Chapter 4

Etiology of Secondary Caries in Prosthodontic Treatments

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Additional information is available at the end of the chapter

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Abstract

When preparing prosthetic restorations, dentists always try to create restorations functionally ideal while not compromising on esthetics. The factors that make a restoration successful include how well they fit both internally and marginally, their ability to withstand punishment without breaking, and their visual appeal. Imperfect marginal adaptation can lead to unpleasant and unwanted side effects such as plaque accumulation, marginal discoloration, microleakage, carious and endodontic lesions, and periodontal disease. If there is a gap between the crown and the prepared tooth, this can result in the dissolution of the luting material. If the fit of the restoration and the thickness of the cement are designed to be favorable, the cement is not dissolved and the abutment tooth is prevented from secondary caries. The marginal fit of the restorations is considerably affected by the materials and techniques used when making dental crowns. This chapter contains reviews on marginal fitting and caries.

Keywords: caries, marginal fitting, restoration

1. Introduction

Throughout the history of dentistry, dental clinicians, prosthodontists, and manufacturers have strived to create dental restorations that are both esthetically pleasing and function perfectly. Multiple factors determine how therapeutic the restorations are and how long they last. Just how successful a dental restoration depends on three principal factors: how esthetically pleasing it is, how resistant it is to fracturing, and marginal adaptation, meaning how well they fit [1, 2]. More recently developed materials have a high esthetic value and are

mechanically very resilient. The factors that affect marginal adaption include how well the restoration bonds to the prepared surface, how effective the seal is, and the characteristics of the adhesive used to bond the restoration to the tooth. When a prosthetic restoration does not fit properly, this can cause plaque accumulation [2, 3]. This in turn can lead to microleakage and endodontic inflammation [4], and it increases the probability of carious lesions [5, 6]. The periodontal and endodontic lesions that form as a result may require the prosthetic restoration to be replaced or necessitate endodontic treatment, or even tooth extraction.

2. Caries

“Dental caries is determined by the dynamic balance between the pathological factors that lead to demineralization and the protective factors that lead to remineralization.” [7] Caries is a tissue consisting of densely packed crystallites formed in a single axis having both inter- and intra-prismatic micropores measuring between 1 and 30 nm in width. Caries appears in the enamel first and this is accompanied by hypermineralization of the dentine below the cavity [8]. One common characteristic of this is sclerotic dentinal tubules [9]. The dentine starts to demineralize at the outer edge of the lesion matching the outer edge of the enamel lesion [10]. Dentinal caries develops and spreads quickly from the dentine-enamel border moving under the enamel, and this results in caries [8].

2.1. Secondary caries

Secondary caries develops at the site where the tooth and the prosthetic restoration interface. They are considered the main reason why prosthetics fail no matter what restorative material is used [11, 12].

If the conditions around the seal become acidic, the site will start to demineralize in a manner similar to primary caries because of the process of demineralization and remineralization [11]. All the factors that accelerate the accumulation of biofilm mass or impede its removal can be regarded as potential causes of secondary caries, and this is likely why secondary caries mainly occur on the adjacent surfaces [13] (**Figure 1**).

2.2. Diagnosis of secondary caries

Secondary caries has to be caught early on in order to increase the treatment’s chances of success and to stop the hard tissue from being destructed [14–16]. To diagnose secondary caries adjacent to restorations, several different radiographic techniques can be used and these include periapical, bitewing, occlusal, and panoramic imaging (**Figure 2**). In order to prevent wrong diagnoses, radiographic examination must be made together with a clinical examination [17]. It is hard to diagnose secondary carries at the buccal or lingual area on the tooth because these methods only give 2D images. There is a 3D imagine method used by clinicians to assess the area being examined without the need to place other objects in the axial,

Figure 1. Image of a crown.

Figure 2. Radiographic image of secondary caries around a prosthetic restoration.

coronal, or sagittal planes. This method is called Cone Beam Computed Tomography (CBCT). It is better than a medical CT because it gives 3D tomographic images while subjecting the patient to less radiation. While it is useful in cases where 2D imaging techniques are inadequate, it nevertheless uses more radiation than 2D radiographic imaging techniques, so the technician has to exercise care when using this method [18].

