Introduction

Pulp canal obliteration (PCO), or calcific metamorphosis, is considered by some authors as the pulp response to trauma and is characterised by the deposition of hard tissue within the root canal space and a yellow discolouration of the clinical crown.\textsuperscript{1,2} The exact mechanism of canal obliteration is still unknown, but damage to the neurovascular supply of the pulp at the time of the injury is the most accepted explanation. Different factors, such as dental trauma (concussion or subluxation), caries, coronal restorations, vital pulp therapy, orthodontic treatment, occlusal pathology, abfraction, abrasion, harmful oral habits and individual aging, can trigger PCO.\textsuperscript{1-4}

PCO usually affects the anterior teeth of young adults and can cause total or partial obliteration of the canal space radiographically.\textsuperscript{3} Generally, the obliteration of the pulp canal space starts in the crown, with the narrowing of the pulp chamber, and then extends apically, followed by a gradual decrease of the root canal space.\textsuperscript{5,6} Complete radiographic obliteration of the pulp space does not necessarily mean the absence of the pulp canal space. In fact, in most of these cases, pulp tissue is present, but the sensitivity of radiographic examinations is too low to allow visualisation of the root canal path.\textsuperscript{1}

Normally, PCO has no symptoms and may be noted by tooth discoloration, yellow or grey, during routine ex-
amination as early as three months after the injury, but in most cases is not detected until a year after.¹,³ In PCO cases, pulp necrosis has been reported in 1 to 16.5 per cent, and the development of apical periodontitis has been estimated at 7.3 to 24 per cent of cases after four years.⁷

There is agreement that root canal treatment is only indicated in cases of PCO when irreversible pulpitis or apical periodontitis is diagnosed. Such a diagnosis represents 1 to 27 per cent of teeth with this clinical condition.⁴

Searching for calcified root canals can be challenging and time-consuming and may create a huge loss of tooth structure that is associated with a high risk of fracture and perforation, compromising the prognosis of the tooth.⁴,⁸ The rate of treatment failure for PCO has been reported to range from 20 to 70 per cent, and it depends on the clinical experience and knowledge of the anatomy of the operator and also the information provided by 2D and 3D radiographic examinations.⁸,¹⁰

Nowadays, the use of new technologies has increased the predictability of the treatment of calcified teeth. Dental operating microscopy enhances visibility of the pulp cavity, and the use of ultrasonic tips allows working at greater depth within the root canal system safely, which may help in identifying the root canal. Cone beam computed tomography (CBCT) is extremely helpful in PCO cases, as it allows 3D images without overlapping adjacent structures, which facilitates the identification of the canals and their anatomy, degrees of obstruction and dimensions.²,⁶,¹¹

A new clinical approach to a tooth with PCO, called “guided endodontics,” has been introduced. This technique combines the use of a guiding template with CBCT, which facilitates the location of severely calcified root canals.²,⁴,⁶,⁸,¹¹ The guide design is based on the anatomy of

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**Fig. 6:** Virtual copy of the drill’s (1.2 × 17 mm) position in the 3D template. **Fig. 7:** Adaptation of the printed template on the original cast model. **Fig. 8:** Occlusal view of the template with the incorporated metal sleeve. **Fig. 9:** Control of the position and fitting of the drill into the template.

**Fig. 10:** Control of the adaptation of the template in the mouth. **Fig. 11:** Pencil mark on the palatal surface made through the sleeve to serve as reference point to start the access. **Fig. 12:** Enamel removal with a diamond bur until the dentine was exposed.
the root canal and the architecture of the tooth and adjacent structures, obtained by CBCT images and an impression or intraoral surface scan, respectively. Software associated with CBCT data and 3D intraoral scanning, such as coDiagnostiX (Dental Wings) or Simplant (Dentsply Sirona), is used for virtual planning of the access cavity. After this, a 3D virtual template is produced to obtain the physical model of the endodontic guide that will orientate the bur into the calcified root canal.

