CHAPTER 2

Review of the literature

According to the American Academy of Pediatric Dentistry (AAPD), young permanent teeth diagnosed with normal pulp or reversible pulpitis can be treated by vital pulp therapy (12). Current treatment concepts include complete caries removal or incomplete caries removal. For the complete caries removal approach, teeth with pulpal exposure can be treated with direct pulp capping or partial pulpotomy. If the lesions do not involve the pulp, protective materials are placed as barriers between the restorative material and the pulp. AAPD guidelines recommend that placement of protective materials, such as calcium hydroxide, dentin bonding agent, or glass ionomer cement is at the consideration of the clinician.

This literature review is divided into seven parts as follows:

2.1 Definition of deep carious lesions

2.2 Effects of deep caries on dentin-pulp complex

2.3 Bacterial invasion in deep caries

2.4 The remaining dentin thickness

2.5 The young and aged dentin-pulp complex

2.6 Irrigation of deep cavity after complete caries removal

2.7 Pulp protection materials: liners and bases

2.1 Definition of deep carious lesions

The treatment of deep carious lesions is currently based on subjective symptoms, clinical appearance, pulpal sensibility tests, and radiographic appearance (13-15). Although the most important decision on the choice of treatment should also base on an assessment of the state of the pulp (13), there is currently no equipment clinically available to measure the degree of inflammation of the pulp. Clinically, it is difficult to specify the penetration depth of deep carious lesion; therefore, radiograph is currently the most common method used to measure the depth of the lesions. The penetration

depth is the ratio between the maximum depth of carious dentin and the total dentin thickness (16). According to Bjorndal et al. (16-18), deep dentin carious lesions are determined radiographically when the demineralized dentin penetrates 75% or more of the entire dentin thickness and a well-defined radiopaque zone exist between the carious lesions and the pulp as shown in Figure 2.1

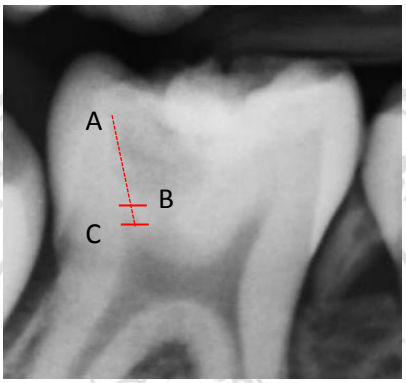

Figure 2.1 Deep dentin carious lesions are determined radiographically
The penetration depth is the ratio between AB/AC
A = ½ distance along DEJ
B = pulpal border of radiolucent lesion
C = border of the pulp

2.2 Effects of deep caries on dentin-pulp complex

Dental caries is an infectious disease that results in lesions affecting enamel, dentin, pulp, and cementum, if the root portion is involved. Carious lesions are characterized by demineralization of the hard tissues of the tooth, accompanied by tissue change in the affected dentin and inflammatory reaction in the pulp (14). There are some disagreements regarding the reaction of the dentin-pulp complex to caries. Some authors have reported that a defense mechanism occurs at the early stage of the carious process in enamel lesions (19, 20) whereas Massler (21) has reported that the dentin-pulp complex reaction only occurs when caries extends into dentin.

The pulp and dentin are usually looked upon as one unit. Therefore, all procedures performed in the dentin have effects on the pulp (22, 23). The dentin-pulp complex exhibits a broad spectrum of responses: injury, defense, and repair events (23). This response is a dynamic process that responds to mechanical, bacterial, or chemical irritations. Cavitated carious lesions provide a niche for bacteria to aggregate and proliferate; bacteria and their toxins can travel through the dentinal tubules into the pulp (2). These injuries can affect the vitality and function of the pulp. A progression of carious lesions may then lead to inflammation of the pulp. The pulp subjacent to deep carious lesions shows the presence of chronic inflammatory cells, including lymphocytes, macrophages, and plasma cells (19). The dentin-pulp complex reacts to stimuli in order to reduce the permeability of the dentin. The most common reactions are the deposition of apatite and whitlockite crystals within the dentinal tubules, leading to dentinal tubule sclerosis (16, 25).

The vitality and dentin repair potential of the pulp are dependent on the survival of the odontoblasts beneath the site of injury (23-25). Survived odontoblasts or replacement of lost odontoblasts by newly differentiated odontoblast-like cells has been described as a part of pulp tissue repair, leading to the formation of tertiary dentin (23).

Unlike the primary and secondary dentin that is secreted by odontoblasts and laid down along the entire dentin-pulp border of the teeth, tertiary dentin is focally secreted by odontoblasts or differentiated odontoblast-like cells positioned beneath the injured dentinal tubules or pulp exposure (26).

