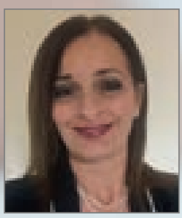
Biodentine™

The dentine in a capsule or more?



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Introduction

Tooth structure is lost by dental caries, trauma and tooth wear and is often replaced by inert dental materials that replace the bulk. If the pulp health is jeopardised a series of interventions need to be undertaken. Initially the pulp vitality needs to be maintained. Later elimination of infection and filling of the pulp space is necessary. When pulpal involvement occurs the choice of material has to change and materials that interact with the pulp or the dentine are indicated. Interactive materials used for dental procedures include calcium hydroxide in its various presentations and more recently hydraulic calcium silicate cements.
The main feature of the hydraulic calcium silicate cements is their hydraulic nature. These materials can be used in wet areas without deteriorating. Thus these materials are indicated for root-end filling and perforation repair. Another important feature of these materials includes the release of calcium hydroxide as a by-production of the hydration reaction. These makes these materials appropriate for use as pulp capping materials, for apexification and apexogenesis and more recently also for regenerative endodontic procedures. The calcium hydroxide creates an environment where calcium ions are released and also antibacterial activity is high.
The choice of material is important for successful clinical outcome. There are a number of hydraulic calcium silicate cements available for the various procedures as indicated in Table 1. These materials vary greatly and it is important that the clinician appreciates the importance of choosing the right material for each clinical application. This article highlights Biodentine™ (Septodont, Saint-Maur-des-Fossés, France) and its suitability for various clinical applications.

Material	Cement type	Radiopacifier	Additives	Presentation	Mixing
Biodentine	Tricalcium silicate	Zirconium oxide	Calcium carbonate, Calcium chloride, polymer	Powder/liquid	Mechanical
MTA Angelus	Portland cement	Bismuth oxide	Calcium oxide	Powder/liquid	Manual
Theracal	Portland cement	Barium zirconate	Strontium glass, resin	Syringe	Premixed
ProRoot MTA	Portland cement	Bismuth oxide	-	Powder/liquid	Manual

Table 1: Hydraulic calcium silicate materials types available for various procedures

Fig. 1: Presentation of Biodentine™ in powder and liquid form.

Biodentine™ characteristics

Biodentine™ is presented as powder and liquid. The powder is placed in a capsule while the liquid is in an ampoule (Figure 1). The powder is composed of tricalcium silicate, zirconium oxide, calcium carbonate and some minor additives of iron oxide added to give the colour. The liquid is made up of water with some additions of calcium chloride and a water soluble polymer. Biodentine™ powder and its hydrated materials have been characterised well. The design of Biodentine™ ensures optimal properties and thus enhanced clinical performance.
The powder is finer than other cement types of this category (Table 2). The finer powder ensures a higher reaction rate. The powder is mostly composed of tricalcium silicate (Table 3) as opposed to the other hydraulic cements which are predominantly Portland cement based as shown in Table 1. The pure tricalcium silicate ensures no inclusions of aluminium (1, 2) and trace metals (3) that are present in Portland cement- based dental cements. The use of zirconium oxide ensures adequate radiopacity and stability with no risk of leaching and discolouration which is implicated with all materials using bismuth oxide radiopacifier (4-6). The main constituents are clearly shown in the X- ray diffraction analysis of the Biodentine™ powder (Figure 2).

Material	BET surface area (m^2/g)
Tricalcium silicate	1.1187
Biodentine	2.8116
MTA Angelus	1.0335

Table 2: Specific surface area measurement of Biodentine™ powder to show its fine powder consistency when compared to other cements.

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Phase identified	Matérial type in mass %		
	TCS	Biodentine	MTA Angelus
Tricalcium silicate	100	80.1	66.1
Dicalcium silicate	-	-	8.4
Tricalcium aluminate	-	-	2.0
Calcium carbonate	-	14.9	-
Calcium oxide	-	-	8.0
Bismuth oxide	-	-	14.0
Zirconium oxide	-	5.0	-
Silicon dioxide	-	-	0.5
Aluminium oxide	-	-	1.0

Table 3: Powder assessment by Rietveld X-ray diffraction analysis to show the main constituents of Biodentine™.

