Compressive strength of different tricalcium silicate–based materials used for primary teeth: in vitro study

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Background and Objectives: One of the most universally accepted properties of a material is to have a good physical and mechanical properties to withstand the masticatory forces which is one of the major problem in dentistry. The objective of this study was to evaluate and compare the compressive strength of three different types of Tricalcium silicate based materials: (High plasticity repair mineral trioxide aggregate, ProRoot and Biodentine).

Materials and methods: Ninety samples from studied materials (4mm diameter and 6mm height) were selected and divided into three equal groups according to the materials used then after each group was divided into three equal sub-groups according to the time (1 day, 1 week and 3 weeks). Compressive strength was evaluated in accordance with ISO 9917-1: 2007 recommendation. Specimens were crushed along their long axis using a universal testing machine. The load was recorded in mega Pascal. Statistical package for the social science (SPSS version 23) program was used to perform the statistical.

Results: Biodentine showed significantly the highest compressive strength values than the other materials ($P < 0.001$), whereas High plasticity repair MTA have the lowest compressive strength values. There was no significant difference between ProRoot and HP Repair MTA-angelus. The compressive strength of ProRoot MTA was significantly lower than Biodentine but significantly higher than HP repair MTA Angelus.

Conclusion: Biodentine and ProRoot have better in mechanical properties than the HP Repair MTA. The time had correspondingly effectively increased impact on the dental materials used in this study.

Keywords: Biodentine, Compressive Strength, HP Repair MTA, ProRoot.

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Introduction

Dental materials are invented materials that are intended for usage in dentistry.[1] Over the years, various types of dental materials have been developed to serve different purposes and to be applied to multiple purpose in the field of dentistry. Mineral trioxide aggregate (MTA), is a unique endodontic cement that was initially introduced as material for root perforation repair by Mahmoud Torabinejad at Loma Linda University in 1993. It is primarily composed of tricalcium silicate, tricalcium aluminate, tricalcium oxide, and bismuth oxide. It is formulated of fine hydrophilic particles that solidify in the presence of moisture or blood. MTA was approved by the U.S. Food and Drug Administration for endodontic use in 1998.[2]

In pediatric dentistry the MTA has been reported to be suitable for use as a pulp capping agent.[3] as a dressing over pulpotomies of permanent,[4] and primary teeth replacing the formocresol Pulpotomy procedure,[5] for obturation of retained primary teeth,[6] and permanent immature[7] and mature teeth,[8] for single visit apexification procedures for immature teeth with necrotic pulps,[9] thus acting as an apical barrier material,[10] and as a root canal sealer cement.[11] MTA became commercially available as ProRoot MTA. Later, gray and white MTA–Angelus were introduced. Despite the favorable properties of MTA type products that support their clinical use, these first few products had drawbacks, such as prolonged setting time, poor handling, and potential of discoloration, therefore newer calcium silicate- based product such as Biodentine material had been introduce to overcome the drawback of the traditional MTA.[12]

Biodentine attracted the attention in the dentistry field because of its fast setting time, ease of handling, excellent sealing ability, high compressive strength, high biocompatibility due to its very high pH (pH=12), it is used in both restorative and repair process without causing any teeth discolration.[1] Recently a new MTA-based material, High plasticity repair MTA (Angelus, Londrina, Brazil), was developed based on the biological and physical properties of calcium-silicate cements, claiming improved performance compared with traditional MTA. One of the differences of this new material over the old formation of white MTA-Angelus was the replacement of the distilled water by a liquid containing water and organic plasticizer this liquid provides a higher plasticity, improving handling and inserting the material to the repair site and improved physical properties, as compared with White MTA. Furthermore, the replacement of the bisthmus oxide radiopacifier by calcium tungstate radiopacifier will avoid dental discoloration.[12] Compressive strength is considered as one of the main physical characteristics of hydraulic cements. it is essential that the cement has the capacity to withstand masticatory forces.[13] The study aims to compare and evaluate the compressive strength properties of the three different tricalcium silicate based materials HP repair MTA, ProRoot and Bio dentine. Mechanical strength is an important property of materials used for root repair, particularly in the coronal third of the root.[13]

Several studies[14,15] have investigated the compressive strength of MTA which is reported to be affected by the type of MTA, mixing liquid, acid etching procedures and mixing techniques. Similarly, a number of physical properties of Biodentine have been investigated such as the setting time, compressive strength, and bond strength to dentine[16-18] Since no studies are available on the comparison of Biodentine with both ProRoot MTA and HP repair MTA, therefore, this study is decided in which the aim of it is to evaluate and compare the compressive strength of these three different types of materials over a period of 1 day, 1 week and 3 weeks.

