22] and selective carious tissue removal [22–24] and the Hall Technique [25] have shown that restorations placed on carious dentin can survive long-term. Achieving good sealing in clinic is, however, not always easy, and is highly material-dependent. Moreover, the sealing capacity of the restoration's margins and its durability are also very important, and more research should focus on studying the long-term seal, microleakage, and percolation phenomena [1]. Even though many cariologists are convinced that secondary caries in fact is a new primary caries lesion next to a restoration, there is growing evidence that marginal gaps and microleakage may play a role in the development of some secondary caries lesions [16, 26] (Fig. 6.2).

6.2.2 The Effect of Carious Microorganisms on the Pulp

There is currently insufficient understanding of the effect of sealed remaining bacteria and their toxins on the pulp. There are reports showing that 2–12% of the previously vital pulps in teeth with (deep) restorations may become necrotic, irrespective of the material used [27]. There is a need of better understanding the permeability of dentin for adverse compounds and the role of tubular sclerosis needs to be fully elucidated. Irritation of the pulp by bacterial toxins may trigger pulpal inflammation and can subsequently induce tubular sclerosis which will reduce the permeability [4]. However, it is not known whether sclerotic dentin can become completely

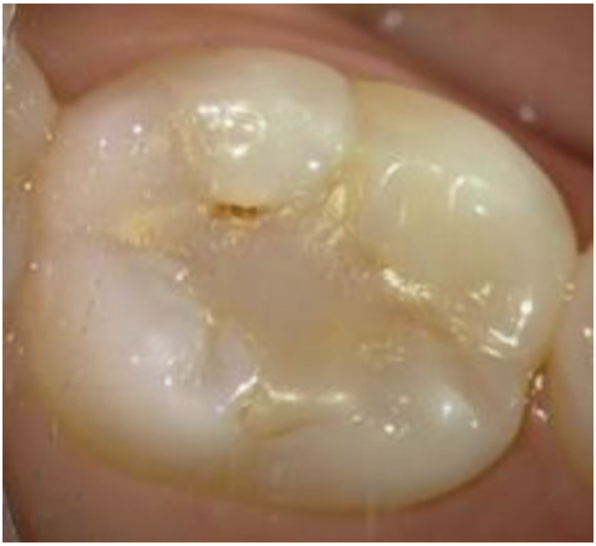

Fig. 6.2 A marginal gap and leakage of a composite restoration resulted in secondary caries adjacent to the restoration (Courtesy of Prof. Paul Lambrechts, KU Leuven)

impermeable [28]. Moreover, the exact cause of pulpal necrosis needs to be further investigated, as it is so far unclear whether it is induced by bacterial toxins or by compounds released from the restoration (for example, methacrylate monomers from adhesives and composites).

Studies on stepwise removal showed that it was possible to cultivate bacteria even after 6 months sealing periods [29]. It was assumed that these microorganisms could survive on nutrients from the pulpal fluid in the dentinal tubules; this is further supported by the surviving bacteria showing metabolic adaptation to glycoprotein nutrition delivered by pulpal fluid.

6.2.3 The Importance of Margins in Sound Enamel and Dentin for the Restoration

Caries is a destructive process, characterized first by gradual demineralization of both enamel and dentin, along with enzymatic and non-enzymatic degradation of the dentin matrix and collagen fibrils [30]. Both phenomena will result in permeable and mechanically softened enamel and dentin. To ensure good sealing and preventing carbohydrates from the oral cavity to reach possible residual microorganisms underneath the restoration, it is recommended to remove all demineralized enamel. As demineralized enamel loses mechanical strength, it is recommended to remove it while placing a restoration, in order to prevent enamel margin chipping and fractures. Chipping at the restoration margins could break the seal and thus will jeopardize the restoration's longevity. In dentin, in particular collagen fibrils denuded from hydroxyapatite are sensitive to hydrolytic degradation, which may compromise the longevity of adhesive restorations. All in all, to ensure the restoration has the best options for long-term clinical success, it is advised to place the restoration's margins in sound enamel and dentin [31].

6.2.4 Possible Disadvantages of Selective Removal to Soft Dentin for the Restoration

Two potential disadvantages of selective removal to soft dentin need to be taken into consideration:

1. The so-called "trampoline" effect: considering the weak and soft nature of carious dentin, it cannot provide much support to the overlying restoration, which may lead to fracture of the restoration, oftentimes "into" the soft dentin [32], leading to lesion reactivation. It is currently speculated that such effects of residual carious dentin depend on (a) how much residual dentin is left [33] but also (b) where exactly such dentin is left (that is, perpendicular to the mechanical forces or in parallel to them) [34].
2. Reduction of bonding area: the quality of an adhesive restoration highly depends on the size and the quality of the bonding area. The larger the bonding area, the stronger the bond of the restoration (see below).

Both disadvantages should be taken into consideration and weighed against the danger of exposing the pulp. It could therefore be advised to limit the amount of residual caries-affected dentin to a minimum that is necessary to ensure pulpal health.

6.3 Different Restorative Materials

Direct restorations are usually the first-line restorative material for restoring deep lesions. Compared with indirect restorations (crowns, inlays, onlays), they are less expensive and require less invasive preparation of the tooth. The indications for indirect restorations may be more difficult to define, but generally, an indirect restoration, and then by preference an indirect partial adhesive restorations such as an adhesive inlay or onlay, may be required for large defects as they can more reliably repair anatomy including approximal and antagonistic contacts. The different restorative materials to restore teeth will be discussed below.

6.3.1 Amalgam

Historically, amalgam was standardly used to restore teeth with carious lesions, and in many countries, it is still the standard material for treating posterior teeth. Amalgam is an alloy of mainly silver and mercury, which are mixed together to form a plastic material that can be placed in a retentive cavity, which will set after a couple of minutes. In spite of its unaesthetic properties, history has proven that amalgams allow successful restoration of decayed teeth. It was shown that amalgam restorations have a good longevity, and that they are especially successful in high-caries-risk patients [35]. This has been attributed to the fact that the corrosion products, which seal the margin soon after placement, have antibacterial properties and may protect against secondary caries [36].

In the past years, the use of amalgam decreased significantly, and countries have committed themselves to phase down the use of amalgam according to the Minamata Treaty [37]. Apart from the unappealing esthetics of amalgam and the environmental issues, there are also other reasons, why some researchers and academics plead against the use of amalgam, especially for treating small lesions. Compared to the adhesive materials, amalgam requires a rather invasive tooth preparation, often with sacrifice of sound tooth tissue. First, the preparation needs to be retentive to assure macro-mechanical retention of the restoration for this non-adhesive alloy. Second, to assure mechanical strength, enough bulk of amalgam needs to be applied, which again leads to additional tooth material loss. Third, typical amalgam preparations consist of large boxes with an occlusal extension, and thus may weaken the tooth severely. In other words, the requirements for an amalgam preparation are dictated mainly by the material requirements. There are only few studies available in which deep cavities that have been treated following selective removal to soft dentin are restored with amalgam [38].

6.3.2 Composites

Conversely, the use of composite has been increasing over the past decades. Recent research has shown that the longevity of composites nowadays is similar to that of amalgam restorations, although composites in high-caries-risk patients seem more prone to secondary caries [13]. Beside the esthetic properties of composites, the fact that they can be glued to tooth tissue with a dental adhesive, without macro-mechanical retention, and that do not require a thick bulk to have sufficient fracture strength allow a minimally invasive preparation. The shape of preparation will not be dictated by the restorative material, but rather by the carious lesion.

Dental adhesives for composites have been optimized during the past decades, and are important to seal the composite restoration, to withstand polymerization shrinkage forces and to ensure retention of the composite restoration to the cavity walls while functionally loaded [12]. There is also evidence that composites bonded to tooth tissue can partially restore the structural strength of a tooth.

In general, the main mechanism behind bonding to enamel and dentin is based on micromechanical retention of the adhesive polymer in microscopic surface irregularities. At the dentin interface, a so-called hybrid layer is formed, which consists of (partially) demineralized collagen fibrils embedded in resin. Additionally, it has been shown that a chemical (ionic) bond may coexist between hydroxyapatite in enamel and dentin and specific functional monomers [39]. While it is known that the first type of bonding mechanism will provide the strength of the adhesion, it is speculated that chemical bonding will be important for the durability of the bond.

In vitro, the quality of the bond is quantitatively assessed using mechanical tests, such as tensile-bond-strength and shear-bond-strength tests. While the absolute values of these tests may vary significantly depending on the type of test and the laboratory in which the test was performed, the average tensile bond strength of current adhesives may vary between 20 and 50 MPa (N/mm^2) [40]. This illustrates that adhesives may be able to take a lot of impact, but also that the bonding area plays a very important role: the larger the bonding area, the better the restoration will withstand oral stresses. Research has indicated that there is a some correlation between the bond strength of an adhesive and the clinical retention of cervical restorations [41], while no such correlation could be found between bond strength and sealing ability [42]. It is generally accepted that the bond to sound enamel is important to guarantee good sealing of the composite [43].

Many different types of adhesives are currently available, but there has been a trend in the past decade towards more simplified systems that require less clinical operator time [44]. The two main classes of adhesives are the etch-and-rinse adhesives and the self-etch adhesives. The main difference is the fact that the latter do not require a separate acid-etching and rinsing step, thanks to the use of acidic functional monomers. As research clearly showed that the separate acid-etching step of dentin with for example 35% phosphoric acid is too aggressive and leads to thick hybrid layers with unprotected collagen, it is currently advised only to etch dentin with mild etchants or to use a mild self-etching primer. On the other hand, it was shown that mild etchants are not able to provide a sufficiently micro-retentive area for enamel, leading to inferior bond strength to enamel and to composites with defective enamel margins. As a result, it is nowadays advised to selectively etch enamel with a strong acid (for example by implementing a separate etch-and-rinse step with phosphoric acid on enamel, followed by dentin bonding using a self-etch adhesive) [44].

In particular, hydrolytic and enzymatic collagen degradation in the hybrid layer may result in impaired longevity of the bond. Research showed that both exogenous (bacterial) and intrinsic (dentin) matrix metallo proteinase enzymes may digest unprotected collagen, resulting in degradation of the hybrid layer and impaired long-term bonding [45]. As these enzymes are activated by acidic actions, the use of low-pH adhesive systems or phosphoric acid on dentin is additionally discouraged [46].

Adhesives nowadays often also contain the functional monomer 10-MDP, which thanks to it amphiphilic structure can chemically bond to calcium in hydroxyapatite, but at the same time form self-assembled layers at the hybrid layer [39]. Much research has already been devoted to these so-called nano-layers, as it is speculated that their hydrophobic structure will protect the hybrid layer from hydrolytic degradation [47].

Whereas bonding to sound enamel and dentin nowadays can be regarded as reliable, bonding to contaminated or demineralized may be much more challenging. In spite of the formation of much thicker hybrid layers in carious dentin, immediate bond strengths were found to be significantly lower than those to unaffected dentin [48]. This was attributed to the low elastic modulus and the increased wetness typical of carious dentin. Yoshiyama et al. stated that this finding should not be a problem provided that enough sound dentin is available [31]. Since bond strength is proportional to the area of the bonded surface, it is logical that the more sound dentin there is to bond to, the better the mechanical strength of the bond will be [40]. As contaminated dentin is characterized by extended demineralization and irreversibly denatured collagen, any bond to such dentin may lead to fractures in the dentin due to polymerization shrinkage stress [49]. As such fracture could be detrimental if they occurred very close to the pulp, it is speculated that the use of a cavity liner for such areas could be beneficial. As will be discussed below, however, this line of thought is not consensus. As for the choice of type of adhesive, there are arguments to recommend the self-etch approach combined with selective enamel etching as discussed above. In particular, the so-called mild self-etch method seems appropriate, as dentin is only partially demineralized, leaving hydroxyapatite covering the collagen fibrils [44].

Already more than 15 years ago, an adhesive with an antibacterial monomer (MDPB, Kuraray, Tokyo, Japan) was commercialized, with the aim to eliminate remaining bacteria under the restoration, and to prevent secondary caries. In spite of promising in vitro results, and some logic as to the use of such adhesives in combination with selective removal to soft dentin, clinical evidence of the benefit of this antibacterial adhesive is so far missing [13].

Although most commercial composites have a similar composition, there have been some new developments. Silorane composites represent a new class of composites based on so-called silorane monomers which are characterized by ring-opening during polymerization [50]. The polymerization shrinkage of siloranes is significantly lower than conventional methacrylate monomers, which might be beneficial especially in deep and extended cavities, where material might be placed in larger bulks. Clinically, however, siloranes were not found advantageous compared with conventional composites [51]; the same can be said from a commercial point of view, possibly because of their handling properties and the fact that they needed a separate adhesive. Currently, most manufacturers are focusing on developing and marketing so-called bulk-fill composites [52]. Bulk-fill restoratives can be applied in thicker layers than 2 mm, and are fast becoming popular as they significantly improve the clinical procedure. They might be especially helpful when dealing with deep lesions. It should be noted that bulk-fills represent a very heterogenous group of composites, for example, they come in two viscosities: flowable and paste-like. The first is used as base in a cavity and needs to be covered by one layer of conventional composite, while the latter can be used to fill the entire cavity. Important concerns with bulk-fill composites are excessive polymerization shrinkage and subsequent microleakage and incomplete polymerization in deep cavities. Compared to conventional composites, polymerization shrinkage with bulk-fill composites is lower than with conventional composites [53], and most bulk-fills can be appropriately cured up to 4 mm or more depending on the brand [54]. A recent study, however, showed that bulk-filling may lead to decreased bond strengths and debonding, even when bulk-fill composites are used [52].

Addressing all new evolutions in dental adhesives would be beyond the scope of this chapter, but in brief, most innovations during the past decade have been focused on simplification of the adhesive systems, with as a result one-step one-bottle adhesives [55] and so-called universal adhesives (which can bond tooth tissue and different restorative materials) [56].