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Biodentine™ includes additives to enhance the material properties. These include calcium carbonate which is present in the powder, calcium chloride and water soluble polymer in the liquid. The calcium carbonate is a source of free calcium ions that are present in solution as soon as the powder is mixed to the liquid. Their

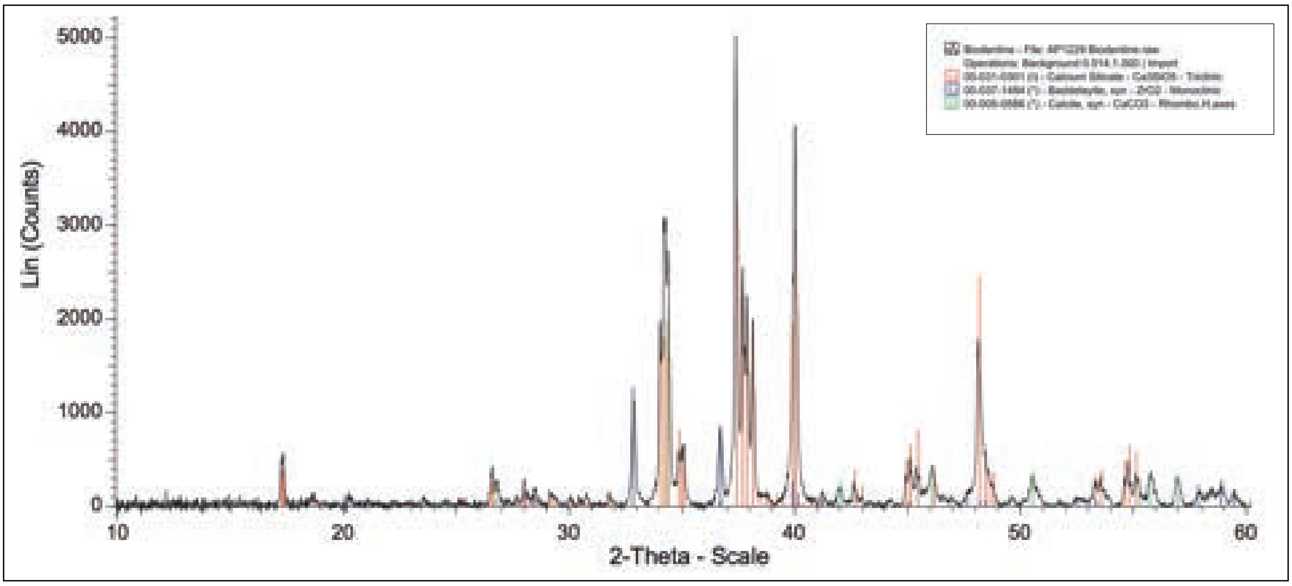

Figure 2: X-ray diffraction analysis of Biodentine™ powder to show the main constituent phases namely tricalcium silicate, zirconium oxide and calcium carbonate.

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presence results in a higher heat flux earlier in the reaction thus enhancing the reaction rate (2) as shown in Figure 3. The calcium chloride reduces the setting time of the Biodentine™ considerably when compared to other similar material types (7, 8). The water soluble polymer enables the reduction of the water to cement ratio thus enhancing the Biodentine's physical properties. In fact the compressive strength and micro-hardness of Biodentine™ are much higher than those reported for other similar material types (7). The microstructure of Biodentine™ (Figure 4) shows how hydration proceeds with the tricalcium silicate reacting and being deposited around the calcium carbonate particles (9). The calcium hydroxide is produced in high amounts as indicated in the X-ray diffraction scan of the hydrated materials (10) where the calcium hydroxide peak is clearly evident at 18 degrees (Figure 5). The specific material chemistry, the fine particle sizes, the low water to cement ratio and the presence of calcium carbonate all contribute to optimal materials properties aimed for clinical performance. Furthermore the material also exhibits low porosity (Table 4) when compared to similar material types (11) and this is also beneficial clinically. Since the material is hydraulic it is very important that it is not allowed to dry out as this will lead to cracks at the interface (Figure 6) and in the material bulk (11).