Material and methods

Three Tricalcium silicate material (ProRoot MTA, HP Repair MTA, Biodentine) were used in this study. The commercial name, composition and manufacturer of all materials used in this study are listed in Table 1.

A total of ninety specimens were used in

Table 1: Descriptive Statistics for leakage groups.

Materials	Brand	Compositions	Manufacturer
Tricalcium silicate materials	ProRoot MTA	Tricalcium silicate, Tricalcium aluminate, Dicalcium silicate, Tetra calcium, Gypsum, aluminofirrate, Free calcium oxide, Bismuth oxide	DENTSPLY, Tulsa, UK
	HP Repair MTA	Tricalcium silicate, Tricalcium aluminate, Dicalcium silicate, Calcium oxide, Ferro aluminate Tricalcium, Bismuth oxide.	PRIMA dental by Angelus (brazil)
	Bio-dentine	Tricalcium silicate powder, Aqueous calcium, chloride solution and excipients	Septodont, USA

this research. The specimens divided randomly into three main groups (thirty specimens in each) according to the type of Tricalcium silicate materials to be evaluated (Group1: ProRoot MTA), (Group2: HP Repair MTA) and (Group3: Biodentine) (Figure 1).

A cylindrical split stainless steel mold (measuring 4.0 mm inner in diameter and 6.0 mm in height according to ISO-9917 recommendation) were used to fabricate the cylindrical samples of the tested materials in the current study to determine the compressive strength (Figure 2). Each material was mixed and placed in the molds within 2 minutes of mixing in which ProRoot MTA was prepared by mixing the MTA powder with sterile saline on a clean glass slab using a metal mixing spatula with 3:1 powder to saline ratio according to the manufacturer's recommendations in order to obtain a putty consistency. While HP Repair MTA was prepared in such away: One package of the powder (0.085 g) was mixed with 2 drops of the liquid for 40 seconds until the ingredients were completely homogenized into putty-like cement with high plasticity. For Biodentine, a capsule was gently taped on a hard surface to loosen the powder then opened five drops of liquid was poured inside then placed on a mixing device at a speed of 4000 – 4200 rotations/min and mixed for 30 seconds. MTA applicator used to deliver each material into the mold, and then the mix was compacted with a slightly moistened sterile cotton pellet to ensure an even coverage of mold thickness. The material was further compacted using a dental plugger to ensure a dense and uniform sample with minimal porosity. Once filled, the excess material was scraped off with the edge of a glass microscopic slide to leave a flat uniform surface and the excess moisture was removed on the surface of the MTA mix with a sterile cotton pellet. The complete assembly was transferred to a cabinet maintained at 37C° for 6 hours, after which removed from the molds and then specimens was immersed in distilled water (Figure 2). Compressive strength assessment was performed using a universal testing machine for three different times 1 day,1 week and 3 weeks after the end of mixing of the material. Each sample was placed with its flat ends between the platens of the universal testing apparatus (Figure 2). 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 mega Pascal 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.

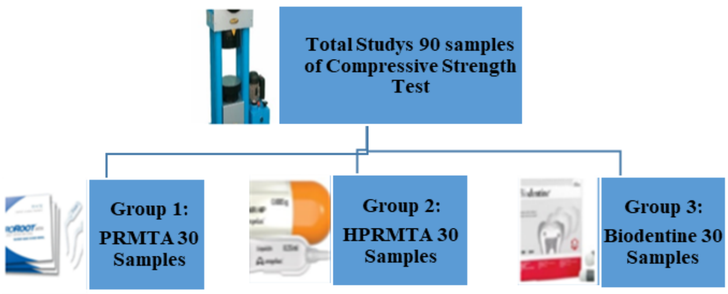

Figure 1: Diagrammatic of experimental design for the groups of the study.

Figure 2: (a) Stainless steel mold, (b) Specimens, (c) Specimens in distill water, (d) Universal machine.

