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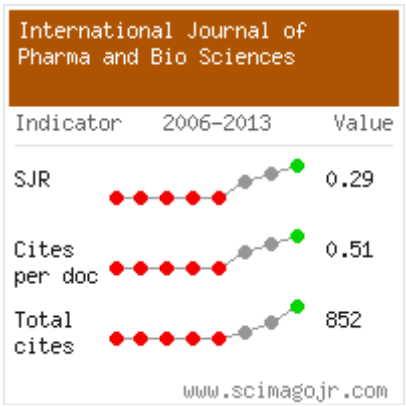

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DENTIN SUBSTITUTES: A REVIEW

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ABSTRACT

Dentin substitutes are cements, which have dentin like mechanical properties and can be used as dentin replacements in the tooth crown and root region. The ideal properties of a dentin substitute are biocompatibility, long-term impermeability, antibacterial properties, induction of hard tissue regeneration, stability, non-absorbability, and ease of handling. There are a wide variety of materials that have been used in the past for replacement of dentin. The materials that can be used are calcium hydroxide, glass ionomer cements, mineral trioxide aggregate, and bioactive materials such as biodentine, bioglass and bioceramics. Thus this review briefly describes the above dentin substitutes, their properties, advantages and disadvantages, and their clinical application.

KEYWORDS: **Dentin, Substitutes, Cements, repair and replacement**

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INTRODUCTION

The physiological integrity of tooth structure is hampered majorly by the loss of dentin. Restorative strategies have been continuously developing to repair and replace lost tooth structures. The lost dentin, coronal or radicular, must be replaced with a substitute to restore this physiological integrity. Dentin substitutes are substances, which have dentin-like mechanical properties and are used for replacing dentin in the crown and root region. An ideal dentin substitute should have good biocompatibility, long-term impermeability, antibacterial properties, ability to induce hard tissue regeneration, good stability, low solubility, non-absorbability, and ease of handling[1]. Many materials have been developed over the years for the replacement of dentin. Calcium hydroxide has been used widely and is one of the earliest introduced cements in the form of dentin substitutes. Its ability to induce reparative dentin formation makes it a gold standard for direct pulp capping agents[2]. For replacement of dentin in the coronal region, such as in case of deep carious lesions, materials such as glass ionomer cement were developed. Glass ionomer cement has been used extensively in many ways. The sandwich technique was developed as a restorative technique using glass ionomer cement as a dentin substitute and composite to replace enamel[3]. However it has its own limitation of inability to induce reparative dentin formation[4]. Further developments were made and the introduction of resin modified glass ionomer cements brought in novel materials to be used as dentine replacement materials. MTA (Mineral trioxide aggregate) another remineralizing dentin substitute, has also been used for a variety of purposes including root end fillings, perforation repairs, pulp capping and pulpotomy, and apexification treatments. However it also comes with its limitations being difficulty in manipulation, longer setting time, and cost factor[5]. Recently, bioceramics a group of biocompatible ceramic materials were introduced which have the ability to either function as human tissues or to encourage the regeneration of natural tissues[6]. Another new bioactive cement named Biodentine was also launched. Also called as smart dentin replacement, it has the same indications and mode of action as calcium hydroxide, but does not possess its drawbacks. Thus this reviews aims to describe the various dentin substitutes, their properties, advantages and disadvantages, and their clinical applications.