6.3.3 Glass Ionomers

As alternative restorative material, glass ionomer cements (or so-called glass polyalkenoate cements) can be used. These cements, which set via an acid–base reaction of a weak polymeric acid with basic glass particles, can be used in different applications. Depending on the filler particles/polymer ratio (or powder/liquid ratio), they can be used as a cement for indirect restorations, as lining material, as fissure sealant, but also as restorative material [57]. Compared with composites, glass ionomers typically exhibit inferior mechanical properties, mainly flexural strength. Currently, glass ionomer cements can be recommended for the restoration of small class I, II, and V restorations, especially in non-load bearing situations [58]. With further improvement of this material class, by continuously increasing flexural strength, but also by improving the surface properties (reducing the surface wear), these materials might, eventually, be suitable for larger cavities. Currently, however, doubts remain as to the suitability of this material for this specific indication [59].

Compared to composites, glass ionomers are often praised for their good biocompatibility and bioactivity, as they do not release monomers, but fluoride, calcium, and other ions. In particular fluoride release, which is very high immediately after placement and will continue at a much lower, but sustained level later on, has been regarded as a clinical benefit [58]. Moreover, it was described that glass ionomers are able to take up fluoride from the environment and thus can be "recharged." However, even though the anticariogenic properties of fluoride are well established, the clinical benefits of fluoride release from glass ionomers remain unclear [60].

As the buffering capacity of a restorative material has recently been described as another important property with regard to secondary caries development [61], glass ionomers might be interesting: Whereas conventional composites are not at all capable of buffering low pH, glass ionomers have the ability to buffer acidic solutions to a certain extent. Not only is this important to avoid demineralization of tooth tissue adjacent to the restorations, but also it will prevent maturation of the microflora next to the restoration into a rather cariogenic plaque [61]. Like composites, glass ionomers can bond to the tooth surface, which allows tooth-sparing preparations. Moreover, and an advantage, glass ionomers have a self-etching potential, and they do not require a separate adhesive [62]. Adhesion to tooth tissue relies both on micromechanical interlocking in irregularities created by the acidic polycarbonate acid component of the cement and on ionic bonding of calcium with the cement carboxylic groups. A conditioning step with polyacrylic acid is, however, recommended to remove the smear layer and improve wetting of the surface by the glass ionomer. A further advantage is the easy and less elaborate placement of glass ionomers restorations, as they can be considered as true "bulk-fill" materials.

6.4 Indirect Restorations

While the indication for conventional crowns has become smaller over the last years due to the advent of adhesive restorations, there is still the possibility to restore teeth with indirect adhesive restorations, such as partial or full crowns either cemented conventionally or bonded to the remaining tooth tissue with a composite cement. Nowadays, the most common material for such indirect restorations is ceramics. Some studies have shown that ceramic restorations may restore a tooth to high strength [63]. Compared with a composite restoration, ceramics will be more biocompatible as they do not release monomers. However, this type of restoration will not be monomer-free as they are bonded with a composite cement (or a restorative composite). More studies are necessary to evaluate other potential benefits, such as marginal adaptation and durability [64]. The growing popularity of ceramic inlays and overlays certainly also goes together with the development of reliable and accurate chairside CAD-CAM techniques (chairside design of the restoration and milling).

Even though this type of restorations requires additional tooth tissue loss to obtain a non-retentive cavity, they conversely may also prevent pulpectomy for the sake of seeking retention with a post, thanks to the fact that they can be adhesively bonded. A most dramatic example of this would be so-called adhesive “tabletop” restorations. (Fig. 6.3) Again, the size and the quality of the surface area to which can be bonded will determine the success of the restoration. Although no information can be found with regard to restoring selectively excavated deep lesions using indirect restorations, it seems logic that selective removal should not be detrimental to restoration survival as long as there is sufficient sound tooth tissue to bond to.

6.5 Cavity Pretreatment, Liners and Bases

Generations of dentists have been taught to disinfect the cavity before placement of the restorations, and to protect the pulp in deep cavities by applying a cavity liner. In light of the ongoing discussion on the harmfulness of residual bacteria underneath a well-sealing restoration, the usefulness of a separate cavity disinfection step could be questioned and more research is necessary to show evidence of the clinical benefit of this additional step. In an attempt to eliminate bacteria, both chemical agents, but also laser and ozone can be applied in cavities. A disinfectant should always be chosen with great care, as it should not interfere with good bonding and thus with the sealing of the restoration [20]. The use of CHX for “re-wetting” dentin which might have collapsed during air-drying after acid-etching comes with some disinfective effect, and has further advantages as it might prevent enzymatic degradation of denuded collagen fibers [46]. However, more clinical trials are necessary to evaluate the clinical benefits [65].

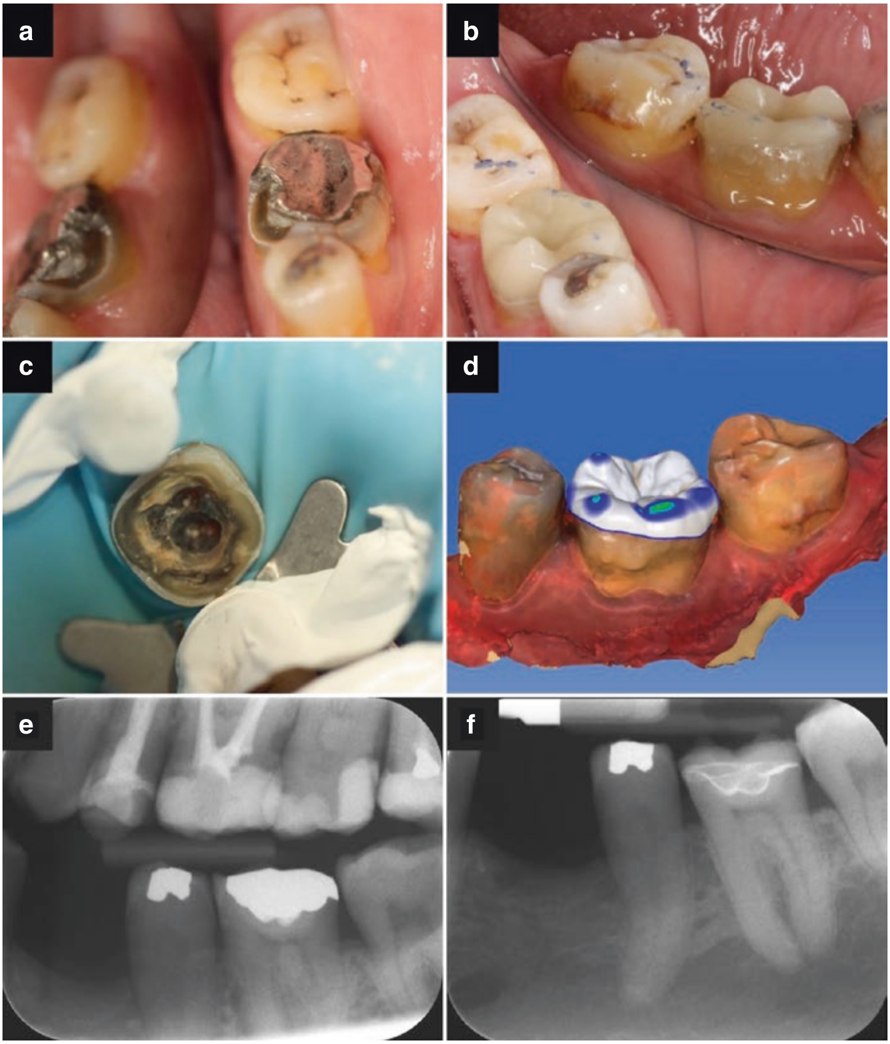

Fig. 6.3 Partial adhesive overlays can restore teeth that would previously have been treated endodontically to find retention in the root canal. Here tooth 36 is treated with an adhesive ceramic CAD-CAM restoration, cemented with composite. These restorations provide sufficient retention and may stretch the restorative death spiral. Note that no root canal treatment and post was necessary. (**a**) and (**b**) show the clinical image before and after treatment. (**c**) Detail of the cavity preparation. (**d**) A chairside CAD-CAM system was used to make the porcelain restoration. (**e**) and (**f**) show the radiographic image before and after therapy

Cavity liners have been used to protect the pulp by isolating against thermal stimuli, chemical agents, bacteria, and bacterial metabolites [66, 67]. Whereas protection against thermal stimuli may be important for heath-conducting restorations such as amalgam and other metal restorations, composites are insulators and do not require extra thermal protection. However, monomers, especially those from the adhesive, may quickly diffuse to the pulp and may irritate the pulp [68, 69]. The permeability of dentin highly depends on the remaining dentin thickness overlying the pulp, and on the patency of the tubules [70]. Although clinical evidence is missing, it may be useful to apply locally a thin layer of a biocompatible liner or base in cases which are perceived to be in immediate adjacency to the pulp. The general use of liners or bases for adhesive restorations is, however, contraindicated, as they will reduce the bonding area, which will impair the overall bond strength. Moreover, the use of a cavity liner for cavity disinfection is increasingly questioned, and clinical proof is missing [70].

Different materials have been proposed as liners and base, such as $Ca(OH)_2$, zinc oxide eugenole (ZOE) cement, glass ionomer, and recently also hydraulic calcium silicate cement (hCSC). $Ca(OH)_2$ and ZOE cement have been used for almost 100 years in dentistry as cavity liner. Both exhibit antibacterial properties. Recently, so-called hydraulic calcium silicate cements (hCSC), with MTA (mineral trioxide aggregate) being the most frequently used, have been proposed as liners or base in deep carious lesions [71]. Their composition resembles Portland cements, which are extensively used in the building industry. It was shown that in the presence of phosphate-containing fluids, the released Ca and OH may result in hydroxyapatite formation, which can result in partial and superficial remineralization of demineralized dentin [72]. Research seems to indicate that MTA is superior compared to $Ca(OH)_2$ as direct capping material, as MTA induces less pulp inflammation and more predictable dentin bridge formation than $Ca(OH)_2$ [73, 74]. Nevertheless, absolute success rates of direct capping of exposed pulps remain unsatisfactory, also with MTA, which is why pulp exposure should be avoided (as discussed in Chaps. 2 and 3).

6.6 Radiographic Diagnosis After Selective Caries Removal

While selective removal of carious dentin has great advantages for maintaining pulp vitality, there are also some disadvantages of selective removal that should be addressed. One disadvantage is that selective removal will very much hinder radiographic diagnosis, as it is impossible to distinguish advertedly sealed carious dentin (left under a restoration during selective removal) from carious dentin which was left by accident, not only in pulpal but also peripheral parts of the cavity [13, 75]. If such dentin is left very peripherally, it can also not be discriminated from secondary carious dentin. The result is a risk for misdiagnosis and overtreatment.

Compared to primary caries, the diagnosis of secondary caries, both clinically and radiographically, is hampered by the sheer presence of the restoration. The diagnosis of secondary caries is often for a large part based on the presence of demineralized tooth tissue underneath a restoration (Fig. 6.4) Also, failing sealing of the restoration could lead to secondary caries, but it is clinically very difficult to evaluate the sealing ability of restorations.

There are, however, some solutions for this problem. First, a good system for medical data storage could already be very helpful. Important will be good transfer of the data to other dentists, for example when a patient moves. Informing the patient, or giving him some records in which is mentioned that a certain tooth was treated using selective removal, may be helpful to some extent, but more research and experience is necessary to evaluate whether patients will correctly transfer this information to other dentists. Moreover, it is likely that this solution may render daily dental practice much more complicated. There will be a lot of uncertainty when radiolucencies underneath restorations are observed on radiographs, which may either lead to overtreatments or more frequent radiographic follow-up to observe progression of the demineralized lesion. More frequent ionizing exposure can hardly be regarded as minimally invasive treatment, especially in young persons. Second, strict application of

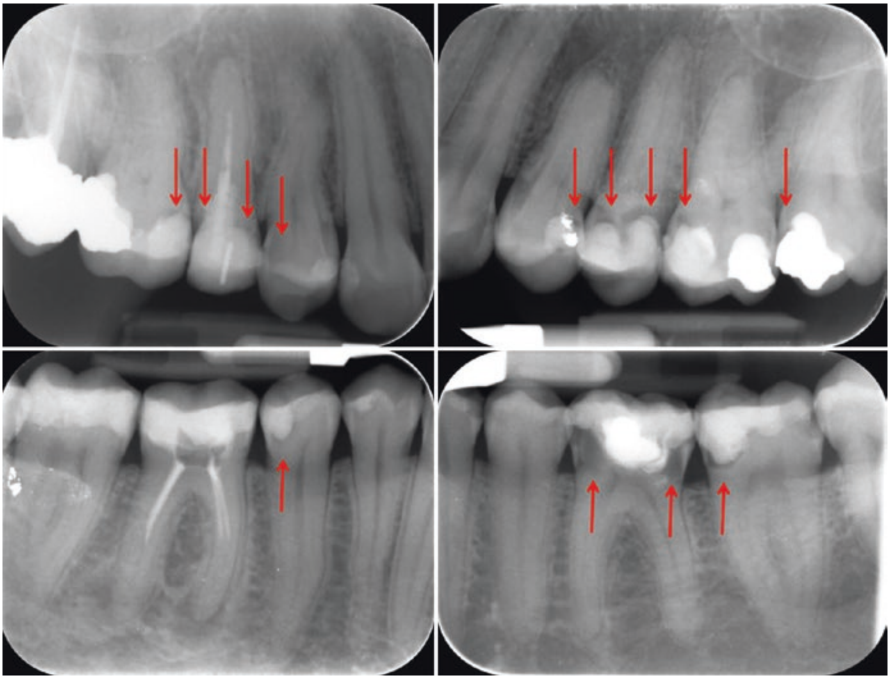

Fig. 6.4 Selective removal of demineralized dentin may render radiographic diagnosis of secondary caries very difficult. In this patient, the dentist might have adopted selective removal to soft dentin; alternative, carious tissue removal might have been performed not up to any standards; indicated by large amounts of carious tissue being left also in the periphery of the cavity. It is impossible to differentiate between remaining carious dentin and newly developed secondary caries. Evaluation of the sealing capacity of a restoration is clinically very difficult

