The physical-mechanical properties and biocompatibility of Biodentine™: A review

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ABSTRACT

Aim Biodentine is a calcium-silicate based material that has been studied in recent years for a wide range of clinical applications in both Endodontics (pulp capping, pulpotomy, apexification, retrograde root end filling, repairing of root perforations and resorptions) and in Restorative Dentistry as a dentin substitute. The aim of this study was to review the physical-mechanical properties (porosity, setting time, compressive strength, bond strength/push-out bond strength, sealing ability, marginal adaptation, radiopacity, solubility, color stability) and biological properties (antimicrobial activity, biocompatibility, bioactivity) of Biodentine™ (BD).
Materials and methods BD has been analysed in its various physico-chemical aspects and mechanical and biological properties.
Results Regarding biocompatibility, bioactivity, antibacterial properties, versatility, stability, sealing properties, compressive and flexural strength, BD fulfils the requirements. Its relatively easy handling, low cost and faster setting are the major advantages of this material when compared to previous calcium silicate cements.
Conclusion Clinical studies of long term efficiency and high evidence are still lacking. BD has great potential to revolutionise the management in Restorative Dentistry and Endodontics, but also in Paediatric Dentistry, both for primary and permanent dentition.

INTRODUCTION

Commercially available since 2009, Biodentine™ (BD) is a biologically active cement used in Dentistry, specifically designed as a "dentin replacement material" (1) because of its dentin like mechanical properties. Some changes were made to the basic composition of already known calcium-silicate cements (Mineral Trioxide Aggregate, MTA), to increase the physicochemical properties (1,2). In fact, BD coinciliates high physical and mechanical properties with excellent biocompatibility, as well as a bioactive behavior and wide range of clinical applications (3,4,5). BD has in fact a wide range of clinical applications in both Endodontic-Pediatric Dentistry (pulp capping, pulpotomy, apexification, retrograde root end filling, repair of root perforations and resorptions) and in Restorative Dentistry as a dentin substitute (3,5,6).
Through a critical analysis of the studies in the literature, this review aims to analyse the characteristics of BD, with particular attention to the physicochemical and biological properties of the material.

COMPOSITION

BD is a two-component material (powder and liquid). Powder is contained in capsules and the liquid in pipettes. The powder is composed of tricalcium silicate (main component), bicalcium silicate (secondary component), calcium carbonate and oxide (filler), iron oxide (colouring agent) and zirconium oxide (radio-opacifier) (3,7). The liquid is composed of calcium chloride (accelerator) and a water-soluble polymer (water reducing agent) (3,7). Powder and liquid can be mixed mechanically by a triturator for 30 seconds (7) at 4000 rpm, until a creamy paste is formed. It is essential to respect the manufacturer's instructions (preparation method, proportions powder/liquid) so as not to influence the mechanical properties and setting time (8).

CHARACTERISTICS

Density and porosity

BD presents a lower porosity than MTA due to low water content in the mixing stage (9). Porosity is a fundamental factor because a larger pore diameter determines larger leakage and bacterial infiltration (9). De Souza et al. found no significant differences in porosity between other silicate-based cements (10).

Setting time

The setting time of BD is about 9-12 minutes (3). However, several authors reported different setting times. According to Jang et al. the setting time is about 15±1 min (11) while according to Dawood et al. it is about 13.1±1 min (12). When BD is compared with other calcium silicate cements, its setting time is shorter (9,13). This is mainly due to the presence of calcium chloride which acts as a reaction accelerator (3), but also due to the increased particle size and reduced liquid component of the material (14).
A fast setting time results in less bacterial contamination and less material loss in the interface during the final processing stages (15). Both saliva and blood contamination increase the setting time of BD (1±6.51 min and 16±8.21 min respectively) (6).

Compressive strength

BD has the peculiar capacity of improving its compressive strength with time until reaching a similar range with natural dentin (290 MPa). During the setting of BD, the compressive strength gradually increases from 100 MPa in the first hour, to 200 MPa within 24 hours, until reaching 300 MPa after one month (16).
Several studies show that the compressive strength of BD is higher than MTA (12,17), for the low water/cement ratio used, and the water-soluble polymer (14).
The exposure of BD to sodium hypochlorite did not modify the compressive strength, while ethylenediamenetetraacetic acid (EDTA) reduced the compressive strength of BD (18). The studies on the compressive strength in different pH environments were contradictory (17,19).
Several studies show higher hardness, flexural strength and elastic modulus than MTA (12,20,21).

Microleakage, marginal adaptation and sealing ability

BD has an excellent adhesion with the underlying dentin (22) that prevents bacterial microinfiltration in the entire thickness of the material (23).
Gjorgievska et al., comparing microleakage and marginal adhesion of different bioactive materials, found that both BD and glass ionomer cements have favorable results as dentine substitutes. However, scanning electron microscope analysis showed that the crystals in BD are more stably linked to the dentine surface (24). This excellent adaptability between BD and the underlying dentine is due to its micromechanical adhesion (1,22,24). Micromechanical adhesion is caused by the alkaline effect during the setting reaction (7).
BD releases calcium and silicon ions and creates a "mineral infiltration zone" along the dentin-cement interface (9). Furthermore, the sealing ability could increase for the apatite deposits, formed by the interaction between phosphate ions of saliva and calcium silicate-based cements (3).
Micromechanical adhesion, together with the small size of the particles and the reduced porosity of BD (25), has improved the sealing capacity and adaptability of BD as a root-end filling material.
Some studies demonstrated that BD has a better sealing ability than MTA (25-27), others a comparable sealing ability (28) and a lower sealing ability than MTA (29).
According to a review, evidence-based data regarding the sealing ability of BD and MTA are lacking (13).