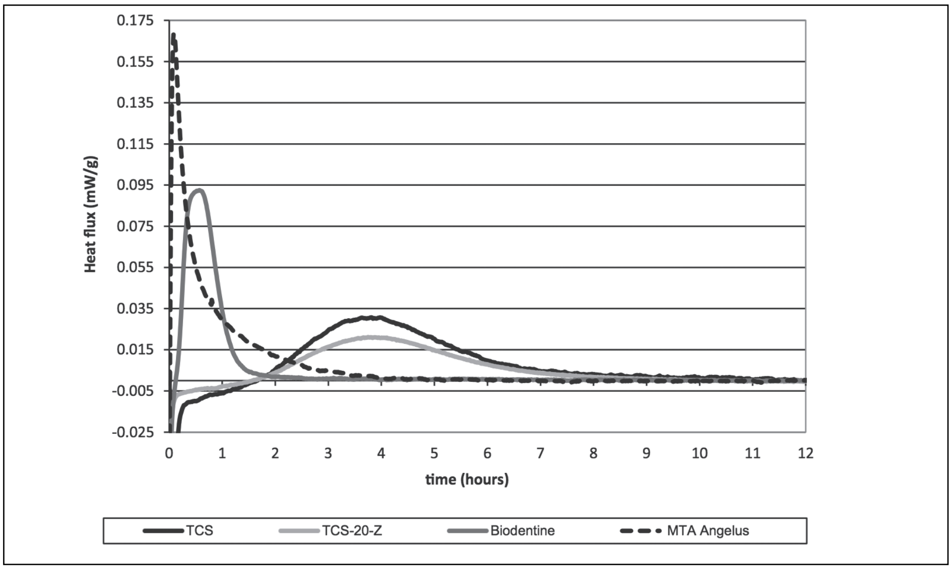

Figure 3: Heat flux assessment of Biodentine™ to show high rate of action early in the hydration. (TCS: Tricalcium silicate cement; TCS-20-Z is a tricalcium silicate cement with 20% replacement of zirconium oxide).

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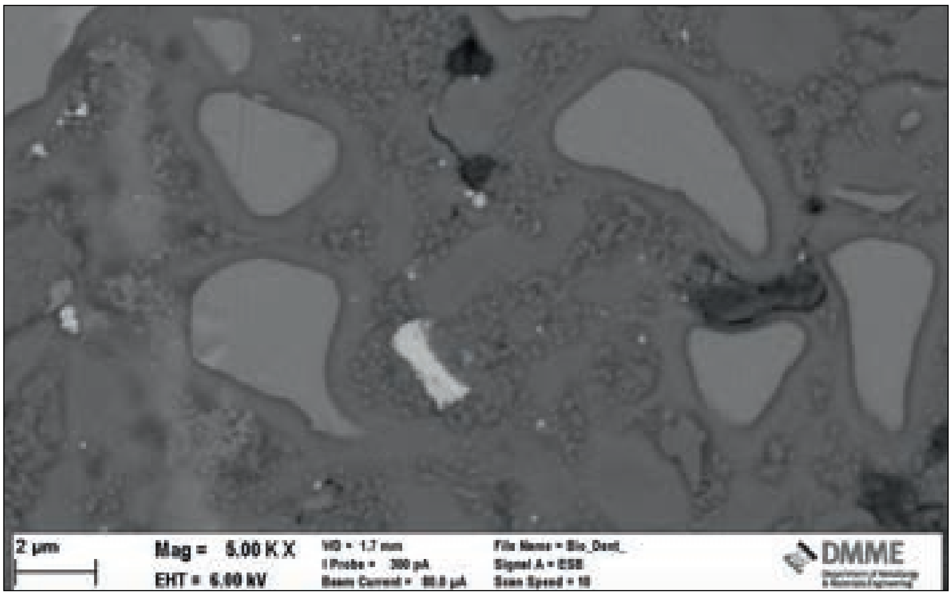

Figure 4: Scanning electron micrograph of set biodentine™ to show the material microstructure.

