of the Max Curve set is used the same way. The delicate apical 2 mm of the 10/.05 file will always remain loose inside the canal, guiding the file through the anatomy without risking engagement and breakage. The 20/.05 that follows will provide the final canal shape to disinfect and obturate the canal.

Instrumentation to larger apical preparations can be achieved the same way to the desired apical instrumentation width. For challenging cases, as seen in Figures 5 and 6, a 20/.05 enlargement might be ideal in order to balance the clinical disinfection procedures with the risks of damaging the challenging anatomy or separating the instruments. The TCA technique aims at minimising the time of engagement with an activated file by using file activation only when needed for advancement. With this instrumentation technique and the HyFlex EDM Max Curve sequence, most anatomical root canal variations can be enlarged safely.

Conclusion

NiTi files with CM effect are extremely flexible and fatigue-resistant. They can be activated inside the canal and move passively around the curves guided only by anatomy itself. The TCA technique minimises the time files are under engagement. This procedure maintains continuous tactile feedback during instrumentation. For challenging anatomies, special sequences like the HyFlex EDM Max Curve set help clinicians to keep on track.

about

Dr Antonis Chaniotis graduated from the University of Athens’s School of Dentistry in Greece in 1998. In 2003, he completed a three-year postgraduate programme in endodontics at the same school. Since 2003, he has owned a private practice limited to microscopic endodontics in Athens. For the last ten years, he has served as a clinical instructor affiliated with the undergraduate and postgraduate programmes at the Department of Endodontics of the University of Athens’s School of Dentistry. From 2012 to 2014, he was a clinical fellow teacher at the University of Warwick in the UK. He lectures extensively nationally and internationally, and he has published articles in local and international journals. He currently serves as an active member of the Hellenic Society of Endodontology, a certified member of the European Society of Endodontology and an international member of the American Association of Endodontists.

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Clinical applications of mineral trioxide aggregate in endodontics

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Bioceramic-based sealers are ceramic products that are designed for medical and dental applications and include alumina, zirconia, bioactive glass, glass-ceramics, hydroxyapatite and calcium phosphates. Bioceramic-based sealers are categorised into two groups: calcium silicate-based sealers and calcium phosphate-based sealers. Also, these materials can be considered bioactive or bio-inert according to their interaction with the surrounding live tissue.

Calcium silicate-based sealers are either based on mineral trioxide aggregate (MTA) or non-MTA-based. MTA is a bioactive material first introduced to seal communication between roots and external surfaces of teeth. It promotes osteogenesis and healing, allowing clinicians to perform therapies that would not previously have been successful (Figs. 1–4). The first formulation of MTA (grey) was composed of silicate, bismuth oxide, tricalcium aluminate, calcium sulphate dihydrate (gypsum) and calcium aluminoferrite. The subsequent version (white) is composed of tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium oxide, aluminium oxide and silicon dioxide. The powder has to be mixed with distilled water to be used. The initial setting time ranges from 8 to 70 minutes, and the final setting time ranges from 40 to 320 minutes. This long setting time is one of the main drawbacks of this product.

The material has peculiar features, such as excellent biocompatibility and sealing ability, even in the presence of

Figs. 1a–e: The radiograph shows the result after surgery performed using amalgam and burs (a). Clinical image after the surgical procedure performed by an oral surgeon (b). Post-op radiograph after using white MTA as a retrofilling material (c). The MTA has sealed the canal of the lateral incisor (d). Two-year recall radiograph (e). Figs. 2a–e: The CBCT shows a buccal perforation in a maxillary left canine (a). Post-op radiograph. The perforation was sealed with traditional white MTA (b). The discoloration is quite evident (c & d). Clinical aspect after bleaching (e).
moisture. It has a hydrophilic nature and good capacity for marginal adaptation, together with good antibacterial properties (thanks to its high pH of 12.5), and it is able to stimulate cementum-like formation, osteoblastic adherence and bone regeneration. Moreover, its sealing, mineralising, dentinogenic and osteogenic potentials make it the preferred choice for numerous clinical applications, such as direct pulp capping, root end filling, apexogenesis and apexitication in immature teeth with necrotic pulp, filling of root canals, treatment of horizontal root fractures, treatment of internal and external resorption, and repair of perforations.\(^5\)

The literature reports good outcomes in perforation repair using MTA with respect to a variety of materials used to fill endodontic perforations, such as amalgam, zinc oxide eugenol cements, calcium hydroxide, composite resin and glass ionomer cements.\(^5\) The outcome of the therapy has been found to be influenced by the experience of the practitioner who performed the treatment, the negative influence of placing a post after treatment, the presence of preoperative lesions and of communication between the perforation site and oral cavity, and the sex (female) of the patient.\(^7,8\) The location of the perforation and the quality of the final restoration have been found to have a significant influence on the outcome of the perforation repair, while the site of perforation (mid-root and apical) and a perforation size of larger than 3 mm have been reported as significant predictors of the recurrence of progressive inflammation.\(^7\)

