A Quantitative Comparison of the Fill Density of MTA Produced by Two Placement Techniques

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Abstract

This study compared the fill density of mineral trioxide aggregate (MTA) produced by hand condensation with that produced by hand condensation with indirect ultrasonic (US) activation. Sixty acrylic blocks with straight or curved canals were instrumented to an apical size 45, and weighed with a digital electronic balance. In 30 randomly chosen specimens, the canal was filled with MTA by hand condensation and weighed. The MTA was removed; the canal was rinsed and dried, and refilled using hand condensation with indirect US activation. In the other 30 specimens, the procedure was carried out identically but in reverse order. The blocks were then reweighed. The weight of the MTA fill produced by the two placement methods in the two canal configurations was analyzed by a two-way ANOVA. Hand condensation with indirect US activation resulted in an MTA fill that was statistically significantly heavier, and thus denser, than that accomplished by hand condensation alone in both curved and straight canals ($p < 0.0001$). *(J Endod 2006;32: 456–459)*

Key Words

Condensation, density, MTA, ultrasonic

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Mineral trioxide aggregate (MTA) was introduced to endodontics by Torabinejad et al. in 1993 (1) and has been used successfully in the repair of lateral root perforations and furcal perforations, as a vital pulp capping agent, as an apical plug in one visit apexification, and as a root-end filling material. A review article by Alhadainy (2) described the ideal perforation repair material as being non-toxic, biocompatible, nonabsorbable, radio-opaque, bacteriostatic, and having excellent sealing properties. MTA has proven to be a material with many of these qualities. Previous studies (3–5) have demonstrated cemental repair, formation of bone, and regeneration of the periodontal ligament when MTA is used in endodontic surgery. It has been shown to be biocompatible in both in vitro and in vivo investigations (6–8). Leakage studies indicate that MTA provides a superior seal even when placed under adverse conditions, such as in the presence of moisture and blood (9–12).

Because of its success as a root end filling material, some investigators have suggested using MTA to obturate the entire root canal system (13–15). Vizgirda and associates (16) evaluated the potential of using MTA as a root canal filling by comparing its apical sealing ability with that of laterally condensed gutta-percha with sealer and high-temperature thermoplasticized gutta-percha with sealer in extracted bovine teeth. MTA was placed into the canal using a lentulo spiral until the material reached the canal orifice. Their results suggested that gutta-percha obturation might provide an apical seal that was superior to MTA. A possible explanation for the poorer performance of MTA was that it was difficult to place and condense in the apical portion of the root canal. Conceivably, the use of US might improve the density of the MTA and thus provide a superior seal. Aminoshariae and associates (17) examined the adaptability of MTA to the walls of plastic tubes simulating root canal walls when placed from an orthograde approach using hand placement and ultrasonic methods. Samples were evaluated with a light microscope and radiograph for the degree of adaptability of MTA to the tube wall and for the presence of voids within the MTA material itself. They found that hand condensation resulted in better adaptation to the tube walls and fewer voids than the ultrasonic method. It is conceivable that the ultrasonic technique used may have actually created voids in the material and reduced its adaptability to the tube walls by the application of excessive ultrasonic energy.

To date, there have been no studies quantitatively comparing the fill density of MTA produced by hand condensation and ultrasonic activation. The purpose of this study was to quantitatively compare the density of MTA root canal filling produced by two different placement techniques: (a) hand condensation (H) and (b) hand condensation with indirect ultrasonic activation (US). In this study, it was hypothesized that placement of MTA with an optimal amount of ultrasonic activation would result in a higher fill density than with hand condensation alone.

Materials and Methods

Preparation of the Samples

There were 30 transparent acrylic blocks with 30-degree curved canals and 30 blocks with straight canals (Pecina & Associates, Waukegan, IL) used. The blocks with straight canals were designated as group S and those with curved canals as group C. For the straight canals, the working length was determined by placing a #15 Flexofile (Denstply Maillefer, Johnson City, TN) into the root canal until it was visible at the reservoir located at the apical end of the canal; 1.0 mm was then subtracted from the file length. This terminus was chosen so that a constricture would be preserved between the canal and the reservoir to prevent MTA from being extruded into the reservoir from which it could not be irrigated out between groups. In the acrylic blocks with 30-degree curved canal, the canal exits directly from the side of the block. Therefore, the working length was determined to be the point where the tip of the #15 file exited the canal so the MTA could be removed between groups by reverse flushing the canal from the exterior. All the canals were instrumented using K3 0.06 taper nickel-titanium (Ni-Ti) rotary files (Sybron-Endo, Glendora, CA) with a crown-down technique. The apical portion of each canal was prepared to a size 45 file with 0.06 taper. Patency was maintained by passing a #15 file to the apical foramen after the use of each rotary file. The canal was irrigated with 1 ml of water between each instrument use. Upon completion of instrumentation, the canal was dried with paper points. Each instrumented block was weighed to the nearest 0.1 mg using a digital electronic balance (Model GD603, Sartorius, Gottingen, Germany).