The condition can only be diagnosed as secondary caries if the mineralized tissues around the strain have become soft or if cavitation occurs at the edge of the restoration. The gap will probably contain bacteria, but that does not always mean that secondary caries is going to occur. It is useful to remember that many types of bacteria exist in the mouth and that only some of them can produce caries and only then under certain conditions. In fact, there is no documented proof of any relationship between the onset of secondary caries lesions and gaps where the prosthetic restoration joins the tooth, other than when the gaps are large, for example, 250 [19] or 400 μm [20].

3. Etiology of secondary caries

3.1. Microleakage

The classic definition of microleakage is the movement of matter, such as bacteria, oral fluids, even ions, into a fluid-filled gap or a naturally occurring structural defect, or between restorations and the tooth [21]. Microleakage is regarded as one of the principal causes of failure in crowns, so it is one of the main factors that determine the clinical lifespan of dental restorations [22]. Not only does microleakage adversely affect a restoration's clinical use, it can also lead to hypersensitivity, discoloration along the margin [23] (**Figure 3**), secondary caries, inflammation, or necrosis of the vital pulp and often requires endodontic treatment [24, 25].

The degree of microleakage depends on several factors including the tooth's own structure, the luting or bonding agents used to cement the restoration, and the interaction of other factors involved with dental restoration [26].

3.2. Marginal and internal fitting

One of the main factors affecting the longevity of dental restoration is marginal adaptation or how well it fits the tooth [27]. Any gap in the seal exposes the cement to the oral environment. With large gaps, the luting agent is more exposed to oral fluids, and this accelerates both the breakdown of the cement and microleakage [28]. These imperfections along the edge make it easier for oral bacteria to stick and for food and other refuse to build up ultimately leading to plaque retention. This alters the way the subgingival flora is distributed, which in turn leads to the onset of periodontal disease [29] and secondary caries [30].

Fit is determined by many factors such as fabrication [31], the type of CAM system used [32, 33], the number of units in the substructure [34], the tooth's location and preparation [35], the rigidity of the material [36], the type and thickness of the luting agent [37], and the presence of a luting agent [38]. Both the size of the gap at the edge and the amount of resin used have to be kept to a minimum in order to provide a better fit and to increase the cement's longevity [39].

Figure 3. Discoloration along the edge of an endocrown restoration.

Maintaining the gap along the edge as small as possible is very important because the potential for microleakage increases as the size of the gap increases [40]. No matter what type of cement is used, gaps between 100 and 120 μm are considered clinically acceptable [41] in terms of minimizing the problems that might result in cement loss [42]; 90 μm or less is the acceptable size for gaps in computer-aided design/computer-aided manufacturing (CAD/CAM)-generated restorations [27, 43–45]. Variations in the internal fit can cause fatigue, possibly weakening the restoration. The thickness of the layer of dental cement along the axial walls of the preparation affects how well the restoration sits in place. Among the factors that influence film thickness are preparation, how the margin is designed and configured, how rough the surface is, how much pressure is applied during cementation and for how long, the cement's powder/liquid ratio, the type of cement, the spacers used, and the method used for cementation [46].

The fitting of the restoration and proximal surfaces may be checked before cementation to prevent any overhangs that can cause plaque accumulation and secondary caries. Even tiny overhangs, which are often hard to detect clinically, can lead to plaque accumulation, periodontal disease, and the onset of secondary caries. The edges of crown's margins are susceptible to microleakage, and clinical tests have shown that large gaps can result in secondary caries [47, 48]. Caries is the second most common biological complaint in crowned teeth next to the loss of pulp vitality [49].

