Original article

A comparison of Physical and Mechanical Properties of Biodentine and Mineral Trioxide Aggregate

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ABSTRACT

Background: Physical and mechanical properties are important during the selection of materials which is used for root repair and root end filling to ensure their success and longevity.

Aim: The aim of this study is to compare the compressive and diametral tensile strengths and solubility of Biodentine and ProRoot Mineral Trioxide Aggregate (MTA).

Material & Methods: Cylindrical samples of tested materials were constructed for compressive and diametral tensile strength. After then, it was immersed in distilled water for 24 hours or 21 days at 37^{o}C before testing. Solubility was determined by preparing discs of each material, and then stored in 50ml distilled water at 37°C for 1, 7, and 21 days. Solubility was measured as the difference between the initial weight and the weight at the end of each storage period. Results were analyzed using One-way ANOVA, Student's t-test, and Tukey's HSD post-hoc test (P<0.05).

Results: Biodentine showed significantly higher compressive and diametral tensile strength values compared with MTA after 1 day (P<0.01). Strength values of Biodentine significantly decreased after 21 days compared with day 1 (P<0.01). On the other hand, MTA showed a significantly higher diametral tensile strength after 21 days compared with day 1 (P<0.01). Biodentine showed higher solubility than MTA (P<0.05). In addition, the solubility of Biodentine and MTA significantly decreased after 21 days compared with 1 day (P<0.01).

Conclusion: Although Biodentine showed higher initial strength than MTA, the values were not significantly different after 21 days. Biodentine was more soluble than MTA.

Keywords: Biodentine, Compressive strength, Mineral trioxide aggregate, Tensile strength, Solubility.

INTRODUCTION

An annual estimation of endodontic procedures suggests that approximately 5.5% of all treatments performed involve root end surgery and root perforation repair [1]. Root end filling materials should be able to establish and maintain an adequate hermetic seal to prevent bacterial egress into periapical tissue [2]. Furthermore, it should be dimensionally stable; radiopaque; nonresorbable; posses adequate compressibility, adequate working time and quick setting time; and it should be well tolerated by the periradicular tissues [2].

One of the mishaps that may occur during endodontic therapy is perforation of the root canal wall or furcation perforation. Materials used to repair perforations should be biocompatible, provide adequate seal, possess adequate strength to resist condensation forces, promote bone formation and healing, and should be easily manipulated and placed [3].

Several materials have been used as root repair and root end filling materials. Therefore, these materials include amalgam, resin composites, ethoxybenzoic acid cements, Cavit™, glass ionomer cements, gutta-percha, zinc oxide eugenol cements, polycarboxylate cements, and Mineral Trioxide Aggregate (MTA) [3]. However, so far, no material has fully satisfied all the ideal requirements.

Despite the widespread use and well-documented advantages of MTA since its introduction for endodontic treatment, it has certain shortcomings. Hence, these shortcomings include difficulty in handling and long setting time which might lead to leakage and loss of marginal adaptation [4].

Biodentine™ (Septodont, St.Maur-des-Fossés, France) is a bioactive calcium silicate cement with dentine-like mechanical properties which is used for the repair of root perforations, apexification, and root end filling. Furthermore, it can be used in direct pulp capping with a similar efficacy to MTA in the clinical setting [5]. The setting reaction of Biodentine involves the hydration of tricalcium silicate that creates precipitates that resembles hydroxyapatite [6]. In addition, Biodentine is biocompatible, non-cytotoxic, and it has the capacity to induce reparative dentine formation shortly after its application [7]. According to the manufacturer, Biodentine™ is suitable as an endodontic repair material which is claimed to be superior to MTA in terms of consistency, handling, and setting time.

Mechanical strength is an important property of materials used for root repair, particularly in the coronal third of the root. Several studies [2, 8] have investigated the compressive strength of MTA which is reported to be affected by the type of MTA [8], mixing liquid [9], acid etching procedures [10-11], and mixing techniques [9]. Similarly, a number of physical properties of Biodentine have been investigated such as the setting time, compressive strength, and bond strength to dentine [10, 12-13].

