

Setting Expansion of Gray and White Mineral Trioxide Aggregate and Portland Cement

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Abstract

One possible reason for the sealing ability of mineral trioxide aggregate (MTA) is its slight expansion upon setting. Both gray mineral trioxide aggregate (GMTA) and white mineral trioxide aggregate (WMTA) are composed of approximately 75% Portland cement (PC). WMTA differs from GMTA in its lower content of tetracalcium aluminoferrite. This difference in composition may affect setting expansion. The purpose of this study was to compare the hygroscopic linear setting expansions of GMTA, WMTA, and PC with a new device. Materials were mixed with water, placed into a cylindrical mold, and covered with sterile water or Hank's balanced salt solution (HBSS). Expansion changes were measured by using a linear variable displacement transformer dilatometer. One-way analysis of variance and post hoc tests ($\alpha = 0.05$) showed the mean expansion at 24 hours was 1.02% for GMTA, 0.29% for PC, and 0.08% for WMTA in water immersion and 0.68% for GMTA and 0.11% for WMTA in HBSS immersion. GMTA expanded significantly more than WMTA in either water or HBSS immersion. (*J Endod* 2008;34:80–82)

Key Words

Linear setting expansion, mineral trioxide aggregate, Portland cement, root repair material

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Certain commercial materials and equipment are identified in this paper to specify the experimental procedure. In no instance does such identification imply recommendation or endorsement by the U.S. Navy or that the material or the equipment identified is necessarily the best available for the purpose.

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Mineral trioxide aggregate (MTA) was introduced in 1993 by Loma Linda University as a possible root-end filling material or for repair of lateral root perforations (1, 2). ProRoot MTA (Dentsply Tulsa Dental, Tulsa, OK) is the commercial version of MTA introduced in 1998 that consists of 75% Portland cement, 20% bismuth oxide, and 5% gypsum by weight (3). MTA has been used for both surgical and nonsurgical endodontic treatments, such as a root-end filling material, pulp capping, apical plug for apexification, barrier for internal bleaching, internal resorption obturator, and a sealer for root perforations (4). MTA is a powder that consists of fine hydrophilic particles that form a colloidal gel in the presence of water that solidifies into hard cement within approximately 4 hours. The manufacturer claims MTA is capable of sealing off all pathways between the root canal system and the surrounding tissues, allowing less bacterial migration.

A white MTA (WMTA) was developed by Dentsply Tulsa Dental in 2002. This version improved esthetics because the original gray-colored MTA (GMTA) was prone to darken overlying tissues. The principal components of MTA are tricalcium oxide, tricalcium silicate, bismuth oxide, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and calcium sulfate dihydrate. WMTA differs from GMTA in that it has a significant reduction in the proportion of the tetracalcium aluminoferrite component (5–8).

A study by Matt et al. (7) compared WMTA and GMTA when used as root apical barriers. WMTA samples were found to leak significantly more than GMTA. The WMTA used in the study was a formulation before the introduction of an improved WMTA available in late 2003. In response to complaints of poor handling properties, the manufacturer altered the particle size of WMTA in 2003. Newer leakage studies have shown that the improved WMTA behaved similarly to GMTA (9–12). In a saliva leakage study, Al-Hezaimi et al. (5) showed more saliva leakage with WMTA compared with GMTA. Four roots of the WMTA samples leaked and one of the GMTA leaked; however, this difference was not statistically significant. Ferris and Baumgartner (11) compared WMTA and GMTA in a bacterial leakage study and also found small but insignificant differences between the two formulations. Although the differences between the two materials in these studies were not significant, perhaps the small differences were caused by differences in setting expansion. Recently, Islam et al. (13) and Chng et al. (14) found GMTA and WMTA to expand 0.28% and 0.30%, respectively. Both studies used the method prescribed for dental root canal sealing materials in International Organization for Standardization (ISO) 6876:2001. However, root-end filling materials have not been included in the ISO technical standards and are not subject to meeting standardized requirements (14). The requirements for compliance for root canal sealers ISO 6876.2:1999 have been set at linear expansion of not more than 0.1% or shrinkage not more than 1%. Root canal sealers may not require the strict limits set forth by ISO because of their low bulk strength. However, this leads to many questions for other classes of cements, such as MTA, where no maximum expansion requirement has been established. Current standards may not be appropriate for linear expansion measurements of core obturation sealers such as MTA. In their study testing the setting dimensional changes of root canal sealers, Orstavik et al. (15) questioned the accuracy of the testing methodology for dimensional changes of 0.1%. With this in mind, a new device was constructed for this experiment that may more accurately measure linear expansion of MTA. The purpose of this study was to compare the hygroscopic linear setting expansions of GMTA, WMTA, and PC with a new device.