CALCIUM HYDROXIDE

Introduced to dentistry in 1921, it is probably one of the oldest dentine substitutes that one can account. The formation of dentinal bridge in an exposed pulpal surface in response to calcium hydroxide was demonstrated first by Hermann and since then calcium hydroxide has been considered as the 'gold standard' for direct pulp capping agents. When calcium oxide (CaO) comes in contact with water, the following reaction occurs: $CaO+H_2 \rightarrow Ca(OH)_2$. CH is a white odorless powder with a molecular weight of 74.08. The material is chemically classified as a strong base with a high pH (12.5) and is only slightly soluble in water with a solubility of 1.2g/l, at a temperature of 25°C.[7] The dissociation of calcium hydroxide into calcium and hydroxyl ions thus results in an increased pH locally, which causes irritation to the pulp tissue, thereby stimulating repair of dentin. This repair of dentin occurs by the release of bioactive molecules such as Bone Morphogenic Protein (BMP) and Transforming Growth Factor-Beta One (TGF-1). [2,8] Thus this induction of mineralization is due to highly alkaline pH of CH. Calcium hydroxide is known for a number of advantages. It has excellent antibacterial properties. In a study by Stuart K et al, 100% reduction in microorganisms associated with pulpal infections was found after one-hour contact with calcium hydroxide[9]. Its ability to stimulate reparative dentin formation and to effect pulpal repair are its other well-known advantages. Calcium hydroxide has a 10year record of clinical success as a direct pulp-capping agent[10, 11]. However it has some disadvantages as well. Some of its drawbacks are inadequate strength, long-term solubility, lack of chemical and mechanical adhesion to the surrounding tissues, poor seal, accelerated degradation after being acid etched during bonding procedures, and tunnel formation in the dentinal bridge formed[12]. This tunnel formation in the reparative dentin is

considered by some as a patency from the site of exposure to the pulp, sometimes with fibroblasts and capillaries present within it[13]. Whereas others have found that the quality of the reparative dentin improves as the dentinal bridge gets thicker[14] and that the tunnel defects are not a common finding[5].

GLASS IONOMER CEMENT

Introduced by Wilson and Kent in 1972,[4] the conventional glass ionomer cements are derived from aqueous polyalkenoic acid such as polyacrylic acid and a glass component such as fluoroaluminosilicate. The setting of the glass ionomer cement can be described as an acid base reaction in which the polyalkenoate salt begins to precipitate, gelation begins and proceeds until the cement has set hard. The setting is facilitated by the early release of calcium ions, which also accounts for the cement's improved physical properties[4]. Later in 1992, resin modified glass ionomers were introduced. These are based on a combination of the acid base reaction of the conventional glass ionomers along with free radical polymerization reaction usually initiated by photo polymerization. Both the conventional and resin modified glass ionomers possess excellent physical properties and are hence used for a wide variety of applications[16, 17]. Other well-known characteristics of glass ionomer cements are their ability to release fluoride[18] and to form fluorapatite in place of damaged dentin, which has been associated with long-term caries inhibition. Further they also chemically bond to the tooth[19]. Treating the tooth surface with a mild acid further enhances bonding. In theory, these bonded glass ionomers seal the cavity, offer pulp protection, eliminate leakage at margins and thereby also prevent secondary caries[17, 20-23]. Compared to composites they have less shrinkage and stress. They also have shown to have less microleakage than adhesion products and thus they seal better with dentin. One of the major applications of glass ionomer cement is its use as a dentin substitute. It makes for an ideal dentin substitute as its physical properties such as coefficient of thermal expansion, dimensional changes, conductivity, opacity and hardness are very close to that of dentin and also its hydrophilicity helps it to bond and adapt well to the dentin surfaces it protects and covers[24]. As the cement requires a little moisture on the dentin for bond formation, it's often considered advantageous to work in a moist environment such as mouth. In 1977, McClean introduced a technique in which glass ionomers were used as liners underneath composite restorations. Thus this technique employed glass ionomers as dentin substitutes. Also known as the sandwich technique, it involves the use of glass ionomers against the tooth surface with composite on the superficial aspects of the restoration as its stronger and more esthetic. There are two techniques that have been proposed: open and closed sandwich techniques respectively. The open sandwich method is usually indicated in situations where only a part of the restoration has a dentin only margin (in case of a deep class II or a class V on root surface). In such cases, the glass ionomer is placed such that it covers dentin and becomes the external material at dentin margin. The latter technique involves the use of glass ionomer when a complete enamel margin is available for bonding and sealing using the phosphoric acid etching technique. Glass ionomer is placed over the dentin prior to the etching and bonding[25-27]. There have been numerous studies supporting the use of this sandwich technique. Composite restorations that are lined with glass ionomers show less cuspal deflection from polymerization contraction stress. Marginal gap and marginal microleakage are also significantly better in the lined composite restorations[28]. Thus its been demonstrated that the use of glass ionomers as dentin substitutes can enhance the success of composite restorations especially in the stress bearing posterior areas[17]. Other applications of glass ionomer include as sealants, luting agents, for crown cementation, orthodontic band cementation, as a cavity liner, dentinal adhesive, for class I, II, III, V restorations[29].