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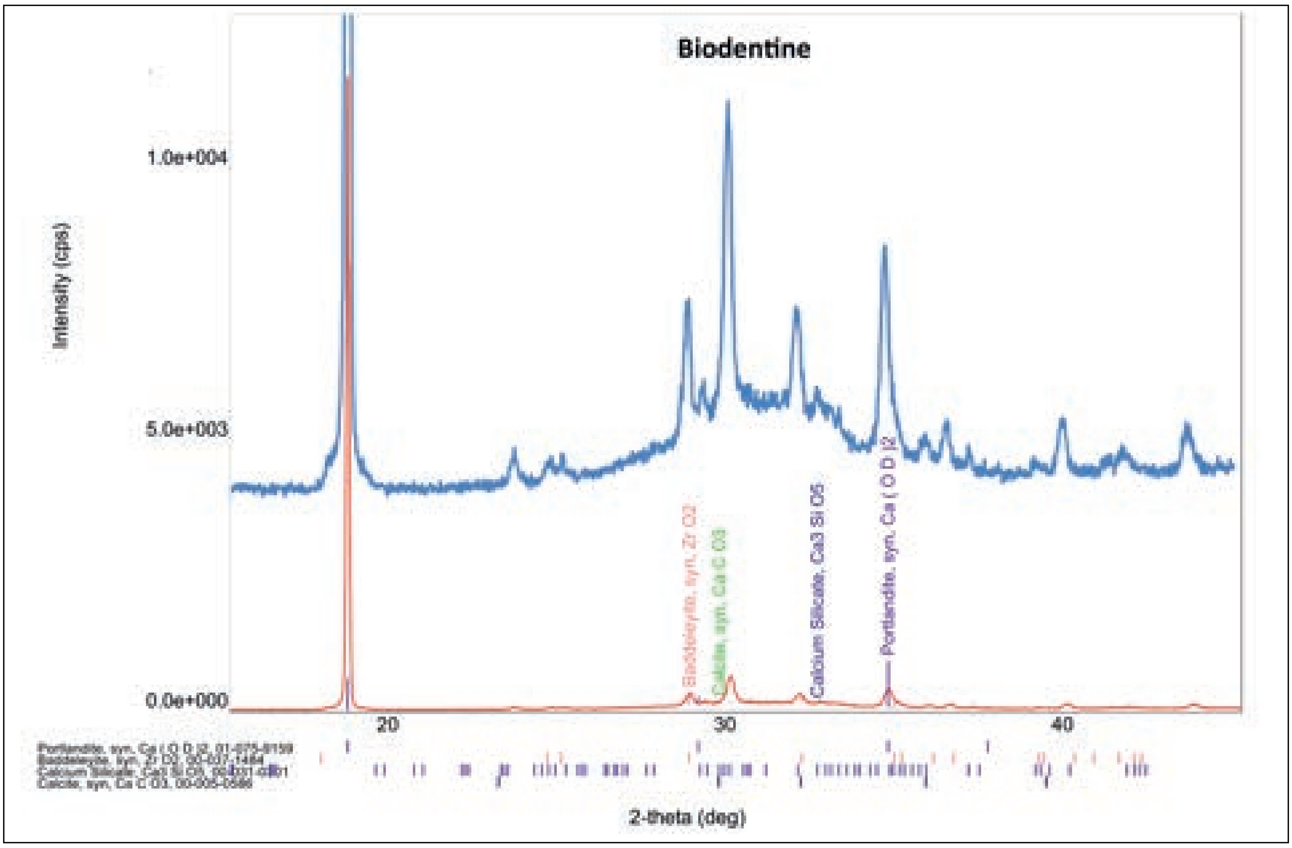

Figure 5: X-ray diffraction plot of set Biodentine™ to show the main phases present after setting. The calcium hydroxide predominates the plot.
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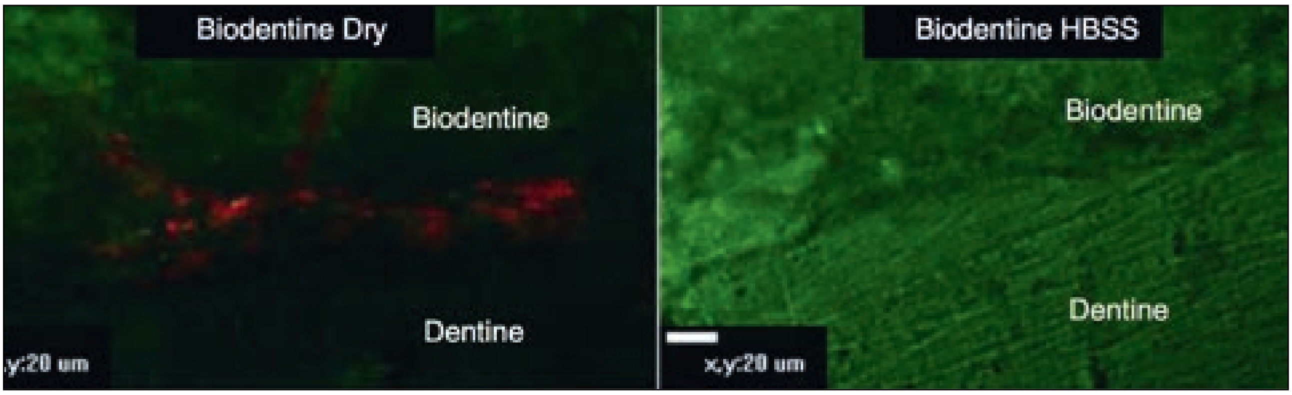

