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Peripheral Seal Zone

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Certification of the Supervisor

I certify that this project entitled **"Peripheral Seal Zone"**

was prepared by the fifth-year student **Mina Riyadh Abdulkhalik** under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment in the graduation requirements for the Bachelor Degree in Dentistry.

Supervisor's name **Dr. Aliaa Muhsin**

Date

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DEDICATION

to my family and friends who have supported me throughout my academic journey. Their unwavering encouragement and belief in me have been instrumental in helping me reach this significant milestone. I am also grateful for the guidance and mentorship provided by my supervisor and colleagues, which have shaped me into the person I am today. Thank you all for being a part of my journey.

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List of Abbreviations

CDD: Caries detecting dye

PSZ: peripheral seal zone

CRE: caries removal endpoints

PH: potential of Hydrogen

KHN: knoop hardness number

KH: knoop hardness

DEJ: dentin-enamel junction

MPa: mega pascal

CSZ: central stop zone

HA: hydroxyapatite

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Introduction

Dental caries is a multifactorial, biofilm mediated, sugar driven disease that lead to the cyclic demineralization and demineralization of tooth hard structure. Caries can develop in both primary and permanent dentitions during life and can damage the crown of the tooth, exposes the root surface in later life. The equilibrium between pathological and protective factors affects caries inception and progression (Pitts et al., 2017). In general, dental caries is a reversible chronic disease at early stage that advances slowly and can be halted by obstructing the plaque biofilm formation. The caries process begins at the enamel surface when microorganisms inside the dental biofilm digest dietary carbohydrates, releasing organic acids as by products that produce a cariogenic environment, resulting in demineralization of the enamel surface, other important contributors of the carious process include time, increased density of the bacterial biofilm, microbiological alterations inside the complex biofilm, pH drop below the critical value (5.5), and oxygen tension (Marquis, 1995; Dawes, 2003). However, the ability of saliva to buffer the acids, exposure to fluoride, and a reduction in the frequency of dietary carbohydrates consumption with physical removal of the bacterial biofilm can all interrupt the caries process (Selwitz et al., 2007).

These factors can produce pH fluctuations at/near the enamel surface, which can result in demineralization or demineralization of the enamel surface when the pH is reduced or increased (Manji et al., 1991) .

Enamel caries in the lesion body are marked by a decrease in the mineral

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contents, while the surface remains relatively highly mineralized. Such lesions can be reversed at an early stage or even demineralized (Featherstone, 2004). The recommended treatment for enamel caries involves fluoride application, as well as oral hygiene and proper diet education.

A systematic review and meta-analysis (Lenzi et al., 2016) claimed that fluoride varnish can be regarded as an effective therapy for the reversal of incipient carious lesions in primary and permanent dentition; indeed, additional clinical trials on the effectiveness of topical fluorides for the treatment of these lesions are still needed. If the lesion advances into dentine, treatment with demineralization frequently fails, operative intervention is usually indicated.

Biomimetic dentistry is a relatively new field of dentistry that focuses on restoring and preserving the natural tooth structure. It is based on the principle of mimicking the natural tooth structure in order to create a strong, durable, and aesthetically pleasing restoration. Biomimetics focuses on preserving as much of the natural tooth structure as possible and mimicking the natural biomechanics of the tooth.

This type of dentistry is becoming increasingly popular due to its ability to provide long-term, durable results with minimal destruction of the natural tooth structure.

Some of the benefits of biomimetic dentistry are:

1. Preserves natural tooth structure: Biomimetic dentistry aims to preserve as much of the natural tooth structure as possible. This approach is better for the overall health of the tooth and reduces the need for invasive procedures, such as root canals or extractions.

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2. Prevents future damage: Biomimetic dentistry aims to restore the tooth in a way that mimics its natural structure and function, which can help prevent future damage to the tooth.
3. Provides a more natural appearance: Biomimetic restorations are designed to closely resemble the natural tooth, providing a more natural appearance than traditional restorations.
4. Long-lasting results: Biomimetic restorations are typically more durable and longer-lasting than traditional restorations, reducing the need for frequent replacements.
5. Minimal discomfort: Biomimetic dentistry uses minimally invasive techniques, reducing discomfort for the patient and promoting faster healing times.

Overall, biomimetic dentistry offers several advantages over traditional restorative dentistry. By preserving natural tooth structure, preventing future damage, and providing a more natural appearance, biomimetic dentistry can help patients achieve healthier, longer-lasting smiles.

The peripheral seal zone (PSZ) and caries removal end point are two of the most important aspects of the biomimetic restorative dentistry, the peripheral seal zone is the 2-3 mm of tooth structure (enamel, dentinoenamel junction and superficial dentin) in which complete caries and crack removal is indicated.

The dentinoenamel junction is identified and complete caries and crack removal should be carried out 1-2 mm inside of the position of dentinoenamel junction. Caries Removal End Points (CRE) are used in order to avoid pulp exposure during caries removal. Complete caries removal is

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carried out in the peripheral seal zone, followed by partial caries removal over the pulp. Even if Caries Detector Dye is staining in these areas, caries removal is halted. The Central Stop Zone (CSZ) is the area inside of the peripheral seal zone. It is the area over the pulp, encircled by the peripheral seal zone, where the partial caries and crack removal is indicated in order to avoid pulp exposure.)Davies, 2023)

Complete removal of caries by the traditional visual and tactile techniques has been fairly unsuccessful. The minimally invasive dental treatments for these smaller lesions using air abrasion, sonic diamond tips, glass-ionomer cement, and bonded composite resin have reduced the need for traditional preparations that eliminate important anatomical structures.(Milicich and Rainey, 2000; Magne and Oganesyan, 2009; Splieth et al.,2010)
However, for lesions of medium and large depth, more sophisticated techniques are required for determining ideal caries removal end points (Figure 1 and 2).