MINERAL TRIOXIDE AGGREGATE (MTA)

Developed by Tirebinejad at Loma Linda University in 1995 as a root end filling material, it has generated considerable interest as a pulp-capping agent only in the recent years. There are two kinds of MTA particularly white and grey. The major components of MTA are a mixture of dicalcium silicate, Ca_3SiO_5, tricalcium aluminate,

tetracalcium aluminoferrite, and trace amounts of SiO_2, CaO, MgO, K_2SO_4 and Na_2SO_4. Grey MTA
(GMTA) is composed of dicalcium and Ca_3SiO_5 and bismuth oxide basically and has addition of iron whereas white MTA (WMTA) consists of Ca_3SiO_5 and bismuth oxide[30]. When MTA powder comes in contact with water, calcium hydroxide and calcium silicate hydrate are first formed which eventually transform into a crystalized and porous solid gel[31]. The MTA powder is mixed with sterile water in a 3:1 powder/liquid ratio. A moist cotton pellet is placed in direct contact with this material which accelerates its setting. Upon hydration the material forms a colloidal gel, which hardens in 3-4hours[32]. The initial pH of the mixed material is 10.2. After a setting time of 3hours the pH rises to about 12.5. Thus it shares some of the same advantages as calcium hydroxide such as high pH, antibacterial properties, good biocompatibility, radiopacity (due to the addition of bismuth oxide) and its ability to induce release of bioactive dentin matrix proteins[33-38]. Being a bioactive material, it is hard tissue conductive, hard tissue inductive, non-mutagenic, non-cytotoxic[39, 40] and has the potential to interact with the natural tissue fluid. MTA has some disadvantages as well. It has demonstrated high solubility with 24%loss after 78 days of storage in water[33, 34]. The presence of iron in the grey version may darken the tooth[37]. Further the prolonged setting time requires pulp capping done with MTA to be done as a two-step procedure. A temporary restoration is placed initially to allow the MTA to set before placing the permanent restoration or a quick setting liner is used to protect the MTA during placement of permanent restoration. Further the handling characteristics of the powder liquid MTA is different from the easy to handle paste formulations of calcium hydroxide. Also, MTA is considered to be very expensive. The cost of one gram of MTA is equal to 24grams of calcium hydroxide base/catalyst paste[2]. Clinical applications of MTA include Direct & Indirect pulp capping, formation of apical plug, root end filling material, perforation repair, furcation repair, repair of resorptive defects and management of immature apices (Apexogenesis/ Apexification).