Results

The means and standard deviations of compressive strength test obtained with tested materials in different assay are shown in (Table 2) in which ProRoot and HP Repair MTA materials, at the first day of the study was recorded with (39.484 and 8.277) respectively, then it dramatically increased to 57.638 and 23.787 after 1 week and steadily went down to 41.714 and 13.532 respectively after 3 weeks. Referencing to Biodentine, like other materials, it was also moved in the same pattern where it was recorded with 35.993 at the 1st day, whereas at 1st week it was kind of doubled to reach 68.308 and the trend went down to 57.446. as it is shown in (Figure 3). It is clear that the time worked differently on the materials. (Table 3) show the effect of time on the tested materials. It enables making the multiple comparisons and see the location of the difference. It is well shown that 1st day and 3rd week had similar effect on the ProRoot MTA as well as HP Repair MTA materials, whereas this is completely different at Biodentine as there is no statistically significance between 1st week and 3rd week. It is obvious that each considered time on the materials showed significant result. Multiple comparison test could be able to locate the exact difference. (Table 4) shows interesting results between the materials with reference to the times. It is worth mentioning that the only material which was affected differently was HP Repair MTA since the p-value is less than 0.05. While there was no significant difference between ProRoot MTA and Biodentine as the p-value (0.738) was equal to 0.05.

Table 2: Descriptive statistics of all material with details.

Materials	Time	Mean and St. Deviation
ProRoot MTA	1Day	39.484 ±8.6
	1Week	57.638 ±8.9
	3Weeks	41.714 ±6.8
HP Repair MTA	1Day	8.277 ±4.1
	1Week	23.787 ±6.7
	3Weeks	13.532 ±7.3
Biodentine	1Day	35.993 ±11.9
	1Week	68.308 ±19.6
	3Weeks	57.446 ±10.7

Table 3: The multiple comparison for the effect of times.

Materials	Tests	Time		Mean	P-Values
ProRoot MTA	Tukye	1 Day	1 Week	-18.15	0.000
			3 Weeks	-2.23	0.815
		1 Week	1 Day	18.15	0.000
			3 Weeks	15.92	0.000
		3 Week	1 Day	2.23	0.815
			1 Weeks	-15.92	0.000
HP Repair MTA	Tukye	1 Day	1 Week	-15.51	0.000
			3 Weeks	-5.25	0.159
		1 Week	1 Day	15.51	0.000
			3 Weeks	10.25	0.003
		3 Week	1 Day	5.25	0.159
			1 Weeks	-10.25	0.003
Biodentine	Games Howell	1 Day	1 Week	-32.31	0.001
			3 Weeks	-21.45	0.001
		1 Week	1 Day	32.31	0.001
			3 Weeks	10.86	0.303
		3 Week	1 Day	21.45	0.001
			1 Week	-10.86	0.303

Table 4: The multiple comparison test between the materials regarding to Time.

Time	Tests	Materials		Mean	P-Values
1 Day	Games-Howell	ProRoot MTA	HP Repair MTA	31.20*	0.000
			Biodentine	3.49	0.738
		HP Repair MTA	ProRoot MTA	-31.20*	0.000
		HP Repair MTA	Biodentine	-27.71*	0.000
		Biodentine	ProRoot MTA	-3.49	0.738
		Biodentine	HP Repair MTA	27.71*	0.000
1 Week	Games-Howell	ProRoot MTA	HP Repair MTA	33.85*	0.000
			Biodentine	-10.67	0.294
		HP Repair MTA	ProRoot MTA	-33.85*	0.000
			Biodentine	-44.52*	0.000
		Biodentine	ProRoot MTA	10.67	0.294
			HP Repair MTA	44.52*	0.000
3 Weeks	Tukey	ProRoot MTA	HP Repair MTA	28.18*	0.000
			Biodentine	-15.73*	0.001
		HP Repair MTA	ProRoot MTA	-28.18*	0.000
			Biodentine	-43.91*	0.000
		Biodentine	ProRoot MTA	15.73*	0.001
			HP Repair MTA	43.91*	0.000