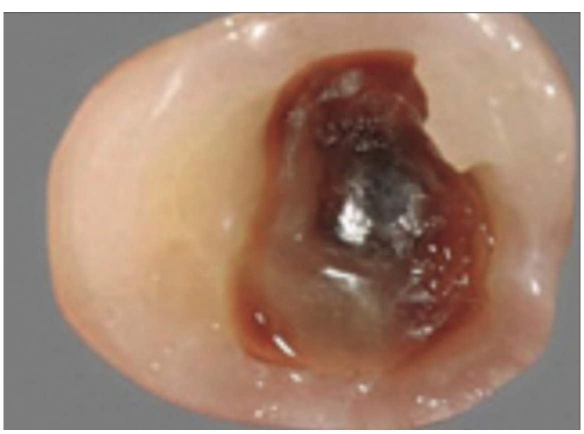

Figure 1. Intermediate and deep

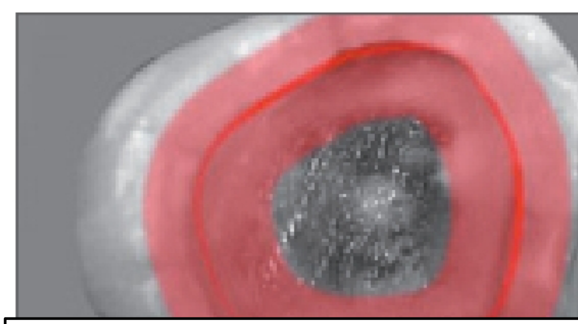

Figure 2. The concept of a peripheral seal zone is that the enamel, DEJ, and superficial dentin constitute the caries-free

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caries lesions have many visual and tactile complexities that can be systematically approached with caries removal end point and peripheral seal zone.

Using traditional visual and tactile techniques for large lesions is often inconsistent for determining optimal caries removal end points and can often progress to exposing the pulp. Ideal caries removal end points are needed to preserve vitality of the pulp without limiting the strength and durability of the adhesive reconstruction. Struggle has been associated with the problem of too much VS not enough when it comes to the removal of decayed tissue. (Neves et al., 2011; Schroeder, 1991)

This approach is based on knowledge of dental anatomy, histology, microbiology and adhesive dentistry.

This knowledge is combined with visual dye staining. Laser fluorescence technologies can also be added to guide the clinician in deep caries diagnosis and removal. This combination of multiple overlapping techniques is superior to using only the tactile and visual method. (Yazici et al., 2005)

The general objectives of this are the maintenance of pulp vitality after restoration by adhesive methods; the elimination of dentinal infections by removing, deactivating, or sealing in bacteria; and the conservation of intact tooth structure for long-term function.

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Chapter One: Review of Literature

1. Traditional Ways of Caries Removal

1.1 Diagnosis of the softened dentin by cutting resistance is not reliable

In conventional treatment the softened carious dentin, as determined by feeling cutting resistance, is removed with a spoon excavator or a round steel bur mounted
on a slow-speed engine. the hardness was determined by (Fusayama, 1980) on the section of carious tooth after removal of the soft dentin. The following facts were recognized.
It was surprising that so much thickness of softened dentin remained between the excavated cavity floor and the softening front of dentin. The hardness immediately under the floor was as low as one fourth to one third that of normal dentin, indicating that the instrument guided by feeling cutting resistance removed only the very soft superficial layer, leaving the greatest part of softened dentin behind. The mean hardness of the floor dentin after excavation was Knoop Hardness number (KHN) 22.8 with the spoon and KHN 28.4 with the bur, the standard deviation of the measurements was surprisingly great.
The result deviated considerably, depending on the operator, The thickness of residual softened dentin also deviated considerably.

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Instrument	Number of Cases	Hardness of floor dentin (KHN)	Thickness of residual softened dentin (Micro meter)
Spoon excavator	16	22.8 (±9.65)	706 (±353)
Round steel bur	25	28.4 (±16.36)	484 (±57)

In result, the hardness of the softened dentin cannot be reliably diagnosed by hand through an instrument and thus can not be used as a reliable guide for caries removal. (Fusayama, 1980)

1.2 Discoloration cannot be used as a general guide for caries removal

The main purpose of carious dentin removal is to remove infection. The superficial layer of carious dentin is invaded by bacteria along dentinal tubules.

- In chronic decay, discoloration is heavy and reaches the comparatively harder and deeper layer and so does bacterial invasion.
- In acute decay discoloration is light and does not reach the harder layer. Bacterial invasion remains at the very soft and superficial layer. Consequently the thickness of the layer that is softened but not infected is generally greater, as great as 1.7 mm in some cases.

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- Hardness cannot be used as a guide for caries removal because the hardness of the bacterial Front is very inconsistent.
- In chronic decay complete removal of remarkably discolored dentin can assure complete removal of infected dentin without excessive overreduction.
- In acute or moderate decay the natural discoloration front is not only unclear but also far distant from the bacterial front, consequently discoloration cannot be an adequate guide for caries removal.
- The softened but not infected dentin of acute decay should be saved if it is remineralizable.

The specific objectives of caries removal end point determination are the creation of a peripheral seal zone and the absolute avoidance of pulpal exposure while generating a highly bonded restoration with excellent prognosis . First, by creating a peripheral seal zone 1 to 3 - mm wide consisting of normal superficial dentin, DEJ, and enamel (Fig 2), a bond strength of approximately 45-55 MPa can be generated. (Shirai et al., 2005; Yoshiyama et al., 2000)

This peripheral seal zone will be confirmed by the total absence of caries detecting dye staining.(Boston and Sauble, 2005; Krause et al., 2007)
This caries free zone can also be confirmed by a DIAGNOdent (KaVo) reading of approxi mately 12.
products such as Caries Detector (Kuraray), Caries Finder (Danville), and Seek (Ultradent) are examples of caries detecting dye.
Second, by leaving the slightly infected and partially demineralized but

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highly bondable affected inner carious dentin inside the peripheral seal zone, a bondability of approximately 30 MPa will be obtained in the deeper areas of the preparation. (Nakajima et al., 1999)
This will be confirmed by light pink staining from caries-detecting dye. DIAGNOdent can also help determine the caries removal end point with readings of approximately 20-24 for intermediate dentin and approximately 36 for deep dentin (figure 3). (Lucci et al., 2000; Yonemoto et al., 2006)

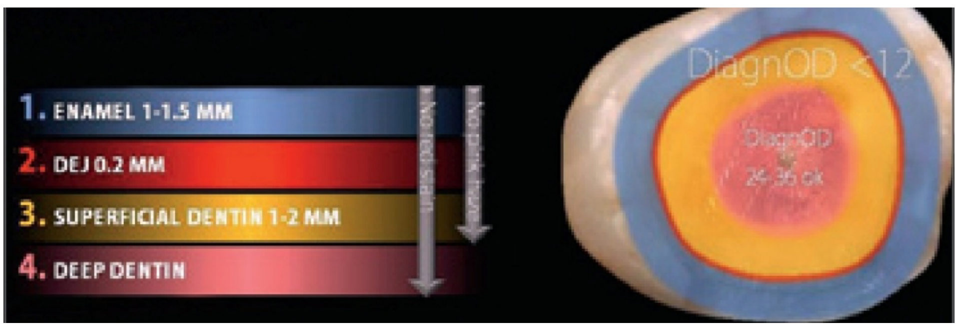

Fig 3 Caries removal end points for the peripheral seal zone can be determined with a combination of caries-detecting dye and DIAGNOdent technologies