Primary dentin is secreted 4 μm per day during tooth development until completion of root formation, whereas secondary dentin is laid down after completion of root formation approximately 0.5 μm per day throughout life (26, 27). Tertiary dentin formation is one of the dentin-pulp defense mechanisms to caries. Tertiary dentin usually localizes to the affected area in order to increase the dentin thickness for protection of the pulp (19, 28).

There are two forms of tertiary dentin formation: reactionary and reparative. Reactionary dentin, sometimes called irregular dentin, is identified as an area of tertiary dentin that is secreted continually. Odontoblasts that have survived injury may up-

regulate to secrete reactionary dentin. With more severe injury, this may lead to differentiation of mesenchymal to odontoblast-like cells, producing reparative dentin (19, 27, 29), which often has atubular structure, as judged by the light microscopy. A differentiation between reactionary and reparative dentin can be made by histological examination of the sections. In addition, tertiary dentin formation is related to the activity of carious lesions. The more active the lesions, the more irregular the structures of tertiary dentin (14, 27). If carious lesions still progress, bacteria can penetrate into deep dentin, and whenever the bacteria reach the tertiary dentin, pulpitis can prevail (19, 21, 28, 30).

2.3 Bacterial invasion in deep caries

Bacteria and their by-products or toxins in the deep layers of dentinal lesions can pass through dentinal tubules and reach the dental pulp. Thus, it is possible, in teeth with deep carious lesions, where there is no clinical evidence of pulpal exposure and the pulp is covered by clinically sound dentin, that small numbers of bacteria can still invade the dental pulp through dentinal tubules (31). The deeper the penetration of the lesions, the greater chances for direct/indirect bacterial toxin exposure to dentinal tubules (2, 14, 31). In cavities with less than 0.5 mm of residual dentin thickness, the number and size of open dentinal tubules allow communication with the pulp. This communication is comparable to a true exposure (23). In addition, young permanent teeth have more permeable dentin and larger dentinal tubule than the aged tooth which allow rapidly progressing of caries (2-4). Therefore, the choice of protective material is crucial in the treatment of such deep carious lesions.

The number of dentinal tubules from the dentino-enamel junction to the pulp per mm^2 varies from 15,000 to 45,000 tubules per mm^2. Deposition of intratubular dentin results in narrowing of the tubules (26). Moreover, deposition is more advanced in superficial dentin than in dentin closer to the pulp, resulting in a tapered tubule with the largest dimensions at the pulp (approximately 2.5 μm in diameter) and the smallest dimensions at the dentino-enamel junction (approximately 0.9 μm in diameter). The average diameter of oral streptococcal cells is approximately 0.5-0.7 μm in diameter; thus, a group of streptococcal cells may intimately contact the dentinal tubular wall (32).

Different regions of carious dentin may contain various bacterial species. The micro flora of deep dentin lesions is dominated by *S.mutans, Lactobacillus spp.,* and *Propionibacterium spp.* According to the study based on molecular technique, *S.mutans* and *Lactobacillus spp.* were dominant in advanced caries. On the other hand, Love and Jenkinson (32) reported that species of *Propionibacterium* and *Bifidobacterium* were the dominating microflora of deep carious dentin. It probably can be assumed that there are several bacterial species and their by-products in deep carious lesions that can invade the pulp through dentinal tubules. Bacterial invasion of the pulp may be clinically insignificant; however, the bacteria may be sensitized to produce immunological reactions and if some bacteria survive and multiply, infection of the pulp would be expected (31). Thus, it is reasonable to consider inhibition of bacteria by irrigant and pulp protection material that possess suitable characteristics for disinfecting dentinal lesions and has antimicrobial capacity.

2.4 The remaining dentin thickness (RDT)

The remaining dentin thickness (RDT) is the remaining sound dentin after a tooth preparation or carious destruction(2). RDT appears to be one of the most significant factors determining the secretion of reactionary dentin (33). RDT relates to pulp repair activity as well as odontoblasts survival because survived odontoblasts secrete dentin matrix that assists in providing pulp protection (34). However, the minimum RDT necessary to protect the pulp is still controversial.

Stanley (35) suggested that RDT of 2 mm. would protect the pulp from injury caused by most restorative materials and procedures. Pameijier et al. (36)reported that RDT of 1 mm. or more would be sufficient to protect the pulp from the cytotoxicity of zinc phosphate (ZnP) and resin-modified glass ionomer. Similarly, some studies demonstrated that if RDT is about 1 mm, there is no significant disturbance to pulpal cells (2, 37, 38).However, some studies concluded that RDT of at least 0.5 mm. is sufficient to protect the pulp tissue from cytotoxic injury (2, 37, 39). Some studies concluded that when the RDT is less than 0.25 mm, histological responses relating to reduction in odontoblast survival, pulp hyperemia and pulpitis occur (22, 28, 40, 41).