Figure 6: Confocal laser microscopy of Biodentine™ stored dry and wet in HBSS and wet to highlight the need to keep it moist at all times.
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Parameter measured	Units	Material			
		TCS-20-Z	Bioaggregate	Biodentine	IRM
Average pore diameter	µm	0.0508	0.0337	0.0121	0.0205
Total pore area	m^2/g	13.101	24.321	21.752	10.545
Bulk Density	g/ml	1.8637	1.8007	2.0444	2.3455
Porosity	%	30.98	36.86	13.44	12.66

Table 4: Percentage porosity of Biodentine™ compared to similar material types.
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Clinical applications

Pulp capping and dentine replacement

Biodentine™ is calcium ion releasing (10, 12) with the initial rate of release higher than other similar material types (12, 13), thus it is ideal for use as a pulp capping material. The Biodentine™ surface exhibits the thickest surface calcium concentration compared to ProRoot MTA, Dycal and Theracal (14). Dentine bridge formation is evident clinically when Biodentine™ is used for direct pulp capping (15, 16, 17). Clinical cases showing evidence of irreversible pulpitis that were treated with Biodentine™ exhibited reduction in the sizes of the apical areas when evaluated with cone beam computed tomography (18). The pulpal reaction to Biodentine™ is similar to other similar material types like mineral trioxide aggregate (19) with favourable cell proliferation and alkaline phosphatase activity of human dental pulp cells (20). This same reaction was observed when testing leachates of Biodentine™ (13). The calcium releasing ability contributes also for the antimicrobial properties of Biodentine™. This property is important since dental caries is a bacterial induced disease. Biodentine™ exhibits adequate antimicrobial properties (13) and which were lower than calcium hydroxide pulp capping materials. However, the increase in the antimicrobial properties of calcium hydroxide was accompanied by higher cytotoxicity (21).

Furthermore its physical properties allow the material to be used in bulk thus avoiding unnecessary layering and interfaces that can allow micro-leakage and restoration failure. In fact Biodentine™ shows less micro-leakage than resin-based dentine replacement materials (22). Placing a final restoration over Biodentine™ can be challenging as it is water-based. The final restoration should be delayed for at least 2 weeks and both total etch and self etch adhesives can be used (23). Total etching can lead to material micro-structural changes (24) and although in vitro composite restorations were all lost on thermocycling the total etch proved to be more effective than self etching (25). The microstructure at the interface of the Biodentine™ and composite resin using total-etch and self-etch adhesive is shown in Figure 7. Biodentine™ was shown to be able to restore teeth for up to six months and when overlayed with a composite resin it provided an effective dentine replacement material (26).

Other tricalcium silicate-based pulp capping materials which are resin-based, thus have an advantage as they can be layered easily with a composite resin providing a strong bond (25). However, the effects on the pulp are adverse (27). The calcium ion release from such materials has been shown to be low and no crystalline calcium hydroxide is formed (10). The resin-based pulp