Obturation of the Canal

In half of the specimens, chosen at random, the canal was first filled with MTA using the hand condensation method; then the block was weighed. The MTA was removed, the canal dried, and the block was weighed again. The same canal was refilled using the hand method followed by indirect ultrasonic activation described below. In the other half of the specimens, the procedures were carried out identically but in reverse order.

The MTA was mixed according to the manufacturer's instructions (Tulsa Dentsply, Tulsa, OK). MTA was delivered into the canal incrementally using a nonsurgical MTA carrier (Micro Apical Placement System, Vevey, Switzerland). A Ni-Ti plugger (Obtura S-Kondenser, Obtura Corp., Fenton, MO) similar in size and taper to a 1-3 plugger was used to condense the MTA to the appropriate length in the apical third. In the middle and coronal third of the canal, a Ni-Ti plugger similar to a 5-7 plugger (Obtura S-Kondenser, Obtura Corp.) was used for the condensation. For both placement methods, each canal was incrementally filled with MTA. Each increment of MTA was immediately condensed using the appropriate Ni-Ti hand plugger. The obturation was judged to be complete when the MTA was filled to the top of the plastic block. A flat metal millimeter ruler was used to wipe off any excess to ensure that the fill was flush. Once completed, each block was immediately reweighed and the difference between the filled and empty weights calculated.

For the US method, after each MTA increment was condensed with a hand plugger to the appropriate length, the end of the plugger remained in contact with the MTA in the canal while it was indirectly activated for one second with a #1 ProUltra ultrasonic tip (Dentsply, Tulsa) in a Spartan ultrasonic unit (Obtura Corp.) set on its lowest power setting unit as shown in Fig. 1. The method and duration of ultrasonic activation of the material were developed in our pilot research.

Cleaning the MTA from the Canal

After the canal was initially filled with MTA using either of the two methods, the filling material had to be completely cleaned from inside the canal before the second obturation. In both groups C and S, the MTA was loosened by carefully threading a size 25 Flexofile into it until the file reached the full working length. In group C, the file was also inserted 3 mm into the canal from the apical foramen to facilitate the loosening of the MTA around the curve at the apical end. A copious amount of water was used to flush out the MTA from the canal. A radiograph was taken of the block to ensure that the canal was free of residual MTA. The canal was dried and the block was re-weighed. If any changes (gain or loss) in weight had occurred during the cleaning process, that specimen was eliminated from the study. The canal was then obturated with MTA using the second method.