COMPARISON OF MTA WITH CALCIUM HYDROXIDE

Compared to calcium hydroxide, MTA has greater ability to maintain integrity of pulp tissue. Animal studies have shown exposed pulp tissue capped with MTA demonstrating a thicker dentinal bridge, with low inflammatory response, hyperemia, and pulpal necrosis and better pulp healing when compared to calcium hydroxide[41, 42].However most of the human studies have demonstrated similar treatment outcomes. In a clinical treatment analysis by Mente et al, MTA was found to be more effective than calcium hydroxide for maintenance of long-term pulp vitality after direct pulp capping[43]. Compared to calcium hydroxide, MTA offers some seal to the tooth structure. In a study demonstrating clinical success of MTA, the pulp-capped teeth were restored with ZOE as a temporary material. Its well known that ZOE leaks significantly and lose their antibacterial eugenol rapidly proving that MTA has ability to provide a seal over pulp exposure that calcium hydroxide does not[44]. However calcium hydroxide has a long-term track record of clinical success. In a review of 14 clinical studies, including over 2300 cases, up to 90%success rates have been demonstrated with calcium hydroxide used by clinicians[45]. Further calcium hydroxide has shown success even in less than ideal circumstances.

BIOCERAMICS

Bioceramics are a group of specifically designed ceramic materials, which include alumina and zirconia, bioactive glass, glass ceramics, coatings and composites, hydroxyapatite and resorbable calcium phosphates and radiotherapy glasses[46, 47]. Bioceramics have been categorized as bioinert, bioactive, and biodegradable[46-48]. They are used in dentistry as they have been found to be biocompatible, nontoxic, chemically stable, and non shrinkable upon setting. They have a unique ability to induce formation of hydroxyapatite and a bond between dentin and the filling materials[49, 50]. It also has bactericidal properties due to the high pH during the setting process[35]. The 20% water in dentin is utilized in the initial hydration of the material followed by which calcium silicates in the powder upon hydration produces calcium silicate hydrate gel and

calcium hydroxide. The calcium hydroxide then reacts with phosphate ions to produce hydroxyapatite and water. This water is again utilized in the formation of calcium silicate hydrate gel[51, 52]. Bioceramics have been proven beneficial as a root repair material, in periapical surgeries, as pulp capping agents and dentin substitute restorative material[6]. During pulp capping, bioceramic material is placed over the exposure area and is then covered with compomer or glass ionomer cement.

BIODENTINE

Introduced by Septodont research group recently, it is a calcium silicate based material. Based on Active Biosilicate Technology™, it is designed to treat damaged dentine for both endodontic and restorative purposes.

Biodentine is made as a capsule containing powder and liquid[53]. The powder consists of the following

- Tricalcium silicate: It regulates the setting reaction and is the main core material.
- Dicalcium silicate: It acts as the second core material.
- Calcium carbonate: Acts as filler.
- Zirconium oxide: provides radiopacity
- Iron oxide: provides the shade.

The liquid consists of the following

- Calcium chloride: Acts as an accelerator.
- Water reducing agent (superplasticizer): It is a hydrosoluble polymer. It reduces the amount of water required by the mix, decreases viscosity and improves handling of the cement.
- Water

SETTING REACTION

The powder reacts with the liquid leading to the setting and hardening of the cement. The hydration of the tricalcium silicate results in the formation of a hydrated calcium silicate gel (CSH gel) and calcium hydroxide[54]. A high level of calcite ($CaCO_3$) content is present in the intergrain areas. This calcite content acts as filler and improves the mechanical properties of the cement. The hydration of the tricalcium silicate takes place by dissolution of tricalcium silicate and precipitation of calcium silicate hydrate. The formation of CSH gel layers occurs 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 impermeable to water, thereby slowing down further reactions. The formation of the CSH gel is due to permanent hydration of tricalcium silicate and it gradually fills up the spaces between the tricalcium silicate grains.

PROPERTIES OF BIODENTINE

Compressive strength

Biodentine has a unique ability to improve in strength with time over several days until it reaches 300 MPa after one month. This value is close to the range of the compressive strength of natural dentine (297 MPa) [55]. Grech et al has demonstrated biodentine to have the highest compressive strength when compared to other materials[56]. Koubi et al. have also shown that biodentine has good marginal adaptation until 6 months when used as a posterior restoration[5]

Vickers hardness

Biodentine has hardness in the same range as natural dentine. Camilleri et al have demonstrated biodentine to have excellent surface hardness when etched. The hardness of biodentine is 51VHN after 2 hours and 69 VHN after 1 month[58].