Besides RDT, cavity preparation, the type of restoration, and biovariability of patients can also affect dentin repair activity (5, 30, 34). Murray et al. (30) assumed that at a mean RDT of 0.574 mm, it is difficult to differentiate the effects of pulpal response from either restorative materials or variable host factors.

From the above review, it is currently unclear regarding the minimum RDT that can protect the pulp from injury. To achieve a good treatment outcome in clinical practice, every effort should be made to reduce tissue injury and promote dentin repair capacity (37).

Another issue relating to RDT is that measurement of RDT is only possible through indirect methods, such as radiographs and electrical equipments. However, there are no clinical standard methods currently available for RDT measurement. Currently, the most common method in estimating the dentin thickness is to assess the lesion from radiographs. Bjorndal et al. (16) measured RDT from bitewing radiographs by using computer software as shown in Figure 2.1. RDT is the distance from point B (the pulpal border of the radiolucent area) to point C (the border of the pulp). Nevertheless, radiographic measurement has some limitations relating to unclear anatomical structures and two-dimension representation of a three-dimensional tooth structure (42).

Electrical equipment is another method used in estimating the RDT. Electrical equipments such as Caries meter, Endo meter, and Prepometer® have been used in measuring the RDT. These electrical equipments measure the impedance between the cavity floors and the oral mucous membrane. Some studies demonstrated that there is unclear correlation between impedance value and the RDT and these impedance measurements do not reflect the physiology of dentin (43-45). Moreover, the use of Prepometer® showed no correlation of the electrical value with the histologically determined RDT (46).

In summary, there have not yet been any accurate indirect methods to measure the RDT. In deep carious lesions, RDTs are usually estimated visually. The basic current approach to clinical practice is to use the pulp protection material beneath restorations to protect the pulp and provide dentin repair capacity.

2.5 The young and aged dentin-pulp complex

In general, young dental pulp has highly active growth factors which regulate the genes controlling cell proliferation and cell differentiation. In contrast with aged pulp, the vitality of the dentin-pulp complex decreased with aging as shown by the low expression of genes encoding for transcription regulators and the high expression of genes involving in apoptotic processes (47). Clinically, placing any dental material close to the pulp should always be made with cautions because it may damage the pulp and may inhibit reparative and regeneration of the pulp cells.

In addition, larger pulp chamber and less dentin apposition of the young teeth correlate with the odontoblasts in pulp chamber that lay close to exposed environment (48). These biological factors must also be considered when select a pulp protection material. Moreover, the young teeth has more permeable dentin structure than do the aged teeth (8). The permeability of the dentin is essential to support the physiology and reaction of the dentin-pulp complex (29). In young newly erupted teeth, most pulpal dentin often has no intratubular lining resulting larger diameters of the tubules than aged teeth. The deposition of intratubular sclerotic dentin is associated with aging. This may decrease the diameters of the tubules, so the aged teeth are more difficult for the bacteria and irritant of materials to diffuse through the dentinal tubules and reach the pulp (34).In contrast, young teeth dentin has more permeability so bacteria and their toxin or chemical irritation from restorative material can easily reach to the pulp (8). However, there has been no study comparing success of treatment with pulp protection between young and aged teeth.

2.6 Irrigation of deep cavity after complete caries removal

After complete removal of deep carious lesions, some microorganisms may be retained in dentinal tubules. It is reasonable to use an irrigant that possesses antimicrobial effect. Chlorhexidine (CHX) and sodium hypochlorite (NaOCl) have been recommended for disinfecting of the prepared cavities (5).

CHX is widely used for disinfection in dentistry because of its good antimicrobial activity. However, CHX has no tissue-dissolving capability. CHX permeates the

microbial cell wall or outer membrane and attacks the bacterial cytoplasmic or inner membrane or the yeast plasma membrane. One of the reasons for the popularity of CHX is its substantivity because CHX binds to hard tissue and retains its antimicrobial effect (49). As a cavity disinfectant, CHX did not affect the bond strength of caries-affected dentin to glass-ionomer or resin composite restorations (50-52).It also has been reported that CHX did not influence the resistance to the dislodgement of Biodentine™ from root dentin (53).