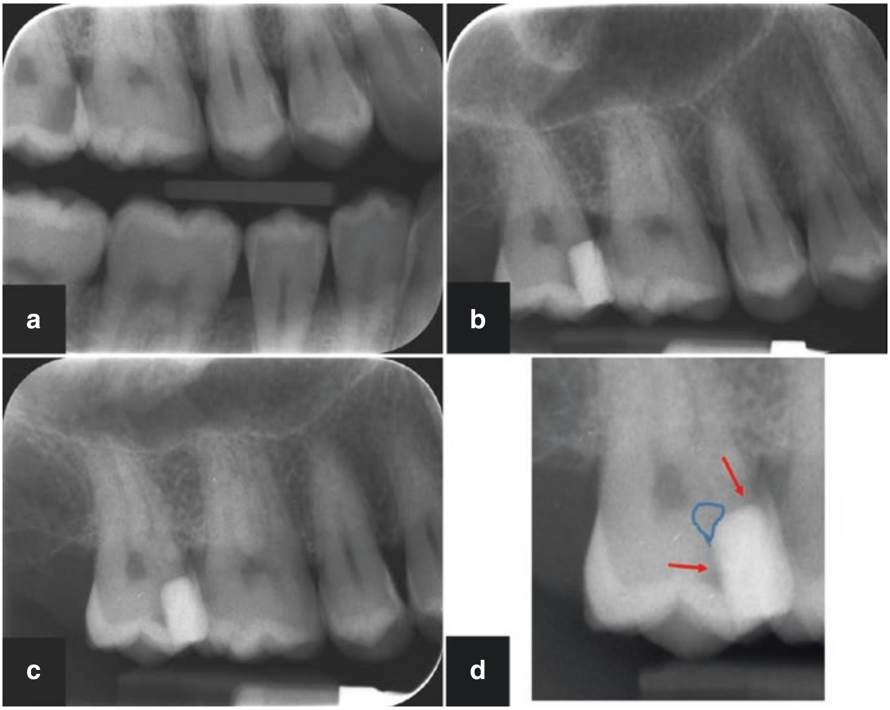

Fig. 6.5 Tooth 17 exhibited a proximal carious lesion mesially (**a**) and was treated following via selective removal to soft dentin and restored with a high viscosity glass ionomer restoration (**b and c**). The preparation margins were in sound enamel, but dentin walls were demineralized. Clinically, this treatment was successful, and the lesion had not progressed after 2 years. However, radiographic diagnosis of secondary caries will be difficult, especially when this patient seeks treatment by another dentist. Leaving demineralized dentin only near the pulp [*blue* in (**d**)] could be a solution. Leaving demineralized dentin away from the pulp has no real purpose (*red arrows*) and may even compromise long-term bonding and sealing of the restoration

selective removal as described—leaving soft dentin only close to the pulp, and removing carious dentin until only hard dentin remains peripherally—could help to cope with this problem (Fig. 6.5). In this case, dentists would be trained to evaluate demineralized areas underneath the pulp as remaining carious dentin, unless there are other clinical signs of leakage or there is progression of the demineralized lesion over time. Leaving carious dentin near the pulp to avoid exposure should thus become the state of the art, and this will also solve current problems with peer opinion, and legal issues with regard to leaving carious dentin underneath a restoration [76]. The use of radiopaque tagging materials, for example during cavity conditioning or bonding, has been evaluated, and found radiographically useful (Fig. 6.6). Such tagging was also found to allow discriminating active (i.e., progressing, not successfully arrested) sealed lesions from inactive (arrested) lesions [75]. Currently, however, this technique is not commercially available, and more research is necessary to develop a tagging method without impairing bond strength [77].

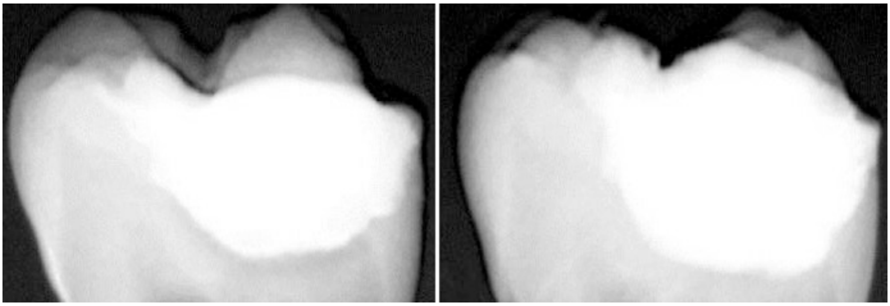

Fig. 6.6 An in vitro study [75] found radiopaque tagging of residual carious dentin (*left*) suitable to mask the lesion (*right*), making it indistinguishable from the restorative material. Such tagging, however, is not available commercially yet

6.7 Summary

- When it is impossible to remove the biofilm in a lesion, a restoration will be useful to stop the caries process and will help to protect the pulp. Additionally, a restoration will restore the function and the esthetics of the tooth.
- Repetitive restorations are, however, destructive and can lead to premature loss of a tooth. This process was coined “death spiral.” In particular, endodontic therapy (direct capping, root canal treatment) should be avoided whenever possible, as both decrease the prognosis of the tooth significantly. Therefore, leaving carious dentin near the pulp should become the new state-of-the-art therapy for treating deep dentin lesions, in order to avoid pulp exposures and keeping the pulp vital.
- It is impossible to achieve sterile cavities, but clinical observations have proven that enclosing bacteria underneath a restoration should not give clinical complications. However, more research is necessary to evaluate the effect of microorganisms and their toxins on the pulp.
- In particular, the sealing ability of a restoration is very important to guarantee the long-term success of a restoration, whether carious dentin is left or not. Leaking restorations can result in secondary caries. Margins in sound enamel and dentin are important for the sealing of the restorations.
- Good sealing by amalgams is achieved by corrosion products, while glass ionomer and composites can be bonded (“glued”) to the remaining tooth tissue. Especially with composites, this bonding technique is highly technique-sensitive and achieving a good bond may be challenging due to polymerization shrinkage, and due to other factors such as contamination by saliva or blood.
- It is advised to restrict the amount of carious dentin that is left underneath the restoration for several reasons:
  - To guarantee that the restoration is as durable as possible. This is important in order to delay the process of dental countdown. Restricting the amount of carious dentin left will ensure that the bonding area is as large as possible, thereby improving the bond strength and thus sealing the restoration, but will also avoid the so-called “trampoline-effect.”
  - Not to hamper radiographic diagnosis, avoiding overtreatment.

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7 Caries Sealing in Permanent Teeth

Margherita Fontana

Abstract

Although numerous strategies are available for the management of carious lesions, one of the strategies with the highest level of supporting evidence for the prevention of lesions as well as for the arrest of non-cavitated lesions and management of the bacterial contamination are dental sealants. Providing sealants in private practice settings as well as in public programs is not only effective, but can be cost-effective especially when targeting high caries risk individuals or groups. More advanced or deeper cavitated lesions can be sealed from the oral environment resulting in lesion arrest but require a stronger material than a dental sealant or use of different techniques, such as Hall crowns, etc. To aid in deciding if a sealant is an appropriate intervention, teeth should be clean, dry, and well illuminated for visual assessment, forceful use of a probe should be avoided, and radiographs and other diagnostic technologies are not necessary for the sole purpose of placing sealants. Regarding the material of choice, as more studies have become available the differences between resin composite and glass ionomer cement materials used as sealants have been less clear to discern, thus it is important to take into account the likelihood of experiencing lack of retention when choosing the material to use. However, even with the strong supporting evidence for sealant use, utilization is still low. Education and training, coupled with a fairer pay scheme, is a reasonable approach to increase provision of sealants.

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7.1 Definition of Sealants and Considerations for Their Use

Modern caries management stresses a conservative and preventive evidence-based philosophy including patient-centered risk-based disease management, early detection of carious lesions, efforts to remineralize and/or arrest non-cavitated lesions, conservative carious tissue removal, and minimally invasive restoration of cavitated lesions. The ultimate aim is to preserve tooth structure and maintain health. Although there is significant evidence supporting many of the individual components of this management philosophy, the best available evidence nowadays supports use of fluorides and sealants for caries prevention and lesion management.

Dental sealants are a physical barrier that inhibits food particles and microorganisms from collecting in pits and fissures, or reaching microorganisms already present in the fissure system, thus inhibiting bacterial growth and metabolic activity. Sealants are placed either to prevent the development of a caries lesion, or arrest an existing carious lesion (Fig. 7.1). As sealants and associated techniques (like infiltration, see below) condition the tooth surface, thus removing few micrometers of dental hard tissues, they belong in the group of "microinvasive strategies" for managing caries and carious lesions (see Chap. 1).

If the material permeates the inside of the lesion, rather than covering it, the process is called infiltration (Fig. 7.2). Infiltration was initially developed as an alternative to sealing of interproximal non-cavitated carious lesions, where wear due to tooth to tooth contact over time might affect retention of the sealant. In addition, as infiltration changes how light is reflected and transmitted through the enamel, it is able to visually mask some of the effects of the demineralization present in non-cavitated lesions. This has been tested, and is used in practice, as a management strategy for non-cavitated lesions that are an esthetic challenge, such as the ones post-orthodontic treatment affecting anterior teeth.

Sealants are one of the most underutilized, yet effective evidence-based strategies we have to prevent dental caries in at-risk pit and fissure surfaces, both in clinical dental settings and in school-based public health sealant programs (SBSP). Infiltration of proximal non-cavitated lesions is also one of the most effective strategies to arrest proximal non-cavitated carious lesions. In many countries, there are large disparities (e.g., by socioeconomic status, race and ethnicity, etc.) regarding access to sealants, with groups with the largest caries experience being in many cases the ones least likely to receive sealants. SBSP result in median caries reductions of 60% [1], leading to the strong recommendation that these programs be included as part of a comprehensive population-based strategy to prevent or control dental caries in communities at risk. In fact, SBSP can be an important intervention to increase the receipt of sealants, especially among underserved children. SBSP could reduce or eliminate racial and economic disparities in sealant use if programs are provided to schools that include a high percentage of high caries risk children, such as those living in lower socioeconomic conditions, or with previous caries experience.

Even though sealant recommendations support their use on both sound and non-cavitated lesions, one of the major barriers in sealant utilization is still nowadays the concern of sealing over active carious lesions. This concern is fueled by

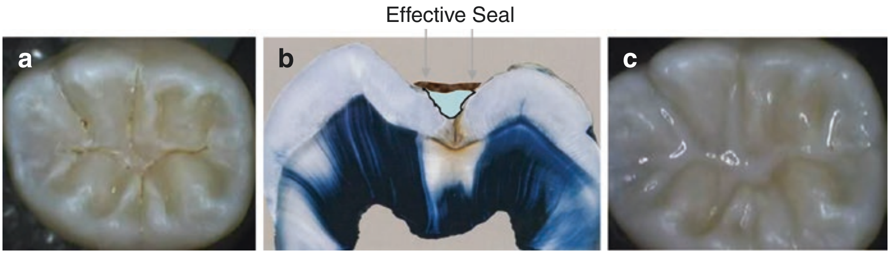

Fig. 7.1 Resin-based sealant (**c**) applied to an early non-cavitated lesion (**a**) to arrest lesion progression. The sealant will protect ("seal") the tooth surface from acids produced by biofilms exposed to fermentable carbohydrates (**b**), thus arresting the sealed caries lesion

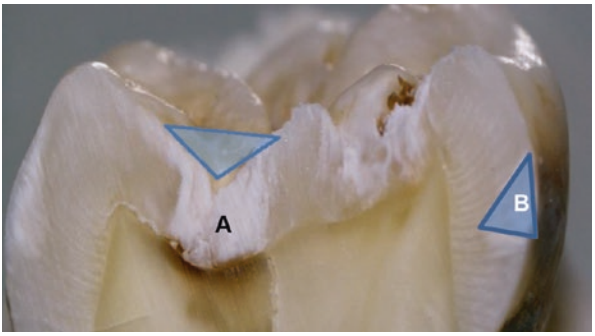

Fig. 7.2 Non-cavitated caries lesion in the occlusal surface (*A*) that is sealed, where the material (represented by the *blue triangle*) is on top of the tooth surface, while the caries lesion in the proximal surface is infiltrated (*B*), where the material (represented by the *blue triangle*) is inside of the lesion

a lack of uniformity in clinical practice around the world for the diagnosis of carious lesions, sealant assessment, and treatment thresholds for invasive and noninvasive or microinvasive (i.e., sealant) interventions for different stages of early caries development. In a 2001 survey of pediatric dentists, 80% of the respondents indicated that they routinely sealed caries-free and questionable occlusal surfaces, but only 20% reported sealing incipient/non-cavitated lesions. None indicated that they sealed overt cavitated lesions [2]. Another survey 10 years later found small gains, with only approximately 40% of dentists and pediatric dentists stating they used sealants to treat non-cavitated carious lesions; even when they were instructed to assume that a radiograph showed no evidence of the lesion extending into dentin, approximately 20–30% of respondents still opted to open the fissure and place a small resin-based restoration [3]. This premature invasive (i.e., restorative) overtreatment of pit and fissure surfaces with non-cavitated lesions will lead to the earlier introduction of the tooth to the costly restoration life cycle, where restorations will eventually fail and be replaced by larger and more costly restorations (as discussed in Chaps. 1 and 2). In examining the reasons for sealant underutilization and treatment decisions for non-cavitated lesions, personal clinical experience is a determining factor in dentists' treatment decisions, in addition to lack of appropriate reimbursement, and mistrust of recommendations. Thus, knowledge of recommendations does not lead to their adoption when the recommendation is incongruent with the dentist's personal experience [4]. Building positive experiences associated with conservative management of non-cavitated lesions, beginning in dental school settings, might contribute to affecting change in sealant utilization over time.

As it will be explained in the next sections, preventive fractions when sealing sound at risk surfaces consistently range between 60 and 80%, depending on the time of follow-up. In addition, sealants do not require patient compliance in order to work, other than returning for checkups for repairs when possible. The majority of existing evidence for sealants is still for studies using resin-based sealants, although the number of studies using materials ranging in the spectrum between resin composite and glass ionomer cements is increasing as time goes on. The effectiveness of sealants to prevent or arrest carious lesions depends on material retention on the surface they are meant to protect, and thus it is greatly affected by technique. However, placement of a sealant does not require any tissue removal, and only minute amounts of tissue are removed during the surface acid-etching or conditioning during material placement.