Flexural strength

22 MPa. It has been inferred that the bending resistance of biodentine is higher than the conventional GIC, but lower than the composite resin[55].

Bond strength

Since biodentine is primarily used as a dentine substitute, it should possess sufficient push out bond strength with dentinal walls in order to prevent its dislodgement. Aggarwal et al. have compared the push out bond strength of biodentine, ProRoot MTA and MTA Plus in furcation perforation repairs, and found that after 24h, MTA had less push out bond strength than biodentine[59].

Setting time

It has a shorter setting time of up to 6 minutes with a final set at around 10-12 minutes.

Density and Porosity

They have a low level of porosity contributing to high mechanical strength. These superior mechanical properties have been attributed to the low water content during the mixing stage.

Resistance to acid

Laurent et al investigated the acid erosion and the effects of aging in artificial saliva on the Biodentine structure and composition. It was found that the erosion of biodentine in acidic solution is limited and lower than the water based cements such as glass ionomer cements[57].

Adhesion

The mechanical adhesion of Biodentine cement to the tooth surfaces is due to the physical process of crystal growth within dentinal tubules resulting in a micromechanical anchor[53].

Microleakage

In a study by Raskin A, microleakage of biodentine was evaluated in vitro and it was concluded that has similar leakage resistance as Fuji II LC at the interfaces with enamel, dentine and dentine bonding agents[60].

Discolouration

Biodentine has shown to exhibit colour stability over a period of 5 days and hence can be used under light cure restorative materials[61].

Biocompatibility

In a study by Laurent et al, it was concluded that Biodentine is non-toxic with no adverse effects on cell differentiation and function[62]. It instead increases TGF-B1 (growth factor) secretion from pulp cells resulting in angiogenesis and progenitor cell recruitment, cell differentiation and mineralization.

Antibacterial activity

During the setting stage of Biodentine, the release of calcium hydroxide ions leads to a rise in pH to about 12.5 which inhibits the growth of microorganisms and account for its antibacterial activity.

Bioactivity

About et al investigated the bioactivity of Biodentine and it was found that it stimulates regeneration of dentin by inducing differentiation of odontoblasts from pulp progenitor cells and mineralization leading to formation of both reactionary dentin as well as a dense dentinal bridge[63].

ADVANTAGES

Biodentine has the following various advantages[53] when compared to the other dentine substitutes:

- It has a relatively reduced setting time.
- Its bioactivity and its ability to induce regeneration of dentin
- Better handling and manipulation properties
- Better mechanical properties
- Excellent sealing properties due to the good microleakage resistance and presence of mineral tags in the dentinal tubules.
- No surface preparation required, as it possesses micro-mechanical anchorage.

CLINICAL APPLICATIONS OF BIODENTINE

- As a dentine substitute under a composite restoration
- As a direct pulp capping material
- In cases of partial pulpotomy and pulpotomy in primary molars
- As a root end filling material
- Apexification procedure
- For repair of perforations

COMPARISON OF BIODENTINE AND MTA

It has almost similar physical, chemical and mechanical features as MTA. However it is superior to MTA in the following[53]:

- The consistency of Biodentine is better than MTA for clinical use.
- Biodentine has better handling and safety properties over MTA
- Biodentine does not require a two-step restoration process as in MTA.
- As the setting time is reduced in the case of Biodentine, there is less risk of bacterial contamination when compared to MTA.

CONCLUSION

The presence of dentin is very important for the physiological integrity of the tooth. Loss of dentin weakens the tooth structure majorly and hence various dentin substitutes as

described above have been introduced to maintain this integrity of the tooth structure. All of them have their own advantages and disadvantages. New materials such as biodentine and bioceramics have been introduced but further clinical trials are required to consider it as a gold standard for dentin substitutes.

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