Therefore, the aim of this study is to evaluate the compressive strength, diametral tensile strength, and the solubility of Biodentine in comparison to MTA over a period of 1, 7, and 21 days. The null hypothesis tested was that there is no statistically significant difference in compressive strength, diametral tensile strength, and the solubility of Biodentine and ProRoot MTA over the designated storage periods.

METHODS

Compressive strength and diametral tensile strength of Biodentine (Septodont, Saint Maur des Fosse´s, France) and ProRoot MTA (ProRoot MTA, Dentsply Tulsa, Tulsa, OK) (Table 1), were evaluated after 1 and 21 days storage period. Also, the solubility of both materials in distilled water was also evaluated after 1, 7, and 21 days.

Compressive and Diametral Tensile Strength Sample Preparation

Split Plexiglass molds of 12 mm in height and 6 mm in diameter were used to fabricate the cylindrical samples of the tested materials in the current study to determine the compressive strength and diametral tensile strength values. Each material was mixed according to the manufacturers' recommendations and placed in the molds within 2 minutes of mixing (n=7 for each material in each storage period, total of 28 samples) [2]. Each mold was packed to excess, and was placed between two glass plates with slight pressure from top and bottom for good packing of the material. The molds were then transferred to an oven with a constant temperature of 37±1° C and a humidity of 100% for 3 hours. After then, the samples were removed from the molds and checked for voids and chipped edges. Thus, only samples with no visible defects were selected for testing. The samples were immersed in distilled water, and were transferred back to the oven for 1 or 21 days before compressive strength and diametral tensile strength testing.

Compressive Strength Test

Each sample was placed with its flat ends between the platens of the universal testing apparatus (Computer control electromechanical universal testing machine model WDW-20). Thus, this was aimed at ensuring that the load was applied parallel to the long axis of the sample at a cross head speed of 1mm/min. The maximum load required to fracture each sample was measured and recorded and the compressive strength was calculated in megapascals according to the formula; Compressive strength = $4P / \pi D^2$, where P is the maximum load applied in Newton and D is the diameter of the sample in millimeters.

Table 1: Composition of tested materials

Material	Composition	Manufacturer
Biodentine	Powder: Tri-calcium silicate, Di-calcium silicate, Calcium carbonate and oxide, Iron oxide, Zirconium oxide. Liquid: calcium chloride, Hydro-soluble polymer Batch Number: B06420	Septodont, Saint Maur des Fosse´s, France
ProRoot MTA	Powder: Portland cement, Bismuth oxide, Gypsum, silica. Liquid: Sterile distilled water Batch Number: 12002493	Dentsply Tulsa, Tulsa, OK

Diametral Tensile Strength Test

The samples were compressed diametrically. Thus, this results in the introduction of tensile stress in the material in the plane of the force application. The load was applied at a cross head speed of 1mm/min until the sample fractured. The tensile stress measured in MPa was calculated by the following formula: Diametral tensile stress = $2P/\pi Dt$. Here, P is the maximum load applied in Newton, D is the diameter of the sample in millimeters, and t is the thickness of the sample.

Solubility Test

Circular stainless steel molds with a 20 mm diameter hole and a thickness of 1.5 mm were used to fabricate the disc samples for solubility testing. A small hole was drilled on the periphery of each mold to allow the suspension of the sample in distilled water. Seven discs of each material were fabricated. The discs were placed in 100% humidity for 24 hours. Then, it was stored individually in plastic bottles containing 50 mL of distilled water at 37°C. Before every testing period (1, 7, 21 days), the discs were desiccated using a desiccation container and placed in an oven with a constant temperature of 37°C for 1 hour. Then, each disc was weighed to the nearest microgram. After weighing, each disc was returned to the same container. The water in the containers was neither changed nor was there any addition during the test periods [2]. Mixing and weighing of the samples were performed by a single operator at 23 ± 2°C and a relative humidity of 50 ± 5%.

The Statistical Package for Social Sciences software (SPSS Inc., version 15, Chicago, IL, USA) was used for data processing and data analysis. T-Test was used to compare the physical properties between Biodentine and MTA at each storage period. One-way ANOVA was used to compare each material with itself at different storage periods.