On average , intermediate dentin is 3 to 4 mm from the occlusal surface and deep dentin is 4 to 5 mm from the occlusal surface. Clinicians can prevent pulp exposure by leaving the infected outer caries inside the peripheral seal zone when removal would risk pulp exposure. This would be in small circumpulpal areas deeper than 5 mm from the occlusal surface. These small infected areas will stain red from caries-detecting dye and have DIAGNOdent readings higher than 36. Achieving these objectives should result in highly bondable preparations that will support adhesive

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layers and remain bonded for the long term, an important requirement for large biomimetic dental reconstructions (Figure 3). (Magne, 2006; Deliperi and Bardwell, 2002; Deliperi and Alleman, 2009)

2. Histology of Carious Lesion

Using histologic, bio- chemical, biomechanical, microscopic, and microbiologic techniques, the researchers were able to distinguish there are two layer of caries and are very different in nature.

The first layer was named "outer carious dentin." It was highly infected, acidic, and demineralized. The collagen fibrils in this layer were denatured, having lost most of their intermolecular cross-linkages. This layer was not sensitive to contact and could be removed without anesthesia because it had lost the hydrodynamic system of intact dentinal tubules. This layer also failed to remineralize in a natural way because the collagen framework could not return to normal even if the acid environment was neutralized.

The second layer was termed "inner carious dentin." This layer was partially demineralized and slightly infected, but the collagen fibrils retained their natural structure around intact dentinal tubules. Because of this remaining structural integrity, the inner carious dentin was sensitive to removal without anesthesia. The lumens of the dentinal tubules in this layer had no peritubular rings of hydroxyapatite [Ca_{10} (PO_4) $(OH)_2$]. Instead, the enlarged lumens were now partially or completely filled with large crystals of tribeta calcium phosphate [Ca, $(PO_4)_2$] called Whitlockite. (Ogawa et al., 1983)

Whitlockite is crystallized into the dentinal tubules as hydroxyapatite is dissolved from intertubular dentin by bacterial acids. This inner layer of the caries lesion was able to be restored to a normal mineralization with a

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hydroxyapatite matrix surrounding the collagen fibrils (intertubular dentin) and around the tubules (peritubular dentin) when the pH was neutralized. (Akimoto et al., 2001)

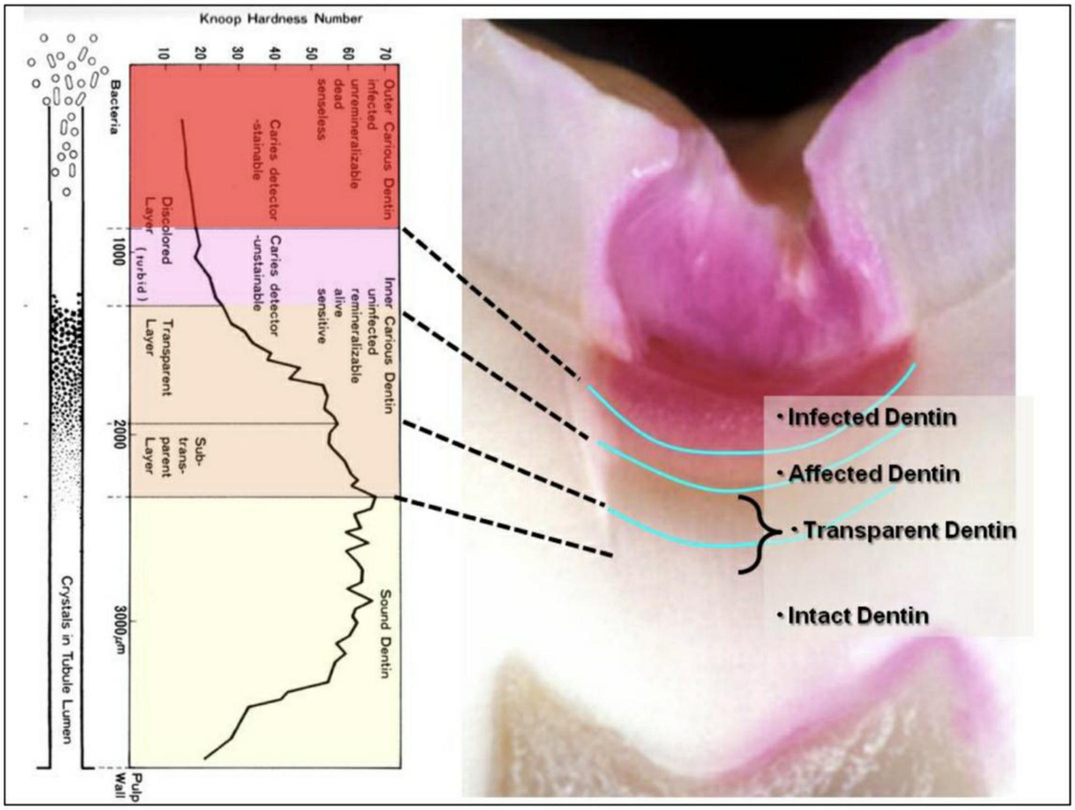

Figure 4 Histology of carious dentin.

3. Methods of Identifying the Peripheral Seal Zone

3.1 Caries Detecting Dye

Caries detecting dyes have been used to facilitate clinical discrimination of

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carious dentin from sound dentin during caries removal. (Sturdevant et al., 1984; Fusayama, 1966)

Dyes such as Caries Detector (Kuraray Medical Inc., Tokyo, Japan) contain 1% acid red in propylene glycol. (Sato et al., 1976)

The use of these dyes, however, does not provide a completely objective method for assessment of caries removal. Excessive removal of dentin (Van de Rijke, 1991) or incomplete removal of bacteria (Fusayama, 1988) has been reported when these dyes were used to remove caries. The extent of bacterial infection in dentin that remains after the use of caries detecting dyes has also been challenged, (Yip et al., 1994; Boston et al., 1989; Fukushima, 1981) as these dyes appear to stain demineralized collagen matrices instead of bacteria. (Fusayama, 1988)

There is also concern that the routine use of these dyes would result in excessive removal of tooth structures. (Van de Rijke, 1991)

For Caries Detector, no microbial invasion was found at the cavity floor stained light pink. (Fukushima, 1981)

It is generally recommended to leave dentin stained light pink with Caries Detector.

