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Biodentine: A Promising Dentin substitute

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Abstract

Biodentine material has been recently introduced in dentistry in order to provide dentin substitute for coronal and radicular pulp. Although number of materials like Amalgam, GIC, Composite and MTA are available in market for repair of dentin loss in tooth structure, none of these possesses ideal properties. Despite of number of advantages of MTA, its limitations cannot be overlooked. These drawbacks have been overcome by a new calcium silicate based material named Biodentine which has good handling properties, short setting time and improved mechanical properties. In nut shell it is able to act as a promising dentin substitute in coronal and radicular portion of tooth.

Keywords: Biodentine; Dentin substitute; MTA; Perforation repair; Vital pulp therapy

Introduction

Loss of dentin is perhaps one of the major losses which hamper the integrity of the tooth structure to a significant extent. Whether be in the coronal portion or the radicular one, the dentin loss must be substituted with an artificial material, which can restore the physiological integrity of the tooth structure. From time immemorial, many materials have been studied for this purpose. While referring to the loss of dentin in the coronal part, such as in case of deep carious lesions, materials like Glass-Ionomer Cement have been used extensively, but with its limitation of not stimulating any reparative dentin formation on its own [1].

Similarly, in endodontic therapy, endodontic repair materials are being used, which ideally, should adhere to tooth structure; maintain a sufficient seal; be insoluble in tissue fluids; be dimensionally stable; non-resorbable, radiopaque and exhibit biocompatibility if not bioactivity. A number of materials have historically been used for retrograde filling and perforation repair such as amalgam, zinc-oxide-eugenol cement, composite resin, and glass-ionomer cement. Unfortunately, none of these materials have been able to satisfy the total requirements of an ideal material.

Mineral trioxide aggregate (MTA) is a biomaterial that has been investigated for applications in restorative dentistry since the early 1990s. Its multiple applications include: Direct & Indirect Pulp Capping, formation of apical plug, root end filling, perforation repair, furcation repair, repair of resorptive defects, management of immature apices (Apexogenesis/ Apexification) etc [2-7]. However, with usage, many limitations of this material have come into picture, such as difficulty in manipulation, longer setting time and cost factor.

Of late, Septodont's research group has developed a new class of dental material named Biodentine™ which could conciliate high mechanical properties with excellent biocompatibility as well as a bioactive behavior. Biodentine is the first all-in-one bioactive and biocompatible dentine substitute based on unique Active Biosilicate Technology™ and designed to treat damaged dentine both for restorative and endodontic purposes [8].

Like ProRoot MTA [3,4,9,10] and Portland's cement [11], it is a calcium-based cement. Compared to others calcium based cements, this material presents two advantages: i) a faster setting time of about 12 minutes and ii) higher mechanical properties. These physico-chemical properties associated with the biological behavior suggest that it may be used as a permanent dentine substitute [12].

Chemical Composition

Biodentine™ is conditioned in a capsule containing the good ratio of powder and liquid as shown in Table 1.

Properties of the different components:

- Tricalcium silicate ($3CaO.SiO_2$): It is the main component of the powder. It regulates the setting reaction.
- Dicalcium silicate ($2CaO.SiO_2$): It acts as second main core material
- Calcium carbonate ($CaCO_3$): It acts as filler.
- Zirconium dioxide (ZrO_2): It is added to provide the radio-opacity to the cement.
- Calcium chloride ($CaCl_2.2H_2O$): It is an accelerator [13].
- Water reducing agent (Superplasticiser): It is based on polycarboxylate but modified to obtain a high short-term resistance. It reduces the amount of water required by the mix (water / cement), decreases viscosity and improves handling of cement.

Active and collaborative research between Septodont and several universities for years led to a new calcium-silicate based formulation Biodentine™, which is suitable as a dentine replacement material whenever original dentine is damaged. The Active Biosilicate Technology™ is a proprietary technology developed according to the state-of-the-art pharmaceutical background applied to the high temperate ceramic mineral chemistry.

Powder	Liquid
Tricalcium silicate ($3CaO.SiO_2$) Dicalcium silicate ($2CaO.SiO_2$) Calcium carbonate ($CaCO_3$) Zirconium dioxide (ZrO_2) Iron oxide	Calcium chloride ($CaCl_2.2H_2O$) Water reducing agent Water

Table 1: Chemical composition of Biodentine.