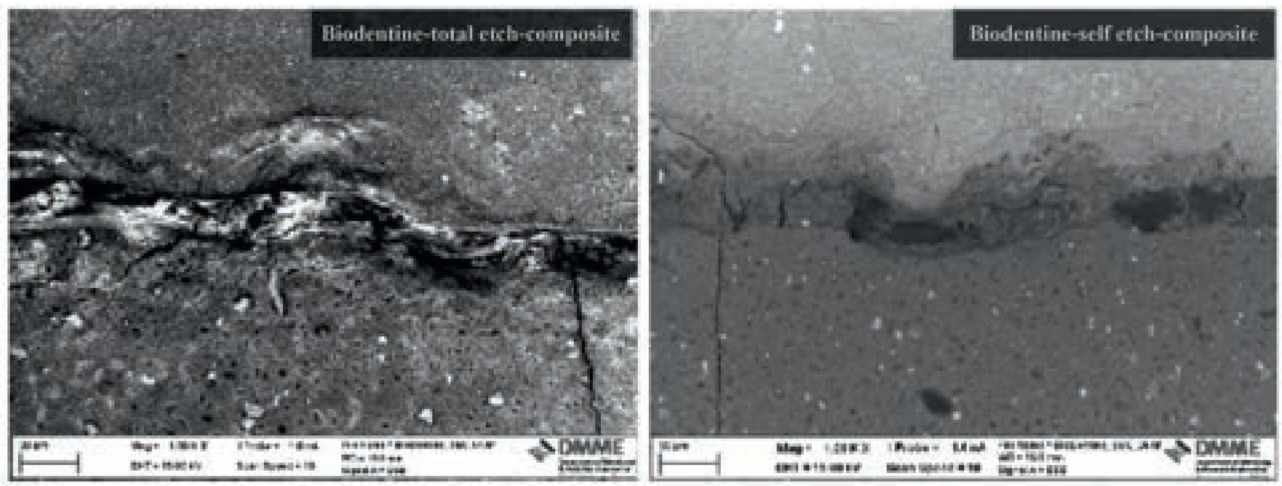

Figure 7: Interfacial characteristics of Biodentine™ and composite resin after total-etch and self-etch adhesive application.

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capping materials such as Theracal depend on the environmental moisture to penetrate and allow hydration of the tricalcium silicate which is the active component of the material. The fluid penetration is not enough and a model using extracted teeth kept in media for 15 days showed limited hydration of the tricalcium silicate in Theracal (28). Also, in agreement with previous published work, in-vitro (29) and in-vivo (30) studies show that Theracal-conditioned media significantly decreased pulp fibroblast proliferation, and induced proinflammatory interleukin 8 release from cultured pulp fibroblasts and entire teeth cultures (29).

Using the whole tooth culture model (31) and in a recent clinical study (30), it is clear that Biodentine™ exhibits better biological and clinical outcomes than resin-based dentine replacement materials.

Biodentine™ has been shown to promote pulp healing using both the whole tooth culture model (29) and also in clinical trials where it presented the best clinical outcome when compared to resin-based pulp capping materials (30).

Pulpotomy procedures

More advanced pulp involvement particularly in primary teeth will necessitate pulpotomy procedures to be undertaken. Biodentine™ exhibited better cytocompatibility and bioactivity than MTA Angelus, Theracal and IRM in contact with stem cells isolated from human exfoliated primary teeth (32). In an animal model the use of Biodentine™ as a pulpotomy agent resulted in thicker mineralised tissue bridges which are more easily detected radiographically when compared to MTA (33).

Clinically, high success rates were shown in pulptotomy procedures performed with Biodentine™ in primary molars showing more favourable results than formocresol, which is the standard treatment methodology (34, 35). When compared to calcium hydroxide in vital pulpotomies in primary molars the group treated with Biodentine™ revealed favourable regenerative potential along with clinical success sharing both indications and mode of action with calcium hydroxide, but without its drawbacks of physical and clinical properties (36). Pulpotomy with Biodentine™ resulted in a predictable clinical outcome similar to that of MTA (37-41). Biodentine™ was superior to less standard treatment methodologies like laser (41) and propolis (39). Biodentine™ used for pulpotomy procedures does not cause tooth discolouration (42).

Treatment of the immature apex

Once the pulp tissue is lost, it is necessary to fill the root canal space. Immature teeth present a problem due to their anatomy as the roots are short and thin and routine canal obturation is difficult due to the root canal configuration. The thin dentine walls are also at risk of fracture.

Apexification procedures allow the formation of a calcific barrier at the root apex thus closing off the root-end from the periapical space. A calcific bridge is created by providing an environment where calcium ions from the dentine form a calcific bridge. Such conditions are created by materials releasing calcium hydroxide. Historically non-setting calcium hydroxide pastes were used. The calcium hydroxide releases calcium ions to create an ideal environment for the formation of a calcific bridge (43). Another advantage of the calcium hydroxide paste is its antibacterial properties as pulpless root canals usually result from non vital teeth which are prone to bacterial colonisation (44). The use of non setting calcium hydroxide involves several visits over a number of months and the calcified bridge formed following apexification was a porous structure (45).

Apexification with hydraulic calcium silicate cements as apical plugs permits apexification procedures to be performed in two visits. The two visits were necessary since MTA has a long setting time and needs to set prior to the placement of the final restoration. More recently it was shown that apexification with an apical plug of Biodentine™ a single visit is enough since wetting the surface of the material did not effect the material properties (46).