As early as 1984, the NIH Consensus Development Conference on Dental Sealants [5] suggested that other than their use on sound surfaces, sealants may also be used to arrest the progression of what at the time were referred to as "incipient or small pit and fissure lesions." In fact, studies since then have shown that targeting non-cavitated carious lesions results in greater reduction in caries rates than targeting sound surfaces [6], and a meta-analysis reported a preventive fraction when sealing non-cavitated lesions of 71% [7]. Also, a systematic review of the effects of sealants on bacteria levels in carious lesions found no significant increases in bacteria under sealants [8], as sealants lowered the number of viable bacteria, including *Streptococcus mutans* and lactobacilli, by at least 100-fold and reduced the number of lesions with any viable bacteria by about 50%.

7.2 Current State of Evidence for Sealant Use

7.2.1 Occlusal Surfaces That Are Sound or Have Non-Cavitated Lesions

Systematic reviews have consistently found that resin-based sealants are one of the most effective strategies in preventing the development of carious lesions on sound pit and fissure surfaces in children and adolescents. The preventive fraction, i.e., the proportion of carious lesions which can be prevented by placing sealants, ranges between 78 and 87% at 12 months, and 60% at 48–54 months [9–11]. After 9 years, only 27% of sealed surfaces had carious lesions in dentin compared to 77% of unsealed controls [12]. An example of some existing systematic reviews is provided next to highlight the consistency and strength of data supporting sealing of sound surfaces to prevent dental caries development.

- In 1993, Llodra et al. [9] performed a meta-analysis that included 14 studies of auto-polymerized sealants. These studies utilized a one-time sealant application and, in general, there were no other preventive exposures. The reduction in carious lesions among children receiving sealants compared to those not receiving sealants was 71%. The variation over time was 78% at 1 year and 59% with 4 years or more of follow-up.
- In 2001, Rozier [13] updated the Llodra review during the NIH Consensus Conference on Dental Caries. Five additional studies were included, but since they varied substantially in design, they were not combined into a summary measure of effectiveness. Most of the studies reapplied sealant over time, yet the studies showed a magnitude of effect ranging from 60 to 70%.
- In 2004, a systematic review was done by the Cochrane Collaboration. The results were in line with all the previous systematic and group reviews, suggesting that children who have their molar teeth covered by a resin-based sealant are less likely to get dental caries in their molar teeth than children without sealant. The reductions ranged from 86% at 12 months to 57% at 48–54 months [10]. This review has been updated twice since then [11, 14], and the conclusions consistently support the application of sealants as a recommended procedure to prevent or control carious lesions. Sealing the occlusal surfaces of permanent molars in children and adolescents reduces caries up to 48 months when compared to no sealant, but after longer follow-up the quantity and quality of the evidence is reduced. At the time, the results of the studies comparing different sealant materials were conflicting, and although the authors noted that the effectiveness of sealants is obvious at high caries risk, information on the benefits of sealing specific to different caries risks was lacking.

The evidence supporting sealing of non-cavitated lesions to arrest lesion development is also strong. When carious lesions are traditionally sealed with opaque sealant materials, lesion arrest is measured over time by looking at bacterial counts (i.e., bacterial counts significantly decrease after sealant placement, leading to a more leathery, less wet dentin over time) or radiographs (Fig. 7.3). Examples of reviews are provided next.

- In 1983, a National Institutes of Health (NIH) sponsored Consensus Development Conference on dental sealants [5] concluded sealants are highly effective and safe, are underutilized, their use should be expanded together with use of fluoride strategies, and they are urgently needed to control dental caries in high-risk population groups. These conclusions are identical to ones we could develop today. In addition, even though sealants had only been available for a little over a decade, it was concluded the evidence was “overwhelming” that the vitality of the pulp was not endangered by sealant placement, and that “minor carious lesions” that are sealed become “inactive” when the caries process arrests.
- Current sealant guidelines for US community programs were published in 2009 by the Centers for Disease Control and Prevention in the USA (CDC) and its Expert Sealant Panel group, and support the use of sealants on sound surfaces and non-cavitated lesions [15]. The previous sealant guidelines for community

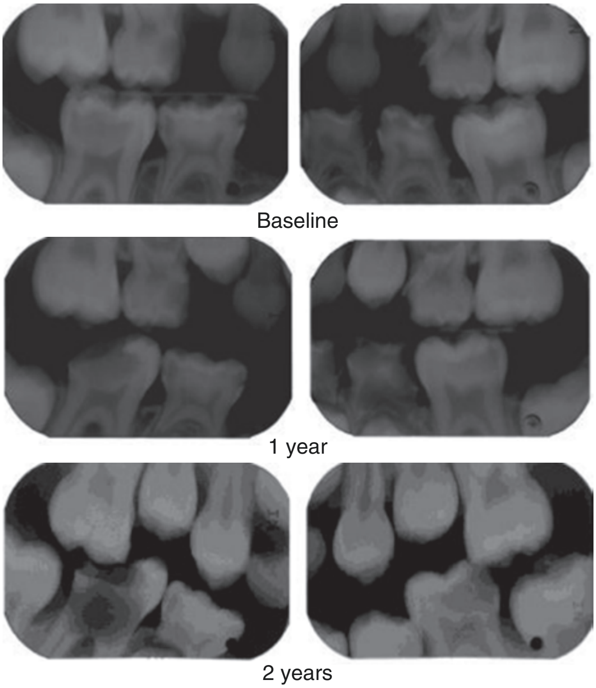

Fig. 7.3 Radiographic follow-up of sealed maxillary first molars (non-cavitated lesion clinically on upper right first molar, and microcavitated lesion clinically on upper left first permanent molar) showing no progression, while the non-sealed mandibular first molars show evidence of progression over 2 years

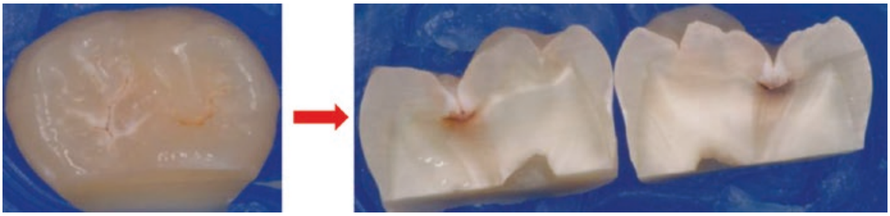

Fig. 7.4 Occlusal non-cavitated caries lesions, such as the one clearly visible on this figure, strongly benefit from being sealed to arrest caries progression, yet these lesions are not only limited to the enamel, but can be into dentin, as shown in the figure

school-based programs had been published in 1995 [16] and suggested sealants be used to prevent caries (i.e., to seal sound, at risk surfaces) and therapeutically (i.e., to arrest "questionable," or what at the time was referred to as "enamel" caries. However, nowadays we understand non-cavitated lesions may have progressed into dentin, Fig. 7.4).

- In 2001, NIH held a Consensus Development Conference on dental caries [17]. One of the topics reviewed was sealants and the panel concluded that sealants are effective in the primary prevention of dental caries, the effectiveness remains strong as long as the sealants are maintained, and the evidence for carious lesion arrest supports their use for this purpose.

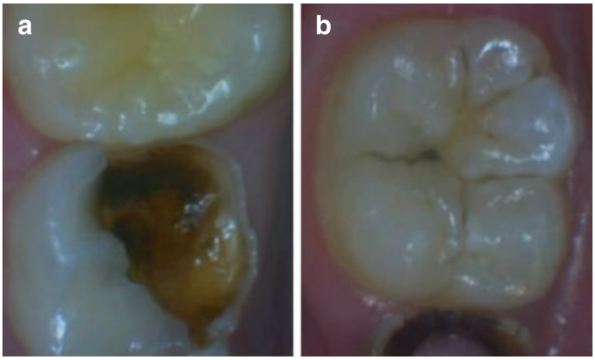

Fig. 7.5 Sealant recommendations support the sealing of sound first permanent molars (**a**, primary second molar has a large cavitated lesion, suggesting the patient is at risk for future lesions, and thus the first permanent molar would benefit from being sealed to prevent caries), and those with non-cavitated lesions (**b**)

- In 2008, a systematic review strongly supported the sealing of non-cavitated carious lesions, with a caries reduction of 71% [7].
- A systematic review focusing on the microbial impact of sealing carious lesions concluded that the percentage of bacteria reductions in carious lesions is high after sealant placement, increasing with time since sealant placement. Bacterial reductions ranged from 50.8 to 99.9% [8].
- Professional organizations' evidence-based recommendations and guidelines support the use of sealants on non-cavitated carious lesions [15, 18, 19]. The proposed threshold for sealant placement in the abovementioned recommendations was selected based on the results of studies that measured carious lesions using diagnostic criteria primarily at the cavitation or "softness" level. These criteria are limited in their ability to discriminate among sound teeth and/or different stages of early carious lesion severity. In addition, none of the reviewed studies evaluated the effectiveness of sealants on progression of more advanced lesions, i.e., small cavitated lesions in which the break can be visually confined to the enamel, or those with signs of undermined enamel (dark coloration around the pit and fissure).
- In 2016, the American Dental Association updated their sealant recommendations. In this systematic review and evidence-based clinical guidelines only studies including materials currently available in the market were included. This precluded inclusion of many of the initial sealant studies using ultraviolet light polymerized sealants, etc. The resulting clinical recommendations are that sealants prevent dental caries better than either nothing (strong recommendation) or fluoride varnish (conditional recommendation) on the pits and fissures of permanent sound teeth, and those with non-cavitated occlusal carious lesions in children and adolescents (Fig. 7.5). The review was unable to determine the superiority of one type of sealant over another due to low quality evidence (conditional recommendation) [19, 20].

7.2.2 Proximal Surfaces with Non-Cavitated Lesions

Most studies associated with microinvasive management of proximal surfaces involve the use of infiltration. Randomized controlled trials on proximal caries infiltration have concluded that caries infiltration is an effective method to arrest progression of non-cavitated proximal lesions extending radiographically into the inner half of the enamel up to the outer third of the dentin [21]. A recent systematic review by the Cochrane Collaboration also supported the use of sealants and infiltrants to arrest proximal lesions in primary and permanent teeth [22]. One of the issues with infiltration is that the material is not radio-opaque, and thus it is impossible to assess at placement and over time. It is possible this may have an impact on its adoption.

7.2.3 Microcavitated Lesions

Few studies have assessed the effectiveness of placing sealants on more advanced lesions (i.e., microcavitated lesions). These lesions are also described as International Caries Detection and Assessment criteria-ICDAS Scores 3 and 4 lesions [23]. The ICDAS system was designed to be a unifying, predominantly visual set of criteria codes based on the characteristics of clean, dry teeth at both the enamel and dentin caries levels, which is capable of assessing both caries severity and activity, and has supporting histological validation. Carious lesions with ICDAS scores 3 and 4 are lesions in which there is a break in the tooth surface that visually is limited to enamel, but can also include signs of undermining enamel, such as a dark shadow around the pit and fissure. In a study conducted in the USA, sealants used on a very high risk population placed on occlusal surfaces ranging from sound, to having non-cavitated lesions or microcavitated lesions (ICDAS 0-4), and radiographically extending no more than half-way through the dentin, repaired yearly when needed, were 98% effective over 44 months in preventing progression. In addition, the study suggested that occlusal surfaces without frank cavitation (ICDAS 0-4) sealed with a clear sealant could be monitored over time using ICDAS, Quantitative Laser Fluorescence, or DIAGNOdent, and that this may aid in prediction of need for sealant repair [24] (Fig. 7.6).

Another study investigated the possibility of postponing restorative intervention of what was referred to as “manifest” occlusal caries (i.e., lesions in need of restorative care) in young, permanent teeth by using dental sealants. The 7 years survival was 37% for sealants vs. 91% for restorations. The median survival time for sealants not replaced by restorations was 7.3 years, and was increased in low caries risk patients and/or those with excellent oral hygiene, in second molars compared with first molars, and in lesions not extending to the middle one-third of dentin radiographically. Survival was not influenced by sex, eruption stage, or clinical surface cavitation. The results suggest that it is possible in some cases to postpone or avoid restorative intervention of occlusal dentin carious lesions in young permanent teeth by using sealants [25].

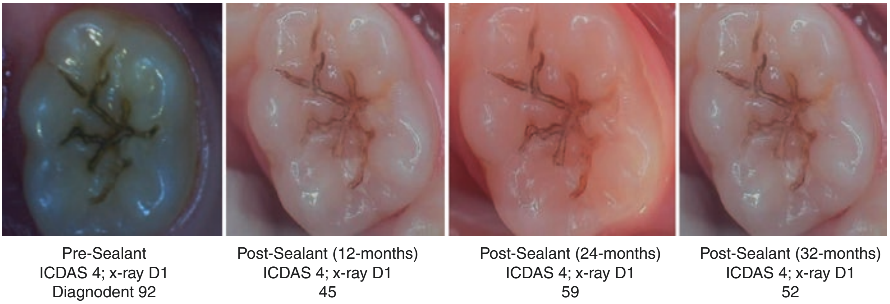

Fig. 7.6 Microcavitated lesion sealed with a clear resin composite sealant and monitored over time

Certain occlusal lesions are clinically non-cavitated but radiographically extend significantly into dentin (more than the outer one-third of dentin). In these cases, it has been suggested that sealants can be used, but the integrity of the sealant needs to be monitored as there is a possibility, until more evidence has emerged, that a "trampoline" effect may lead to failure of the sealant and a restoration may be required [26], as described in Chap. 6. In fact, the more severe the lesion, the greater the percentage of sealants that need repair [24]. In a recent systematic review and meta-analysis comparing sealants to minimally invasive (MI) restoration and noninvasive treatment of carious lesions (control), 14 studies representing 1440 patients and 3551 lesions in permanent teeth (shallow or moderately deep-outer two-thirds of dentin) demonstrated that sealants and MI treatments required less invasive retreatments than the control. However, sealants required more re-sealing than other groups [27].

