A significant problem in clinical dentistry in general, and in restorative dentistry and endodontics in particular, is isolation of the operative field for moisture control. The root canal system to be obturated must be dry in order to obtain a good seal, and contamination with blood must be avoided. During a direct pulp capping procedure, hemorrhage must be controlled. When attempting to seal a root perforation, a dry field is essential. Further, during apical surgery, the retropreparation must be absolutely dry.

Recently, Torabinejad and colleagues developed a new cement named Mineral Trioxide Aggregate (MTA; ProRoot MTA, Dentsply Tulsa Dental) (Fig. 1), which appears to have all of the characteristics of an ideal cement to seal communication between the root canal system and the oral cavity (mechanical and carious pulp exposures), and between the root canal system and the periodontium (iatrogenic perforations, open apices, resorbed apices, root-end preparations).

MTA is an endodontic cement that is extremely biocompatible, capable of stimulating healing and osteogenesis, and is hydrophilic. MTA is a powder that consists of fine trioxides (Tricalcium silicate, Tricalcium aluminate, responsible for the chemical and physical properties of this aggregate), which set in the presence of moisture. Hydration of the powder results in formation of a colloidal gel with a pH of 12.5. The gel solidifies to a hard solid structure in approximately three-four hours. This cement is different from other materials currently in use because of its biocompatibility, antibacterial properties, marginal adaptation and sealing properties, and its hydrophilic nature.

In terms of biocompatibility, Koh et al. and Pitt Ford et al. demonstrated the absence of cytotoxicity when MTA came in contact with fibroblasts and osteoblasts, and the formation of dentin bridges when the material was used for direct pulp capping. Other studies demonstrated the growth of cementum, periodontal ligament, and bone adjacent to MTA when used to seal perforations, as well as when employed as a retrofilling material in surgical endodontics.

Torabinejad et al. demonstrated that the antibacterial properties of MTA are superior to that of amalgam, IRM (a zinc-oxide eugenol cement reinforced with polymethyl methacrilate), and SuperEBA (a zinc-oxide eugenol cement reinforced with aluminum oxide and with ethoxybenzoic acid). Nonetheless, its antimicrobial spectrum is limited, and if bacterial contamination is suspected or if acute inflammation is present, it is advisable to raise the pH and disinfect the root canal using a calcium hydroxide paste for one week before MTA. Furthermore, the marginal adaptation and sealing properties of MTA are far superior to amalgam, IRM, and SuperEBA.

As noted, the characteristic that distinguishes MTA from other materials used...
to date in endodontics is its hydrophilic properties. Materials used to repair perforations, to seal the retro-preparation in surgical endodontics, to close open apices, or to protect the pulp in direct pulp capping, are inevitably in contact with blood and other tissue fluids. Moisture may be an important factor due to its potential effects on the physical properties and sealing ability of the restorative materials. As shown by Torabinejad et al, MTA is the only material that is not affected by moisture or blood contamination: the presence or absence of blood seems not to affect the sealing ability of the mineral trioxide aggregate. In fact, MTA sets only in the presence of water.

Pulp capping with MTA
Among the materials available today for direct pulp capping, MTA is the material of choice. Pulp capping is indicated for teeth with immature apices when the dental pulp is exposed, and there are no signs of irreversible pulpitis. In such cases the maintenance of pulp vitality is extremely important, and MTA is preferred to calcium hydroxide. Recent studies have shown that MTA stimulates dentin bridge formation adjacent to the dental pulp; dentinogenesis of MTA can be due to its sealing ability, biocompatibility, and alkalinity. Faraco and Holland demonstrated that in teeth treated with MTA all bridges were tubular morphologically and in some specimens, the presence of a slight layer of necrotic pulp tissue was observed in the superficial portion of these bridges. This suggested that the material, similar to calcium hydroxide, initially causes necrosis by coagulation in contact with pulp connective tissue. This reaction may occur because of the product’s high alkalinity, whose pH is 10.2 during manipulation and 12.5 after 3 hours. In a previous article, Holland et al demonstrated the presence of calcite crystals in contact with MTA implanted in rat subcutaneous tissue. Those calcite crystals attract fibronectin, which is responsible for cellular adhesion and differentiation. Therefore we believe that the MTA mechanism of action is similar to that of calcium hydroxide, but in addition, MTA provides a superior bacteria-tight seal.