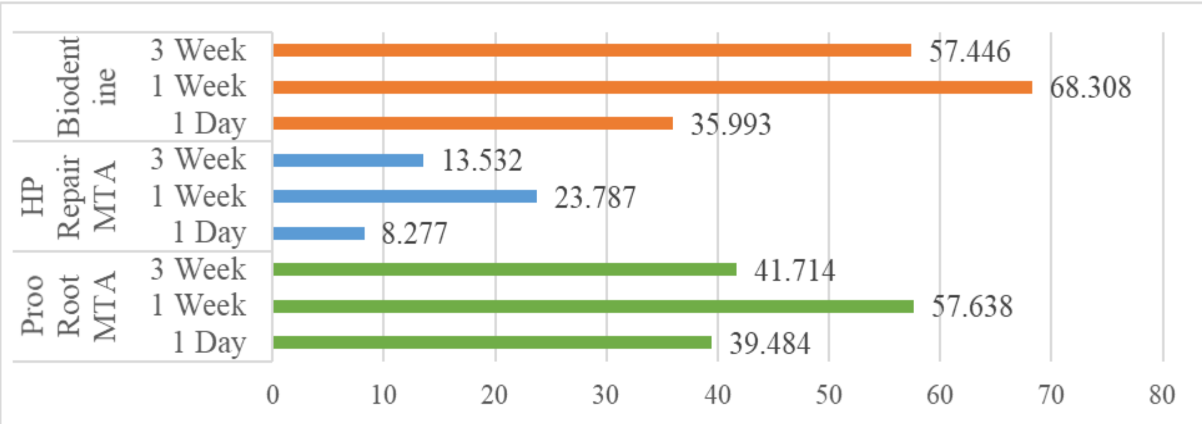

Figure 3: Mean value of compressive strength for all materials upon time.

Discussion

The evaluation of mechanical parameters allows for physical properties to be correlated with clinical performance. In vital pulp therapy, the applied cement must remain in place despite experiencing dislodging forces resulting from operative procedures. The higher mechanical properties of the cement are considered an important feature when this cement is used as pulp capping or as a coronal restorative material where it is subjected to occlusal loads. Typical test parameters to assess mechanical properties of hydrated cement include compressive and tensile strengths.[19,20]

Compressive strength is considered as one of the main physical characteristics of hydraulic cements. Considering that a significant area of usage, in vital pulp therapies while in mature or immature teeth. It is essential that the cement has the capacity to withstand masticatory forces.[13,16] Respectively it was showed in the study of Masoud (2009) that the compressive strength of hydraulic cement affected by many several factors, including the type of cement, the powder/liquid ratio, the amount of entrapped air, the pH value of the mixing liquid, characteristics of the mixture, method of mixing, condensation pressure, humidity of the environment, the type of storage media, the pH value of the environment, the type of vehicle, the length of time between mixing and evaluation, thickness of the material, and temperature. And it was believed that some of these factors cannot be controlled easily; therefore, different results might be obtained during a study on physical properties of hydraulic cement.[21]

Three different time intervals were selected for examination in this study; in particular, 1 day was selected to allow the cements to set. However, the postponement of restorative procedures for at least 96 hrs. after mixing the cement is recommended; therefore, a second- and third-time interval was also assessed. According to the results of the current study, HP repair MTA had the lowest compressive strength whereas Biodentine is illustrated by a sharp increase in the compressive strength reaching 68.30 at 1week which is the highest statistical significant mean value among all the groups used in this study at the all different times intervals, and also according to the material itself when comparing to 1 day 35.99 MPa. Later in 3 weeks the compressive stress of Biodentine is recorded as non-statistical significantly decreased to record about 57.44 MPa.

The enhanced strength of Biodentine may be attributed to its composition in which it based on tricalcium silicate in addition to setting accelerators and other components to improve strength and manipulation. In addition, the elimination of aluminates that leads to weakening and fragility of the set material as reported by the factory. Furthermore, the addition of poly-carboxylate-based hydro soluble polymers in the liquid of the cement explain this result since it acts as water reducing agent and allows low water/powder ratio. Therefore; the resulting structure of the material has lower porosity and, consequently, higher compressive strength since the Porosity is a common characteristic of cements and occurs as a result of the gaps between the un hydrated cement grains.[22]

As the hydration reaction progresses, the hydration products fill these gaps and reduce the porosity. Material porosity is dependent on the water-cement ratio. If a high water-cement ratio is used during mixing, high amount of water eventually dries off and leaves voids that are not filled by hydration products Porosity is observed to increase with an increase in water to cement ratio.[22] Furthermore, the set Biodentine consists of 5 μm round particles embedded in a calcium silicate hydrate matrix.[23] A dense micro-structure is seen in set Biodentine as the porosity is almost filled by calcium silicate hydrate and calcium hydroxide. An isothermal calorimetry analysis performed at 37°C to follow the kinetics of hydration of the cement paste revealed the following; Biodentine paste displayed a narrow and intense exothermic peak after 30 min, whereas pure tricalcium silicate paste displayed a broad exothermic peak after 210 min. This indicates that Biodentine has greater kinetics of hydration than pure tricalcium silicate. The early exothermic peak after 30 min is also an indicator of the rise of mechanical strength of the set Biodentine cement.[24]