7.2.4 Cavitated Lesions

Theoretically, sealing cavitated lesions from the oral health environment to arrest their progression is possible. Evidence supports sealing infected and demineralized tissue will have a large impact on reductions of microbial growth over time, regardless of the size of the lesion [8], with remaining microorganisms "entombed" and deprived of nutrition, which leads to alteration of the flora with subsequent caries arrest and re-hardening of formerly soft dentin. The evidence supports that in deep carious lesions, selective removal of tissues to soft dentin over the pulp and stepwise caries removal are the treatments of choice to reduce the risk of pulp exposure, and to slow down the restorative cycle by preserving tooth tissue and retaining teeth long-term [26]. However, dental sealants are not the material of choice to "seal" large or deep cavitated lesions, as they are mechanically not as strong as other restorative options. Thus, to handle these deep or larger cavitations, we need stronger materials, or need to use different techniques (e.g., Hall crowns, etc.).

7.2.5 Sealants Vs. Preventive Resin Restorations

It is important to stress that sealing non-cavitated lesions or microcavitated lesions is not the same as placing a "preventive resin restoration" (PRR). A PRR is a restoration placed on a cavitated lesion, not a sealant. The term "Preventive Resin Restoration" was first reported in 1977 by Simonsen and Stallard [28] as a ways to call attention to a move in philosophy away from the traditional GV Black's "extension for prevention" to a more conservative approach possible with the use of resin-based materials. The idea was that limited cavitated lesions within pits and fissures would be restored with composite resin, while the remaining healthy fissures (with or without minimal exploratory openings; which are not recommended nowadays) would be sealed with a pit and fissure sealant. In addition, three types of PRR were initially suggested [29–31]: Type I PRR was indicated where there was uncertainty if the fissure showed a carious lesion or there was a "minimal lesion in enamel" (note nomenclature used at the time). Type II and III PRRs had very similar indications: when an exploratory opening of the fissure was greater than 1 mm in cross section or the caries had penetration into the dentin in an isolated pit or fissure area.

Over the years there have been several modifications or additions to these initial publications, adding to the confusion around what a PRR is or when it is indicated. More recently, Simonsen [32] proposed a simplification of the PRR concept as a restoration of a cavity that is limited to a small portion of the occlusal surface. He stated that with the advances in remineralization techniques, the use of Type 1 PRR should be abandoned in favor of remineralization. He also supported the use of sealants for non-cavitated lesions, but suggested that when the lesion has clearly progressed into dentin radiographically, the PRR may be a more suitable option than a sealant.

If a PRR is a restoration limited only to a small occlusal cavitated lesion, with sealant placed in the remaining at risk occlusal fissures/pits, then shouldn't every resin-based restoration aim to be a PRR whenever possible? While the term PRR was a necessity when it was introduced, nowadays it is obsolete as defined above and has the potential, because of confusion, to interfere with the implementation of sealing of non-cavitated carious lesions.

7.2.6 Sealants Vs. Fluoride Varnishes for Management of Occlusal Surfaces

Although the number of studies addressing this question is still limited, the conclusion is that resin-based sealants should be preferred to fluoride varnishes (FV) in permanent molars with non-cavitated lesions, as they appear to be more effective in preventing and arresting carious lesions [19, 20, 33]. Regarding glass ionomer sealant versus fluoride varnish comparisons, a recent Cochrane Collaboration systematic review concluded the quality of the evidence was very low and so no conclusions could be drawn [33]. These conclusions are more relevant for public health programs than private practice settings, as in the latter case sealants and FV are in many cases used together to manage caries in the entire dentition in high-risk subjects. Unfortunately, no economic analyses were reported in any of the included studies to inform this decision [34].

7.3 Material Choices for Use as Sealants

Sealants have been around for more than 40 years. Over time different types of sealants have become available for clinical use: resin-based non-fluoride releasing [chemically cured, ultraviolet light cured (not used any more), cured using white light], and fluoride-releasing sealants [that can be a resin composite, a glass ionomer, or a material in between the spectrum between these two previous categories]. As resin-based sealant materials have been around the longest, there are a large number of studies assessing their retention and effectiveness for caries control. However, as fluoride-releasing sealants release fluoride, a well-known agent to control dental caries, these materials have gained clinicians' attention when managing high-risk patients. Yet, the numbers of studies on glass ionomer or other fluoride-releasing materials are proportionally less to those focusing on non-fluoride releasing resin composite. In addition, glass ionomer materials wear over time, affecting clinically visible sealant retention. Yet, even when the material is not visible clinically, laboratory studies of sectioned teeth suggest that remnants of the glass ionomer cement are retained in the bottom of the fissures, aiding in caries control. As retention is a common surrogate for effectiveness for resin-based materials (i.e., the sealant works if physically present to "block" or "seal" the fissure), studies on glass ionomer sealants cannot use sealant retention as a surrogate to effectiveness, in the same way as resin-based sealants, as explained below.

7.3.1 Retention of Dental Sealants

It is generally accepted that the effectiveness of resin-based sealants depends on long-term retention. Retention levels decrease over time (e.g., 79–92% = 12 months, 71–85% = 24 months, and 61–80% = 36 months [11]), increasing the need for replacement or repair. A recent Cochrane Collaboration systematic review confirmed that the caries reduction effectiveness of resin-based sealants is related to the retention of the sealant, and in the studies comparing sealant with a control without sealant resin sealants were retained completely on average in 80% of cases [14]. Another recent systematic review argued that complete retention of pit and fissure sealants may not be a valid surrogate endpoint for caries prevention for glass ionomer sealants, because the risk of retention loss was associated with the risk of caries for resin-based but not for glass ionomer sealants [35]. Auto-polymerizing resin-based sealants have a 5-year complete retention rate of 64.7% (95%CI = 57.1–73.1%), while for resin-based light-polymerizing sealants the retention rate is of 83.8% (95%CI = 54.9–94.7%). In contrast to these high retention rates, poor retention rates have been documented for UV-light-polymerizing materials, compomers, and glass ionomer cement sealants (5-year retention rates were <19.3%; [36]). Retention rates combined with the faster and less error-prone clinical application of light-polymerizing resin-based materials make them a great choice for daily dental practice.

7.3.2 Resin-Based Vs. Glass Ionomer Sealants

Many evidence-based recommendations for sealant use in the last decade recommend that resin-based sealants be considered the first choice of material when sealing a tooth, and that glass ionomer cement be used as an interim preventive agent when there are concerns about moisture control that prevent the use of a resin-based material [15, 18].

As more studies have become available, the differences between resin composite and glass ionomer cement materials used as sealants have been less clear to discern. A recent Cochrane Collaboration systematic review of existing randomized clinical trials suggests that is it unclear if glass ionomers are similar to resin-based sealants for caries control [14]. The ADA recently updated their sealant recommendations to include only studies of materials currently in the market, and concluded it was unclear if one sealant material was superior to another. Yet, the expert panel stated that it is important to take into account the likelihood of experiencing lack of retention when choosing the type of material to use. Thus, for example, if dry isolation is difficult (Fig. 7.7), then a material that is more hydrophilic (such as glass ionomer cement) would be preferable. But if a tooth can be isolated to ensure a dry site, and long-term retention is desired, then a resin-based sealant is preferable. While both types of materials must be monitored over time, this is especially important for materials experiencing a higher risk of retention loss (i.e., glass ionomer cements) [19].

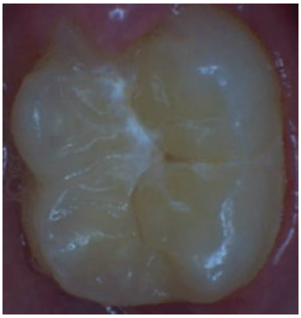

Fig. 7.7 Erupting first molar with a non-cavitated lesion. If the tooth cannot be maintained dry, and long-term sealant retention is not a concern, then the material of choice would be a glass ionomer sealant

7.4 Sealant Application Considerations

7.4.1 Recommendations for Sealant Application

When placing sealants [18, 19]:

- The tooth surface should be cleaned with a toothbrush and water to correctly assess the surface and to increase retention prior to placing a sealant. A systematic review concluded that sealant retention rates for teeth cleaned with a toothbrush are at least as high as for teeth cleaned with a handpiece [37].
- Routine mechanical preparation of enamel (e.g., opening the fissure system through fissurotomy, enameloplasia, etc.) before acid etching is not recommended as there is no data that it enhances the caries preventive effect of sealants, and if the sealant is lost after a preparation, the tooth could be at enhanced risk.
- When possible, a four-handed technique should be used for placement of resin-based and glass ionomer sealants to ensure proper isolation. A systematic review concluded that four-handed sealant placement is associated with higher retention rates than two-handed placement [38].
- The choice of material should be based on level of drying that can be achieved and desired long-term retention. To obtain optimal levels of retention, clinicians should carefully follow the manufacturer's instructions for each type of sealant material.
- A compatible one-bottle bonding agent, which contains both an adhesive and a primer, may be used between the previously acid-etched enamel surface and the sealant material when, in the opinion of the dental professional, the bonding agent would enhance sealant retention in the clinical situation. A systematic review recently concluded that adhesive systems beneath fissure sealants can increase the retention of the sealants [39].
- Use of available self-etching bonding agents, which do not involve a separate etching step, is not recommended, and etch-and-rinse systems are preferable [40].
- The oral health care professional should monitor and reapply sealants as needed.

7.4.2 Partially Lost Sealants and Caries Management

One of the main questions to consider when placing a sealant is what happens if a sealant is partially lost over time. A systematic review suggests that the risk for lesion development in previously sealed teeth that have lost some or all sealant remains is less or equal to caries risk for never sealed teeth [41]. These findings suggest that a child at risk should not be deprived of the benefits of a sealant even when follow-up care cannot be ensured. These findings, however, do not suggest that practitioners can be any less careful in their sealant-application technique or in the evaluation or maintenance of sealants after placement in clinical practice. Because current guidance recommends sealant placement only when there is a risk of caries development, and because sealant effectiveness is linked directly to retention (at least for resin-based sealants and if retention is assessed clinically, not histologically), the maximum protection against caries can be achieved when a sealant is fully retained.

7.5 Threshold for Sealant Use

Several methods have been traditionally used during the assessment of occlusal tooth surfaces to help improve the detection of carious lesions that can be targeted for sealant use, including visual assessment, use of explorer, air-drying, magnification, radiographs, and technology-aided detection tools. The interest in detection methods to guide sealant placement is not new. In 2001, at the NIH Caries Consensus Development Conference on dental caries, a discussion on sealants suggested that "improved caries detection and diagnostic methods would help determine the appropriate cut-point or threshold separating the clinical decisions to do nothing or preventively seal, or to therapeutically seal or surgically treat and restore. Theoretically, laser fluorescence could be useful for determining whether a tooth is sound and does not require intervention, has evidence of a low level of caries activity and is appropriate candidate for a sealant application, or has a higher degree of disease severity that requires surgical intervention. Ideally it could subsequently be used to monitor sealant effectiveness…" [42].

As explained earlier, the current threshold for recommending sealant use is generally considered lesion cavitation, as this is the basis for lesion detection criteria used in the majority of sealant studies to date. A non-cavitated lesion, commonly referred to as a "white spot lesion," can be defined as a carious lesion whose surface appears macroscopically to be intact. It may appear as white/yellow/brown coloration, which may be limited to the confines of the pits and fissures. A cavitated lesion, on the other hand, is a lesion in which there is a discontinuity or break in the surface. By the time this occurs, demineralization has in most cases progressed histologically, radiographically and/or clinically into the dentin. The break can be limited to enamel but with signs of undermined enamel (dark coloration around the pit and fissure) or can expose dentin directly to the oral cavity. The presence of dentinal involvement, such as an underlying dark shadow, can be determined without extensive drying of the tooth surface.

Unaided visual examination is the simplest method of choice to decide whether a tooth is cavitated, and whether a sealant should or not be placed. The array of options available in a traditional clinical setting further enables practitioners to focus on differentiating among cavitated, non-cavitated and sound pit and fissure surfaces, and allows for targeted prevention or treatment. To determine presence of this level of lesion severity, teeth should be clean, dry, and well illuminated for visual assessment. Forceful use of a probe should be avoided. Radiographs should not be taken for the sole purpose of placing sealants. Other diagnostic technologies are not necessary for the sole purpose of placing sealants [43]. More details are explained in the next paragraphs.

7.5.1 Use of the Explorer

Use of an explorer to confirm cavitation ("catch") in pit and fissures was one of the most commonly used criteria in the past to measure dental caries experience and was widely used in early protocols for detecting carious lesions. The literature indicates, however, that forceful use of a sharp explorer for the sole purpose of detecting carious lesions is highly discouraged in today's practice of dentistry as non-cavitated lesions can become damaged through pressure from the explorer during examination, and introduce a pathway for continued lesion progression. Further, evidence suggests that the use of the explorer does not improve accuracy of visual assessment on the detection of pit and fissure lesions. However, the explorer may be safely used in several applications: to gently remove plaque and debris from the tooth surface; in cases where there is doubt about the presence of a cavitation, the explorer can be moved gently to detect changes or breaks in surface contour; to evaluate the smoothness/roughness of the tooth surface to help determine lesion activity; and once the tooth is sealed, the explorer can be used to help assess sealant integrity and retention.

7.5.2 Use of Magnification

There is relatively little research on the use of magnification to assess the caries status of occlusal surfaces of permanent teeth. Among the in vitro studies that do exist, comparisons of visual assessment with or without magnification present conflicting results [44–46]. In addition, there is limited evidence in the scientific literature to support the adoption of magnification for visual assessment of tooth surfaces for sealant placement, and its impact in terms of effectiveness and retention is unknown. While magnification is not contraindicated, and it is possible it may be useful for surface assessment, sealant application, and retention checks, the unaided visual assessment of occlusal surfaces is the appropriate approach for detection of cavitation as a threshold for sealant placement.