This treatment methodology can be considered as predictable, and may also be an alternative to the use of calcium hydroxide (47). The hydraulic nature of these material types and the formation of

calcium hydroxide make these materials ideal for such procedures. Biodentine™ has been shown to release more calcium ions in solution than MTA (2). Its success when used as apical plug in apexification cases has been reported (48-53). Its hydration is optimised by the addition of calcium carbonate as a nucleating agent spiking up the reaction rate in the early stages. The addition of calcium chloride accelerator and the water soluble polymer allow low water/powder ratios (2). There are no additives of pozzolanic materials and other cementitious substances as indicated in Table 1. The addition of such materials has been shown to restrict the formation of calcium hydroxide which is necessary when treating apexification cases (54, 55). The fracture resistance of immature teeth with an apical plug of Biodentine™ was similar to that of MTA and higher than the control (52).
Biodentine™ has also been used successfully in cases of regenerative endodontics (56-58). The fracture resistance in the cases was also reported to be similar to that of MTA (59). Biodentine™ showed the least discolouration potential when used in these clinical cases (60), thus it is the material of choice for regenerative endodontics, especially for cases where aesthetics is a concern.

Root end filling and perforation repair

Materials used for root-end filling need to exhibit specific properties since they have to perform and attain clinical success under very adverse conditions. The hydraulic nature of all tricalcium silicate cements is thus a desirable property. In fact these material types were invented for this purpose. The main issue with the hydraulic cements is that they react with the environment they are placed in. At the root-end the materials are placed in contact with blood as soon as they are placed. They are also in contact with the root dentine and remnants of gutta-percha and sealer used to obturate the root canal. The physical properties of Biodentine™ are not adversely affected by contact with tissue fluids and blood (61). The bond strength of Biodentine™ was better than that of MTA when used as a root-end filling material. Both materials were adversely affected by blood contamination (62). Less bacteria in apical root dentine were found when cases were treated with Biodentine™ and compared to MTA (63) indicating that the antimicrobial properties of Biodentine™ are superior too those of MTA. The biocompatibility of Biodentine™ was considered to be marginally better than that of MTA with better cell adhesion to the materials when it was used as a root-end filling material (64).
Biodentine™ was also found to be adequate to repair root perforations (65) producing a positive tissue response and mineral deposition at the perforation site. This response is related to the release of calcium hydroxide in solution. It also seals well the area (66, 67) since perforations are inadvertently highly infected thus an adequate seal is necessary.
Root perforation repair materials are also subject to dislodgement during tooth restoration. Biodentine™ shows high early push-out bond strength which did not deteriorate in contact with blood (68). Furthermore it was not affected by the irrigating solutions used (69) indicating material stability.

Conclusions

Biodentine™ is a second generation hydraulic calcium silicate material that is composed mainly of tricalcium silicate and it also contains zirconium oxide radiopacifier and some additives. It is scientifically engineered for a specific purpose to be used as a dentine replacement material. The research undertaken so far shows that Biodentine™ performs well as a dentine replacement but also for other clinical applications. Thus it certainly is more than just dentine in a capsule.

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Biography

Professor Josette Camilleri obtained her Bachelor of Dental Surgery and Master of Philosophy in Dental Surgery from the University of Malta. She completed her doctoral degree, supervised by the late Professor Tom Pitt Ford, at Guy's Hospital, King's College London.

She has worked at the Department of Civil and Structural Engineering, Faculty for the Built Environment, University of Malta and at the Department of Restorative Dentistry, Faculty of Dental Surgery, University of Malta. She is currently a senior academic at the School of Dentistry, University of Birmingham, U.K. Her research interests include endodontic materials such as root-end filling materials and root canal sealers, with particular interest in mineral trioxide aggregate, Portland cement hydration and other cementitious materials used as biomaterials and also in the construction industry.

Josette has published over 100 papers in peer-reviewed international journals and her work is cited over 4000 times. She is the Editor of "Mineral trioxide aggregate. From preparation to application" published by Springer in 2014. She is a contributing author to the 7th edition of "Harty's Endodontics in Clinical Practice" (Editor: BS Chong) and "Glass ionomer cements in Dentistry" (Editor: SK Sidhu). She is an international lecturer, a reviewer and a member of the scientific panel of a number of international journals including the Journal of Endodontics, Scientific Reports, Dental Materials, Clinical Oral Investigation, Journal of Dentistry, Acta Odontologica Scandinavica and Acta Biomaterialia.

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