NaOCl is an antimicrobial agent frequently used in the treatment of endodontic and periodontal infections. NaOCl presents antimicrobial activity originated by hydroxyl ions which act on bacterial essential enzymatic sites and possess chloramination action (54). This irrigant presents several good properties, such as antimicrobial effects and tissue dissolution capacity. However, the major disadvantages of this irrigant are its cytotoxicity to oral tissue, foul smell, and taste (55). Moreover, NaOCl can decrease bond strength of dentin to resin composite (56).

2.7 Pulp protection materials: liners and bases

Protection of the dentin-pulp complex is necessary, especially in deep cavities. The American Academy of Pediatric Dentistry (AAPD) recommends placement of a material on the floor of the prepared cavity to act as a protective barrier between the restoration material and the pulp of the tooth (57). The protection of the dentin-pulp complex consists of the application of one or more layers of material between the restorative material and dentinal tissue.

Ritter and Swift (2) have classified pulp protection materials into five groups: bases, liners, varnishes, sealers, and dentin adhesives. This part of review will focus on liners and bases. From the review, it can be concluded that liners are material that applied in thin layer to seal the dentin floor and cavity wall (2, 58, 59). On the other hand, bases are thick layers of material that are strong enough to support restorations during function and can be shaped and contoured to specific forms in tooth preparations (2, 58-61). The purposes of placing liner and base material are to seal dentinal tubules, reduce dentin permeability, decrease toxicity of restorative materials and bacterial penetration due to microleakage, act as a barrier to protect the dentin-pulp complex,

stimulate the pulp odontoblasts to create reparative dentin, and also promote remineralization of existing dentin (2, 5, 58-63).

To date, several pulp protection materials have been developed to place in deep cavities. Materials that are placed on the tooth as protective layer must be biocompatible. They should also protect dentin-pulp complex in order for it to maintain its function. Moreover, selection of pulp protection materials also depends on the good mechanical and physical properties.

This review will focus on some common liners and bases material: calcium hydroxide (CH), glass ionomer (GI), and resin-modified glass ionomer (RMGI). Moreover, the newly introduced, calcium silicate-based cement, is also covered.

Calcium hydroxide (CH)

CH was introduced to dentistry by Hermann (8) in the 1920s. Calcium hydroxide (CH) has been the liner of choice in deep cavities for many years. CH products are available in either paste-paste or a liquid formulation. Examples of CH paste-paste product are Dycal® and Life™ and of liquid formulation is Hydroxyline®.

For the paste-paste formulation, it has two components: a base and a catalyst. The base is composed of calcium tungstate, tribasic calcium phosphate, and zinc oxide. The catalyst is composed of calcium hydroxide, zinc oxide, and zinc stearate (5). CH is easy to manipulate and harden rapidly when applied in thin layers. Its high pH, approximately 12, is considered to have a bactericidal effect. It has been suggested that the pH increase due to the presence of free hydroxyl ions may initiate mineralization. The high pH of CH can induce dentin bridge formation which can be seen histologically. Even though the quality of dentin bridge of CH is suspected, it provides a physical barrier to protect the pulp (64). CH is still one of the most favorable liners in deep carious lesions (65, 66). Unfortunately, it has low strength and dissolves over time. With the dissolution of the material, microleakage allows penetration of microorganisms through the pulp, causing pulpal inflammation (62).Regarding the major disadvantages of CH, it has long-term solubility, poor bonding to dentin, and its failure to bond to resin-based restorative materials. These reasons why are not use CH alone for adhesive restoration (64, 67).

Glass ionomer (GI) and resin-modified glass ionomer (RMGI)

Glass ionomer (GI) was developed by Wilson and Kent in 1971 and later introduced to the market in the early 1970s (62). This material has several advantages, such as fluoride release, a good coefficient of thermal expansion, a modulus of elasticity similar to that of dentin, bonding to enamel and dentin, and biocompatibility. Because GI possesses limitations relating to susceptibility to dehydration and poor physical properties, resin-modified glass ionomer (RMGI) has later developed. Polymerizable water-compatible monomers, such as 2-hydroxyethyl methacrylate (HEMA), has been added to the conventional GI leading to flexural strength, elastic modulus and wear resistance that are higher than that of conventional GI (62). However, RMGI has been characterized as being cytotoxic when it is placed close to, or directly on, the pulp tissue. Several studies have demonstrated that HEMA in RMGI can easily diffuse through the dentinal tubules and reach dental pulp cells (8-10, 62). Nevertheless, an *in vivo* study has demonstrated that when RMGI (Vitrebond™) was applied as a liner in very deep (non-carious) Class V cavities, it caused no inflammatory pulp response even when RDT was thinner than 300 µm. The authors of that study suggested that RMGI (Vitrebond™) is an appropriate dental material to be applied as a cavity liner or base (68, 69).