7.5.3 Use of Radiographs

Sealants on occlusal surfaces are commonly placed in permanent molars soon after eruption. At this age, the most commonly affected surfaces are occlusal, not proximal. In general, radiographs should be taken only when there is an expectation that the diagnostic yield will affect patient care. The current recommendations to seal sound and non-cavitated lesions in occlusal surfaces argue against the routine use of radiographs for deciding to place a sealant, as radiographs have very low accuracy to detect early occlusal lesions, and determine presence of small cavitations. Further, radiographic images of proximal surfaces are not necessary to evaluate pit and fissure surfaces for sealant placement. However, if radiographs of target teeth are available for other reasons than sealant placement alone, they should be considered in case there is a non-cavitated occlusal lesion radiographically deep into dentin, or a deep proximal lesion that may affect treatment of the occlusal surface. On the other hand, when referring to infiltration, radiographs are absolutely essential to determine the depth of the lesion and thus, likelihood of cavitation, and to monitor the effectiveness of treatment on lesion arrest over time.

7.5.4 Use of Other Assessment Methods

There has been a concerted effort over the last decades to identify more technologically advanced methods to detect/quantify demineralization in non-cavitated lesions. Some of these technologies include Quantitative Light-Induce Fluorescence (QLF, Inspektor Research Systems, Amsterdam) and Laser-Induced Fluorescence (e.g., DIAGNOdent, Kavo, Biberach). These are aids to help with detection and monitoring of non-cavitated lesions, but are not stand-alone detection methods that can be used in place of the dentist's clinical judgment. In addition, these detection methods do not help detect lesion cavitation and are expensive, thus their use is not justified solely for sealant placement.

7.6 Cost-Effectiveness of Sealants

Studies of cost-effectiveness are affected by dental caries prevalence, who can apply the sealants, and costs associated with treatment outcomes in different areas of the world. Regardless of the setting, available evidence and review of systematic reviews on cost-effectiveness support the conclusion that placement of sealants over sound and non-cavitated carious lesions prevents/arrests the disease process and is cost-effective [47]. Furthermore, recent evidence indicates the benefits of SBSP exceed their costs when they target schools attended by a large number of high-risk children [48].

7.7 Recommendations for Sealants Use

Dental caries, one of the most common diseases of childhood, is manifested predominantly as carious lesions in pits and fissures of teeth in this age group. Fortunately, there is strong evidence for sealant effectiveness preventing dental carious lesions, and managing non-cavitated lesions and bacterial infection, and providing sealants in public programs is not only effective but can increase access to care for underserved children. Consequently, current recommendations support the use of sealants on sound occlusal surfaces and on non-cavitated carious lesions (Fig. 7.8). However, sealant utilization is still low, and many dentists are reluctant to adopt evidence-based clinical recommendations regarding sealing carious lesions. One of the major barriers in sealant utilization is the concern of sealing over active carious lesions, that cannot be monitored after being sealed, fueled by a lack of uniformity in caries diagnosis, sealant assessment and reimbursement, and treatment thresholds for operative/nonoperative intervention for early/moderate stages of caries development [24]. What will it take to change? Education and training, focusing on enhancing early career experiences, coupled with a fairer pay scheme, is a reasonable approach to consider in order to change the balance in favor of provision of preventive measures, including sealants, by dentists [49, 50]. While sealants cannot be used to manage deep carious lesion, the idea of removing no carious dentin but controlling the lesion activity (as described in Chaps. 1 and 2) has inspired various techniques, which are nowadays mainly used on primary teeth. These are described in the next chapter.

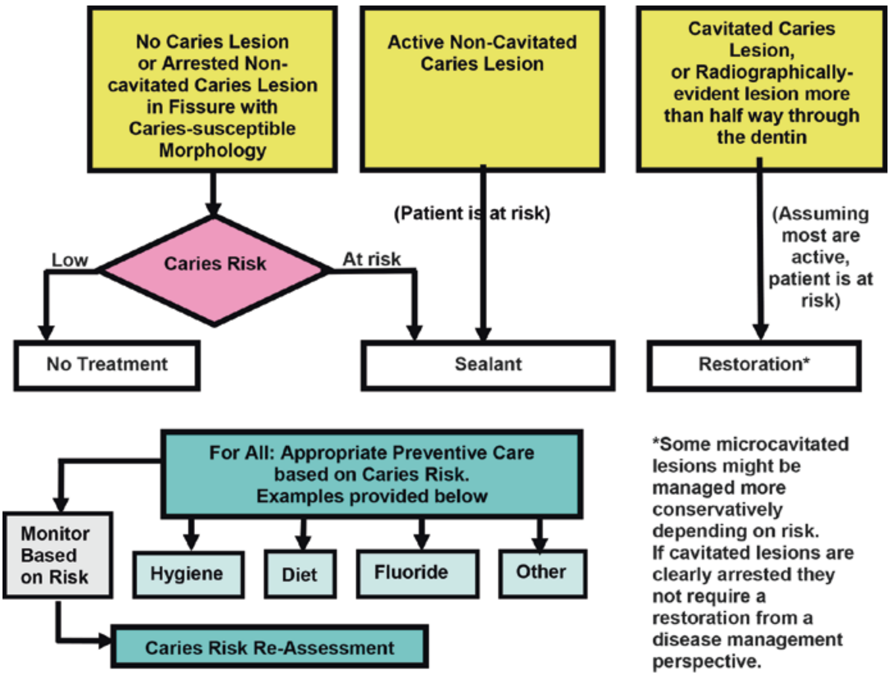

Fig. 7.8 Recommendations for use of sealants in pits and fissures of permanent teeth in private practice settings

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Management of Deep Carious Lesions Through Sealing in Primary Teeth

8

Nicola Innes

Abstract

The changes towards more conservative approaches to managing carious lesions in the permanent dentition have been mirrored for primary teeth. Prevention is key to treatment planning for the child with a carious primary dentition as the presence of the disease means that prevention has failed at some stage. Correct diagnosis of the presence/absence of carious lesions should be followed by investigation of whether each lesion is active/inactive and whether it is deep (advanced) or initial. Next a diagnosis of the status of the dental pulp must be made, to rule out irreversible pulpitis or infection of the dental pulp. The alternatives for managing carious lesions in an asymptomatic tooth (i.e., a tooth without signs or symptoms of irreversible damage to the dental pulp—pain/infection) are: Selective Removal to Soft Dentin and place a restoration; Sealing over the lesion with fissure sealant or resin infiltration; Sealing over the lesion with a crown using the Hall Technique; and No caries removal and no restoration using the Non-Restorative Cavity Control approach. These procedures are covered in detail in this chapter, their indications for different types of lesions and a flow chart to guide care planning is given.

8.1 Care of the Child with Deep Carious Lesions in Primary Teeth

Recently, there have been some notable changes in our approach to managing the child with carious lesions extending into dentin in their primary dentition. Historically, pediatric dentistry was considered as only a branch of traditional restorative dentistry and did not take into consideration the wider aspects of caring

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for children with the disease. Alongside that, a greater understanding of the carious process has led to more conservative approaches to managing the lesion and teeth with the aim of preserving the dental pulp and tooth structure as much as possible through managing the biofilm [1] rather than trying to completely excise it [2]. This chapter deals with different approaches to, and methods for, managing the deep carious lesion in a primary tooth and discusses treatment planning and building a care plan. The differences between caring for primary teeth compared to permanent teeth and the core principles of treatment are discussed. We then look at carious lesion diagnosis specific to primary teeth and mention diagnosing for the dental pulp. The different treatment options are summarised, then explained in detail and this is followed by treatment planning for these options.

8.2 Differences Between Restoring Teeth for Adults and Children

The most obvious differences between managing caries in the primary dentition compared with the permanent dentition are anatomical ones: smaller teeth in small mouths; more bulbous teeth; larger pulp to crown ratio; less mineralized and thinner enamel; and splayed, ribbon-shaped roots that resorb. However, there are other fundamental differences that complicate providing care; child patients are different: they cannot look after their own oral health for a significant part of their childhood; they need to be brought for appointments; they like operative care even less than adults do; and they have less sense of "pain today for gain tomorrow" as they live in the present. As well as children being cognitively different from adults and holding a different place in society, primary teeth are morphologically different to permanent teeth and they exfoliate. However, children have the same rights to general and oral health as adults. Furthermore, adult dental disease begins in childhood, so prevention and education must be core to management.

Re-establishing successful prevention is a key part of managing established disease. Before considering managing dental caries, there must be acknowledgment that prevention has failed and a strategy has to be put in place to reconstruct successful preventive practices. For the child in the primary or mixed dentition stage, this must involve the parent/carer. Although they may develop the dexterity to carry out the physical activity of tooth brushing quite early, the age at which they have the cognitive ability to make decisions around caring for themselves comes much later. Until then, this is the responsibility of the adult caring for them.

8.3 Core Principles of Treatment Planning

The presence of disease does not mean that restorative management is necessary (see Chaps. 1 and 2). Instead, carious lesions can be sealed using different methods [3, 4]; options for sealing lesions have grown in number and include:

- Selective Removal to Soft Dentin where the lesion is sealed but the aim of avoiding damage to the dental pulp is balanced against the need for longevity of the restoration, as described in Chap. 5.

- Sealing of non-cavitated lesions using fissure sealants; the enamel surface must be relatively intact to allow an effective sealant, as described in Chap. 7.
- Sealing lesions under preformed crowns; the Hall Technique.

As well as sealing approaches for managing carious lesions, there is another option, employing a non-restorative approach:

- Regular and frequent removal of the biofilm through tooth brushing using a non-restorative cavity control approach. The carious lesion is made cleansable to allow repeated removal of the biofilm, preventing the lesion from progressing and promoting remineralization of the tissues.

Regardless of whether a sealing-in or biofilm removal care plan is derived or even if a restorative approach is resorted to, prevention needs to be reinstated as an active part of that care plan. This is just as important when non-cavitated (initial, white spot, etc.) lesions are present.

As the principles in Chap. 1 state: a restoration may not be necessary if it is possible to arrest the disease and overtreatment should be avoided. If carious tissue removal and a restoration are needed, the dental pulp vitality should be maintained.

The core principles, adapted and expanded from [5], can be summarised as: **Recognition** (of contributory factors); **Reorientation** (of lifestyle factors); **Remineralization** (of all lesions—visible and not visible, cavitated and non-cavitated); **Repair/restore** (where no other solution is possible) and **Review** (of the child, their oral health and their situation).

8.4 Carious Lesion Diagnosis in Primary Teeth

Diagnosis of the presence of dental carious lesions is not simply a binary decision on whether a carious lesion is present or not. It involves several decision steps.

8.4.1 Lesion Presence/Activity/Depth

Treatment possibilities for each lesion depend on its stage, activity and how advanced it is, therefore diagnosis needs to consider, for each surface of a tooth:

- Is there a carious lesion present—yes/no

  If yes, then for each lesion:

- Is the lesion—active/inactive?

  Deciding on activity

- Is the lesion—deep (advanced) yes/no?

8.4.2 Defining Lesion Activity

It can be difficult to tell whether a lesion has arrested or not at a single appointment as the true definition of an arrested lesion is one that does not progress over time. Nevertheless, it is often necessary to make a judgement on this at a single timepoint (although following up the tooth and child will confirm the diagnosis or will lead to a change in care if the lesion is seen to progress). Although this book is about deep dentinal lesions, for completion, enamel lesion characteristics are also mentioned.

For carious lesions that are confined to the enamel, the enamel surface will be rough when the lesion is active [6]. For dentinal lesions where the surface is exposed, the degree of hardness indicates how likely a lesion is to be arrested [6]. The harder the tissue, the less likely the lesion is to progress. Cleansability and presence of biofilm over vulnerable surfaces are two further factors that can influence a decision around whether a lesion is likely to be arrested. The less cleansable and more biofilm, the less likely the lesion is to be, become, or remain arrested. Of course, often the cleansability of the tooth can be influenced through non-restorative cavity control (see later in this chapter).

8.4.3 Defining Lesion Depth

There are no agreed definitions for lesion staging and here they are broken down depending on whether the lesion is considered initial or deep/advanced. The following definitions are used to allow identification of deep lesions and recommendations for their treatment to be specified:

8.4.3.1 Occlusal Lesions (Molar)

- Initial—Clinical-visually, these lesions are usually non-cavitated, often with dentin shadowing or minimal enamel cavitation; radiographically, they extend into the outer 1/3 of dentin at most.
- Advanced/deep—Clinical-visually, the lesions show a dentin shadow or cavitation with visible dentin; radiographically, the middle or inner 1/3 dentin is affected, but a clear band of dentin is still visible between the advancing front of the lesion and the dental pulp.
- Extremely deep—These lesions share similar characteristic to the deep lesions, but without the radiographic band of dentin between the lesion and the pulp; they are often much harder to manage whilst maintaining the pulp (the pulp prognosis is much poorer, as often pulps are inflamed). More details can be found in Chap. 3.

8.4.3.2 Proximal Lesions (Molar)

- Initial—Clinical-visually, these present as white spot lesions or can be detected as shadowing; radiographically, the lesions are confined to enamel or just into the dentin (extending into the enamel–dentin junction, but not much beyond).

- Advanced/deep—Clinical-visually, these show enamel cavitation or dentin shadow, or cavity formation with visible dentin; radiographically, they extend up to inner 1/3 dentin but a clear band of dentin is still visible between the advancing front of the lesion and the dental pulp.
- Extremely deep proximal lesions are similarly defined and characterized as those on occlusal surfaces.

8.4.3.3 Anterior Tooth Lesions

- Initial—Clinical-visually, they are white spot lesions without dentinal affection.
- Advanced/deep show cavitation or dentinal shadow.

8.5 Diagnosis of the Dental Pulp Status

Having diagnosed the presence, activity and depth of the carious lesion, a further diagnosis relating to the dental pulp must be made. This is to ensure it is not irreversibly inflamed or infected. A careful clinical and radiographic assessment will establish whether there is irreversible pulpitis or peri-radicular periodontitis. Ensuring these are not present then allows options for the carious lesion to be determined. Management of the irreversibly inflamed and/or infected dental pulp with a pulp therapy of some kind is beyond the scope of this book.

8.5.1 Clinical Diagnosis and the Dental Pulp

The deep carious lesion can cause symptoms of pain. In the primary dentition, it can be difficult to determine whether the pain is due to reversible pulpitis, irreversible pulpitis or peri-radicular periodontitis.