Guided endodontic access in PCO cases in anterior teeth has been previously reported in the literature and described as a safe and predictable technique to give minimally invasive access to calcified canals. This may help to preserve tooth structure and avoid technical errors, and lead to an improvement in the long-term prognosis.

Case report

A 22-year-old female patient was referred to a private clinic with a history of pain in the maxillary left central incisor. The patient had a history of a dental trauma that had occurred nine years earlier. The tooth was discoloured and yellow, and it presented tenderness to percussion (Fig. 1). Thermal and electrical sensitivity tests were negative.

Radiographic examination showed a severely calcified root canal (Fig. 2). The presence of a radiolucent image compatible with apical periodontitis was confirmed by the CBCT scan (i-CAT, Imaging Sciences International; Fig. 3).

The root canal space could be identified in the apical third with initial radiographic and 3D imaging. Based on the results of clinical and radiographic examination, a diagnosis of necrotic pulp with symptomatic apical periodontitis was made, and root canal therapy recommended. After analysis and discussion with the patient, guided endodontics was chosen as the most appropriate treatment approach.

A silicone impression was taken, and a gypsum dental model was created and scanned (iTero, Align Technology; Fig. 4). Both CBCT imaging and model scans were aligned and processed with coDiagnostiX. A virtual copy of a drill with a diameter of 1.2 mm and a length of 17 mm (Meisinger) was superimposed on to the scans in a position that allowed its access to the identified root canal system within the apical one-third of the tooth (Fig. 5). The position of the drill was checked in 3D. Subsequently, the 3D template was exported as an STL file and sent to a 3D printer (Form 2, Formlabs; Figs. 6–9).

After confirming the adaptation of the guide (Fig. 10), a pencil mark on the palatal surface of the tooth was made (Fig. 11), through the sleeve, to serve as reference point to start the opening access. A conventional opening access was initiated with a high-speed long-neck diamond round bur (BR-154, MANI). The enamel in the palatal surface was removed until the dentine was reached (Fig. 12). The bur position was checked in the mouth. The bur was coupled to a low-speed handpiece set to 600rpm. Drilling was performed with pumping movements to penetrate through the calcified part of the root canal under copious irrigation with saline solution. After each millimetre apical advance, radiographs at two different angulations were taken to confirm the correct position of the bur (Figs. 13 & 14). The patent apical root canal was reached, and a rubber dam
was placed (Figs. 15 & 16). D Finder hand files of sizes 8 to 15 (MANI) was used for glide path creation, and the root canal length was electronically (Root ZX II, J. Morita) and radiographically confirmed (Figs. 17 & 18). The tooth was instrumented up to 35.04 rotary NiTi Silk files (MANI; Fig. 19) with TriAuto ZX2 (J. Morita) and irrigated with 5.25 % sodium hypochlorite (NaOCl) during the entire treatment.

A final irrigation protocol was performed with 17 % EDTA and 5.25 % NaOCl. The irrigant was activated with a calibrated master cone using a manual dynamic activation technique. After drying the root canal, obturation was performed with a single-cone technique with the BioRoot RCS bioceramic sealer (Septodont; Figs. 20 & 21). The access cavity was cleaned and sealed with a glass ionomer cement (Ionoseal, VOCO) and restored with composite resin. A final CBCT scan was done after the treatment to confirm the cantered position of the access (Figs. 22 & 23).

At the six-month follow-up, the tooth was asymptomatic (Fig. 24).