Bond strength and push-out bond strength

BD presents low strength during the initial stages of setting (30). For this reason, according to Hashem et al., the placement of the final composite restoration should be delayed by at least two weeks after the application of BD, so that it achieves an adequate bond strength (30).
Also, BD should possess high push out bond strength in perforation repair to prevent the dislodgement of the material (9). Dislodgement resistance of BD could be related to a smaller particle size that has the potential to enhance penetration of cement into dentinal tubules with the formation of "mineral tags" (6,31).
BD's push-out bond strength was significantly higher than MTA and was not significantly different when immersed in various endodontic irrigants (3.5% sodium hypochlorite, 2% chlorhexidine gluconate, saline solutions) (32). But the push-out bond strength decreases with the removal of smear layers in the root canal in calcium silicate cements (33) and decreasing pH form 7.4, 6.4, 5.4 to 4.4 (34). Moreover, it was demonstrated how blood contamination had no effect on push-out bond strenght (35).

Radiopacity

Radiopacity is an important feature for an endodontic cement as these materials are often applied in small thicknesses and need to be easily distinguishable from the surrounding tissues (1). ISO 6876:2001 has established that 3 mm aluminium is the minimum radiopacity value for endodontic cements (22).
Grech et al. evaluated the radiopacity of calcium silicate and BD cements, and showed that all materials had a radiopacity value higher than 3 mm aluminium (14). However, radiopacity in BD was significantly lower than in other endodontic cements (20,36).
In BD the radio-opacifier is zirconium oxide, while in other calcium silicate cements this function is performed by bismuth oxide (3). The reason for this choice is due to its biocompatible characteristics, favorable mechanical properties and high corrosion resistance (1). However, the disadvantage is that zirconium oxide is not adequately visible in X-rays (3).

Solubility

Grech et al. investigated the physical properties of BD and reported how it exhibits negative solubility values. This is due to the deposition of substances such as hydroxyapatite on the surface of the material in contact with biological fluids (14).

According to ISO 6876:2001, studies confirmed that BD shows a solubility similar to that of MTA in the first days of exposure and it shows a marked increase after 10 days (20,37). Although the solubility values of BD were higher, this solubility occurred only on the surface exposed to the solution and caused a negligible dimensional change (38).

Colour stability

Valles et al. conducted an *in vitro* study to assess color stability of different calcium silicate cements, which were exposed to different light and oxygen combinations for 5 days. The spectrometric analysis showed the chromatic stability of BD (39).

Other studies show that BD maintains chromatic stability for up to 6 months and shows significantly less discoloration than MTA (40). According to several studies, sodium hypochlorite, chlorhexidine gluconate and blood can result in a perceptible discoloration in BD (40,41).

Biocompatibility and bioactivity

Biocompatibility of dental materials is a major factor that should be taken into consideration for an endodontic cement that is directly in contact with biological tissues (1,23). A biocompatible material should exhibit a low toxicity and mild or no inflammatory reaction in the tissues (42). According to the study by Mori et al., BD showed an initial inflammatory response, but after 2 weeks this was quickly followed by a stability of the tissues (42).

Laurent et al. concluded that BD is a biocompatible, bioactive and non-cytotoxic material. The authors also showed how BD increased the cellular secretion of the growth factor TGF- β1, which promoted angiogenesis, recruiment of progenitor cells, cell differentiation and the synthesis of repair dentin (43). When placed in direct contact with the pulp, BD preserves pulp vitality (biocompatibility) and promotes proliferation, migration and adhesion of pulp stem cells (bioactivity) (44) and induces tertiary dentin synthesis (8).

Perard et al. assesed the biocompatibility of BD and the effects of BD/MTA on the expression of genes involved in odontogenic differentiation, matrix secretion and mineralisation, using three-dimensional multicellular spheroid cultures. The authors observed that BD and MTA may modify the proliferation of pulp cell lines and induce the formation of reparative dentine (45).

Several studies showed that BD can be safely applied in pulp capping treatment during vital therapy, thanks to its biocompatibility and pulp regeneration capacity (46,47).

Compared to normally used calcium hydroxide, BD has a higher capacity to induce regeneration of surrounding tissues and dentin bridge formation (48). Tran et al. demonstrated that BD induces *in vivo* the formation of a homogeneous dentin bridge at the site of the lesion, which is significantly different from the porous repair tissue induced by calcium hydroxide (48).

Some studies demonstrated that BD has a better biocompatibility than MTA (49,50), but others showed that in this respect both materials are comparable (51,52).

Antimicrobial activity

The antibacterial property of the BD and MTA is related to the high pH of these materials. This high alkalinity has an inhibitory effect on the growth of microorganisms and determines the disinfection of surrounding hard and soft tissue (9).

Several studies showed the significant antimicrobial efficacy of BD against Enterococcus faecalis, Streptococcus sanguis and Escherichia coli (50,53).

CONCLUSION

BD has great potential in revolutionising the management of the affected tooth in Restorative Dentistry, Pediatric Dentistry and Endodontics (5,8). A wide range of clinical indications have been published regarding the use of BD, but clinical studies reporting high evidence of its long term efficiency and high evidence are still lacking and further studies are needed to broaden the potential and future opportunities of this very promising material (4,13,22).

BD has been analysed in its various physicochemical aspects and all studies fall in favour of its mechanical and biological properties. Regarding biocompatibility, bioactivity, antibacterial properties, versatility, stability, sealing properties, compressive and flexural strength, BD fulfils the requirements. Relatively easy material handling, low cost and faster setting are the major advantages of this material when compared to previous calcium silicate cements.

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