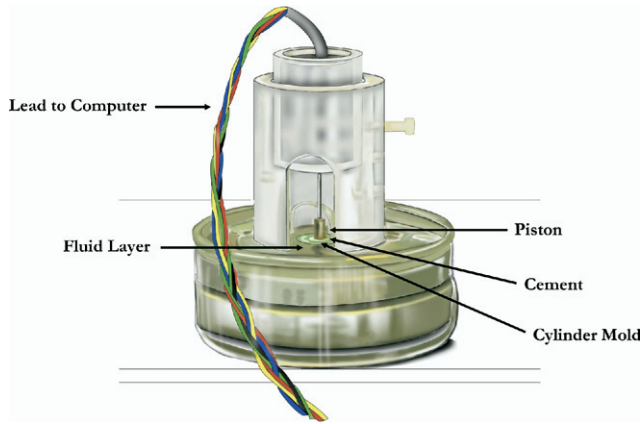


Figure 1. LVDTD linear expansion measuring device.

Materials and Methods

A novel linear expansion measuring device was fabricated for this study at the American Dental Association Foundation Paffenbarger Research Center, National Institute of Standards and Technology, Gaithersburg, MD. It consisted of a dilatometer and a nylon piston attached to a linear variable displacement transformer (LVDT). The dilatometer housed a centralized cylindrical polyvinyl siloxane mold measuring 10 mm in height and 5 mm in diameter yielding a specimen of approximately 0.6 g total mass. GMTA and WMTA powders were mixed on a nonabsorbent paper pad with the supplied ampoule of sterile water according to the manufacturer’s instructions. Portland cement (Quikrete Portland Cement Type 1; The Quikrete Companies, Atlanta, GA) and water were weighed at a mass powder-to-liquid ratio of 3:1 to correspond with the powder-to-liquid ratios of the MTA mixtures. Each mixture was vibrated into the cylindrical mold to avoid the inclusion of air. The MTA samples and mold were covered on one end with either distilled water or Hank’s balanced salt solution (HBSS) and allowed to harden at room temperature. Portland cement was only tested under covering with distilled water because it served primarily as a general comparison to previous studies. The mold was constrained so that displacement caused by linear change could only occur at one end of the mold. To measure the linear setting changes of each specimen, a nylon piston attached to a linear variable displacement transformer was placed on the surface of the setting cement (Fig. 1). A computer logged the piston position once per second for 24 hours. The testing apparatus had a resolution of 0.02 μm, translating to an accuracy of 0.002% for

TABLE 1. Mean Percentage of Linear Setting Expansion of GMTA and WMTA Submerged in Distilled Water or HBSS and PC Submerged in Water

Groups	300 min (SD) (n)	460 min (SD) (n)	24 hrs (SD) (n)
GMTA/water	0.47 (0.09) (5)	0.74 (0.15) (3)	1.02 (0.19) (3)
GMTA/HBSS	0.34 (0.04) (3)	0.45 (0.06) (3)	0.68 (0.12) (3)
WMTA/water	0.04 (0.01) (5)	0.06 (0.01) (5)	0.08 (0.01) (3)
WMTA/HBSS	0.09 (0.03) (3)	0.10 (0.03) (3)	0.11 (0.03) (3)
PC/water	0.24 (0.05) (5)	0.26 (0.04) (5)	0.29 (0.04) (5)

SD, standard deviation.

the 10-mm specimens. Three to five specimens of each material were tested over the 24-hour period and statistically compared by using analysis of variance and a Student *t* test. Early statistical analysis showed the data were so tight and the standard deviations so small that it would only be necessary to complete the study by using group sample sizes of 3. The significance level was set at α = 0.05.