Recently, a new caries detecting dye (Caries Check, Nippon Shika Yakuhin, Shimonoseki, Japan) was developed to prevent excessive dentin removal. This product contains 1% acid red in polypropylene glycol instead of propylene glycol. The molecular weights of the glycol component employed in Caries Check and Caries Detector are 300 and 76, respectively. It has been shown that dyes that were dispensed in higher molecular weight carriers exhibited reduced diffusional properties in porous tissues. (Iwami et al., 2004; Nakajima et al., 1999) Thus, caries detecting dyes prepared

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with higher molecular weight polypropylene glycols may prevent over-staining and excessive removal of caries-affected or sound dentin.
Many studies reported that the use of caries detecting dyes reduced the propensity of microorganisms in tooth cavities but did not completely eliminate them. (Schroeder, 1991; Yazici et al., 2005; Anderson and Charbeneau, 1985)
A previous study also suggested that occlusal dental caries may be arrested for up to 10 years by resin sealing. (McComb, 2000)
It is uncertain whether the entrapment of bacteria under fillings influences the prognosis of the restored teeth.

Figure 5 Caries removal step by step using caries

Although it is dubious that carious dentin may be truly arrested by resin seals without complete removal of the overlying infected dentin, it is possible that the bacteria in the dentinal tubules may not be cariogenic after the tubules are sealed with current restorative materials.

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Takao Fusayama made a progress by finding two propylene glycol-based colored solutions (one purple, one red) (Fusayam, 1988) that stained the outer and inner carious dentin layers differently. The outer carious dentin stained dark red, and the inner carious dentin stained lighter (pink for the red dye formula). The interphase between the outer and inner carious dentin was referred to as the turbid layer. This interphase is a mixture of parallel groups of tubules, some of which are outer carious dentin and some of which are inner carious dentin (depending on how long the tubules have been infected and under the influence of bacterial acids). Under the turbid layer, the inner carious dentin becomes the transparent zone. The transparent zone is translucent in histologic examination with a light microscope. The pink staining (often referred to as a pink haze) in the turbid layer becomes lighter as it moves into the transparent zone. In this zone, the large lumens of the dentin tubules are filled to some degree with Whitlockite. These large crystals slow bacterial invasion and reduce dentin permeability. This reduced permeability decreases the outward flow of pulpal fluid, which is referred to as "transudation." It also reduces the movement of pulpal fluid caused by temperature changes. Underneath the transparent zone is an interphase of the transparent zone, as well as normal sensitive dentin called the "subtransparent zone" (fig 4 and 5).

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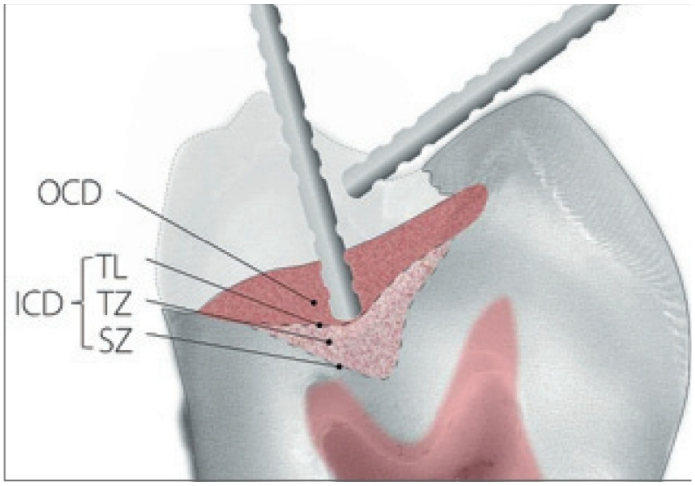

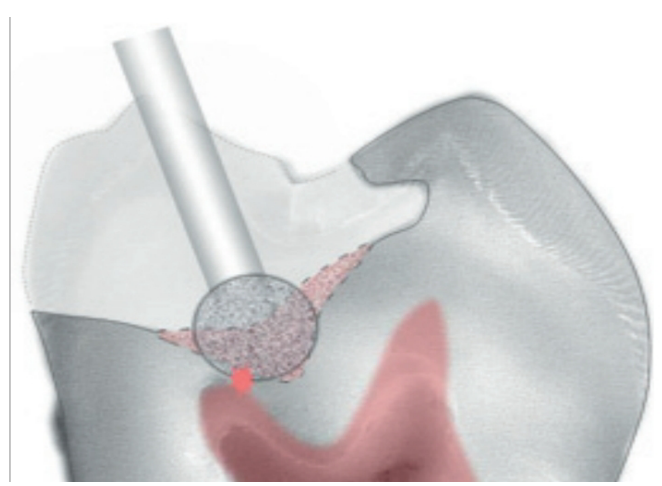

Figure 6. The subtransparent zone stains even more lightly than the transparent zone. Removal of the transparent and subtransparent zones in an attempt to reach hard dentin exposure.

Figure 7. By using only visual and tactile methods for deep caries removal, the pulp is often exposed because the transparent zone, the subtransparent zone, normal deep dentin, and reparative dentin are all

The pink haze staining of the inner carious dentin wasn't discussed by Fusayama, he only referred to stained or unstained caries. (Anderson and Charbeneau, 1985; McComb, 2000; Banerjee et al., 2003)
Other researchers in Japan who helped with Fusayama's original research came to the conclusion that the lightly stained areas were mostly uninfected with intact collagen fibrils surrounded by high levels of hydroxyapatite and Whitlockite and should therefore be preserved for

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remineralization. (Fukushima, 1981; Sano, 1987; Iwami et al., 2006; Wei et al., 2008).

3.2 DIAGNOdent:

In the late 1990s, a new laser-fluorescence technology (DIAGNOdent) was introduced as a way to diagnose initial caries lesions (figure 6). investigators in Germany and Switzerland found that bacterial metabolic products called porphyrins would fluoresce when irradiated with a 655-nm red laser. This fluorescence can be read and given a numeric value that corresponded approximately to the amount of bacteria present. (Buchalla et al., 2008; Lussi et al., 1999).

DIAGNOdent proved its efficiency for the nondestructive diagnosis of pit and fissure caries. (Lussi et al., 1999; Lussi et al., 2001). In vivo investigations using DIAGNOdent showed that it might also be used to establish a caries removal end point that correlated with traditional excavation techniques. DIAGNOdent readings for the superficial dentin end point were 8.26 ± 2.69 = (< 12). The end points for intermediate to deep dentin were 18.75 ± 17.10 = (< 36).

