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The Effect of Three Commonly Used Endodontic Materials on the Strength and Hardness of Root Dentin

J. Derek White, William R. Lacefield, L. S. Chavers, and Paul D. Eleazer

The purpose of this study was to determine if calcium hydroxide, mineral trioxide aggregate, or sodium hypochlorite caused a change in the force required to fracture root dentin. Ten bovine central and lateral incisors were machined using various saws and drills to produce a cylinder of dentin with a 6.0-mm outer diameter 3.5-mm inner diameter and a length of 10 mm. The cylinders were cut lengthwise into four symmetrical pieces. The canal sides of the sections were then placed into Petri dishes containing a 1-mm depth of calcium hydroxide, mineral trioxide aggregate, sodium hypochlorite, or physiologic saline (control). The samples remained in the dishes for 5 weeks and were then shear tested by using an Instron machine. Data were analyzed using an ANOVA test for comparison of the groups as a whole, and a *t* test was used to compare each quarter section with its control from the same tooth. A 32% mean decrease in strength was discovered for calcium hydroxide, a 33% decrease in strength for mineral trioxide aggregate, and a 59% decrease for sodium hypochlorite. All decreases in strength were statistically significant: $p < 0.001$ for calcium hydroxide, $p = 0.027$ for mineral trioxide aggregate, and $p < 0.001$ for sodium hypochlorite. Results indicated that root dentin was weakened after 5 weeks of exposure to calcium hydroxide, mineral trioxide aggregate, or sodium hypochlorite.

The use of calcium hydroxide in endodontics was popularized by Hermann in 1920 (1). Although well documented at its inception, the clinical applications during the ensuing years were poorly reported (2). Reports in the past 40 yr frequently cite the use of calcium-hydroxide-based materials as preobturation endodontic medications to disinfect the root canal and to induce apexogenesis and apexification (3). Calcium hydroxide is normally mixed with water to form a slurry and inserted into the tooth. Several properties of calcium hydroxide have led to its popularity. First, diffusion of hydroxyl ions across the dentin leads to pH elevation, which may decrease osteoclast activity especially where the cemental layer has been broken (4). Secondly, the diffusion of calcium ions from the material into the dentin may aid in mineralization (5). Third, its antiseptic properties may aid in the elimination of remaining bacteria after proper instrumentation of the canal system (6).

In apexification Dannenberg recommends that calcium hydroxide remain in the root canal for a period of 6 months to 1 yr to allow for the complete closure of the apex (7). The goal of apexogenesis is for the vital apical pulp beneath a calcium hydroxide dressing to continue root-end development. Its pH is approximately 12.4 when freshly introduced into the canal (6).

Sodium hypochlorite is the endodontic irrigation fluid used by many practitioners (8). Its strong proteolytic action on pulp tissue remnants aids canal debridement. Research and clinical experience have shown that sodium hypochlorite has several properties that contribute to effective chemical debridement of the root canal system. It acts as a lubricant for instrumentation and can flush loose debris from root canals (9). Sodium hypochlorite is also an effective antimicrobial agent with the capability of disinfecting the root canal (10). Furthermore, it is effective in dissolving both vital and nonvital tissue, and it has been shown to significantly increase the permeability of dentin (11). Many practitioners leave sodium hypochlorite in the canal between appointments. Its pH is 11.85 in 5.25% concentration (12).

Mineral trioxide aggregate (MTA) is a powder of oxides combined with other mineral hydrophilic particles, which crystallize in the presence of moisture (13). The major components of MTA are tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide (13). Hydration of the powder results in a colloidal gel, which solidifies in a few hours. Research has indicated that MTA seals better than amalgam, intermediate restorative material, or Super EBA, and it reportedly adapts better to the surrounding dentin of the root-end preparation (14). MTA is used by many endodontists for surgical and nonsurgical root-end filling and perforation repair. Its effect on dentin has not been previously reported. Recent studies have also shown favorable results in the use of MTA as an apical barrier material for root-end closure in apexification and apexogenesis (15). Its pH is 12 to 13 in aqueous solution (13).