Laser videography [50], profile projection [51], micro-CT, and CAD/CAM scans [52] are some of the ways in which the adaptation of prosthetic restorations can be assessed. One commonly used technique is the cement analog or Replica Technique (RT). This method allows the dimensions of the internal and marginal gaps in prosthetic restorations to be estimated with a fair degree of accuracy [53]. This nondestructive technique involves sitting the restoration on top of a prepared die using an impression material instead of cement. Once set, the impression material and the restoration are carefully removed from the die and the thickness of the cement analog layer is measured [54–58]. Another nondestructive method that can be used to check the size and shape of gaps in prosthetic restorations is the "Weight Technique" (WT). It costs less than RT and is easier to do. In WT, the material used to simulate the cement layer is weighed at certain points rather than having its thickness measured like in RT. The weight corresponds to the thickness of the gap between the restoration and the die [59].

The gap between the tooth and the edge of the restoration, known as the marginal gap, is measured to determine how well the restoration fits the tooth and is called absolute margin discrepancy [60, 61]. Marginal gap has been given several definitions: vertical marginal discrepancy, horizontal marginal discrepancy, over-extended margin, under-extended margin, seating discrepancy, and absolute marginal discrepancy. Of them all, absolute marginal discrepancy is regarded as the best method for measuring the marginal gap because it yields the largest error [62]. Currently, there is no standard method for measuring how well the margin fits but the most popular method is to use a microscope to measure the distance once the embedded specimens have been sectioned. This method cannot be used "in vivo" [63].

The gap between the inside surface of the crown and the outside surface of the tooth can be checked using a silicone paste in order to evaluate discrepancies. This technique is not without its faults, and readings can be adversely affected by defects in the silicone material in the area being measured and by inaccuracies when reading the measurement of the thickness of the paste under a microscope [64].

3.3. Material type

Different materials such as metal or ceramic are used to make the framework for the prosthetic restorations. The "gold-standard" metal-supported restorations have superior mechanical properties and proven longevity in clinical trials and are the restoration of choice today [65]. While metal-ceramic hybrid crowns are very strong, the increase in the popularity of esthetically attractive restorations in recent years has promoted the development of crowns that are entirely ceramic [37]. Zirconia has started to become popular as a framework material in all ceramic restorations because of such characteristics as high biocompatibility, superior mechanical properties, corrosion resistance, low affinity for plaque accumulation, no allergic reaction to metal in the gingiva, as well as its poor ability to conduct heat and electricity [66]. Zirconia also has some downsides such as phase transformation in reaction to surface treatments, being opaque, and degrading at low temperatures [67]. The most common complication observed in zirconia substructure restorations is reportedly the superstructure ceramic layer coming away from the substructure in layers or by fracturing [68, 69].

All ceramic crowns are esthetically very pleasing and work just as well with anterior teeth as with posterior ones. They interact well with the gingival tissues and offer a great biocompatibility [70]. On the downside, however, they can be brittle (particularly those made from glass or feldspathic ceramics). They fracture easily and can cause excessive wear on the opposite teeth. They also necessitate a greater tooth reduction and tend to favor certain techniques over others [71].

Contrary to direct composite restorations, CEREC composite blocks are produced under the best conditions possible, thus improving the degree of monomer polymerization and preventing voids from being formed, thereby giving them optimal mechanical properties [72].

Semi-sintered zirconia requires shorter milling times and produces less wear on the cutting burs. However, this technique requires a final sintering stage after milling [73]. This sintering procedure entails a certain amount of shrinkage. This technique does have its downsides such as uncertainty with respect to the correct enlarging factor and a marginal fit that does not meet the most exacting demands. On the contrary, milled, fully sintered zirconia is subjected to hot isostatic pressing and offers a much better marginal fit [63].

The strength and fit of the final restoration are affected by such factors as the different materials and techniques used when manufacturing it [74]. Clinicians are advised to adhere closely to the technical guidelines in order to overcome the problems inherent with marginal gaps. It is recommended that they use only the highest-quality materials when constructing prostheses so as to achieve the best marginal compatibility [75, 76].

3.4. Fabrication method

Prosthetic restorations can be made in a number of ways depending on the material used for their cores [77].