Figure 8 DIAGNOdent reads bacterial products called porphyrins and is used

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These findings were reproduced in a second study at the University of Bern.(Lucci et al., 2000; Reich et al., 1999)

The different readings in deeper lesions correspond approximately to the proportional differences in pulpal fluid/mm2 at the DEJ vs circumpulpal areas. This is because dentinal tubules are three times more concentrated near the pulp than they are near the DEJ.(Schroeder, 1991; Brannstrom, 1982)

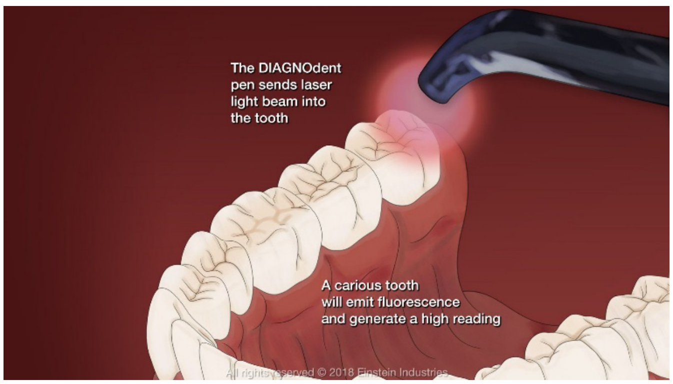

Figure 9 The deep caries lesion has two parts: outer and inner carious dentin. The inner carious dentin has three parts: the turbid layer, transparent zone, subtransparent zone, and normal dentin

Depending on the permeability of the inner caries (which is related to the amount of Whitlockite in the dentinal tubules), there will be a greater or lesser diffusion of the porphyrins (hence, the high variance in the DIAGNOdent readings in intermediate and deep inner carious dentin). An increase of demineralized dentin in inner carious dentin and denatured collagen with high demineralization in the outer carious dentin will increase the volume of pulpal fluid in the outer and inner carious dentin. In turn, this will allow the porphyrin diffusion to increase, which will cause higher DIAGNOdent read- ings in the outer carious dentin and deep inner carious dentin. Boston and Sauble (Boston and Sauble, 2005) confirmed the German and Swiss experiments and correlated them with the Japanese research using caries-detecting dye. Boston and Liao also investigated the light pink staining of circumpulpal dentin and concluded that it was due to the higher percentage of collagen not completely surrounded by the

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hydroxyapatite matrix and not from denatured collagen (as in outer carious dentin) or from acidic demineralization (as in inner carious dentin) (Neves et al., 2011; Boston and Liao, 2004; Cortes et al., 2003)

Staining and remineralization also makes for higher variability and less predictability of any technology.
For superficial dentin, the DIAGNOdent readings of 11 or 12 corresponded to a nonstaining and bacteria- free caries-removal end point. (Magne and Oganesyan, 2009)
A group at Showa University in Tokyo developed a poly- propylene glycol-based Caries-Check dye (Nishika) that stained only the outer carious dentin and not the inner carious dentin. This type of caries-detecting dye gave the same results in superficial dentin (DIAGNOdent < 12 with no staining) as Fusayama's propylene glycol-based caries-detecting dye. (Itoh et al., 2009)
But because this higher molecular weight caries- detecting dye formula does not lightly stain the turbid layer, transparent zone, and sub-transparent zone, it is not as useful to find the caries removal end point that is ideal for the highest dentin bond strength in the peripheral seal zone. (Boston et al., 2008)
This is because clinicians are not able to detect inner carious dentin that should be removed for the highest bond strength in the peripheral seal zone.

Combining caries-detecting dye and DIAGNOdent can give clinicians another way to determine when the excavated lesion is essentially bacteria-free while at the same time not removing affected inner carious dentin inside the peripheral seal zone. (Lennon et al., 2007)

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The anatomical depth of the lesion needs to be monitored to make the correct determination on whether to proceed with the removal of outer

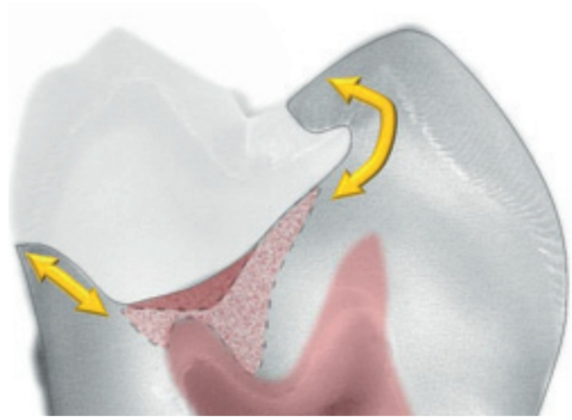

Figure 10 Deep caries lesion showing the outer carious dentin staining red and extending to the circumpulpal dentin (> 5 mm from the occlusal surface).

Figure 11 Caries removal end points for a deep lesion. The peripheral seal zone has been created without exposing the pulp. A small amount of

carious dentin inside the peripheral seal zone. Measuring from intact tooth structure with one or two periodontal probes (see Fig 4) is a useful technique to determine when the excavation is into circumpulpal areas (5 to 6 mm from the occlusal surface). If the excavation is into intermediate dentin (3 to 4 mm from the occlusal surface), the caries removal end points with light pink staining can be achieved predictably inside the peripheral seal zone by further excavation of the red outer carious dentin. However, when excavation is near the pulp (> 5 mm from the occlusal surface or > 3 mm from the DEJ) and the caries-detecting dye still stains red, excavation should stop. This protocol will eliminate most pulp exposures (Figure 8 to figure 10).

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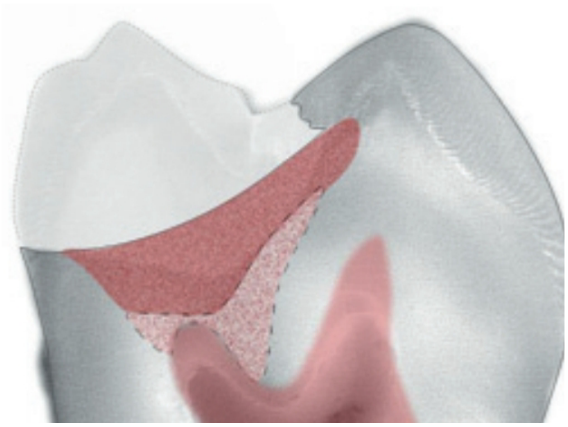