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Setting Reaction

The reaction of the powder with the liquid leads to the setting and hardening of the cement. The hydration of the tricalcium silicate leads to the formation of a hydrated calcium silicate gel (CSH gel) and calcium hydroxide [14]. The cement located in inter-grain areas has a high level of calcite ($CaCO_3$) content. The hydration of the tricalcium silicate is achieved by dissolution of tricalcium silicate and precipitation of calcium silicate hydrate. In general, it is designated by chemists as C-S-H (C=CaO, S=SiO_2, H=H_2O). The calcium hydroxide takes origin from the liquid phase. C-S-H gel layers formation is obtained after nucleation and growth on the tricalcium silicate surface. The unreacted tricalcium silicate grains are surrounded by layers of calcium silicate hydrated gel, which are relatively impermeable to water; thereby slowing down the effects of further reactions. The C-S-H gel formation is due to the permanent hydration of the tricalcium silicate, which gradually fills in the spaces between the tricalcium silicate grains. The complete hydration reaction is summarized by the following formula [14,15].

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

C3S **CSH**

Chemistry and Structure of Cement

The surface of the cement observed with the SEM one week after mixing is loaded by calcite–rich structures ($CaCO_3$) of variable sizes. The calcite is a chemical or biochemical mineral crystallizing in the rhombohedra system (a=b=c; α, β, $\gamma \neq 90$). Crystals of $CaCO_3$ diamond-shaped (or rhombohedra form) are observed at the surface. Taylor (1997) observed that calcium hydroxide crystallizes in the form of hexagonal plate or prism. The surface of $CaCO_3$ crystals is rough and irregular. Therefore, CSH gel, considered as the matrix of the cement, and the crystals of $CaCO_3$ are filling the spaces between grains of cement. Calcite ($CaCO_3$) has two distinct functions: as an active agent it is implicated in the process of hydration and as filler it improves the mechanical properties of the cement [16].

The hardening process results from of the formation of crystals that are deposited in a supersaturated solution. Setting reaction of 3CaO.SiO_2 includes four elements: the unreacted particles of cement, surface products (CSH gel), the content of the pores (Ca $(OH)_2$) and porous capillary space.

Properties of Biodentine

The electrochemical properties of this cement are due to the solid phase and ion mobility of free ions inside the pores filled with the electrolyte [17,18]. Impedance spectroscopy is a technique that allows studying the process of hardening of cement. This is a non-destructive method that may monitor the hardening process. The electrical resistance increases when the porosity of the system is reduced. The setting reaction of Biodentine leads to the formation of initial porosities that are gradually filled after several days by new crystal compounds. During this final step, the solid phase increases and finally reaches a maximum.

Compressive strength

A specific feature of Biodentine™ is its capacity to continue improving with time in terms of strength over several days until reaching 300 MPa after one month. This value becomes quite stable and is in the range of the compressive strength of natural dentine (297 MPa) [19]. Grech et al. [20] studied that Biodentine showed highest compressive strength as compared to other tested materials due to its low water: powder ratio. According to Koubi et al. [21], Biodentine revealed good marginal adaptation until 6 months when used as a posterior restoration.

Vickers hardness

Biodentin exhibits sufficient hardness to be used as dental material. After 2 hours, the hardness of biodentine™ is 51 VHN and reaches 69 VHN after 1 month. In an interesting study, Camilleri [22] evaluated microhardness of Biodentine, Fuji IX conventional GIC and resin modified GIC and found that Biodentine exhibited excellent surface hardness when etched.

Flexural strength

High flexural strength is a definite pre-requisite for any restorative material for its long term efficiency in oral cavity. The 3 points bending test is used as a parameter to measure the flexural strength of a material and this test has a high clinical significance. The value of the bending obtained with Biodentine™ after 2 hours was 34 MPa as compared with other materials such as 5-25 MPa for Conventional Glass Ionomer Cement; 17-54 Mpa for Resin modified GIC and 61-182 MPa for Composite resin [19]. Therefore, it has been inferred that the bending resistance of Biodentine™ is superior to conventional GIC, but still much lower than the composite resin.