Metal-ceramic crowns are still the most common way to make full coverage crowns and fixed partial dentures [78]. Many studies have been done into the fit and distortion of metal-ceramic crowns, including how the manufacturing process affects fit. Since the ceramic veneer and the alloy coping expand at different rates under heat, firing the ceramic might affect how the crown fits. The casting process is a complex one. This plus the different rates at which the various materials expand and contract make it very difficult indeed to ensure that a casted coping will fit.

The classic method for making the metal core is the "lost-wax technique." However, this technique has several disadvantages such as possible distortion of the wax patterns, imperfections in the cast metal, complicated procedures, and it takes up much time. These disadvantages have been countered now by CAD/CAM and processes such as milling and Direct Metal Laser Sintering (DMLS), which are used now in fabricating the metal frameworks for metal-ceramic crowns. In the CAD/CAM milling system, CAD is used to design a pre-production digital frame, which is then manufactured (CAM) using this CAD data [79, 80]. A solid Co-Cr blank is milled into shape using the digitally created frame as a template. DMLS is a fabrication technology that uses metal powder as an additive. By means of a high-temperature laser beam, metal powder is smelted and forged into the shape of the digital CAD template to make the framework. A thin layer of the beamed area becomes fused, and the metal framework is manufactured by building up layer upon layer of metal in order to achieve the final shape [81]. CAD/CAM and DMLS make laboratory procedures easier and save time [82].

In contrast to metal-ceramic crowns, a high-strength ceramic framework is used that is resistant to loads when constructing ceramic crowns. In addition to being fracture resistant, ceramic crowns owe their success and quality to their esthetic value and near perfect marginal and internal fit [83, 84]. The use of the ceramic systems has increased as new technologies are developed [77].

Various different high-strength materials and manufacturing methods are used in making the framework for ceramic crowns [85–88]. Techniques such as slip casting [89], heat pressing [90], copy milling [85], CAM [86], and CAD-CAM [87, 88, 91] are widely used in the production of copings.

The use of full-ceramic materials in dentistry has developed in parallel with the introduction and use of CAD/CAM systems. Crowns, inlays, onlays, laminate veneers, and abutment are among the many dental restorative methods that make use of CAD/CAM systems [92, 93]. Resin composites or porcelain shaped using CAD/CAM technology give patients esthetically pleasing restorations that are of similar appearance to teeth and that can be cemented into the patient's mouth during the same appointment. This decreases the treatment time and makes interim prostheses unnecessary (**Figures 4** and **5**). With the CAD/CAM milling of porcelain blocks and optimum manufacturing conditions, the restorations that have a higher intrinsic strength in the laboratory can be fabricated [94, 95].

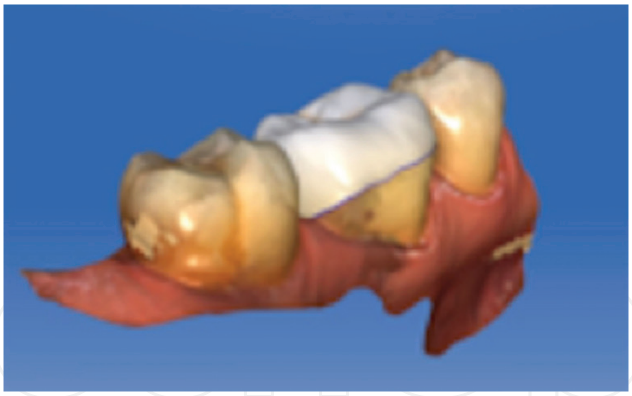

Figure 4. CAD imaging.

Figure 5. All-ceramic restoration.

In CAD/CAM systems, extra space for the cement can be programmed, potentially making for a better fit both marginally and internally [63]. When casting a prosthetic restoration die, spacers have to be added to form the space for the cement but this space can be created and minutely adjusted digitally using CAD/CAM. The accuracy of fit was found to depend much on the spacing of dies [96].