When apical surgery is performed, the choice of the root end filling material can have a significant influence on the outcome of the therapy. Amalgam has been the most popular root end filling material for a long time, but it has been demonstrated that its use is related to an increase of blood mercury levels within one week of the procedure.\(^8\) Moreover, the sealing ability of amalgam does not ensure good results over time when used in apical surgery. Since MTA has been introduced, it has become the gold standard for this procedure because of its excellent sealing ability, hard-tissue induction and conduction, and success rate over time.\(^8\) The literature shows that MTA presents similar or better outcomes in terms of regeneration of periapical tissue compared with SuperEB (Keystone Industries), amalgam, Intermediate Restorative Material (Dentsply Sirona), 4-META/MMA-TBB resin and thermo-plasticised gutta-percha.\(^9,10\)

The excellent biocompatibility of MTA makes it the material of choice for filling the apices of large root canals and for apexitication/apexogenesis in immature teeth with necrotic pulp. For this latter procedure, in fact, the contact between MTA and periapical tissue promotes the formation of hard tissue and promotes the survival of the tooth over time (Fig. 5).\(^11,12\) MTA is also used in the therapy of vital pulp, such as pulp revitalisation and pulp capping, taking the place of calcium hydroxide as the material with the best performance and the fewest side effects (Fig. 6).\(^13,14\)

Several investigations evaluated other bioactive endodontic cements (BECs) as pulp capping agents with short-term follow-up. More research with longer-term follow-up is needed to evaluate alternative pulp capping materials to MTA. In addition to the material used for direct pulp capping, there are several other factors that may influence the final outcome; therefore, these variables should be controlled in future studies.\(^14\)

The literature has reported some disadvantages related to the composition of MTA. The presence of bismuth oxide as a radiopacifier in the MTA formula has been proved by several studies to potentially lead to tooth discoloration, both via bismuth changing from its oxide form to metal by reduction, resulting in a black compound and subsequent tooth staining, or via bismuth undergoing oxidation when in contact with a strong oxidising agent (i.e. sodium hypochlorite), producing bismuth carbonate, which results in a black precipitate when exposed to light.\(^8\)

Since MTA’s discoloration potential has been stated as a main shortcoming in vital pulp therapy and in perforation repair (Fig. 7), alternative bioactive cements, with similar clinical applications and shorter setting times, were de-
veloped (Fig. 8). Some of them had the same discoloration problem when in contact with sodium hypochlorite. Other formulations, containing tricalcium silicate, dicalcium silicate, tricalcium aluminate, calcium oxide and tungstate as an opacifier (i.e. PD MTA White, Produits Dentaires), reached the goal of avoiding staining and discoloration without changing the biological or chemical features of MTA.

One of the major problems when using MTA in vital teeth is bleeding management. Several studies have reported blood contamination as a factor that exacerbates discoloration in calcium silicate-based materials; bismuth oxide-free Portland cement also presents colour alteration subsequent to blood exposure. The hypothesis of unset MTA presenting surface porosities that take up blood elements has been proposed to explain the discoloration of calcium silicate-based cements, as erythrocytes can penetrate into the material, and after their haemolysis, both the cement and the tooth could present discoloration. Another suggested mechanism for tooth discoloration after MTA placement may be the oxidation and incorporation of the remaining iron content into the set material: contact with blood triggers loss of the ferrous ion (Fe$^{2+}$) contained within the centre of the porphyrin ring through a natural redox reaction that originates Fe$^{3+}$, a dark brown component that promotes material and tooth discoloration. Furthermore, the penetration of blood into the tooth structure, with haemoglobin or haematin molecules present within the dentinal tubules, may induce discoloration. In this regard, the release of fast-setting MTA can represent a significant advantage, limiting fluid and blood absorption and thereby preventing discoloration and promoting a pleasant aesthetic outcome. White MTA is good from this point of view because it starts setting after 10 minutes and setting is completed after 15 minutes. While setting, the material does not shrink, and after setting, it is dimensionally stable, ensuring a tight seal over time. The fast setting also allows performance of the restorative procedures in the same appointment in which the MTA is placed, improving the workflow of the practitioner.

Other bioactive endodontic materials that contain ZrO$_2$ to provide radiopacity and guarantee superior colour stability have been suggested in order to overcome MTA-related problems. The literature reports that some BECs have shown promising results, above all in vital pulp therapy, in terms of cementum deposition over the materials when used for root end filling, while others are associated with a significantly higher inflammation of the periapical tissue compared with tooth-coloured MTA. However, the number of studies comparing these products to MTA is still limited and few histological investigations have evaluated BECs as root end filling materials. Their shortcomings include short-term follow-up, absence of controls, a large number of excluded specimens, placement of root end filling materials in intact
teeth with healthy pulps that had no periapical lesions prior to treatment, preparing root end cavities without prior canal debridement and filling, and root resection and preparation of root end cavities prior to root canal instrumentation.8,16 Future investigations with rigorous methods and materials are needed to exactly compare the performance of these materials.