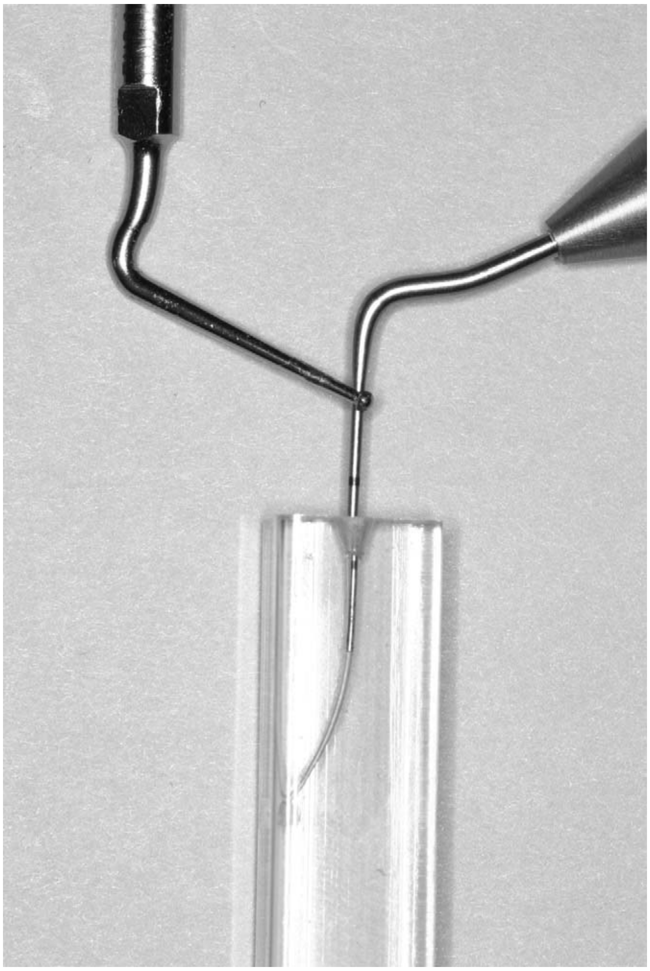

Figure 1. Ultrasonic condensation of the MTA in the plastic block achieved through indirect activation of a Ni-Ti plugger.

This study employed the repeated measured design used by Deitch et al. (18). Each sample, serving as its own control, was sequentially filled with MTA using two different placement methods and the weight of the MTA after each placement was compared. Data was analyzed by a two-way ANOVA for repeated measures, followed by the Tukey-Kramer Multiple-Comparison Test.

Results

In every sample in both groups C and S, the use of 1 s of indirect ultrasonic activation resulted in a greater fill density than that achieved using hand condensation alone (Fig. 2). The mean weight increases of the MTA using the two placement methods in the two canal types are presented in Table 1. There was a statistically significant increase in weight of MTA in the US group over the hand condensation group in both group S ($p < 0.0001$) and group C ($p < 0.0001$). In group S there was a mean net weight increase of 3.3 mg in using the US method, which was a 9.1% increase over the hand condensation method. In group C the mean weight increase in the US group was 3.5 mg, which was 10.07% higher than the hand condensation group. There was no statistically significant difference in weight increase between the straight canals and the 30-degree curved canals; and there was no interaction between the variables.

Discussion

According to its MSDS (19), MTA consists of approximately 75% Portland cement, with the addition of 5% gypsum to control the setting

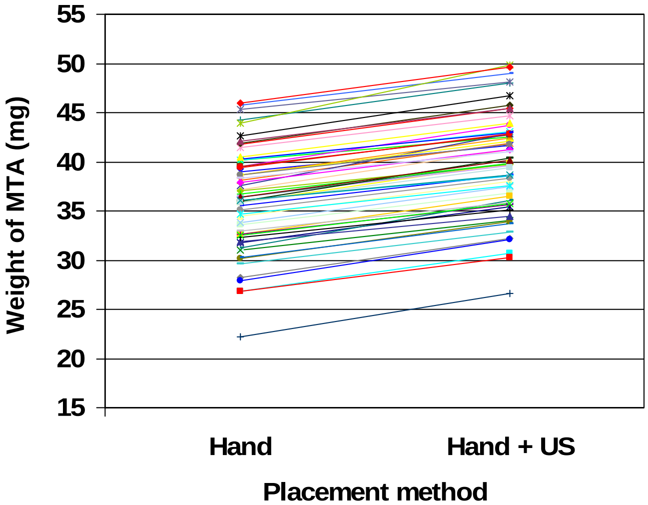

Figure 2. Comparison of the weight of MTA in the blocks achieved by hand condensation alone (H) versus that achieved by hand condensation followed by US. Note the uniformly and consistently greater weight achieved by the latter method.

time (20) and 20% barium sulfate to effect radiopacity (3). Studies analyzing MTA and Portland cement have concluded that with the exception of the added bismuth there is no significant difference in elemental composition between the materials (21, 22). From a therapeutic standpoint, both materials show similar results when used for pulp capping (23, 24), similar low cytotoxicity (25, 26), and comparable resistance to leakage when used as a coronal seal (27). Therefore, the rheology, the flow of fluids, and deformation of solids under stress and strain, should also be similar for the two materials.