There are some factors that can influence the marginal fit when using CAD/CAM system such as the scanning, the design software, sintering, and milling processes themselves, any and all of which can lead to errors when manufacturing the ceramic framework. One reason for the difference in marginal gaps seen between copings made using CAD/CAM technology and those made using only CAM technology might be the long fabrication chain involved in the CAM process, which is as follows: (1) preparing the master cast and spacers, (2) adding the wax, and then (3) removing the wax pattern from the master cast. Manually adding the wax can result in nonuniform layers, and this in turn can create a distorted product during the sintering process. Taking the cast off can also adversely affect accuracy. Furthermore, it is harder for a scanner to scan the concave inner surface of the wax pattern than the convex master cast [63].

There have been many studies evaluating marginal and internal fitting of fixed prosthetic restorations prepared with different production techniques from different materials [82, 97, 98]. No significant difference between the various manufacturing techniques was reported. While the thickness of occlusal cement was highest with the laser-sintering method, used for making the metal framework, this thickness is approved as acceptable values [82].

Even with all the advances in manufacturing technology, it is still a major challenge to create a long-lasting and well-sealed marginal fit where the tooth meets the crown [99]. As a result, CAD/CAM systems may be more advantageous because ceramic materials with a high mechanical resistance can produce more esthetic restorations in a shorter time.

3.5. Cementation

Marginal gaps that are an important component in fixed prosthetic restorations need to be sealed effectively with luting cements, and cements preserve the tooth from microbial invasion [100]. Microleakage and marginal openings are important causes of fixed restoration failures. The increase of the marginal gap in the fixed restorations results in greater microleakage and cement disintegration with cement exposed to oral fluids [37]. Because of the cement decomposition or dissolution in oral fluids, shrinkage on setting, the cement losses the bonding effect between the cement and the dentine or cement and restoration [101]. When the cement does not seal the gap properly, this can lead to inflammation in the pulp and subsequent pulpal necrosis, which in turn adversely affects longevity of the restorations [100, 102]. Other factors contributing to microleakage include the mechanical properties of the cement and the degree to which the cement adheres to the tooth. One final factor contributing to the severity of microleakage is the adhesive having weak-bonding properties [103].

Another cause of failure of nonmetallic esthetic restorations is clinical fractures [104]. It has been shown that resin-luting agents have the strength necessary for all-ceramic esthetic restorations when used together with established bonding procedures, resulting in a very strong luting unit with good retention properties and that is almost insoluble. Generally, resin cements are capable of dual polymerization and are known for being mechanically strong and having excellent esthetic properties [105, 106].

The past 20 years have seen ceramics and composites being used more and more in posterior teeth as well, thanks to the important improvements made in their mechanical properties in addition to advances in cements and their properties [21]. With the development of dentine-bonding agents and the improvements seen in the properties of resin composites for direct filling, resin-based cements have become popular with clinicians working with all-ceramic restorations [37, 106, 107]. The mechanical- and/or chemical-bonding properties of resin-luting agents between the tooth and the restoration are what contribute to the success of indirect, fixed restorations with resin bonding [108]. Resin-based cements possess many ideal properties such as insolubility, very good strength, better adhesion, and the ability to form a solid bond with the tooth [109].

Other factors affect how effectively the adhesive bonds are related to the actual material and they include filler content, monomer composition, and curing mode. The nature of the substrate surface, for example, enamel, alloys, ceramics, dentin, or composites, can also affect

the strength of the bond [110]. Significant differences have been noted between adhesive-luting agents in studies investigating at their ability to prevent leakage between the surfaces in cemented restorations [21, 111, 112].

Typically, there are three steps in the process of adhesive cementation: etching, priming, and applying the cement. Every step of this process is technique-sensitive and requires attention to detail [100, 113, 114]. The latest generation of proprietary self-adhesive resin cements is self-etching and bonds to dentine without the need for additional primers or etching agents. Resin cements are self-adhesive and dual-polymerizing. By design, they are easy to use and have good mechanical properties, high esthetic values, and adhere well to both the restoration and the tooth [115]. Even so, the durability of the bond, the resin cement to the tooth and the resin cement to the ceramic surface, is still a crucial point [116–118].