For those reasons MTA is preferred to calcium hydroxide. Nevertheless, MTA has only recently been introduced, and no long-term studies on its efficacy have been published. Therefore, it is necessary to recall treated patients on a regular basis to determine if treatment has been successful, or if root canal therapy is needed.

Operative sequence for pulp capping
After achieving anesthesia and isolation with a rubber dam, the exposed pulp is irrigated with NaClO to control bleeding. The MTA powder is mixed with sterile water and the mixture is placed in contact with the exposure using a Dovgan carrier (Fig. 2). Compress the mixture against the exposure site with a moist cotton pellet. Place a moist cotton pellet over the MTA and fill the rest of the cavity with a temporary filling material. After four hours, the patient
is seen again, the rubber dam is positioned, the temporary filling material and cotton are removed, and the set of the material is assessed. Then, the tooth can be restored (Figs. 3a-f).

Perforation repair with MTA
Recently, the prognosis of teeth with a perforation has improved with the use of the operating microscope and the introduction of MTA. When clinicians want to predictably repair a perforation, they face two challenges: 1) to establish hemostasis, and 2) to select a restorative material that is easy to use, seals well, does not resorb, and is biocompatible, supporting new tissue formation. Generally, a barrier is created to achieve a dry field, and prevent the extrusion of the restorative material. On the other hand, all of the restorative materials currently used (amalgam, Super EBA, IRM, composite resins) require a dry field and do not promote a new tissue formation. For the above reasons, and primarily

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Fig. 3a
Preoperative radiograph of the lower right quadrant. The young patient is only six years old and the lower molar is erupted only with the mesial cusps. A deep decay is already present with a pulp involvement. The tooth is completely asymptomatic.

Fig. 3b
After the removal of the decay, the pulp exposure was covered with MTA, a wet cotton pellet and a temporary cement.

Fig. 3c
Seven month recall.

Fig. 3d
Fifteen month recall.

Fig. 3e
Two year recall.

Fig. 3f
Four year recall. The pulp tests vital, is completely asymptomatic and there is no evidence of calcification in the pulp chamber.
because it is hydrophilic, MTA can today be considered the ideal material to seal perforations. In fact, cementum has been shown to grow over MTA, allowing for normal attachment of the periodontal ligament. Furthermore, MTA doesn’t require a barrier, is not affected by moisture or blood contamination, and seals better than any other material in use today (Figs. 4a-d).

Operative sequence for treatment of a perforation
The operative sequence to treat a perforation of the root or of the floor of the pulp chamber is as follows:

1) isolation of the operative field with a rubber dam
2) cleansing of the perforation site
3) in case of bacterial contamination, application of calcium hydroxide for one week. If this step is performed, the patient goes home, then return to resume steps 4-7 at the second visit.
4) application of 2-3mm of MTA
5) radiograph to check the correct positioning of the material
6) application of a small wet cotton pellet in contact with MTA
7) temporary cement

second visit
1) after 24 hours, removal of temporary cement to check if MTA is set
2) completion of therapy.

Criteria for assessing success
To be able to state that success has been achieved following treatment of a perforation, the treated tooth must meet the following requirements:
1) absence of symptoms, such as spontaneous pain or pain on palpation or percussion
2) absence of excessive mobility
3) absence of communication between the perforation and the oral cavity/gingival crevice.
4) absence of a fistula
5) normal function
6) absence of a radiolucency adjacent to the perforation
7) thickness of the periodontal ligament adjacent to the obturating material no more than double the thickness of the adjacent ligament.