Portland cements are made by pulverizing clinkers (nodules of sintered materials) produced by calcining, or roasting, raw materials that contain lime, iron, silica, and alumina at very high temperatures. The proportion of these components is carefully controlled to produce five major types of Portland cements and numerous sub-types with various physical and chemical characteristics appropriate to their end use (28). During the calcining process, the lime combines with the silicates to make dicalcium silicate ($2CaO{\cdot}SiO_2$) and tricalcium silicate ($3CaO{\cdot}SiO_2$), and with the aluminates to make tricalcium aluminate ($3CaO{\cdot}Al_2O_3$) and tretracalcium aluminoferrite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$). This mixture is combined with calcium sulfate dihydrate or gypsum ($CaSO_4{\cdot}2H_2O$) to control the setting speed (29, 30). White Portland cement with identical physical properties is produced by simply removing the tetracalcium aluminoferrite (at higher cost) (3, 29). The relationship of white to gray MTA is apparently analogous to that of white and gray Portland cement (22, 31). These compounds theoretically occur if all components are at phase equilibrium, and thus may not reflect the complex crystalline and amorphous structures that depend upon the effects of many or the effects of actual kiln conditions in manufacturing. The behavior of the cements, however, will depend upon the mixture of these components (32).

Portland cements are hydraulic cements that harden by combining with water. During this hydration reaction a node forms on the surface of each cement particle that grows and expands until it coalesces with nodes from other cement particles (33). The internal microstructure of the hydrated cement continues to develop after the cement is set, and may continue for months or years so long as water is available (32). Curing the cement by keeping it moist for an extended time period ensures that this process continues and that the cement reaches its maximum strength (33).

Because the strength of Portland cement decreases as the water/cement ratio increases, it is desirable to limit the amount of water as much as possible. Similarly, MTA has been shown to solubilize more with time at higher water/cement ratios (34). A dry mix, however, will not have the necessary flow and workability needed for it to conform to the irregularities of the space into which it is placed. It will also contain a honeycomb internal structure that contains air pockets (33), with air comprising from 1 to 30% of the volume (35, 36). To minimize these flaws, increase strength, and improve density and homogeneity it is desirable to use some method of compacting the material during placement (33). Vibration accomplishes this by producing a series of rapid compressive impulses that reduce the surface friction between the cement particles that enabled the cement to support itself in a honeycombed condition. The mix now becomes unstable, individual particles begin to rotate, and the cement starts to flow. During this process the particles are re-arranged into a denser mass and the unwanted entrapped air escapes to the surface (36).

As the tip of the ultrasonic unit, or an instrument activated by the tip, moves it must displace any cement in its path. The degree of displacement and the amount of force determine the speed at which the consolidation takes place. The degree of displacement depends on the amplitude of the vibratory motion. The force equals mass X acceleration of the tip, while the acceleration in turn depends on the amplitude and the frequency of the motion. The greater the amplitude, the stronger is the impact against the cement. The greater the speed or frequency, the more impacts per second the cement receives. Because acceleration varies as the square of the frequency, it is more important than amplitude.

In previous studies where MTA unexpectedly failed to produce a good seal (16, 37), investigators speculated that the method used for placement of the material into a long canal, as opposed to a relatively shallow apical retropreparation, might be the cause of the material's failure rather than the material itself. Neither study attempted to vibrate or compact the material mechanically. Because there is an optimum vibration rate for every type of cement (36), we empirically investigated various combinations of time and ultrasonic power in pilot studies to arrive at the optimum values for each parameter.

We used the weight of the MTA as an indicator of fill density because the formula for density is: Density = Mass/Volume. Because the volume of the canal was kept constant in this study by using the same block for both condensation methods, any increase in weight of MTA would correspond to an increase in the fill density.

In the pilot phase of the study, we examined the difference in fill density of MTA that resulted from varying the number of seconds of indirect US activation at the lowest power from 1 to 5 s, and found that one second of indirect US produced the highest weight of MTA. Longer activation time produced voids with sufficient diameter to be detected radiographically, which resulted in a lower weight of MTA.