Symptom reporting from the patient's history can be through the child or the parent and the clinical examination will allow clinical signs to be detected. Together these give information that will help to inform whether there are any signs or symptoms of irreversible pulpitis/peri-radicular periodontitis.

Irreversible pulpitis is characterized by spontaneous pain, pain from the tooth wakening the child or keeping them awake at night, and/or pain not resolved on removal of a stimulus—hot, cold, sweet. This can be a difficult judgement to make:

- children are not good reporters of symptoms especially when young and cognitively it can be difficult for them to understand what they are feeling and to express it;
- reversible pulpitis does not present with distinct and discernible symptoms that suddenly completely change to those of irreversible pulpitis. The transition is a gradual one towards irreversible pulpitis with episodes of progression, regression and intermittent resolution of symptoms; and
- there are multiple roots and multiple root canal systems. In a departmental audit of pulp vitality during pulp therapy, (in 2007), in around 1/3 of cases where there was a sinus or abscess, the dental pulp was still vital is one or more canals. This adds to the complexity of diagnosis.

Signs of pulpal infection include the tooth being tender to percussion when there is peri-radicular periodontitis as the peri-radicular tissues are inflamed. There may be an abscess or sinus associated with the peri-radicular (usually the furcal) area of the tooth. This tends to be seen at the mucogingival junction, or draining from the gingival sulcus of the tooth.

8.5.2 Radiographic Diagnosis and the Dental Pulp

A recent radiograph with the furcation area visible should show no signs of infection. Established infection will be visible as a radiolucent area in the furcal area (Fig. 8.1) although this can take a number of months to be significant enough to appear on a radiograph. This can often be seen clearly on a horizontal bitewing radiograph although sometimes it might be necessary to take a vertical bitewing to visualise the inter-furcal area clearly.

The bitewing radiograph serves another important diagnostic function that can help with determining whether the tooth is likely to have irreversible damage to the dental pulp; it allows an assessment of the extent of the carious lesion. Although it is not possible to gauge lesion depth with the same accuracy that would be achieved histologically, with skill and experience, the clinician can determine whether the lesion has already reached the dental pulp and therefore, whether it is too late to stop the progress of the lesion from reaching the pulp, in which case a pulp therapy should be performed (as has been discussed in Chaps. 1 and 3). When the carious lesion is viewed on a good quality bitewing radiograph, there is a band of dentin between the advancing lesion and the dental pulp (Fig. 8.1) (for further information on the well-defined deep lesion, see Chap. 3). This key sign is related to clinical success.

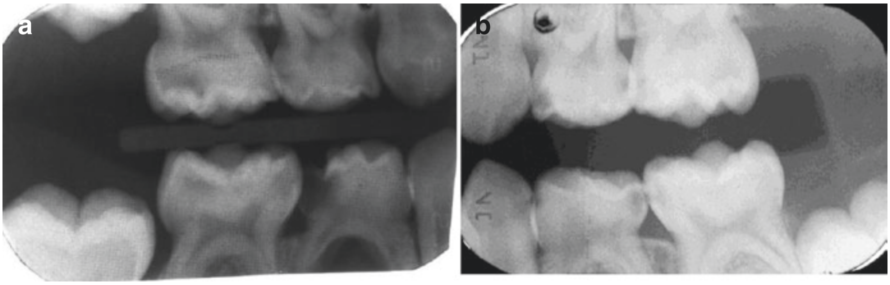

Fig. 8.1 (**a**) Tooth 84 (lower right first primary molar) has a distal lesion extending into the dental pulp and there is no clear band of dentin between the lesion and the pulp. There is also a peri-radicular radiolucency visible. (**b**) Tooth 74 (lower left first primary molar) has a carious lesion on the distal surface extending into the middle 1/3 of dentin but a clear band of dentin is visible beween the advancing surface of the lesion and the dental pulp

8.6 What Alternatives Are There for Management?

Having established our parameters for deep lesions in the asymptomatic (i.e., no signs or symptoms of pain/infection) primary tooth, the groups of treatments are listed below. These options still follow the aims and principles established in Chap. 2: avoiding pulp exposure, preserving the dental pulp vitality, retaining tooth structure and avoiding unnecessarily invasive treatment. The details on these options presented in Sects. 8.7, 8.8, 8.9 and 8.10.

8.6.1 Selective Removal to Soft Dentin, Place a Restoration

This follows the same principles as those for permanent teeth (see Chaps. 2 and 5).

8.6.2 Sealing Over the Lesion with Fissure Sealant

This, as discussed in Chap. 7, involves using resin or glass ionomer cement materials to arrest the lesion through sealant placement. Sealants have been shown to be effective for fissure lesion prevention [7–11] but also management of proximal carious lesions [12].

8.6.3 Sealing Over the Lesion with a Crown Using the Hall Technique

As a method for sealing over carious primary molars this technique involves no tissue removal, tooth trimming or local anaesthesia. A correctly sized crown is simply pushed over the teeth and the lesion is sealed in, preventing ingress of nutrients and slowing or stopping progression of the lesion.

8.6.4 No Carious Tissue Removal and No Restoration; Non-Restorative Cavity Control (NRCC)

This is a method where an active decision is made to manage the lesion with no carious tissue removal. The cavity and lesion are made cleansable through removal of overlying enamel and dentin and ensuring that the lesion and tooth are cleaned frequently and regularly to remove the biofilm. Fluoride is often applied to help with the aim of this treatment option—to arrest the lesion and stop it from progressing as has been briefly discussed in Chap. 2.

8.6.5 Fluoride Adjuncts

Sodium fluoride varnish and silver diammine fluoride (SDF) have also recently become of interest (in the case of SDF this is re-interest) to assist the process of arresting lesions with NRCC and when sealing. It has been used alongside atraumatic restorative treatment (ART) and prior to placing a restoration. This has been called SMART (Silver Managed ART). Using medicaments to help arrest and remineralise tooth substance has also been tried under Hall Technique placed crowns (called SMART Hall by proponents). There is, as yet, no evidence to support SDF as an adjunct and it is not known whether such pretreatment improves outcomes or just adds an extra step to the treatments.

We will now describe all these options in more detail.

8.7 Selective Removal to Soft Dentin, Place a Restoration

The selective removal of carious tissue can, as described, be achieved using hand excavation with sharp instruments such as an excavator. This allows tactile feedback to indicate when to stop removing the lesion [2], and uses the same techniques as are used for cavity preparation via ART [13]. The aim is to preserve tooth tissue, avoid pulpal damage and exposure and retain as much residual dentin on the pulp floor as possible. Again, similarly to permanent teeth, this aim must be balanced against the cavity requirements to achieve maximum restoration longevity. In the pulpal area of a cavity, soft carious dentin is left defined if needed [14]. At the periphery of the cavity, to obtain an effective seal and maximize restoration survival the enamel and dentin are prepared to hard dentin. Figure 8.2 shows an upper primary molar managed with selective removal to soft dentin.

8.8 Fissure Sealants; Why Sealing Is an Option, but Sealants Might Not Do It

Fissure sealing has evidence to support its use for managing both proximal [12] and occlusal lesions [3, 15, 16]. However, evidence for sealants over carious lesions has mainly been obtained from studies of shallow lesions where there is no cavitation of the lesion. As discussed in Chap. 2 and the last chapter, fissure sealants are low-filled resins and when taken in a thin section are very brittle. The properties of the materials mean that they are not currently suitable for use in lesions where demineralisation of enamel and dentin have taken place to such an extent that the ability of the tooth to withstand biting forces has been compromised. Sealants will provide protection from the ingress of bacteria but will not add much to the strength of the tooth. In cases where the lesion is very deep, the sealant will usually not prevent the tooth beneath it from breaking down if the

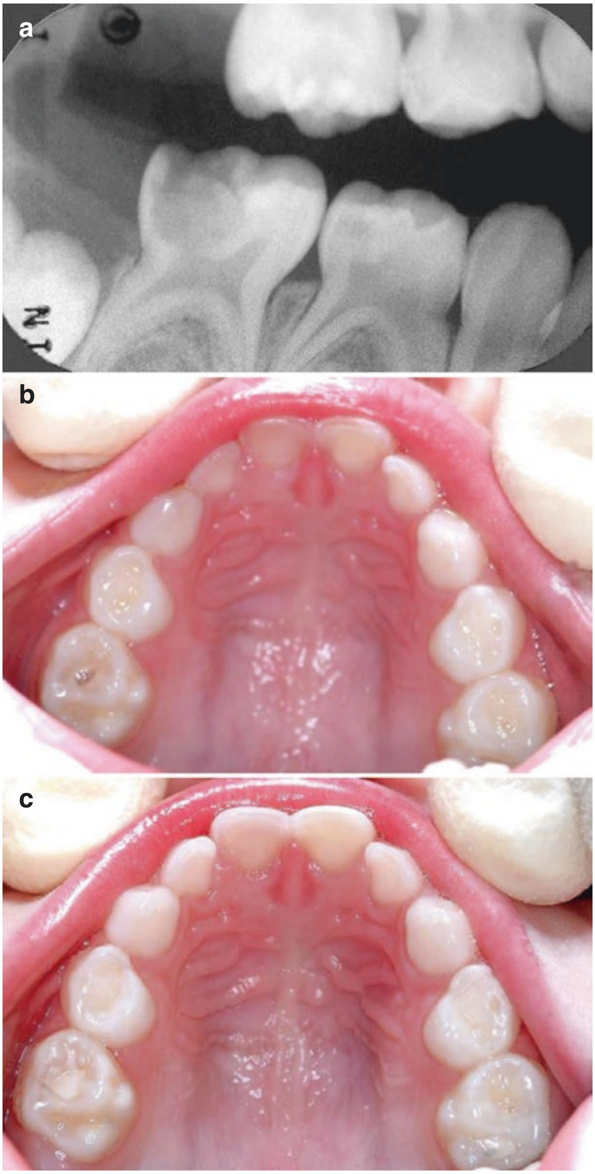

Fig. 8.2 Management of an occlusal carious lesion in a primary molar. (**a**) Tooth 55 (upper right second primary molar) has a carious lesion on the occlusal surface extending into the middle 1/3 of dentin but where there is a clear band of dentin visible between the advancing edge of the carious lesion and the dental pulp. Tooth 85 (lower right second primary molar) has an occlusal lesion that has extended into the dental pulp and there is no clear band of dentin visible. (**b**) Clinical picture of tooth 55 (same child as A) before treatment and (**c**) shows the same tooth after treatment using selective removal to soft dentin by hand instruments and restoration with glass ionomer

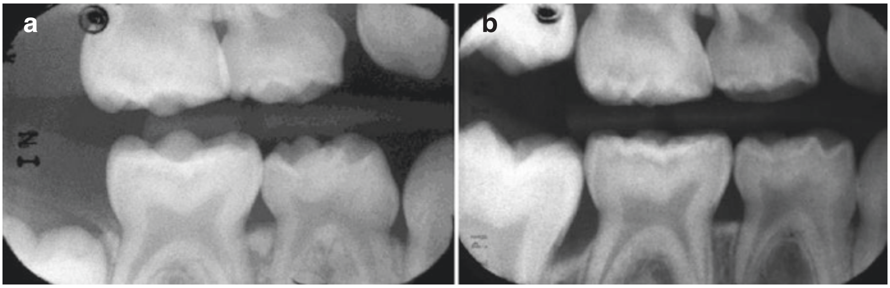

Fig. 8.3 Sealing over occlusal carious lesions in primary molars. (**a**) Radiograph taken when the child was 5 years old showing initial carious lesions in all four first primary molars. These were sealed and radiograph (**b**) was taken 2 years later. There is no evidence of progression of any of the lesions

forces are too great. Figure 8.3 shows a case where radiographically the carious lesion is visible as extending into dentin although it should be noted that such a lesion would not be considered deep. A sealant was placed on the occlusal surface and 2 years later (Fig. 8.1b) there is no radiographic evidence of lesion progression. The "amount" of carious dentin that can be sealed under a sealant, or the exact extent of the lesion where this treatment option is likely to be successful, has not been measured in any detail.

8.9 The Hall Technique

There are several options for managing primary teeth with carious lesions that take advantage of being able to slow or stop the lesion progression by sealing the carious biofilm from the oral environment. One of the most predictable ways of creating a seal is to place a preformed metal (stainless steel) crown onto the tooth using the Hall Technique. No carious tissue is removed, no tooth preparation is carried out and no local anaesthesia needed. Crowns that have been manufactured for traditional use are simply pushed over the tooth. The Hall Technique offers a carious lesion management method for children that they, their parents and dentists find more acceptable [17, 18]. Crowns are known to be a durable and successful restoration but are greatly underused [19] and it is thought to be due to underteaching or anxiety by clinicians about their use [20], even though they often consider them a good restorative option [21]. The Hall Technique provides a way of fitting crowns using a simpler but highly successful method.