TABLE 1. Force needed to fracture dentin based on weight of each sample, in Newtons/gram

	Force to break samples (mean)	Force to break samples (range)	Standard Deviation	% weaker than control (mean)	% weaker than control (range)
Control	1317.6	927.7 –1729.6	235.7	—	—
Calcium hydroxide	892.1	432.9 –1337.1	309.6	32.3%	8.89 –61.5
MTA	885.2	329.6 –1661.9	365.2	32.8%	1.9 –173.3
Sodium hypochlorite	539.2	193.8 –883.6	242.4	59.1%	17.4 –86.0

Right two columns are percentages comparing each section with the control section from the same tooth.

These three materials are used routinely for the treatment of various problems involving the pulp and root canal system. More specifically MTA and calcium hydroxide are often used in trauma cases in which the tooth is immature to encourage apical root closure. The inter- and peritubular dentin in such teeth is not fully developed. Andreasen et al. (16) theorized that the proteolytic action of calcium hydroxide could weaken a tooth by up to 50% and this weakness could lead to an increase in fracture. It could also be possible for other proteolytic agents such as sodium hypochlorite or MTA to weaken root dentin. The purpose of this study was to determine if these three commonly used materials lessen the force required to fracture root dentin.

MATERIALS AND METHODS

The in vitro model for preparation of dentin test specimens originally described by Haapasalo and Ørstavik (17) was used in the present study with some modifications. Freshly extracted, intact bovine incisors were used for the experiment. Bovine teeth are readily available and share basic microscopic morphological similarity with human teeth. The cows were of various ages and this was apparent by the canal sizes encountered when processing the teeth. The teeth were kept in physiologic saline to prevent dehydration and to maintain an environment similar to that in vivo. The apical 5-mm and two-thirds of the crown were removed with a water-cooled, rotating diamond saw at 700 rpm (Isomet; Buehler Ltd., Lake Bluff, IL, U.S.A.). The root sample was aligned in a lathe, and a 3.5-mm diameter twist drill was used to eliminate the canal. A cylinder of uniform wall thickness was made with a water-cooled bone biopsy hole saw (Stryker Corp., Kalamazoo, MI, U.S.A.) at low speed ($<$100 rpm). This produced a symmetrical cylinder of dentin of 6-mm outer diameter, 3.5-mm inner diameter, and approximately 15-mm long. The end of the dentin cylinder was embedded in self-cure acrylic resin in an acrylic block. These cylinders were cut lengthwise into four symmetrical pieces using the rotating diamond saw. A cross-section cut was made near the acrylic with the rotating saw, leaving four pieces 10 mm in length. All sections were then weighed on a Mettler balance (Mettler Instrument Company, Highstown, NJ, U.S.A.) to verify accuracy of slices and for use in later calculations. Each of the dentin sections was assigned to a control or an experimental group by random draw. The sections were then placed into one of four Petri dishes containing a 1-mm depth of calcium hydroxide, sodium hypochlorite, MTA, or physiologic saline. The samples remained in the dishes for 5 weeks with water added to the calcium hydroxide and MTA every 3 to 4 days as needed to maintain moisture. Saline and sodium hypochlorite were also added to their respective dishes as needed to maintain their proper 1-mm levels. Upon completion of the 5-week period, each sample was rinsed with saline. Samples were embedded in self-cure acrylic resin within a premanufactured brass cup such that exactly 6 mm protruded from the cup. Each cup was then placed into a holding device and the dentin sample loaded under shear stress with an Instron Universal Testing Machine (Instron Corp., Canton, MA, U.S.A.) exactly 2 mm from the acrylic base. The Instron attachment used to fracture the samples was a blade-shaped device (0.3 mm in width) custom made for a similar experiment. Because of the circular shape of the samples, the Instron attachment had only a point contact with the samples and the surface area was impractical to determine. This prevented us from reporting results as force per unit area. The load was applied by the Instron at a rate of 0.02 mm/min. The force required to fracture the dentin was recorded and subjected to statistical analysis. An ANOVA test was used for comparison of the group totals, and a *t* test was used to compare each quarter section with its control from the same tooth.

RESULTS

The force required to fracture the test samples and controls are presented in Table 1. The individual weights of each sample and the force required to fracture each respective sample are presented in Table 2. The right column in Table 2 is the sum of all four samples of each tooth divided by four to give the mean weight of each quarter.

The mean force required to fracture the calcium hydroxide samples was 892.1 N/g. The mean force required to fracture the control was 1317.6 N/g. The range for the calcium hydroxide specimens was 432.9 to 1337.1 N/g, and the range for the controls was 927.7 to 1729.6 N/g. This was 32% lower in strength for the calcium hydroxide. The values showed statistical significance at $p < 0.001$.