A survey in 2005 regarding teaching of liners and bases for resin composite restoration in deep cavities in dental schools in North America revealed that the most frequently used liners were GI (35.9%), followed by CH (28.2%) (70). Similarly, a survey in 2007 regarding the teaching and use of resin-based materials for restoring posterior teeth in dental schools in North and South America, Europe, and Asia, found that GI and CH were commonly used as liners in moderate and deep cavity preparations (middle and inner thirds of dentin) (7).

Histologically, pulpal responses to CH, RMGI, dentin adhesive, and MTA in deep cavities are shown in Table 2.1. When compared to RMGI, CH demonstrated better pulp response outcomes, including higher intact odontoblast numbers at different RDTs (33, 34, 37, 41), lower inflammatory response (9, 33), lower tissue disorganization (9), and more frequency of reactionary dentin secretion (9, 33, 34). However, some studies

demonstrated that both CH and RMGI did not exhibit inflammation (68) and similarly showed thin layer of reaction dentin (71).

CH is a biocompatible material when applied as a cavity liner. It has been recommended to use as a thin layer before RMGI is placed. RMGI when used in conjunction with resin composite restorations, resulting in the lower frequency of bacterial leakage in RMGI than that in CH, when both were used as liners in teeth without pulp exposure (9, 30). Because RMGI is a material that can provide an excellent seal and commonly recommended for preventing microleakage (5, 8, 33), thusthe use of CH in combination with GI or RMGI is the most common practice regarding protective materials for deep cavities (7, 70, 72, 73).

Clinically, Marchi et al. (74) reported that there was no difference of clinical and radiographic outcome between pulp protection with CH and RMGI after two years. Leye Benoist et al. (72) demonstrated that CH had higher thickness of dentin formation than that of MTA at 3 months. They also reported 73% clinical success rate of pulp protection with CH (Dycal®) in combination with GI (Fuji IX) at 6 months. Welburry and Murray (75) and Memarpour et al. (76) showed that all teeth with deep cavities treated with pulp protection with CH and RMGI under composite restoration in children maintained vitality and none of the patients complained about postoperative sensitivity. Nevertheless, in a survey of teaching the use of protection materials in dental schools in North America, the author indicated that 20% of the patients reported having postoperative sensitivity after receiving a protection layer with CH and GI in a deep composite restoration (70). Surprisingly, Unemori et al. (45) reported that a combination of CH and GI or RMGI as pulp protection, frequently chosen for deep cavities, showed 11% of postoperative sensitivity, which was higher than that of no protection. They suggested that further studies are required to investigate whether other types of pulpal protection could be more effective in lowering the incidence of postoperative sensitivity in deep cavities. Moreover, several factors, such as individual profile, the shape of the cavity, and protection of the dentin-pulp complex, can also relate to the causes of postoperative sensitivity.

Table 2.1 Pulp response to different pulp protection materials in deep cavities

Pulp responses	Authors	Material	Outcomes
Decreased odontoblast number RDT ≥ 0.5 mm	Murray et al. (37)	CH (Dycal®)	13.6% - 33.7 %
RDT < 0.25 mm	Murray et al. (33)	CH (Dycal®) RMGI (Vitrebond™)	11.3% 62.3%
Maintained odontoblast number RDT ≥ 0.5 mm.	About et al. (41)	CH (Dycal®) RMGI (Vitrebond™)	100% 42.8%
RDT < 0.25 mm	Murray et al. (34)	CH (Dycal®) RMGI (Vitrebond™)	100% 64.3%
Inflammatory response	Costa et al. (9) Murray et al. (33)	CH (Dycal®) RMGI (Vitrebond™)	Not exhibited inflammation Exhibited mild-moderate inflammation
	Costa et al. (68)	CH (Dycal®) RMGI (Vitrebond™)	Both groups did not exhibit inflammation
	Hebling et al. (71)	CH (Dycal®) Dentin adhesive (All bond 2)	Less inflammation Greater inflammation
Tissue disorganization	Costa et al. (9)	CH (Dycal®) RMGI (Vitrebond™)	Not exhibited tissue disorganization Exhibited tissue disorganization and odontoblast layer

Table 2.1 (continued)

Pulp responses	Authors	Material	Outcomes
Frequency of reactionary dentin secretion	Murray et al. (34)	CH (Dycal®) RMGI (Vitrebond™)	100% 64.3%
	Murray et al. (33)	CH (Dycal®) RMGI (Vitrebond™)	100% 62.3%
	Hebling et al. (71)	CH (Dycal®) RMGI (Vitrebond™)	Both groups presence thin layer of reaction dentin.
Thickness of dentin formation	Leye Benoist et al. (72)	CH (Dycal®) MTA (ProRoot®)	3 months; +0.136 mm. 6 months; + 0.221mm. 3 months; +0.121 mm. 6 months; + 0.235mm.