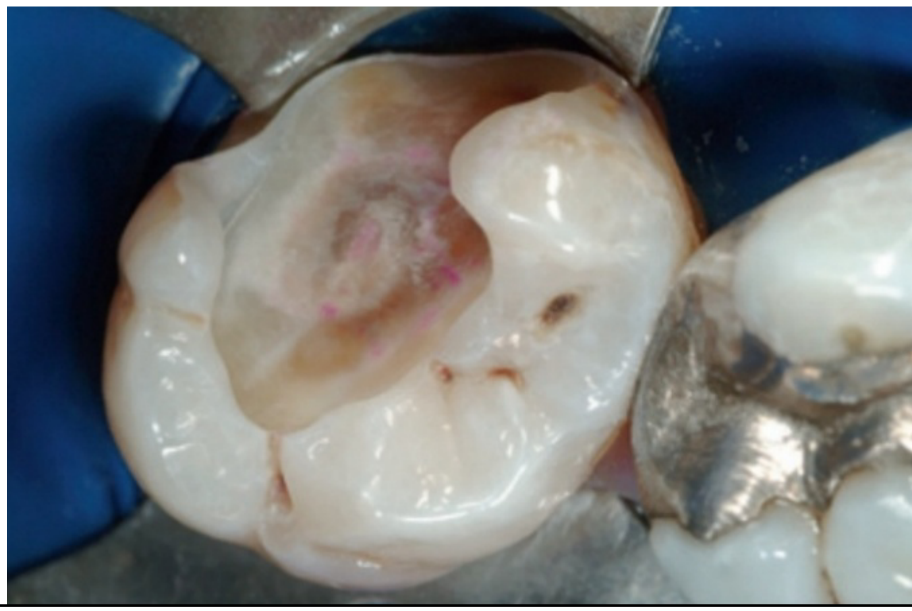

Figure 12 Clinical case illustrating Fig 8. The ideal caries removal end points for highly bonded restorations without pulpal exposure.

Avoiding direct pulp caps has been shown to reduce the need for subsequent endodontic treatment. (Thomson et al., 2008; Gruythuysen et al., 2010; Casagrande et al., 2010). Conserving more dentin in tooth preparations has also been shown to reduce the incidence of irreversible pulpitis (Zollner and Gaengler, 2000).

By eliminating or reducing the surface area and thickness of the nonelastic and deformable outer carious dentin, the performance of a bonded

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composite under functional loads will also improve (Hevinga et al., 2010)

The final goal of ideal caries removal end points and peripheral seal zones is to create an adhesive bond that will be preserved for as long as possible. Such a bond to dentin should mimic the strength of a natural tooth. The tensile strength of the DEJ has been measured at 51.5 MPa.
Only bonding to sound dentin can achieve and even exceed this tensile bond strength. (Urabe et al., 2000)

4. Gold Standards for Peripheral Seal Zone

Using the "gold standards" three-step total- etch or two-step mildly acidic self-etching dentinal bonding systems are the most consistent bonding strategies to obtain these high bond strengths.(Shirai et al., 2005; De Munck, 2004).
Adhesive bonding to normal and carious dentin has been studied for the past 15 years at the Medical College of Georgia under the direction of David Pashley. (Nakajima et al., 1999)
These studies have been continued at many Japanese universities. This research has established the bond strengths of normal and carious dentin. Inner carious dentin loses 25% to 33% of its bondability (Yoshiyama et al., 2003).
Outer carious dentin has a reduction of bondability of over 66% (Yoshiyama et al., 2002).
This reduction in bondability corresponds to the amount of demineralization in the outer and inner carious dentin (Pugach et al., 2009)

The Carisolv chemomechaical technique of caries removal leaves a thin

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layer of residual outer carious dentin that may reduce the microtensile bond strength (mTBS), (Albrektsson et al., 2001; Yazici et al., 2003).This technique can be clinically successful in shallow restorations but is not ideal in larger load-bearing situations. (Oikawa et al., 2009)

Simplified two-step total-etch dentinal bonding systems lose 40% to 50% of mTBS when bonded to inner carious dentin (Zanchi et al., 2010). The same decrease in bond strength will occur if acid etching is performed on dentin that is to be bonded with a mild two-step self-etching dentinal bonding system(Yazici et al., 2004; Proenca et al., 2007).

Dual-cure dentinal bonding systems can have the same negative effect (Say et al., 2005).

The acid from caries lesions also activates endogenous collagenase enzymes called matrix metalloproteinases. In the presence of matrix metalloproteinases, a 25% to 30% reductio in bond strength will be observed after (approximately in the first 12 months) restoration placement. A 0.2% to 2.0% chlorhexidine solution will deactivate the matrix metalloproteinases and preserve the maximum bond strength (Pashley et al., 2004; Hebling et al., 2006; Breschi et al., 2010).

Mild self- etching dentinal bonding systems produce an acid/base resistant zone of a 1 to 1.5 micron thickness referred to as "super dentin" because of its ability to withstand high and low pH attacks. SE Protect (Kuraray) with the unique proprietary methacryloyloxydo- decylpyridinium bromide monomer containing pyridinium bromide produces this super dentin and also deactivates matrix metal- loproteinases. Other mild self-etching dentinal bonding systems also produce the acid/base resistant zones but need additional matrix metalloproteinase-deactivating chemicals such as chlorhexidine (Consepsis, Ultradent) or benzalkonium chloride (Micro-

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Prime B, Danville or Etch-37, Bisco) (Nikaido et al., 2009; Donmez et al., 2005; Tezvergil et al., 2011).

The anatomical location of the peripheral seal zone dentin must also be considered to predict potential bond strength. Cervical root dentin loses approximately 20% of its bondability compared with coronal superficial dentin. If the cervical root dentin has inner carious dentin present, the bond strength is only 50% of sound coronal dentin(Doi et al., 2004)
Deep dentin vs superficial dentin bond strengths are also dependent on the type of dentinal bonding system used. Three-step total-etch and two-step mild self-etching dentinal bonding systems bond equally well to deep dentin, but simplified two-step total- etch and one-step highly acidic self-etching systems can lose up to 50% of their bond strength in deep dentin(Proenca et al., 2007; Nakajima et al., 1999).
During placement of the restorative material, the ratio of bonded to unbonded surface areas of each layer or increment of composite (the configuration factor or c-factor)(Feilzer et al., 1987) will affect the stress of polymerization shrinkage that is applied to the maturing bond to dentin. Higher c-factors always increase stress on the bond to dentin, which decreases its mTBS (Yoshikawa, 1999) (unless it is a flowable composite with a low modulus of elasticity compared to dentin). Therefore, high c-factor layering with high modulus compos- ites (thicker than 0.5 mm) should be avoided while the bond to dentin is maturing. This can best be accomplished by using an indi- rect or semidirect restorative technique (Lida et al., 2003)
If direct restoration is necessary for socioeconomic reasons, compensatory measures are required to prevent excessive stresses to the