The literature reports more potential drawbacks of MTA, such as the difficult handling.18 It has to be said that, if the practitioner follows the instructions provided by the manufacturer, mixing MTA is straightforward. It is sufficient to place the contents of one sachet of MTA on to a glass slab and add one drop of distilled water next to the powder. Mixing has to be carried out gradually, bringing the liquid into the powder and mixing it evenly for 30 seconds, until the mixture shows a creamy consistency. Once mixed, it is important to position the material precisely into the site that has to be filled. This step can be tricky if no specific carrier is available. A number of dedicated carriers are available on the market. These are of different sizes, according to the amount of material to be placed and to the area of the root canal to be reached. Carriers should allow fast, efficient and precise positioning of the material. This implicates the possibility of delivering the material into the carrier effortlessly, bending the tip and delivering the desired amount of MTA to the target site.

The MAP system (Produits Dentaires) is a dedicated carrier that was developed to adapt to every clinical situation, because it can be used with tips of different sizes and angles and with different materials. In general, triple-angled stainless-steel tips are used in endodontic surgery, because they improve the visibility of the operative field and make retrograde obturation easier. The classic curved stainless-steel tips are meant to be used in or-

Figs. 6a–g: Pre-op radiograph of the maxillary right first molar, showing deep decay involving the pulp tissue (a). The image shows the exposed pulp (b). PD MTA White positioned over the exposed pulp (c). After setting, the cavity was restored in the same visit (d). Clinical aspect of the restoration (e). Post-op radiograph (f). One-year recall radiograph (g).

Figs. 7a–e: Pre-op radiograph of the maxillary right central incisor. The tooth had a buccal perforation in the middle third of the root (a). The granulation tissue was occupying part of the pulp chamber (b). After removing the granulation tissue, the perforation was sealed with white MTA (c). Post-op radiograph (d). Three-year recall radiograph (e).
thograde treatments or pretreatments, in order to perform direct pulp capping, root canal obturation during apexogenesis and revascularisation procedures, apexification of immature teeth and repair of root canal perforations. The advantage of the MAP System is the possibility of employing nickel-titanium tips. These can be used in both orthograde and surgical procedures and allow placement of the material exactly where it is needed because they can be bent as necessary (Fig. 9). After sterilisation, the tips resume their initial straight shape (Fig. 10).

When using an MTA carrier, it is mandatory to avoid the material hardening inside of the applicator, because it may be almost impossible to remove it afterwards. Cleaning the tip (better done with dedicated tools) immediately after MTA extrusion helps maintain the efficiency of the instrument.

The amount of MTA to be used is dependent on the clinical procedure, but in general, it is not recommended to completely fill a root canal with MTA, because it would be difficult to remove the material from the root canal after setting. A rigorous protocol and the use of specific tools help achieve good outcomes in primary and secondary endodontic treatments using MTA as an obturation material.

Editorial note: A list of references is available from the publisher.

Since 1980, Dr Arnaldo Castellucci has limited his activity as a dental specialist to the sole specialty of endodontics. Thanks to the rich clinical experience he acquired through the instruction he received while attending the Department of Endodontics, then under the chairmanship of Prof. Herbert Schilder, at Boston University School of Graduate Dentistry (now the Boston University Henry M. Goldman School of Dental Medicine) in the USA, he was able to successfully pursue intense educational activity, as well as present lectures at both national and international congresses, becoming one of today’s most cited endodontists worldwide. In his dental practice, Dr Castellucci offers his patients the maximum clinical professionalism and the best specialisation to treat endodontic pathology with the most recent clinical and surgical technology. Furthermore, thanks to the highly equipped didactic environment that Dr Castellucci has set up over the years in his practice, he is able to convey his experience with the maximum effectiveness to all those dental professionals pursuing specialisation in endodontics through educational courses that he personally organises and presents.

Dr Matteo Papaleoni graduated from the University of Florence in Italy in 2004. He received his master’s degree in endodontics and restorative dentistry from the University of Siena in Italy in 2006. Since 2008, he has collaborated with Dr Castellucci, particularly regarding aesthetic dentistry and tooth restoration with minimally invasive techniques. He is currently a presenter in Dr Castellucci’s annual course on the restoration of the endodontically treated tooth. Dr Papaleoni has contributed to numerous scientific publications on endodontics and is a member of the Italian Society of Endodontics.

Dr Francesca Cerutti graduated from the University of Brescia in Italy in 2007. In 2013, she obtained her PhD in materials for engineering from the University of Brescia, and in 2016, she completed a master’s degree in aesthetic medicine. She collaborates with Prof. Dino Re at the University of Milan in Italy, where she conducts clinical research and, since 2018, has been a visiting professor. Dr Cerutti has published several articles in peer-reviewed journals and has co-authored books on restorative dentistry and endodontics. Dr Cerutti has spoken at national and international congresses on postendodontic restoration and aesthetic reconstruction of teeth. She is a reviewer for international journals such as the Journal of Adhesive Dentistry, the European Journal of Paediatric Dentistry and Biomaterials. Dr Cerutti is a member of the Italian Society of Endodontics and served as editorial coordinator of Giornale Italiano di Endodonzia from 2008 to 2011. She is a silver member of Style Italiano Endodontics.