TABLE 1. Comparison of mean weight of MTA achieved by hand versus hand plus US condensation in straight and curved canals

Group	Hand (H)	Hand plus US	Difference	% increase	p
Straight	37.4 mg	40.7 mg	3.3 mg ± .0004	9.1% ± 1.66	<.0001
Curved	35.3 mg	38.8 mg	3.5 mg ± .0008	10.07% ± 2.66	<.0001

The results of our study demonstrated that hand condensation of MTA followed by indirect ultrasonic activation resulted in a 10.07% increase in mean weight in curved canals and 9.1% increase in straight canals in plastic blocks. These results differ from those reported by Aminoshariae and associates (17). Their study evaluated the adaptability of MTA to the walls of polyethylene tubes using hand condensation and ultrasonic placement and concluded that hand condensation resulted in a fill that was more uniform and had fewer voids than ultrasonic placement. Several differences between these two studies are worthy of note. First, our study was quantitative in nature while theirs was qualitative, relying upon evaluation with a light microscope and radiograph to determine the degree of adaptability of MTA to the tube wall and to detect voids within the MTA material itself. Their analysis was limited to a surface view of the material; any internal voids could easily have remained undetected. A quantitative analysis that measures the weight of the MTA in the canal may provide a more accurate evaluation of the density of the fill.

Second, their study used direct ultrasonic activation whereas we used indirect activation. In our study, the ultrasonic tip was not used to directly activate the MTA because even the smallest US tip was unable to extend to the full length of the curved simulated canal. A small Ni-Ti plugger that was flexible enough to follow the canal curve was used instead.

Third, the method of ultrasonic activation varied between the two studies. They first obturated the tubes to different levels (3, 5, 7 mm, etc.) with MTA and then activated the ultrasonic tip continuously as a last step to condense the MTA apically. Although the exact duration of activation in their study was not specified, we speculated that excessive US may have incorporated air into the MTA and contributed to a fill that was less dense and less uniform than that produced by hand condensation. Our pilot work with different times and intensities demonstrated that very low intensity vibration for a short time period was necessary to prevent this occurrence.

This study compared the fill density of MTA in simulated root canal, using two placement methods: hand condensation and hand condensation with indirect US. The results demonstrated that hand condensation with indirect US resulted in an MTA fill that was denser than that accomplished by hand condensation alone in both straight and curved canals.