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bond and remaining hard tissue. This can best be accomplished by multiple thin horizontal layers (which take more time to apply) on a thin layer of flowable composite (Shirai et al., 2005; Nikolaenko et al., 2004).
A thin (500-micron) microfilled flowable composite or a thick dentinal bonding system adhesive layer (50 to 80 microns) can secure the dentin bond and create a fail-safe layer. Such a resin coating will stay bonded even when overlaying layers fail under high stress (Jayasooriya et al., 2003; Magne et al., 2007).
In shallow preparations in superficial dentin, the detrimental effect of resin shrinkage is not as great because the c-factor is reduced (Shimada et al., 2008; Schmidlin et al., 2008). Polyethylene fiber nets used to line high c-factor preparations have also been shown to reduce the effects of polymerization stress and cervical microleakage.(El-Mowafy et al., 2007; Nikaido et al., 2002).
If c-factor stresses are not reduced, the bond strength is decreased by 30% to 50% during the first 24 hours and by another 10% during functional loading in the first years of service.(Nikaido et al., 2002).Careful operators who take all of these considerations into account during caries excavation and bonding procedures can decrease the array of differences in regional bond strengths in their restorations. (Shono et al., 1999).

5. Treatment Goals for Deep Caries Lesions

1. Create a peripheral seal zoe of enamel, DEJ, and normal superficial dentin near the DEJ (this should bond at 55 MPa) (Figs 11 and 12).

2. Leave the inner carious dentin inside of the peripheral seal zone (this

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should bond at 30 MPa) (compare Figs 2 and 3 with Figs 11 and 12).

3. Remove highly infected outer carious dentin inside of the peripheral seal zone without exposing the pulp. Small areas of circumpulpal outer carious dentin are left to prevent exposure (see Figs 8 to 10).

4. Seal in and deactivate any remaining bacteria left inside the peripheral seal zone.

5. Use adhesive restorative techniques that will maximize the bond strength of the peripheral seal zone and the inner carious affected dentin inside the peripheral seal zone. (Shono et al., 1999)

6. Step-By-Step Technique for Achieving Peripheral Seal Zone

1. Test for pulpal vitality with ice or aerosol refrigerant Endo-Ice (Coltene-Whaledent). If the test is positive, proceed with cares diagnosis and treatment. If the test is ambiguous Or negative, inform the patient of the possible need for endodontic treatment

2. Anesthetize the tooth Isolate it using rubber dam or other isolation techniques

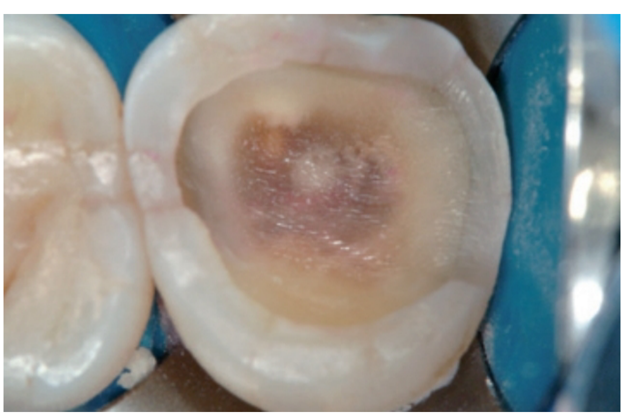

Fig 13 Ideal caries removal end points and peripheral seal zone developed in an intermediate-depth lesion using combined

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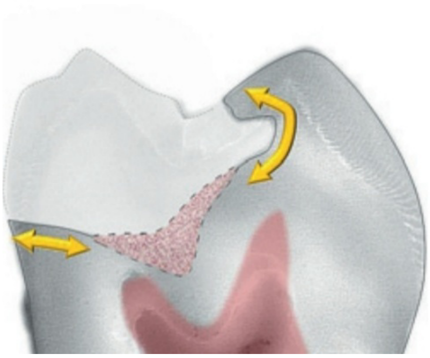

Fig 14 The peripheral seal zone is free of outer and
inner carious dentin. Inside the peripheral seal zone,

3. Access the lesion after removal of any failed restorations. Stain the caries
lesion with red caries-detecting dye. Wait 10 seconds and rinse (see Fig 13).
4. Starting near the DEJ, use a 1-mm round diamond bur of fine to medium grit (30
to 100 microns) to create a peripheral seal zone area free of red-stained outer
caries and pink-stained inner caries. This superficial normal dentin will be
1- to 2-mm wide depending on whether it is on the buccal or the occlusal areas
of a molar (1.5 to 2 mm) or on the mesial or distal root dentin (1 mm). Premolars
are smaller, and the superficial dentin is narrower in all areas (Figs 11 and 12).
5. Staining and removing outer and inner carious dentin is repeated until
the caries removal end point in the peripheral seal zone is stain free. This can be

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confirmed by DIAGNOdent readings of approximately 12 (see Fig 3) and the total absence of caries-detecting dye. (This indicates virtually bacteria-free superficial dentin.)

6. Remove the red-stained outer carious dentin from the area inside the peripheral seal zone (being careful to avoid the pulp horn areas). Measure from
the occlusal surface to determine if the excavation is in superficial (outer third), intermediate (middle third), or deep (pulpal third) dentin (see Fig 4).

7. After removing the red and leaving the pink between the pulp horns, the pink
inner carious dentin areas in these intermediate dentin areas can be evaluated with DIAGNOdent. The numbers should read approximately 24 (accept-
able range, 12 to 36). Those readings indicate a virtually bacteria-free area in
the intermediate to deep dentin inside the peripheral seal zone.

8. Move to the deep pulp horn areas last. Carefully remove red-stained outer cari-
ous dentin until deep dentin is reached (5 mm from occlusal surface). If the tissue continues to stain red and measurements with the periodontal probe indicate that you are deeper than 5 mm from the occlusal surface (> 3 mm from
the DEJ), stop excavation to avoid pulp exposure (compare Figs 4 to 8).

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Figure 15 Measuring CRE clinically. Note that the PSZ concept and CRE measurements also relate to the buccal and lingual aspects of the tooth.