If even only one of these criteria is lacking, therapy is not successful.

Immature pulpless teeth
Despite the demonstrated clinical success of calcium hydroxide apexification, there are some disadvantages of this technique. The apical closure is unpredictable. The time necessary to achieve the final result is variable, and for adults an acceptable result may never be achieved. The treatment time necessary for induced apical closure in pulpless teeth in humans has not been established. This therapy requires multiple appointments for either reapplication of calcium hydroxide or to check its presence inside the root canal, and the time interval between visits is at least three months. This may lead to loss of the coronal seal with consequent recontamination and exposure of the healing tissues to bacteria. In these cases an acute exacerbation and delayed healing response may occur. For these reasons, many clinicians advocated obturation of teeth with open apices without inducing a natural apical barrier. In fact, the concept of obturating teeth with immature apices without first inducing a natural apical barrier is not new; several investigators have likewise indicated that success is attainable with this approach, which does not require repeated applications of calcium hydroxide.

The apex of a tooth should be considered as a dynamic area, capable of self repair. Occasional instances of continued root growth and apical closure in the presence of a periapical pathology are explained on the basis of remnants of vital tissue in the area. However, a procedure that requires multiple appointments involving frequent dressing changes and instrumentation may cause injury to the local tissue. For all the above mentioned reasons, and taking into consideration the work of Koenigs et al. and Roberts et al. who demonstrated the efficacy of tricalcium phosphate in inducing apical closure respectively in monkeys and in men, Coviello and Brilliant suggested a one-appointment procedure for obturating permanent teeth with nonvital pulps and open apices, using tricalcium phosphate as an immediate apical barrier against which gutta-percha would be condensed. In their study, they found no statistical difference in the success rate comparing the multi-appointment and one-appointment techniques; they did not observe overfilling for teeth treated with the one-appointment technique; the procedure was faster; fewer radiographs were required; there was less discomfort for the patient; and the results were predictable.

Buchanan in 1996 suggested the use of freeze-dried demineralized bone to be packed to the end of the immature root canal to create a one-visit biocompatible apical matrix. The use of an operating microscope in such cases was extremely helpful, as it allows the clinician to observe to the areas of the apex or bone graft matrix.

MTA has been suggested as an ideal material to promote the formation of an apical barrier in a one-visit procedure. According to recent studies, when compared to calcium hydroxide and to the osteogenic protein-1, MTA induced the same amount of apical hard tissue.
formation, and without an inflammatory response. Other studies demonstrated newly formed bone, periodontal ligament, and cementum in direct contact with MTA. Therefore, because it provides a good apical seal (better than was observed with amalgam, IRM, and Super EBA), its antimicrobial properties, biocompatibility, and hydrophilic properties, and taking into consideration the successful clinical cases reported in the literature, MTA should now be considered the material of choice for the apical barrier technique in the treatment of pulpless teeth with open apices.

Operative sequence for pulpless teeth with open apices

After application of the rubber dam and preparation of an adequate access cavity, the root canal system should be cleansed with copious irrigation using sodium hypochlorite (which can be delivered ultrasonically for enhanced activation). The root canals require only minimum shaping, and because of their size and the thinness of the dentinal walls, they need to be cleansed more than shaped in order not to increase fragility.

To improve disinfection of the canals, Torabinejad suggests using an intracanal medication with calcium hydroxide for one week. After rinsing calcium hydroxide from the root canal with irrigation and drying with paper points, the MTA powder is mixed with saline or sterile water and the mixture is carried to the apical area with the pre-fitted Dovgan carrier. MTA must be positioned exactly at the foramen, as the material must be in direct contact with periapical tissues. Overfilling should be avoided (Figs. 4a-d). In general, the resistance of the periapical tissues is enough to prevent overfilling; nevertheless, there is no contraindication to the use of a resorbable matrix (Collacote), against which MTA could be condensed to the apex. For this purpose, the pre-fitted Schilder pluggers, as well as paper points, can be used. The thickness of the apical plug must be 3-4 mm. In order not to have voids, the use of ultrasonics is suggested (while slightly condensing the MTA with the pluggers, the assistant is asked to touch the pluggers with the ultrasonic tip). After completion, the extension of the apical plug is checked radiographically. If the apical plug is not satisfactory, the MTA is removed via saline solution irrigation, and the filling procedure is repeated.