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References

1. 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.
2. Alhadainy HA. Root perforations: a review of literature. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1994;78:368–74.
3. Torabinejad M, Hong CU, Lee SJ, Monsef M, Pitt Ford TR. Investigation of mineral trioxide aggregate for root-end filling in dogs. J Endod 1995;21:603–8.
4. Torabinejad M, Pitt Ford TR, McKendry DJ, Abedi HR, Miller DA, Kariyawasam SP. Histologic assessment of mineral trioxide aggregate as a root-end filling in monkeys. J Endod 1997;23:225–8.
5. Pitt Ford TR, Torabinejad M, McKendry DJ, Hong CU, Kariyawasam SP. Use of mineral trioxide aggregate for repair of furcal perforations. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79:756–63.
6. Kettering JD, Torabinejad M. Investigation of mutagenicity of mineral trioxide aggregate and other commonly used root-end filling materials. J Endod 1995;21:537–42.
7. Torabinejad M, Hong CU, Pitt Ford TR, Kettering JD. Cytotoxicity of four root-end filling materials. J Endod 1995;21:489–92.
8. Torabinejad M, Pitt Ford TR, Abedi HR, Kariyawasam SP, Tang H. Tissue reaction to implanted root-end filling materials in the tibia and mandible of guinea pigs. J Endod 1998;24:468–71.
9. Torabinejad M, Higa RK, McKendry DJ, Pitt Ford TR. Dye leakage of four root-end filling materials: effects of blood contamination. J Endod 1994;20:159–63.
10. Bates CF, Carnes DL, del Rio CE. Longitudinal sealing ability of mineral trioxide aggregate as a root-end filling material. J Endod 1996;22:575–8.
11. Nakata TT, Bae KS, Baumgartner JC. Perforation repair comparing mineral trioxide aggregate and amalgam using an anaerobic bacterial leakage model. J Endod 1998;24:184–6.
12. Torabinejad M, Rastegar AF, Kettering JD, Pitt Ford TR. Bacterial leakage of mineral trioxide aggregate as a root-end filling material. J Endod 1995;21:109–12.
13. Koh ET, Ford TR, Kariyawasam SP. Prophylactic treatment of dens evaginatus using mineral trioxide aggregate. J Endod 2001;27:540–2.
14. Pitt Ford TR, Torabinejad M, Hong CU, Hariyaswasm SP. Use of MTA for repair of furcal perforations. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79:759–63.
15. O'Sullivan SM, Hartwell GR. Obturation of a retained primary mandibular second molar using MTA: a case report. J Endod 2001;27:703–5.
16. Vizgirda J, Liewehr FR, Patton WR, McPherson JC, Buxton TB. A comparison of laterally condensed gutta-percha, thermoplasticized gutta-percha, and mineral trioxide aggregate as root canal filling materials. J Endod 2004;30:103–6.
17. Aminoshariae A, Hartwell GR, Moon PC. Placement of mineral trioxide aggregate using two different techniques. J Endod 2003;29:679–82.
18. Deitch AK, Liewehr FR, West LA, Patton WR. A comparison of fill density obtained by supplementing cold lateral condensation with ultrasonic condensation. J Endod 2002;28:665–7.
19. ProRoot MTA, MSDS, Dentsply Tulsa Dental, Tulsa, OK 74136.
20. Dammaschke T, Gerth HUV, Züchner H, Schäfer E. Chemical and physical surface and bulk material characterization of white ProRoot MTA and two Portland cements. Dental Materials 2005;21:731–8.
21. Funteas UR, Wallace JA, Fochtman EW. A comparative analysis of Mineral Trioxide Aggregate and Portland cement. Aust Endod J 2003;29:43–4.
22. Camilleri J, Montesin FE, Brady K, Sweeney R, Curtis RV, Pitt Ford TR. The constitution of mineral trioxide aggregate. Dental Materials 2005;21:297–303.
23. Holland R, de Souza V, Murata SS, et al. Healing process of dog dental pulp after pulpotomy and pulp covering with mineral trioxide aggregate or Portland cement. Braz Dent J 2001;12:109–13.
24. Menezes R, Bramante CM, Letra A, Carvalho VG, Garcia RB. Histologic evaluation of pulpotomies in dog using two types of mineral trioxide aggregate and regular and white Portland cements as wound dressings. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;98:376–9.
25. Ribeiro DA, Duarte MA, Matsumoto MA, Marques ME, Salvadori DM. Biocompatibility in vitro tests of mineral trioxide aggregate and regular and white Portland cements. J Endod 2005;31:605–607.
26. Saidon J, He J, Zhu Q, Safavi K, Spangberg LS. Cell and tissue reactions to mineral trioxide aggregate and Portland cement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95:483–9.
27. Tselnik M, Baumgartner JC, Marshall JG. Bacterial leakage with mineral trioxide aggregate or a resin-modified glass ionomer used as a coronal barrier. J Endod 2004;30:782–4.
28. Kett I. Engineered Concrete: Mix design and test methods. [Web document] Boca Raton, FL: CRC Press, 2000. [Accessed July 28, 2005].
29. Goss A. The concrete and metal project. Concrete: technical. [Web document]. Owen Sound, Ontario, Canada. http://www.makersgallery.com/concrete/tech.html [accessed July 28, 2005].
30. Material safety data sheet for Portland cement. [Web document]. Allentown, PA: Lehigh Portland Cement Company, 1997. http://www.vincistone.com/library/msds_lehigh_portland_cement.htm [Accessed July 28, 2005].
31. Asgary S, Parirokh M, Eghbal MJ, et al. Chemical differences between white and gray mineral trioxide aggregate. J Endod 2005;31:101–3.
32. Portland cement. [Web document]. FHWA Materials Group, 1999. <http://www.fhwa.dot.gov/infrastructure/materialsgrp/cement.html> [Accessed July 28, 2005].
33. Cement and concrete basics. [Web document]. Skokie, IL. Portland Cement Association. http://www.cement.org/basics/concretebasics_concretebasics.asp. [Accessed July 28, 2005].
34. Fridland M, Rosado R. MTA solubility: A long term study. J Endod 2005;31:376–9.
35. Nemmers CJ. Portland cement; concrete pavement. Application description. [Web document]. McLean, VA: U.S. Department of Transportation, Federal Highway Administration. <http://www.tfhrc.gov/hnr20/recycle/waste/app2.htm> Accessed July 28, 2005.
36. Newatia S. Concrete vibrators. [Web document] Aurtech Global. <http://www.aurtechindia.com/con-vib.htm> [Accessed July 28, 2005].
37. Hachmeister DR, Schindler WG, Walker WA III, Thomas DD. The sealing ability and retention characteristics of mineral trioxide aggregate in a model of apexification. J Endod 2002;28:386–90.