Discussion

Nowadays, treatment of teeth with PCO is classified as the highest level of difficulty by the American Association of Endodontists.\textsuperscript{13} The literature shows that the success rates of treating teeth with calcified root canals with apical periodontitis did not exceed 62.5 per cent. Still, success rates in these cases increased up to 89 per cent when the procedures were performed by endodontic specialists.\textsuperscript{8, 11} Although it has been established that the most experienced endodontists can achieve high levels of success, even with the help of a dental operating microscope, long-neck burs and ultrasonic tips, the accomplishing of an adequate access cavity and the localisation of the root canal may lead to excessive loss of tooth structure, a higher risk of fracture and perforation.\textsuperscript{2, 4, 7, 14} In cases of PCO, guided endodontic access may be indicated for more predictable access, allowing maximum preservation of the dental structure and reducing iatrogenic accidents.\textsuperscript{15, 15} This may lead to an improved long-term prognosis.\textsuperscript{11}

Krastl et al. was the first to describe a guided endodontic technique \textit{in vivo} in a maxillary central incisor with PCO and apical periodontitis, introducing the term “guided endodontics.”\textsuperscript{15} This technique was first described in implantology and then applied to endodontics, surgery and conventional access.\textsuperscript{8} The present method consists of accessing and locating root canals by means of a guiding template created by tomographic planning.\textsuperscript{14} The template sleeves direct the position of the access bur, increasing the perforation precision during access and reproducing adequate tomographic planning.\textsuperscript{14}

Two ex vivo studies were performed to prove the high accuracy of the guided endodontics technique. Buchgreitz et al. concluded that the mean distance between the drill path and the target was less than 0.7 mm,\textsuperscript{18} and Zehner et al. showed that deviations of planned and prepared access cavities were low, with means ranging from 0.17 mm to 0.47 mm at the tip of the bur, and the mean angle deviation was 1.81°.\textsuperscript{8, 19}

The accuracy values of guided splints depend on multiple factors, such as the type of support and study, technique used to produce the template, planning software, discrepancy between the drill and cylinder guide, degree of wear of the drill and number of guides used.\textsuperscript{17} Nevertheless,
guided templates have been associated with a number of limitations, such as inaccuracy, high economic cost, long therapeutic time and complications.\textsuperscript{17}

Inaccuracies are partly related to the loose fit between the drill and the sleeve, which is necessary to avoid heat development during preparation.\textsuperscript{8, 18} A recent study performed in mandibular incisors \textit{ex vivo} reported a mean linear deviation of 0.12 to 0.34 mm from the apical target point. This improvement was achieved by optimising the fit between the bur and the sleeve, which is essential to avoid gaps and consequently deviation in angulation.\textsuperscript{19} A metal sleeve should be placed for controlling the drill; however, a study that did not use a metal sleeve reported a burn on the plastic corridor after drilling.\textsuperscript{20} To avoid the heat created by the tight contact of the rotating bur with the sleeve, care should be taken to irrigate during drilling.\textsuperscript{7} Temperatures generated on the root during drilling may represent an injury to the periodontal ligament and adjacent bone.\textsuperscript{4}

One reason for the higher accuracy measurements of guided endodontics may be related to the fact that, unlike with implant cavity preparation, only a single bur was used.\textsuperscript{8} Another fact is that the template is normally only supported by mucosa, which might lead to an uncertain fit and resiliency on support.\textsuperscript{9} Nevertheless, the mechanical properties of dentine compared with the alveolar bone are different.\textsuperscript{8} This technique is a relatively new procedure and the available drills and sleeves are limited, as implant surgical template fixing drills have been used.\textsuperscript{14} The first studies performed on maxillary teeth used burs of 1.5 mm diameter.\textsuperscript{8, 15} Recently, the use of small-diameter burs of 0.8 mm and 0.85 mm diameters have been used for the treatment of small and narrow roots.\textsuperscript{4, 19, 20} This may have a positive impact not only by preserving the tooth, but also

\textbf{Fig. 22 & 23}: CBCT scan after root canal therapy from a coronal (Fig. 20) and sagittal (Fig. 21) view. \textbf{Fig. 24}: Radiographic control after six months.

\textbf{Fig. 25–27}: Flowchart for static guided endodontic access.
by reducing the heat generation on the root. The preparation bur may cause microcracks in the dentine, as the forces generated, particularly by the tip of the bur, are increased compared with post space preparation procedures, because of the larger contact area with dentine walls. However, there are no guide rings for high-speed handpiece burs, so it is not possible to cut enamel, ceramic and cast restorations.