Another possible clarification for high compressive strength of Biodentine may be related to smooth structure of the set cement comprised of fine particle that may be responsible for causing the particles to adhere to one another and low water/cement ratio.[25] In Biodentine the crystallization of the material continues up to 4 weeks, resulted in improving the strength. Therefore, in clinical usage such as direct pulp capping, the use of Biodentine appears to have advantages, particularly because it can be placed in bulk and has a short setting time suggesting it would be better to postpone restorative procedures for 96 hours to 1 week. The manufacturer of Biodentine also recommended delaying the placement of the final restoration for at least 1 week to achieve more mature crystalline formations.[25]

According to current study, the result of compressive strength of HP repair MTA Angelus was significantly lower than ProRoot MTA in all different time intervals. ProRoot MTA and HP repair MTA Angelus were highly significantly increased in the first week according to their first day, from setting time, then they are both shows significantly decreased after 3 weeks and showed non-significantly increased comparing to the first day. This difference in compressive strength values can be because of differences in their structure composition. ProRoot MTA consists of 75% Portland cement, 20% bismuth oxide, and 5% calcium sulfate dehydrate; while, HP repair MTA Angelus contains 80% Portland cement and 20% bismuth oxide with no addition of calcium sulfate in an attempt to reduce the setting time.[16,17]

The structure of ettringite crystals depends on the presence of calcium sulfate dehydrate, and because of the lack of this component in HP repair MTA Angelus, it may be concluded that this formulation of MTA lacks ettringite crystals. The lack of these crystalline formations was most probably the reason for the lower compressive strength values of HP repair MTA Angelus compared with ProRoot MTA. In another hand, high sulfate contents can cause gradual dissolution and decomposition of the products of the hydration process that acts as the binding agent of silicate-based cements. Consequently, the calcium to silicate ratio declines, resulting in a loss of strength.[16,17]

These results of MTA are agreeing to those who recorded by the researcher Torabinejad et al.[14] in 1995 which was shows highly significance increasing in compressive strength. The researcher investigated the compressive strength of MTA after 1 day and 3 weeks' 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 3 weeks. In the current study, a similar trend was shown since the compressive strength of both ProRoot and HP repair MTA are increased after 3 weeks about 13.53 and 41.71 MPa. Nevertheless, this growing was not statistically significant according to the first day. from the setting time which was reported as 39.48 and 8.27 both were measured in MPa. This difference may be attributed to differences in material composition since it was first introduced.[14]

The HP repair MTA in our study recorded as the lowest degree of the compressive strength in all different time intervals. That's mean the HP repair MTA Angules is grainy and has poor consistency, making it difficult to handling and manipulation in clinical situation. powder consists of fine hydrophilic particles. The principle compounds present in this material are tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide. In addition, there are small amounts of a few other mineral oxides that are responsible for the chemical and physical properties of this aggregate.[26]

The ProRoot MTA was significantly lower than Biodentine in compressive strength, but was significantly higher than HP repair MTA Angules. The advantages of Biodentine relative to ProRoot MTA include mechanical mixing, which avoids inconsistencies within the material, and improved handling characteristics. ProRoot MTA exhibited higher porosity than Biodentine. ProRoot MTA includes 20% bismuth oxide. [27] Thus, the effective water -cement ratio of ProRoot MTA is high.[28] The set HP repair MTA cement possessed coarser structure in comparison with that of Biodentine. This may explain why it exhibited lower strength than latter.[28] The in vivo environment cannot be replicated using the in vitro method employed to assess compressive strengths in the current study. However, the study results might provide information that can aid clinicians in selecting the best CSC, particularly in cases involving vital pulp therapy or the repair of furcation perforations.

Conclusion

According to this in vitro study the compressive strength of the MTA is increased with the time but it needs more time to set which is difficult to the clinician, therefore; Biodentine and ProRoot seems to be better in mechanical properties than the HP Repair MTA Angules.

Our findings indicate that post ponding the restoration procedures until 1week after cement placement used as base material is recommended to reduce the possibility of displacement.

Conflicts of interest

The authors reported no conflicts of internets.

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