Bond strength

As Biodentine is recommended for use as a dentin substitute and perforation repair material, it should have sufficient amount of push-out bond strength with dentinal walls for the prevention of dislodgement from operated site. Aggarwal et al. [23] evaluated push-out bond strength of Biodentine, ProRoot MTA and MTA Plus in furcation perforation repairs and found that after 24 h, MTA had less push-out strength than Biodentine. Guneser et al. [24] showed Biodentine as good repair material even after being exposed to NaOCl, chlorohexidine and saline irrigating solutions.

Setting time

The working time of Biodentine™ is up to 6 minutes with a final set at around 10-12 minutes. This represents a great improvement compared to the other calcium silicate dental materials (ProRoot MTA), which set in more than 2 hours (Table 2).

Density and porosity

The mechanical resistance of calcium silicate based materials is also dependant on their low level of porosity. Lower the porosity, higher is the mechanical strength. The superior mechanical properties of Biodentine™ have been attributed to the low water content in the mixing stage.

Radiopacity

Biodentine contains zirconium oxide, allowing identification on radiographs. According to the ISO standard 6876, Biodentine displays a radiopacity equivalent to 3.5 mm of aluminum. This value is over the minimum requirement of the ISO standard (3 mm aluminum). This

Material	Initial setting time (Minutes)	Final setting time (Minutes)
MTA	70	175
BIODENTINE	6	10.1

Table 2: Setting time of MTA and Biodentine.

makes Biodentine™ particularly suitable in the endodontic indications of canal repair.

Resistance to acid

Concerning the durability of water based cements in the oral cavity, one of relevant characteristics of the dental materials is the resistance to acidic environment. It is known that glass ionomers have a tendency to erode under such conditions. The acid erosion and the effects of aging in artificial saliva on the Biodentine™ structure and composition were investigated by Laurent et al. [12]. They concluded that the erosion of Biodentine™ in acidic solution is limited and lower than for other water based cements (Glass Ionomers). In reconstituted saliva (containing phosphates), no erosion has been observed. Instead, a crystal deposition on the surface of Biodentine™ occurs, with an apatite-like structure. This deposition process due to a phosphate rich environment is very encouraging in terms of improvement of the interface between Biodentine™ and natural dentine. The deposition of apatitic structures might increase the marginal sealing of the material.

Adhesion

The mechanical adhesion of Biodentine™ cement to dental surfaces may result from a physical process of crystal growth within dentine tubules leading to a micromechanical anchor. The possible ion exchanges between the cement and dental tissues constitute an alternative hypothesis, or the two processes may well combine, eventually contributing to the adhesion of the cement, as it appears at the interface of Biodentine™ - adhesive systems.

Biodentine interfaces

The quality and durability of the interface is a key factor for the survival of a restorative material in clinical conditions. The marginal adaptation and the intimate contact with the surrounding materials (dentine, enamel, composites and other dental materials) are determinative features of its success. This was investigated by erosion in acid solutions, electron microscopy and microleakage tests. In the case of Biodentine™, the dissolution/precipitation process, which is inherent to the setting principle of calcium silicate cements, differentiates its interfacial behavior from the already known dental materials (composites, adhesives, glass ionomers).

Microleakage

The interfacial water tightness is an important parameter of the functionality and longevity of a restoration. The interface with dentine and enamel was examined using dye penetration methodology (silver nitrate), which is one of the most commonly used assays to assess, *in vitro*, the interfacial seal, by measuring the percolation of a dye along the different interfaces studied [26]. They concluded that Biodentine™ has a similar behavior in terms of leakage resistance as Fuji II LC at the interface with enamel, with dentine and with dentine bonding agents. Biodentine™ is then indicated in open sandwich class II restoration without any preliminary treatment. Biodentine exhibits low penetration at enamel/dentin interface.

Discoloration

Biodentine exhibits color stability over a period of 5 days and can serve as an alternative for use under light cure restorative materials in highly esthetic areas [27].

Biocompatibility

Laurent et al. [28], revealed that Biodentine is non-toxic and has no adverse effects on cell differentiation and specific cell function. They reported that Biodentine increases TGF-B1 (growth factor) secretion from pulp cells which causes angiogenesis, recruitment of progenitor cells, cell differentiation and mineralization. The material is inorganic and non-metallic and can be used in direct and indirect pulp capping procedures as a single application dentin substitute without any cavity conditioning treatment.