This guided approach has been proved to have a sufficient accuracy to establish a safe treatment method for teeth with PCO and no significant difference between operators, which might facilitate endodontic treatment of these difficult cases even for less experienced professionals.

A limitation of this technique is the straight drill path that does not take a curvature into account—although it is rare that a root canal is calcified until its apical third. It is thus important to consider that this technique has anatomical limitations not only in severely curved canals, but also when radicular grooves, isthmuses or oval roots are present. A lack of interocclusal distance to accommodate the template and the additional instrument length required are also problems. Consequently, this technique is contra-indicated in curved canals and limited mouth opening. In these cases, dynamic guided endodontic access should be considered.

Conventional root canal therapy and apical surgery are alternative treatment options for teeth with PCO. It is possible to achieve success with conventional root canal therapy; however, it is time-consuming and associated with a higher risk of iatrogenic errors and excessive radiation exposure. Regarding apical surgery, this is a more invasive and uncomfortable approach for the patient.

Access guides are manufactured by overlapping the CBCT data with an intraoral scan of the target area. The CBCT scan is essential for the preoperative visualisation of the exact location and anatomy of the root canal system in complex cases. Although it has a high radiation dose, it has contributed to increasing the success rate of endodontic treatment by optimising technical treatment planning. In 2015, the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology updated their guidelines on the use of CBCT imaging in endodontics. They recommend CBCT imaging for the location of calcified root canals because of the high level of difficulty associated with this procedure.
Without this guidance, even the most experienced clinicians should be cautious and take several radiographs to ensure the correct insertion position of the instrument used to achieve the canal. The reduction in the number of radiographs with this approach is also of benefit and compensates for the patient’s radiation exposure in CBCT scanning. Still, periodic intraoperative radiographs should be taken to control the drill path. Also, stepwise control is suggested using a microscope, and as soon as a canal can be negotiated, conventional instrumentation can be carried out.

The planning of guided endodontics is very time-consuming compared with conventional root canal therapy because of CBCT acquisition, intraoral scanning, virtual planning and printing (Figs. 25–27). When the root canal disease is symptomatic, usually prompt treatment is needed and the patient and dentist do not want to wait. However, the time that it takes for an endodontic specialist with or without an operating microscope to localise calcified root canals can be more time-consuming than with the help of a 3D guide, as the chair time with this technique is minimal.

The additional cost, including a CBCT scan, intraoral scan, software and fabrication of templates, may be justified by the reduction of iatrogenic errors and the better prognosis of the tooth, compared with the costs for an implant.

Isolation by rubber dam is essential for the success of endodontic treatment. In guided endodontics, the adaptation of the guide is fundamental for the outcome, and so initial access without a rubber dam may be necessary. Once the canal is located, it is mandatory to place a rubber dam before instrumentation of the root canal.

Another disadvantage, as mentioned by Van der Meer et al., is the restricted visualisation of the treatment when the guide is used despite its transparent nature. The intermittent removal of the guide may be needed to ensure that the proper path is still being followed. In the field of endodontics, the use of guided templates assisted by CBCT images has been described not only for treating teeth with PCO, but also for development anomalies that affect the root canal system, apical microsurgery, selective canal retreatment and fiber post removal.

Conclusion

Negotiation of obliterated root canals is a tremendous challenge for clinicians. The use of new technologies, knowledge of pulp anatomy and interpretation of radiographs are the keys to achieving success in the treatment of PCO.

Guided endodontics appears to be a safe, reliable and clinically useful method for treating teeth with PCO. The use of endodontic guides may facilitate the localisation of the canal and allow a more predictable approach to these cases. However, it is still necessary to develop burs with smaller diameters and different lengths to allow access to calcified canals in longer and narrow teeth, such as canines and mandibular incisors. Further improvements are also necessary to allow this technique to be used in the treatment of posterior teeth and curved canals, the guidance of retreatment of selective canals and the removal of fiber posts.

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