Crowns that are cemented using self-etching resin cements demonstrated much lower average microleakage scores than using self-adhesive resin cement. This might be due to differences in the different cements' adhesion mechanisms. Self-etching resin cement comes with an etch-prime agent with a 2.4 pH and monomers possessing low-molecular weight. They diffuse selectively into the dentine [119] and create a hybrid complex [120, 121]. As a result, these monomers create a small amount of dentine demineralization that allows the cement and the dentine to bond. However, this is not the case with self-adhesive resin cements. They contain multifunctional phosphonic acid methacrylates, and these react with hydroxylapatite [122]. One recent study showed that self-adhesive resin cement presented no evidence of decalcification/infiltration into dentine even though the initial pH value was acidic [123].

Resin-based materials have a tendency to accumulate more plaque, and this plaque is more cariogenic than that found on enamel and other materials used for restoration. Even so, one study has shown that cariogenic bacteria on enamel, glass ionomers, and resin-based materials are the same [124].

Glass-ionomer cement has properties that make it ideal for cementation such as a reduced film thickness and a very low coefficient of thermal expansion coupled to its strong physicochemical bond to both dentin and enamel, as well as its hydrophilic qualities and low solubility. Moreover, glass-ionomer cements leach calcium fluoride giving it the advantage of inhibiting caries [125]. The molecular interactions, ionic and polar, between the cement and the tooth affect the adhesive quality of glass-ionomer cement. These mechanisms are only effective if a close intermolecular contact is achieved between the cement and the tooth. One reason why glass-ionomer cements fail may be the porosities that can appear when the cement is mixing, and these porosities reduce the intermolecular contact between the tooth and the cement [74].

Rosentritt et al. [126] concluded that the resin cements and self-adhesive materials demonstrate good marginal integrity with minimal microleakage. They noted that the easily applied self-adhesive resin cements have the potential to be an alternative to resin cements.

Traditionally, water-based cements have been used to fill the space between the tooth and the restoration. However, the water-based cements are highly soluble in oral fluids, so their ability to seal depends largely on how well the restoration fits [75].

Different cements have different degrees of microleakage [104]. A study of the microleakage results obtained using resin, zinc phosphate, and glass-ionomer cements showed that zinc-phosphate cement is not as successful as glass-ionomer and resin cements in reducing microleakage. One reason for this may be the high solubility of zinc-phosphate cement when compared to glass-ionomer and resin cements in addition to the properties of its bond with dentine, which is entirely mechanical. Clinical studies have shown that despite these negative characteristics, restorations fixed with zinc-phosphate cement are stable for long periods of time. Resin and glass-ionomer cements are less soluble than zinc-phosphate cement and their chemical composition allows them to bond strongly both chemically and mechanically with dentine. In experimental conditions, resin and glass-ionomer cements performed better in terms of microleakage when compared to zinc-phosphate cement. However, only though long-term clinical trials will the advantages and disadvantages of the various cements in terms of durability become clear [127, 128].

Furthermore, maintaining microleakage to a minimum requires the use of cements with good sealing properties. Of all the different types of cements that are used in dentistry, resin-based and glass-ionomer cements have shown the best results due to their leaching of fluoride ions, creating an additional mechanical bond with the tooth [75, 76].

4. Conclusion

Nowadays, with the developing technology, there are many restorative materials and different fabrication methods for prosthetic restorations. Marginal adaptation is the most important factor for clinical use and success of the restorations. Failure to provide marginal adaptation increases microleakage and causes microorganisms to colonize between tooth and restoration, thus causing secondary caries. In fixed prosthetic restorations, CAD/CAM technologies can be used to prepare infrastructures to have optimal marginal and internal fitting, mechanically resistant, biocompatible, and low cement spacing. More bonding efficiency and less water solubility of the adhesive resin cements result in less microleakage than other cements; for this reason, adhesive resin cements can be preferred for a suitable option. In glass-ionomer cement, secondary caries risk is decreased because of the presence of fluoride. Before the planning of prosthetic restorations, abutment teeth, periodontal tissues, prosthetic material, cement, and fabrication method must be chosen carefully.

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