Calcium-silicate-based cements

Calcium-silicate-based cements were first introduced to dentistry in 1993. Ordinary Portland cement (OPC) was developed to produce the mineral trioxide aggregate (MTA). Recently, two forms of MTA have been available in either the grey or white forms. MTA is composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, silicate oxide, and added bismuth oxides for radiopacity(77). MTA has been proposed as the material of choice for root end filling, pulp capping, perforation repair, and apexification(78). Although, MTA has not been designed as a pulp protection material, there are two studies using MTA as a pulp protection material for the dentin–pulp complex of permanent teeth. Leye Benoist et al. (72) reported 93% success rate of MTA as pulp protection material at 3 months and 89.6% at 6 months. Petrou et al. (79) reported 94% success rate of MTA as an indirect pulp capping material at 6 months.MTA has some drawbacks such as long-setting time, setting in moist environment, and discoloration (78). Recently, a quick-setting calcium-silicate based dental cement,

Biodentine™, was introduced in 2009 by Septodont (Saint-Maur-des-FassesCedex, France). Biodentine™ was developed as a dentin replacement material and advertised as a bioactive dentin substitute (80-82). Although calcium-silicate based cement appears to be a common ingredient in both MTA and Biodentine™. There are some different compositions between both materials, as shown in Table 2.2

Biodentine™ actually uses the MTA-based cement technology and improves some properties, such as physical qualities and handling. The use of Biodentine™ varies in clinical applications. An overview of potential clinical applications of Biodentine™ is summarized in Table 2.3

Biodentine™ may be a good candidate for a pulp protection material in teeth with deep caries. Several studies have demonstrated the physical and biological properties of this material, as shown in Table 2.4

Table 2.2 The composition of two different calcium-silicate based cements: Biodentine™ and ProRoot® MTA

	Biodentine™	**ProRoot® MTA**
Manufacturer	Septodont®	Dentsply®
Cement composition	Tricalcium silicate Dicalcium silicate Zirconium oxide Calcium carbonate and calcium oxide Iron oxide	Tricalcium silicate Dicalcium silicate Bismuth oxide Calcium sulfate dehydrate or Gypsum Tricalcium aluminate
Liquid Composition	Hydrosoluble polymer Calcium chloride	Water

Modified from Biodentine™ material characteristics and clinical applications: a review of the literature (74).

Table 2.3 Overview of potential clinical applications of Biodentine™

Liners and bases in deep cavities
Apexification, apexogenesis
Pulp chamber floor perforation
Lateral root perforation
Root-end filling
Direct pulp capping
Indirect pulp capping
Partial pulpotomy , Pulpotomy
External root resorption

Modified from Biodentine material characteristics and clinical applications: a review of the literature and a review on biodentine, a contemporary dentine replacement and repair material (81, 82).

Table 2.4 Studies demonstrating physical and biological properties of Biodentine™ and other pulp protection materials

Properties	Author	Materials	Outcomes	
Cytotoxicity	Laurent et al. (83)		Direct contact to culture medium	Indirect contact to culture medium
		Biodentine™	No cytotoxicity No genotoxicity	None of the materials was cytotoxic
		ProRoot® MTA	No cytotoxicity	
		CH (Dycal®)	Higher cytotoxicity	
Remineralization	Watson et al. (80)	Biodentine™	A high pH: more favorable for hydroxyapatite (HA) formation	
		GI (Glass Carbomer®)	A lower pH: less favorable for HA formation	
	Laurent et al. (11)	Biodentine™	Both induced an early formation of reparative dentin	
		ProRoot® MTA		
Dentinogenesis	Tziafa et al. (84)	Biodentine™	Higher thickness of tertiary dentin formation	
		Dycal® + Biodentine™	Less thickness of tertiary dentin formation	
Microleakage	Koubi et al. (85)	Biodentine™	Both groups presented similar glucose diffusion at the interface between materials and dentin wall	
		RMGI (Ionolux)		
	Raksin et al. (86)	Biodentine™	Sealing efficacy did not differ between the materials	
		RMGI (Fuji II LC)		
	Camilleri (87)	Biodentine™	Exhibited leakage	
		GI (Fuji IX)	No leakage	
		RMGI (Vitrebond™)	No leakage	

Table 2.4 (continued)