There is a strong body of evidence to support the Hall Technique generated in a variety of countries, different settings and with different operators and comparisons [18, 22–29]. The performance of the Hall Technique and child, parent and carer preferences have been evaluated in randomized control trials [18, 24]. Longitudinal evaluations of the technique in different settings and with a variety of operators [28, 30] have also been carried out. However, all studies have consistently shown the technique to either outperform or match standard restorations, including conventional placement of crowns using local anaesthetic. Table 8.1 gives indications and contraindications for use of the technique. Sometimes before a crown can be fitted, it is necessary to create space proximally. Space can be gained by placing

Table 8.1 Indications and contraindications for choosing the Hall Technique as a treatment option for primary molars

Indications for the Hall Technique include teeth with:	• Proximal lesions, cavitated or non-cavitated • Occlusal lesions, non-cavitated – If the child is unable to accept a fissure sealant • Occlusal lesions, cavitated – If the child is unable to accept selective removal and intra-coronal restoration
Contraindications for the Hall Technique include teeth with:	• Where no "clear band of dentin" can be seen on a radiograph (lesion no longer well-defined: high risk of irreversible pulpitis or pulp necrosis, see Chap. 3) • Signs or symptoms of pulpal exposure, irreversible pulpitis, pulp necrosis, or peri-radicular periodontitis • Crowns/teeth that are so broken down, they would be unrestorable with conventional techniques • Children where the airway cannot be managed safely

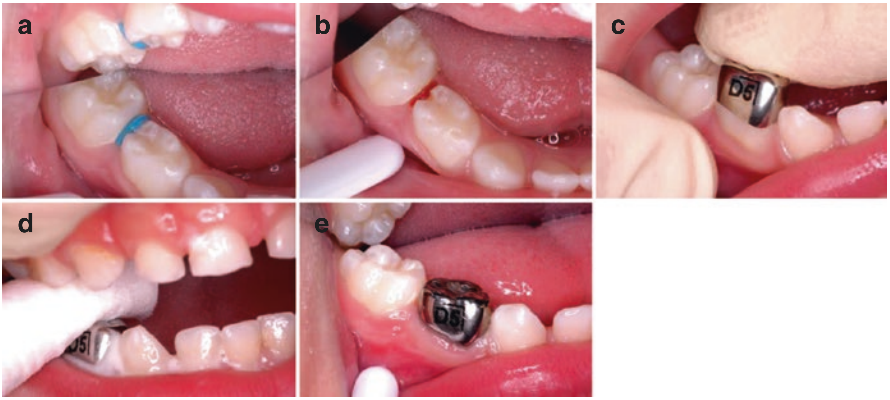

Fig. 8.4 Placement of a Hall Crown. (**a**) An orthodontic separator placed between tooth 84 and tooth 85 and (**b**) shows the space created following its removal after 3 days. (**c**) A crown being tried on to tooth 85 to check for the correct size. Different crowns are tried over the tooth until the correct size is found (covering the cusps and giving a feeling of "spring back"). (**c**) The crown is filled with glass ionomer cement. (**d**) The crown is seated over the tooth (there is no local anaesthetic, tooth preparation or carious tissue removal) and, in this case, once the crown has been pushed over the tooth enough to engage the contact points, the child is using their bite force to seat the crown with cotton wool to help distribute the force. Excess cement is cleared away (mainly to remove the bitter taste of the glass ionomer which children do not like as well as to allow the area to be fully visualised) and position of the crown is checked before the cement sets. This is to ensure that it has not been pushed on in a more buccal or palatal direction or has failed to fully engage the mesial and distal undercuts. The crown should be well seated all around. At this stage, because the cement is still not set, the crown could be removed using a spoon excavator under the skirt of the crown if necessary and the procedure started again. (**e**) The crown has been fitted and the gingiva is blanching as the crown is sitting slightly subgingivally. The increase in the occluso-vertical dimension will resolve within a few weeks

orthodontic separators between the contacts for several days. The crown is fitted by choosing the correct size of crown, filling it with glass ionomer cement (luting consistency) and simply pushing it over the tooth (Fig. 8.4). More detailed and updated explanation and discussion of the technique and a step-by-step guide can be found at https://en.wikipedia.org/wiki/Hall_Technique.

Placing a Hall crown will disrupt the occlusion if there is an opposing tooth to the one being treated. This should be monitored before the crown is fitted, immediately afterwards (to ensure that the occluso-vertical dimension has not been disrupted by too much), and then at follow-up (to confirm the occlusion has returned to its pre-crown state). This can be done by measuring the distance from the lowest point on the gingivae on the lower canine to the tip of the upper canine (these are usually the most stable teeth in this age-group of children and should not be exfoliating or erupting).

8.10 Non-Restorative Cavity Control

As described in Chap. 2, Non-Restorative Cavity Control (NRCC) is a useful technique for where the tooth is so broken down that it cannot be restored and has been advocated by some for teeth with cavitations but where the lesions are cleansable (and being cleaned) although this is more contentious. In all cases, however, the tooth must be free from signs and symptoms of irreversible pulpitis or peri-radicular infection. Although there is some evidence for NRCC, this is still sparse and has tended to involve cohorts or other non-randomised control designs, making it difficult to gauge the comparative success rates for NRCC. Furthermore, different ways of carrying out NRCC have been described with some clinicians placing nothing over the cavity once it has been made cleansable and others applying a thin layer of a restorative material such as a cavity liner glass ionomer. Still others advocate placing and reapplying sodium fluoride varnish or silver diamine fluoride at different intervals. This adds to the difficulty in comparing NRCC with other techniques and makes giving parents/carers information on treatments' likely success relative to one another, difficult.

There is currently only one randomised control trial and this investigates cavitated proximal lesions treated with NRCC and compared it to the Hall Technique and conventional restorations. All lesions were occluso-proximal into dentin (International Caries Detection and Assessment System [ICDAS] codes 3–5) but restorable. The Hall Technique statistically and clinically significantly outperformed both the conventional therapy (non-selective carious tissue removal to hard dentin and a compomer restoration) and the NRCC (which performed similarly with no statistical difference to the conventional therapy). NRCC teeth experienced 5% restoration failure rates and 3% pain/infection after 1 year, the conventional restorations 11% and 5%, respectively, and for the Hall Technique teeth this was only 1% and 0%. Although the data is only from one study, it indicates that the Hall Technique is more likely to be clinically successful in restorable lesions and that NRCC might be best restricted to non-restorable lesions. Futhermore, a recent longitudinal study also cast doubts as to the effectiveness of NRCC as only 50% of the teeth in the study survived successfully without pain, pulpal or periapical pathology [31].

Traditionally NRCC has been considered for the occluso-proximal lesions where enamel has had to be removed to allow the active lesions to be opened to the environment. However, the principles of removing overlying tooth tissue (Fig. 8.5) that

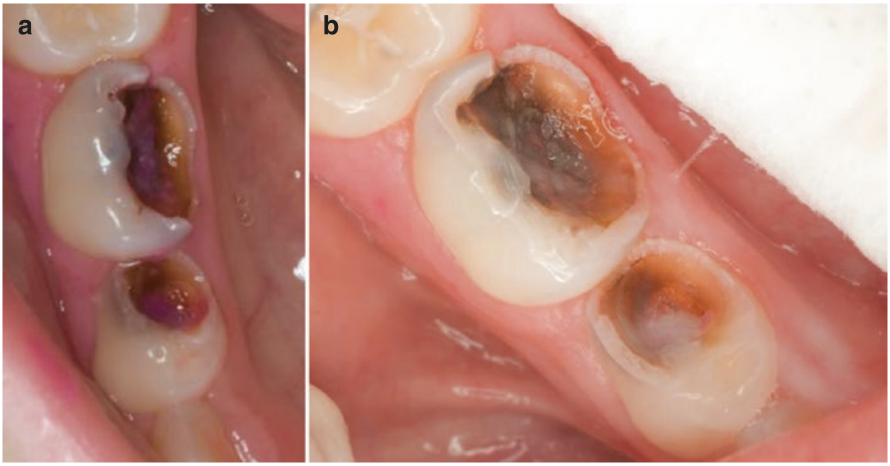

Fig. 8.5 Non-restorative cavity control. (**a**) Teeth 84 and 85 (lower right first and second primary molars) with cavitated lesions which are still active. However, there is limited ability to clean them as demonstrated by the pink disclosing solution remaining in the cavities after toothbrushing by both the child and the parent under the clinician's supervision. (**b**) The teeth after some of the overhanging occluso-buccal enamel has been removed and the lesions are more open making them easier to be cleaned. Further enamel might be removed in stages in the future if this is necessary

is preventing the lesion from access to saliva, brushing and fluoride from toothpaste remain the same regardless of the shape of the lesion. The lesions shown in Fig. 8.6 are an example of lesions in primary molars that are not restorable and not easily cleansable but were opened up, making them cleansable and allowing them to be maintained.

Each tooth needs to be judged on its own merits as to whether this is a suitable treatment option. However, more importantly, there are a number of wider conditions that have to satisfy for NRCC to be successful. These involve willingness and ability of the patient or the patient/carer to accept responsibility and their role in ensuring the success of the procedure.

The steps involved in NRCC are:

1. The cavities must be made accessible to a toothbrush or adjunct (compare with cases in Chap. 2)
2. When carrying out tissue removal to make the lesion accessible to cleaning, the following points should be kept in mind:
   - If trying to expose occluso-proximal lesions in molars, try to keep the molars in contact towards the gingival margin area to prevent drifting.
   - If necessary, make a chamfer preparation.
   - Do not excavate.
   - Make the lesion accessible for adequate cleaning with a toothbrush.
   - The enamel–dentin junction does not need to be clean.

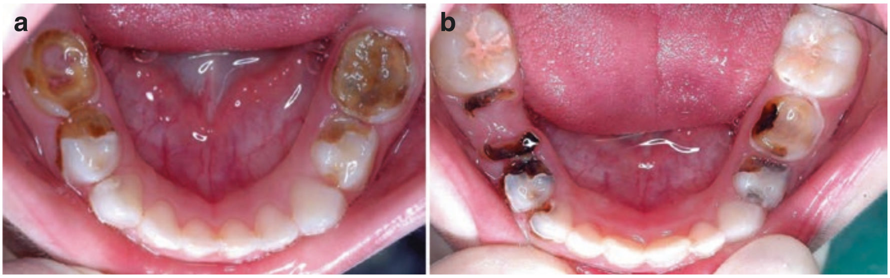

Fig. 8.6 Lower arch of a 4-year-old boy with active, soft lesions in all primary molars. (**a**) Despite the extensive carious lesions, there is no pain and no signs of infection (no abscesses or sinuses or swellings). A highly intensive preventive programme was built with his mother and (**b**) shows the lesions arrested and hard 2 years later. The mesial lesion on the lower left first primary molar is trapping plaque and is not cleansable so it needs to be managed by being opened up

3. Sodium fluoride varnish or silver diamine fluoride varnish should be applied to the cavity to help the process of lesion arrest and remineralisation. Placing a layer of resin-modified glass ionomer cement-lining cement can be considered. This would be done after removing the biofilm with a prophy brush and toothpaste.
4. There should be some way of monitoring the lesions for progression, possibly through successive clinical photographs. These can be used to discuss the treatment success with the patient or parent/carer and whether a change in strategy is needed.
5. There is likely the need for intensive communication (using a theory-based approach such as motivational interviewing or coaching) and action planning is likely to be helpful.

Opening up lesions and using NRCC will only be successful if every one of these steps is taken into account. The technique is still commonly misunderstood as a “do nothing” treatment when it is very much the opposite. To be successful, there must be twice daily maintenance. However, this cannot be carried out by the clinician—their responsibility is to hand over care of the lesion to the patient or parent/carer and this can be very much more challenging than carrying out technically difficult dentistry [31]. Figure 8.6 shows what can be achieved when habits are changed and open lesions are brushed twice a day.

8.11 When Is Each Option Appropriate?

This section gives some guidance, for different types of lesions, which options might be the most appropriate to help with treatment planning. In all cases discussed here, these options relate to the deep carious lesion in the asymptomatic primary tooth with no infection.

8.11.1 Management Options for Arrested Lesions

For deep lesions in primary teeth that are not active (i.e., can be considered arrested), the carious lesion may be manageable with a non-restorative approach. In the past, a restoration would always have been recommended for any carious lesion in a restorable primary tooth on the basis that this is what has always been done for a permanent tooth. However, in the child, where the lesion is arrested and the tooth will exfoliate before the lesions progress to give pain or infection, placing a restoration may not provide any actual health benefit for the child. Non-restorative cavity control in this situation might provide the means for keeping the tooth present, avoiding pain and infection. It also avoids invasive treatment with its associated costs (both time and monetary), potential negative psychological impacts and possible iatrogenic damage to adjacent teeth or through damaging the pulp.

8.11.2 Management Options for Active Lesions in Teeth that Are Not Restorable

For teeth where there is so much tooth substance lost that it is no longer restorable, the management options are limited to non-restorative cavity control. If the tooth becomes symptomatic or signs of infection develop (as is often seen in cases where patient/carer compliance is not adequate), it will need to be extracted.

8.11.3 Management Options for Active Lesions in Potentially Restorable Teeth

A variety of treatment options are available for active lesions in such teeth. Often more than one option is clinically appropriate for a lesion/tooth depending on the lesion stage. However, other factors such as the child's ongoing caries risk status and how long the tooth is likely to be in the mouth before exfoliation need to be considered alongside these options.

8.11.3.1 Primary Molar with Occlusal Lesion

Selective Removal to Soft Dentin is the first choice for these lesions because it is less invasive than placing a crown. Similar to the permanent tooth, the cavity depth is driven by the need to obtain sufficient depth for the restorative material. It is likely that simply placing a fissure sealant over a deep lesion will not be adequate as the lesion is likely to be cavitated or the tooth too weak to withstand forces. In such cases the Hall Technique might be a good alternative. The Hall Technique might also be chosen when the child is very young and adequate moisture control cannot be achieved to carry out a high quality, direct restoration.

8.11.3.2 Primary Molar with Proximal Lesion

The Hall Technique is the first choice for these lesions, and it has been shown to have good longevity and very high success rates. A suitable alternative might be selective carious tissue removal and restoration. Whether this is followed by an intra-coronal restoration or a preformed crown will depend on the size of the lesion, preferences of the child and parent, and time to exfoliation.

8.11.3.3 Primary Anterior Teeth

For advanced lesions, selective carious tissue removal to soft dentin would be the treatment of choice and then the tooth should be restored with an aesthetic adhesive filling material or a composite strip crown. However, it may be necessary to remove more of the lesion to reach firm dentin, if adequate depth and area to bond to cannot be achieved without further removal. In some cases, non-restorative cavity control might be suitable, for example, where the lesions can be opened for cleansing and fluoride adjunctive treatment should be considered.

8.12 Summary

- A greater understanding of caries and carious lesions has led to more conservative management approaches, supporting preservation of tooth substance, health of the pulp and providing child-centred treatment options.
- The core principles for treatment planning management of carious lesions for the child's primary dentition are the same as those described in Chap. 2.
- Diagnosis of the lesion is followed by diagnosis of the status of the dental pulp and only then can treatment options be determined.
- The carious lesion can be: selectively removed to soft dentin and then sealed; sealed into the tooth with a fissure sealant; sealed under a crown using the Hall Technique; not removed and managed with non-restorative cavity control.
- Treatment options are determined by the lesion, tooth child, their circumstances and the limitations of the techniques available.

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