9. Optional step: Treat the peripheral seal zone, inner carious dentin, and outer
carious dentin with 0.2% to 2.0% chlorhexidine for 30 seconds to inactivate both
the matrix matalloproteinases and any remaining bacteria; 0.1% to 1.5% benzal-konium chloride solution in the acid-etch or

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methacryloyloxydodecylpyridinium
bromide monomer in the dentinal bonding system will also achieve these goals. (Tezvergil et al., 2011)
If using a three-step total-etch dentinal bonding system, this step is performed
after acid etching and rinsing. If using a two-step self-etching dentinal bonding
system, after applying chlorhexidine or benzalkonium chloride, dry the prepara-
tion for 10 seconds before applying the self-etching primer. (Toledano et al., 2004).

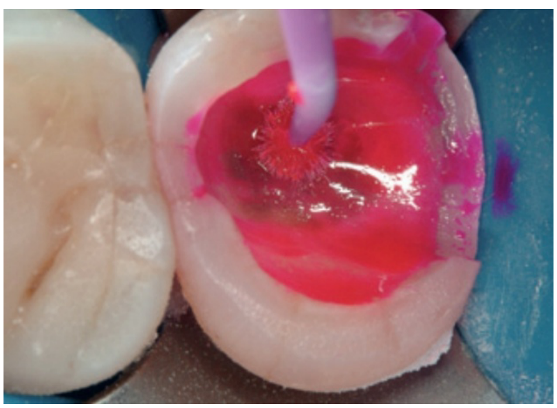

Fig 17 Magnification of 6.5× to 8.0× is ideal for implementing minimally invasive caries removal.

10. Optional step if using a mild two

Fig 16 Application of caries-detecting dyes guides the creation of the peripheral seal zone using DIAGNOdent and 3D measurements to make end point decisions in the intermediate and

-step self-etching dentinal bonding system:
Use air abrasion on the preparation to maximize the mTBS (Van Meerbeek et

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al., 2003)

11. Start dentin bonding with a three-step total-etch or a mild two-step self-etching dentinal bonding system. These techniques for caries removal end point determination and peripheral seal zone development are the foundation of
conservative dentistry. Such minimally invasive procedures are best performed under magnification. This type of microdentistry is greatly aided by using high-magnification prismatic loupes of 6.5>< to 8.0>< or with an operatory microscope with similar magnification (Fig 13). The peripheral seal zone in superficial
dentin will allow biomimetic bond strengths of approximately 45-55 MPa to be created.

The intermediate and deeper areas of light pink—stained inner carious dentin will likely generate a dentin bond of 30 MPa. If any outer caries is left in deep circumpulpal areas to prevent pulp from being exposed, the m-TBS in those small areas will be approximately 15 MPa. To maximize all of these bond strengths, the dentinal bonding system can be allowed to mature for a certain length of time (3 minutes to 24 hours) before being bonded to another layer of polymerizing resin cement or composite rresin. (Dietschi et al., 2002; Asaka et al., 2006).
This is why it is important to use the immediate dentin sealing technique possible.(Magne et al., 2005; Dietschi, 2003).

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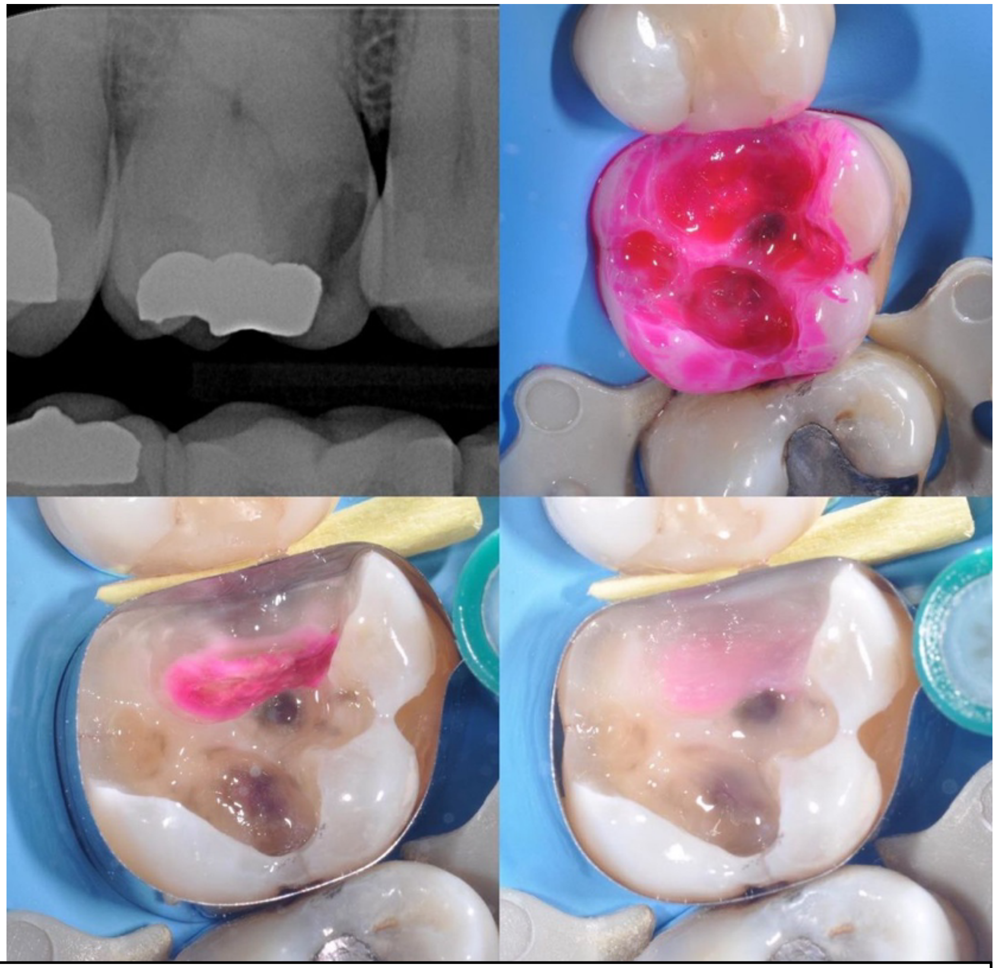

Figure 18. Clinical example showing application of CDD (top right). After complete caries removal in the PSZ and partial caries removal over the pulp, CRE are established

Conclusion

By combining detailed anatomical and pathohistologic knowledge with the technologies of caries-detecting dyes and laser fluorescence, an ideal caries removal end point can be achieved for vital teeth with deep caries lesions. These ideal end points will preserve more vital pulps, conserve more dental hard tissue, and create a highly bondable peripheral seal that

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will mimic the natural tooth when restored with low stress adhesive techniques. (Hosoya, 2007).

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