Bioactivity

In both direct and indirect application, Biodentine does not seem to affect the target cells specific functions. About et al. [29] in 2005 investigated that Biodentine material is non-cytotoxic and non-genotoxic for pulp fibroblast at any concentration and stimulates dentin regeneration by inducing odontoblasts differentiation from pulp progenitor cells and promote mineralization, generating a reactionary dentine as well as a dense dentine bridge.

Antibacterial activity

Biodentine exhibits significant amount of antibacterial activity as well. Calcium hydroxide ions released from cement during setting phase of Biodentine increases pH to 12.5 which inhibits the growth of microorganisms and can disinfect the dentin.

Advantages of Biodentine

Amongst the wide range of advantages of this dentin substitute, the ones with clinical significance are:

- Reduced setting time
- Better handling & manipulation
- Improved mechanical properties
- Bioactivity of material

Uses/Clinical Applications of Biodentine

- It is used as a dentin substitute under a permanent restoration, and can be categorized as Indirect pulp capping material.
- It is used as a direct pulp capping material
- It can also be used in cases of partial pulpotomy.
- It has been advocated for use in performing Pulpotomy in primary molars
- It can be used for the Apexification procedure.
- It finds a significant application for repair of perforated root canals and/or pulp chamber floor
- Its use has also been advocated as a root end filling material

Applications of Biodentine in Restorative Dentistry

Use of Biodentine™ as a dentine substitute under a composite restoration

As stated by the manufacturer, Biodentine material can be used in class II fillings as a temporary enamel substitute and as permanent substitute in large carious lesions. A Study conducted by Septodont to compare the Biodentine with Filtek™ Z100 as posterior restorative material showed that Biodentine™ has easy handling, excellent anatomic form, very good marginal adaption and establishes a very good interproximal contact.

Stimulation of reactionary dentine in indirect pulp capping

Biodentine™ is able to stimulate a reactionary dentine which is a natural barrier against bacterial invasions. The reactionary dentine formation stabilizes at 3 months, indicating that the stimulation process is stopped when a sufficient dentine barrier is formed [30].

Use of Biodentine™ as a direct pulp capping material

Clinical trial conducted by Septodont showed that Biodentine™ can be used in direct pulp capping indications with a good success rate. Perard et al. [31] assessed the biological effects of Biodentine for use in pulp-capping treatment, on pseudo-odontoblastic and pulp cells and found that MTA and Biodentine modify the proliferation of pulp cell lines. Nowicka et al. [32] concluded that Biodentine had a similar efficacy to that of MTA in clinical setting and can be considered as alternative to MTA in pulp capping treatment because it preserves pulp vitality and promotes its healing.

Application in Endodontics

Use of Biodentine in pulpotomy

Villet et al. [33] performed partial pulpotomy in an immature premolar and detected fast tissue response (radiologically evident) by the dentin bridge formation and continuation of root development in shorter time. They experienced increased speed of pulpal response and homogenous bridge formation making Biodentine good choice than calcium hydroxide [34-36].

Use of Biodentine™ as an endodontic repair material

The endodontic indications of Biodentine™ are similar to the usual calcium silicate based materials, like the Portland cements and MTA. Biodentine has been recommended for perforation repair, formation of apical plug and furcation repair.

Biodentine™ is used as an root end filling material

The use of Biodentine as root end filling material has also been suggested. To evaluate, this application, Soundappan et al. [37] compared MTA, IRM and Biodentine as retrograde filling material and found that at 1mm level there was no difference among tested materials but at 2mm level MTA was superior to both IRM and Biodentine. The results reveal that further research is required before Biodentine can be advocated as root end filling material.

Advantages of Biodentine Over MTA

- Biodentine™ consistency is better suited to the clinical use than MTA.
- Biodentine™ presentation ensures a better handling and safety than MTA.
- Biodentine™ exhibits better mechanical properties than MTA.
- Biodentine™ does not require a two step restoration procedure as in the case of MTA.
- As the setting is faster, there is a lower risk of bacterial contamination than with MTA.

Conclusion

The good handling properties of Biodentine associated with its favorable biological, mechanical and physical properties indicate that material can be used efficiently in clinical practice as a pulp capping agent and as an endodontic repair material. The easy handling and fast setting time are the major advantages in comparison to other similar materials available commercially. However, long term evaluation in clinical situations is required for further inferences.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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