Results

The expansion of the samples was monitored as a function of time. All three materials expanded upon setting. A representative kinetic graph of expansion versus time for the three materials is shown in Figure 2A. Both MTA materials achieved approximately half of their final linear setting expansion by 300 minutes, with approximately 75% of expansion occurring by 460 minutes (7 hours 40 minutes) and the final 25% of total expansion occurring between 460 minutes and 24 hours. The PC showed much faster expansion, with nearly 80% of total expansion occurring within the first 300 minutes (5 hours). The final steady state linear setting expansion under distilled water covering at (mean ± standard deviation) 24 hours was GMTA = 1.02% ± 0.19%, PC = 0.29% ± 0.04%, and WMTA = 0.08% ± 0.01% (Fig. 2B and Table 1). The linear expansion of all three materials was significantly different from each other at p < 0.05.

The comparison of final linear setting expansion between GMTA and WMTA covered with HBSS showed a similar significant difference with GMTA = 0.68% ± 0.12% and WMTA = 0.11% ± 0.03% (mean ± standard deviation) at p < 0.05. The kinetics of linear expansion for both materials was also similar to that observed in water. A comparison of the final linear expansion between water and HBSS coverings showed a reduction in linear expansion for GMTA that was insignificant (mean water/HBSS = 1.02/0.68, p = 0.054) and a small increase in linear expansion for WMTA that was also insignificant (mean water/HBSS = 0.08/0.11, p = 0.179).

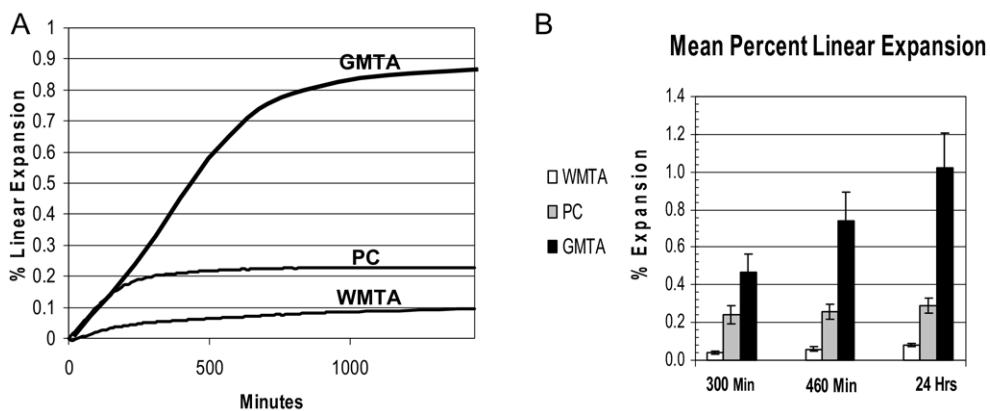


Figure 2. (A) Representative linear setting expansion kinetics for GMTA, PC, and WMTA (submerged in distilled water). (B) Mean linear setting expansion results for WMTA, PC, and GMTA with standard error bars (submerged in distilled water).

Discussion

To mimic the practice of MTA placement *in vivo*, the specimens in this study were covered with distilled water or HBSS so that they could imbibe water and gain mass during curing. Overall, net linear expansion occurred. Bentz et al. (16) found that in a sealed condition (nonsaturated) typical physical shrinkages of hydrating Portland cement pastes are on the order of 0.01% to 0.1% in contrast to the chemical shrinkage that can be on the order of 10% by volume (17). Although not yet completely understood, in a saturated environment, cement hydration is often accompanied by overall expansion because of crystal growth and possible swelling of gel hydration products (16). Thus, setting of GMTA and WMTA would also be expected to exhibit slight linear expansion in a saturated environment.

Sterile water immersion was selected to comply with the manufacturer's recommendation that MTA be covered with a moistened cotton pellet during set. HBSS immersion was selected to more closely simulate the environment that MTA would be exposed to while setting in surgical use. HBSS has a similar osmolality of $280\% \pm 5\%$ mOsm/kg H₂O compared with the osmolality of blood of 270 to 300 mOsm/kg H₂O. The WMTA immersed in HBSS had an insignificant increase in expansion when compared with immersion in water. GMTA had a decrease in expansion that nearly reached significance. The small sample size (3) may have reduced the ability to confirm this difference. HBSS contains sodium hydrogen phosphate (HNa₂O₄P). Phosphate buffering could possibly affect setting expansion, or the iron-containing component could have been more or less reactive in a phosphate environment. The primary difference between GMTA and WMTA is the higher level of tetracalcium aluminoferrite in GMTA. If this component reacts differently in HBSS than in water, it could explain the reduction in expansion observed only in the GMTA.