<table>
<tr><th>Properties</th><th>Author</th><th>Materials</th><th colspan="2">Outcomes</th></tr>
<tr><td rowspan="8">Compressive strength</td><td rowspan="4">Kayahan et al. (88)</td><td>Biodentine™</td><td rowspan="4">Etched with 37% phosphoric acid</td><td>did not reduce compressive strength</td></tr>
<tr><td>ProRoot® MTA</td><td>did not reduce compressive strength</td></tr>
<tr><td>MTA- Angelus</td><td>reduced compressive strength</td></tr>
<tr><td>CEM cement</td><td>reduced compressive strength</td></tr>
<tr><td rowspan="4">Grech et al. (89)</td><td>Biodentine™</td><td colspan="2" rowspan="4">Biodentine™ exhibited superior values than all the materials tested</td></tr>
<tr><td>Bioaggregate</td></tr>
<tr><td>IRM</td></tr>
<tr><td>Prototype tricalcium silicate cement</td></tr>
<tr><td rowspan="3">Bond strength</td><td rowspan="2">Hashem et al. (90)</td><td rowspan="2">Biodentine™</td><td><u>Bonding technique Self-etch & Total-etch</u></td><td><u>Early and delayed time of bonding</u></td></tr>
<tr><td>No significant difference between adhesive modes</td><td>Significant reduction occurred in early time of bonding</td></tr>
<tr><td>Odabas et al. (91)</td><td>Biodentine™ with different adhesive systems
-Etch and rinse
-Two step self-etch
-One step self-etch</td><td colspan="2">No significant differences of shear bond strength were found between 3 adhesive systems</td></tr>
</table>

Table 2.4 (continued)

Properties	Author	Materials		Outcomes
Push-out bond strength	Guneser et al. (53)	Biodentine™ with various irrigants - NaOCl - CHX -saline solutions		The push-out bond strength of Biodentine™ was not significantly different after being exposed to various irrigants
Micro-hardness	Camilleri (87)	Biodentine™		Micro-hardness of Biodentine™ washigher than those of Fuji IX &Vitrebond™
		GI (Fuji IX)		
		RMGI (Vitrebond™)		
Color stability	Valles et al. (92)	Biodentine™		Maintained color stability overtime
		ProRoot® MTA		Showed dark discoloration after light radiation
		MTA-Angelus		
	Keskin et al. (93)	Biodentine™	-5% NaOCl -2% CHX	Discoloration when contact CHX >NaOCl
		BioAggregate		Discoloration when contact NaOCl> CHX
		MTA-Angelus		Discoloration when contact NaOCl> CHX
		ProRoot® MTA		Most severe discoloration when contact NaOCl& CHX

Table 2.4 (continued)

Properties	Author	Materials	Outcomes	
Color stability	Shokouhinejad et al. (94)	Biodentine™ OrthoMTA ProRoot® MTA Endo Sequence Root Repair Material (ERRM)	Blood contamination Color change: occurred in all materials (no significant difference among 4 materials)	Saline contamination Color change: Biodentine™, ERRM less than OrthoMTA, ProRoot® MTA

Todate, there has been only few studies regarding the biocompatibility and remineralization activity of Biodentine™. Laurent et al. (83)demonstrated that Biodentine™ was non-cytotoxic and non-genotoxic to pulp cells when the material is used as either a direct pulp-capping or a lining material.Watson et al. (80) demonstrated that a high pH environment of Biodentine™ was more favorable for hydroxyapatite formation than did GI. Laurent et al. (11) showed that Biodentine™ has potential to increase TGF-β1 secretion from pulp cells and induce an early formation of reparative dentin. Another study evaluating dentinogenic activity of Biodentine™ in deep cavities of swine teeth demonstrated that the application of Biodentine™in direct contact with the deep cavity floor provided significantly higherstimulatory activity in inducing tertiary dentin formation in comparisonwith the application of Dycal® and Biodentine™(84).

The sealing ability of Biodentine™ was evaluated in many studies. In their *in vitro* study, Koubi et al. (85)assessed microleakage in the cavities restored with the open sandwiched technique and showed that glucose diffusion at the interface of Biodentine™ and the dentin wall was similar to that of RMGI and the dentin wall. According tothe *in vitro* study by Raskin et al. (86), Biodentine™ provided efficient sealing at the interface of enamel, dentin and dentin-bonding agent, similar to that did RMGI.However, in another *in vitro*study, Biodentine™ exhibited leakage at the dentin-

to-material interface, whereas Fuji IX and Vitrebond™ exhibited zero-leakage when used in a sandwich restoration as bases under resin composite restorations (87).