RESULTS

The results of compressive strength, diametral tensile strength, and solubility tests were summarized in Table 2.

Table 2: Mean values and standard deviation of compressive strength (CS), diametral tensile strength (DTS), and solubility of MTA and Biodentine after 1, 7, and 21 days

	Biodentine			MTA		
Storage period	CS (MPa)	DTS (MPa)	Solubility (g)	CS (MPa)	DTS (MPa)	Solubility (g)
1 day	95.1±10.6	7.9±1.9	0.0348±0.007	40.9±10.2	4.4±0.7	0.0199±0.006
7 days	_	_	0.0322±0.007	_	_	0.0057±0.007
21 days	56.1±20.4	5.0±1.1	0.0208±0.005	49.8±13.2	6.2±1.6	-0.0101±0.006

Compressive Strength

Biodentine showed significantly higher compressive strength than MTA after 1 day (P= 0.001). However, at 21 days, there was no statistically significant difference between the two materials (P= 0.601). The compressive strength of Biodentine significantly decreased after 21 days compared to day 1 (P = 0.003). On the other hand, MTA had comparable strength values in both storage periods (P = 0.180).

Diametral Tensile Strength

The diametral tensile strength of Biodentine after 1 day was significantly higher than MTA (P= 0.004). However, after 21 days, there was no significant difference between the two materials (P= 0.189). The diametral tensile strength of Biodentine continued to decrease with significantly lower values after 21 days compared to 1 day (P= 0.004) whereas the diametral tensile strength of MTA improved and became significantly higher after 21 days compared to its 1 day strength value (P= 0.008).

Solubility

The results showed weight loss with time for both materials except for MTA at 21 days which showed gain in weight (Table 2). Biodentine had significantly more weight loss compared to MTA after 1, 7, and 21 days (P=0.01, 0.001, 0.000 respectively). The total weight loss of Biodentine was 0.0878 g after 21 days, while MTA had a total weight loss of 0.0155 g.

The solubility of Biodentine after 21 days was significantly lower compared to its solubility after 1 and 7 days (P= 0.001, 0.005 respectively). Similarly, MTA showed significantly lower solubility after 21 days compared to 1 and 7 days (P= 0.000, 0.001 respectively).

DISCUSSION

The null hypothesis that was postulated in the current study was rejected regarding the solubility of Biodentine and MTA. However, it was accepted for compressive and diametral tensile strengths after 21 days. The compressive strength of Biodentine was higher than ProRoot MTA with statistically significant difference after 1 day storage period, which is comparable to previous studies [10, 12, 14]. The enhanced strength of Biodentine may be attributed to its low water/cement ratio [15].

Biodentine is based on tricalcium silicate in addition to setting accelerators and other components to improve strength and manipulation [16]. On the other hand, MTA has difficult handling characteristics due to its grainy texture following mixing; hence, this makes it difficult to pack and condense [4, 17].

Furthermore, the manufacturer of Biodentine reported that the compressive strength of Biodentine has the capacity to continue improving with time reaching a value of 300 MPa after one month, which is similar to natural dentine that has values of compressive strength ranging from 275 to 300 MPa [16, 18]. However these values are well above the values found in this study and in previous studies which ranged from 45 to 95 MPa over storage periods starting from 24 hours up to 28 days [10-14].

Elnaghy [19] (2014) found the compressive strength of Biodentine at 1 day to be 95.2 MPa at neutral pH compared to 71 MPa for White MTA (WMTA) which may be related to the difference in microstructure of both materials. In the current study, the compressive strength of Biodentine after 1 day was comparable to the values reported by Elnaghy [19] (2014) (95.1MPa). In a comparative study by Grech, Mallia and Camilleri [13] (2013), Biodentine showed the highest compressive strength after 28 days storage period (67.15 MPa) compared to prototype zirconium oxide cement, Bioaggregate, and IRM, while in the current study, the compressive strength of Biodentine after 21 days was 56.1 MPa. Dawood, et al. [20] (2014) reported higher compressive strength of Biodentine (78.5 MPa) compared with MTA (46.4 MPa) after 1 day. The higher strength of Biodentine was attributed to its low water/powder ratio required for good workability of the cement. Thus, this was achieved by incorporating a hydro-soluble polymer into the liquid component of the cement in addition to adding a water soluble polycarboxylate to the cement's powder [21].