When the radiographic appearance looks ideal, a wet paper point is placed in direct contact with the MTA and the access cavity is closed with a temporary seal, and allowed to set for 3-4 hours. At the next visit the rubber dam is placed, the temporary seal and paper point are removed, the hardness of the material is checked, and then root canal therapy is completed by filling the root canal with warm gutta-percha (Figs. 5a-d). If the canal walls appear to be thin and fragile, it has been suggested that the rest of the root canal be completely filled with adhesive composite resin (without using gutta-percha) to strengthen the root structure.

As stated previously, the use of the operating microscope is essential in these cases. Furthermore, to facilitate the positioning of the material, the clinician can carry the dry powder to the site. Touching the MTA powder with a wet paper point will, by capillary action, provide the necessary hydration.

The apical barrier technique using MTA is indicated for adult patients with pulpless teeth and immature apices. Using
the traditional technique that employs calcium hydroxide will not be effective for these cases. Further, patients may find the calcium hydroxide approach unacceptable due to the multiple visits that are required.

The same technique using MTA is also indicated in the young patient, only if the traditional access cavity will allow a perfect visualization of the apical foramen using the operating microscope. If this is not obtainable and a further removal of crown structure should be necessary, in this case the traditional technique with calcium hydroxide remains the treatment of choice.

Root end filling
Due to its sealing properties, biocompatibility, and hydrophilic nature, MTA is considered the best choice for a retrofilling material. Its handling characteristics are considered to be excellent. In particular, the material can be used in the presence of blood.

Operative sequence for root end filling
After the preparation of the root end has been completed with ultrasonic instruments, the MTA is placed with a carrier and gently compacted with a small plugger. The best instruments for this purpose include the use of amalgam carriers like the Messing gun (R. Chige, Inc., Boca Raton, Florida), or the new Dovgan MTA carriers which are straight, bendable, or pre-bent (Quality Aspirators, Duncanville, Texas).

Another method of comfortably carrying MTA into the cavity is by using a carrier described by Edward Lee (Figs. 6 a-g). The material remains attached to a small spatula, as we were used to using with SuperEBA. This method has the advantage of being less cumbersome and therefore allowing easier access even to small cavities on posterior teeth, without the long wait necessary for the mixing and therefore the setting with SuperEBA (a delay generally in the region of 8–12 minutes, before being able to carry out the completion).

The material should be kept relatively dry so it does not readily flow, yet moist enough to allow manipulation and a workable consistency. If the assistant touches the plugger with an ultrasonic tip during the placement process, voids are eliminated, the density of the fill is better, and radiopacity is increased.

The working time of MTA is approxi-
approximately two hours, and this eliminates problems related to rapid setting that accompanies other materials. Finishing of MTA is accomplished by simply carving away excess material with a spoon excavator to the level of the resected root end. The moisture necessary to achieve the final set is from the blood, which fills the crypt after surgery (Figs. 7a-d).

Conclusion
Mineral Trioxide Aggregate (MTA) is a relatively new material that has become the material of choice for certain endodontic applications. This article has
The use of Mineral Trioxide Aggregate in clinical and surgical endodontics

Fig. 7a
Preoperative radiograph of the lower left first premolar. The previous surgical procedure is failing.

Fig. 7b
A fistulous track is present.

Fig. 7c
Postoperative radiograph after the surgical retreatment. The old amalgam has been removed and the retroprep has now been filled with MTA.

Fig. 7d
The one year recall is showing a complete healing, with the lamina dura surrounding the end of the root.

described those applications, including the operative sequence for specific procedures.
BIBLIOGRAPHY

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