For the compressive strength, Kayahan et al. (88)concluded that acid etch with 37% phosphoric acid had no effects on the reduction of compressive strength of Biodentine™. Moreover, Biodentine™ showed significantly higher compressive strength values than did MTA and CEM cement. In addition, Biodentine™ was the strongest material tested. Biodentine™ exhibited superior values compared to Bioaggregate, Prototype tricalcium silicate cement, and IRM (89). The enhanced strength is attributed to the low water/cement ratio used in Biodentine™ which is permissible as a water soluble polymer is added to the mixing liquid.

Regarding the bond strength of Biodentine™ and resin composite restorations, Hashem et al. (90) showed that there was no significant difference of bond strength between using the self-etch and total-etch. Moreover, the authors recommended that placing the overlying resin composite should be delayed for at least two weeks because there was a significant increase in bond strength after two weeks. Similarly, Odabas et al. (91)assessed the bond strength of Biodentine™ with different adhesive systems and concluded that the different adhesive systems, etch and rinse, two step self-etch, and one step self-etch, did not affect the bond strength of Biodentine™ to resin composite. Guneser et al. (53)evaluated the effect of various endodontic irrigants on the push-out bond strength of Biodentine™ and found that the push-out bond strength of Biodentine™ was not significantly different when Biodentine™ was exposed to NaOCl, CHX, and saline solutions.

For the micro-hardness, Camilleri (87) found that Biodentine™ exhibited higher surface micro-hardness than did both Fuji IX and Vitrebond™. Moreover, several studies demonstrated that the micro-hardness of Biodentine™ was not affected by etching (87, 90, 91).

In addition, Biodentine™ exhibited color stability over time in an oxygen environment and light irradiation. Whereas MTA showed dark discoloration after light irradiation, proving that Biodentine™ is suitable for use under light-cured restorations in esthetic areas (92). Biodentine™ exhibited more discoloration when contact to CHX,

whereas BioAggregate and MTA-Angelus exhibited more severe discoloration when contact to NaOCl than CHX did (53, 93). From the *ex vivo* study, when Biodentine™ was used in blood contaminated condition, tooth color change can increased over time (94).

Regarding the operating and setting time, Biodentine™ has longer setting time than that does RMGI. Biodentine™ needs at least 12 minutes of setting time due to polymerization in the silicate phase. According to the manufacturer, Biodentine™ can be immediately covered with final restoration or delayed to the next visit. A case report where

Biodentine™ was used for direct and indirect pulp cappingindicated thatthe material was allowed to set and then the tooth was restored with resin composite within the same visit (95). However, Hashem et al. (90) suggested that, the placement of overlying resin composite should be delayed for two weeks to allow sufficient intrinsic maturation of material to withstand contraction forces from the resin composite.

Regarding properties of Biodentine™ as pulp protection material compared to Dycal® and Vitrebond™,Biodentine™ seems to be a potential and biocompatible pulp protection material. As shown in Table 2.5

Table 2.5 Properties of Biodentine™ compared to Dycal® and Vitrebond™

Properties	**Dycal® and Vitrebond™**		**Biodentine™**
	Dycal ®	**Vitrebond™**	
Biocompatibility	Good (5)	Good (62)	Good (83)
Sealing effect	Not bond to dentin (5)	Micro-mechanical and chemical bond to dentine (62)	Tag-like structures bond to dentin (96)
Promote healing	Yes	Yes	Yes
Reservoir for hydroxyl ion	Solubility overtime (5)	N/A	Reservoir for hydroxyl ion (80)
Bactericidal effect	Bactericidal effect (5)	Bacteriostatic effect (62)	Bactericidal effect (80)

Table 2.5 (continued)

Properties	Dycal® and Vitrebond™		Biodentine™
	Dycal ®	Vitrebond™	
Dentinogenesis	Induce reparative dentin formation (5)	Induce thin layer of reactionary dentin formation (71)	Induce reparative dentin formation (84)
Compressive strength	26-32 MPa (97)	82-106 MPa (98)	213 MPa (99)

However, there is only one clinical study that used Biodentine™ as a pulp protection material in deep carious lesions. Koubi et al. (100)reported that Biodentine™ can be subsequently covered with Z100®. At 1 year follow-up, all teeth maintained vitality, did not have any marginal discoloration, absence of secondary caries, and absence of post-operative pain.

With limitation of clinical study, there are no studies comparing the outcomes of pulp protection with conventional liner and base, such as calcium hydroxide (Dycal®) and resin-modified glass ionomer (Vitrebond™) to the new calcium-silicate-based cement (Biodentine™) in young permanent teeth with deep caries. Therefore, the purpose of this study was to compare the outcomes of Dycal® and Vitrebond™ or Biodentine™ as a pulp protection material in deep carious lesions in permanent teeth of 6-18 years old patients.