Torabinejad, et al*.* [2] (1995) investigated the compressive strength of MTA compared to amalgam, Super-EBA, and IRM after 1 day and 21 days storage in distilled water. The compressive strength of MTA after 1 day (40 MPa) increased with time to reach a value of 67.3 MPa after 21 days. In the current study, a similar trend was shown since the compressive strength of MTA increased after 21 days. Nevertheless, this increase was not statistically significant. This difference may be attributed to differences in material composition since it was first introduced [17].

The diametral tensile strength of both Biodentine and MTA showed similar trends to compressive strength values with a decrease in diametral tensile strength of Biodentine after 21 days compared to a significant increase in the diametral tensile strength of MTA. The diametral tensile strength of WMTA was reported to be 4.4 MPa after 24 hours storage in distilled water [22]. Hence, this is comparable to the values reported in the current study. No data is currently available on the diametral tensile strength of Biodentine or the diametral strength of MTA over an extended period of time. Generally, the diametral tensile strength and the compressive strength values are not critical for root-end filling. However, as a root repair material, certain situations such as condensation of the coronal restoration can create a tensile force on the pulp capping or root repair material. Therefore, knowledge of diametral tensile strength of these materials may prove to be of use.

In the current study, solubility was determined following the method outlined by Torabinejad, et al. [2] (1995). Measuring the solubility of root end filling and root repair materials is essential since these materials come in contact with periapical and periodontal tissue fluid when used. In the current study, Biodentine was significantly more soluble than MTA in distilled water, with a decrease in the solubility of both materials after 21 days. The difference in the degree of solubility between both materials can be attributed to a difference in composition [15]. An *in vitro* study by Gandolfi, et al. [23] (2013) showed a higher 24 hour solubility of Biodentine with a percentage of 11.93% compared to the reported value in the manufacture brochure (6.8%) [16]. On the other hand, MTA had a solubility value of 10.7% which was lower but not significantly different from Biodentine. In the current study, the reported 24 hour solubility of Biodentine was significantly higher than MTA (0.0347g, 2.91% vs. 0.0199g, 1.75% respectively). It should be noted here that the solubility test performed in the current study is different from the technique used by Gandolfi, et al. [23] (2013) who performed the solubility test following ISO 4049 by calculating the decline in mass (weight loss) after storage in deionized water. It was suggested that the reduction in the original weight of the materials tested can be partly attributed to the evaporation of the mixing liquid during the final drying of samples rather than the actual reduction of the original weight. Therefore, the interpretation of solubility measurement results should be done with great care [15].

Dawood, et al. [20] (2014) reported similar results to the current study with higher 24 hour solubility of Biodentine compared with Angelus® MTA. This was attributed to the presence of hydro-soluble polymer in the liquid component of Biodentine which may disperse the cement by applying a charge on the particles surfaces leading to higher dissolution when testing solubility [24]. Furthermore, higher solubility of Biodentine was correlated with its higher Ca^{+2} release compared with MTA. This was attributed to a higher content of calcium-releasing products found in Biodentine [21], in addition to the presence of calcium chloride which has been shown to induce Ca^{+2} release [25].

Different investigators reported different degrees of solubility for MTA. Nonetheless, most of them declared that MTA has low or no solubility. Torabinejad, et al. [2] (1995) investigated the solubility of ProRoot MTA over a period of 24 hours, 7 days, and 21 days in distilled water. The reported values of solubility of MTA were expressed as sample weights showing no significant change in samples weights over the storage time periods. In the current study, both tested materials showed decreasing solubility with time with weight gain for MTA samples after 21 days storage in distilled water. Previous studies reported that MTA contains higher values of open and apparent porosity compared to Biodentine which might explain its gain of water after 21 days in the current study [6, 15].

CONCLUSION

Biodentine and ProRoot MTA showed comparable values of compressive and diametral tensile strength after 21 days. Biodentine showed more solubility than MTA throughout the study. However, both materials became less soluble towards the end of the study compared to solubility after 1 day.

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