The mean force required to fracture the MTA samples was 885.2 N/g versus the control value of 1317.6 N/g. The range for MTA was 329.6 to 1661.9 N/g. This was 33% less than the force needed to fracture the control. The MTA samples tested showed statistical significance at $p = 0.027$.

The mean force required to fracture sodium hypochlorite samples was 539.2 N/g versus the control at 1317.6 N/g. The range for sodium hypochlorite was 193.8 to 883.6 N/g. The sodium hypochlorite mean was 59% less than the control. This was statistically significant at $p < 0.001$.

DISCUSSION

Through this experiment we observed a weakening of all samples with exception of one sample in the MTA group that was strengthened (tooth 10). A possible explanation for this is that the

TABLE 2. Raw data of weights and force to fracture of each tooth section

Tooth	Calcium Hydroxide		MTA		Sodium Hypochlorite		Control		Total Weight (mean)
1	0.116	135.8	0.110	36.3	0.138	50.8	0.132	187.0	0.496/4 = 0.124
2	0.134	106.7	0.122	96.1	0.132	77.1	0.144	134.1	0.502/4 = 0.126
3	0.112	75.0	0.153*	101.6	0.107	67.7	0.110*	158.3	0.482/4 = 0.121
4	0.114	128.1	0.096*	72.1	0.137	120.3	0.128	172.2	0.475/4 = 0.119
5	0.110	140.4	0.124	143.8	0.118	22.9	0.134	187.7	0.486/4 = 0.122
6	0.116	103.6	0.139*	159.2	0.120	40.9	0.106	123.7	0.481/4 = 0.120
7	0.105*	68.1	0.119	91.2	0.162*	143.1	0.134	143.5	0.520/4 = 0.130
8	0.130	173.8	0.110	87.7	0.131	48.3	0.122	211.0	0.483/4 = 0.123
9	0.085*	50.7	0.090	59.8	0.096	37.2	0.149*	230.9	0.420/4 = 0.105
10	0.073*	31.6	0.141*	234.3	0.100	75.5	0.083*	77.0	0.397/4 = 0.099
Average	0.110	101.4	0.120	108.2	0.124	68.4	0.124	162.5	

* Greater than 15% variation of sample weight due to cutting inaccuracy.

Left column in each series is dentin section weight in grams, and second column for each material is force required to fracture sample in Newtons.

MTA used in this experiment might not have been a homogeneous mixture. The sectioning of tooth 10 was less than ideal even though results were expressed in Newtons per gram. The MTA samples also showed the greatest range in force required to fracture. Previous studies have noted MTA being soft or mushy upon reentry into the canal (18). This seems to be caused by a failure of the MTA to set, which could also be attributed to a nonhomogenous mix. If this were true, the various components that make up MTA might not have been proportionate in our mix, and each of the samples could have been exposed to different concentrations of these components. The one sample that was strengthened in our experiment could have been exposed to a greater proportion of an MTA component, which strengthened the sample. We also used an early version of MTA (obtained from Dr. Torabinejad, Loma Linda, CA, U.S.A.) that had perhaps separated during storage.

We propose that the weakening observed was caused by breakdown of the protein structure caused by the alkalinity of the materials used. Previous studies have reported that alkaline materials can cause conformational change of proteins, and it seems feasible that this phenomenon could be causing the weakening observed in this experiment. We currently have other studies planned to further investigate these changes. This study suggests a possible advantage of minimal time of treatment when using these materials in the canal to decrease the weakening of treated teeth. Development of effective materials with more neutral pH may be desirable. Use of restorative materials that strengthen the tooth should be considered because of this weakening of dentin by alkaline materials during endodontic treatment.

Dr. White is an endodontics resident; Dr. Lacefield is professor, Department of Restorative Dentistry; Mr. Chavers is a research instructor, Department of Diagnostic Sciences; Dr. Eleazer is professor and chair, Department of Endodontics & Pulp Biology, University of Alabama at Birmingham, Birmingham, AL. Address requests for reprints to Paul D. Eleazer, DDS, MS, Professor and Chair, Department of Endodontics & Pulp Biology, University of Alabama at Birmingham, School of Dentistry #417, 1530 3rd Avenue, South Birmingham, AL 35294-0007.

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