As previously mentioned, Islam et al. (13) and Chng et al. (14) compared the physical properties of GMTA to WMTA and found GMTA to expand 0.28% and WMTA to expand 0.30%. They also found setting times to be 2 hours and 55 minutes for GMTA and 2 hours 20 minutes for WMTA. The different findings between these and the current study are likely caused by the difference in testing methods. Both studies above used Gillmore needles to determine setting time as a change in material viscosity in accordance with ISO 6876:2001. In the current study, the LVDTD measured sample elongation as an indicator of setting for a period well beyond the recommended setting time. The LVDTD provided a highly sensitive method for detecting linear expansion that might not be possible using ISO 6876:2001 standards; a 1-mm thick sample is set in a ring covered top and bottom with glass plates. Linear expansion is determined by measuring any increase in distance between the glass plates upon final set. The LVDTD in the current study was not able to be thermostated to body temperature, and the kinetics of expansion was likely slower because of the lower setting temperature.

The purpose of an endodontic filling material is to seal the root canal to prevent bacterial ingress or egress. To seal, the material must adapt and preferably adhere to the root canal dentin surface and have good dimensional stability (15). Newer leakage studies have shown GMTA and WMTA to respond similarly, although there is still a trend for

WMTA to have more leakage. This study suggests differences in setting expansion as one possible reason for this tendency. A difference between 0.1% versus 1.0% expansion may significantly affect the seal of MTA. It is unknown what significance this may have under clinical conditions.

Under the conditions of this study, GMTA linear setting expansion was significantly greater than that of WMTA and the Portland cement control. The descending order of expansion was GMTA > PC > WMTA.

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References

1. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. *J Endod* 1993;19:541–4.
2. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. *J Endod* 1993;19:591–5.
3. Material Safety Data Sheet (MSDS). ProRoot MTA (mineral trioxide aggregate) Root Canal Repair Material. Tulsa, OK: Dentsply Tulsa Dental; 2002.
4. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. *J Endod* 1999;25:197–205.
5. Al-Hezaimi K, Naghshbandi J, Oglesby S, Simon JH, Rotstein I. Human saliva penetration of root canals obturated with two types of mineral trioxide aggregate cements. *J Endod* 2005;31:453–6.
6. Asgary S, Parirokh M, Eghbal MJ, Brink F. Chemical differences between white and gray mineral trioxide aggregate. *J Endod* 2005;31:101–3.
7. Matt GD, Thorpe JR, Strother JM, McClanahan SB. Comparative study of white and gray mineral trioxide aggregate (MTA) simulating a one- or two-step apical barrier technique. *J Endod* 2004;30:876–9.
8. Al-Hezaimi K, Al-Hamdan K, Naghshbandi J, Oglesby S, Simon JH, Rotstein I. Effect of white-colored mineral trioxide aggregate in different concentrations on *Candida albicans* *in vitro*. *J Endod* 2005;31:684–6.
9. Tselnik M, Baumgartner C, Marshall JG. Bacterial leakage with mineral trioxide aggregate or resin-modified glass ionomer used as a coronal barrier. *J Endod* 2004;30:782–4.
10. Hamad HA, Tordik PA, McClanahan SB. Furcation perforation repair comparing gray and white MTA: a dye extraction study. *J Endod* 2006;32:337–40.
11. Ferris DM, Baumgartner JC. Perforation repair comparing two types of mineral trioxide aggregate. *J Endod* 2004;30:422–4.
12. Parirokh M, Asgary S, Eghbal MJ, et al. A comparative study of white and grey mineral trioxide aggregate as pulp capping agents in dog's teeth. *Dent Traumatol* 2005;21:150–4.
13. Islam I, Chng HK, Yap AU. Comparison of the physical and mechanical properties of MTA and Portland cement. *J Endod* 2006;32:193–7.
14. Chng HK, Islam I, Yap AU, Tong YW, Koh ET. Properties of a new root-end filling material. *J Endod* 2005;31:665–8.
15. Orstavik D, Nordahl I, Tibballs JE. Dimensional change following setting of root canal sealer materials. *Dent Mater* 2001;17:512–9.
16. Bentz DP, Jensen OM, Hansen KK, Olesen JF, Stang H, Haecker CJ. Influence of cement particle-size distribution on early age autogenous strains and stresses in cement-based materials. *J Am Ceram Soc* 2001;84:129–35.
17. Bentz DP. Three-dimensional computer simulation of Portland cement hydration and microstructure development. *J Am Ceram Soc* 1997;80:3–21.