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Guided access cavity preparation using cone-beam computed tomography and optical surface scans – an *ex vivo* study

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Abstract

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Aim To evaluate *ex vivo*, the accuracy of a preparation procedure planned for teeth with pulp canal obliteration (PCO) using a guide rail concept based on a cone-beam computed tomography (CBCT) scan merged with an optical surface scan.

Methodology A total of 48 teeth were mounted in acrylic blocks. An apical canal preparation was created to simulate remnants of an apical root canal that acted as the target for a drill path. The test blocks were surface scanned, and merged with a CBCT scan, and a guide rail was made. A pathway for the bur was created through a metal sleeve within the guide rail into dentine. The distance was measured between the centres of the performed drill path and the apical target by two examiners. A maximum distance of 0.7 mm was defined based on the radius of the bur (0.6 mm) and the radius of a root canal just visible on a radiograph (0.1 mm). The t-test was used for evaluation, and intra- and inter-examiner reproducibility was expressed by intraclass correlation coefficients.

Results The mean distance between the drill path and the target was significantly lower than 0.7 mm, and null hypothesis H_0: $\mu = 0.7$ was rejected (CI 95%: 0.31;0.49, $P < 0.001$). Intra- and inter-examiner agreements reached excellent levels.

Conclusions The combined use of CBCT and optical scans for the precise construction of a guide rail led to a drill path with a precision below a risk threshold. The present technique may be a valuable tool for the negotiation of partial or complete pulp canal obliteration.

Keywords: access cavity, CBCT, endodontics, pulp canal obliteration, trauma.

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Introduction

The canal system may partly or completely obliterate as a consequence of physiological ageing and/or external injuries, such as attrition, caries, previous operative procedures, as well as trauma (Andreasen & Kahler 2015, Qassem *et al.* 2015). Root canal treatment is only advocated when apical periodontitis develops (Robertson *et al.* 1996) or with signs such as tenderness to percussion, PAI scores ≥3 and a negative response to sensibility testing (Oginni *et al.* 2009). Traumatized incisors with radiographic signs of pulp canal obliteration (PCO) most often represent clinically complete PCO and may pose particular diagnostic and treatment challenges (McCabe & Dummer 2012). The American Association of Endodontists Case Assessment criteria place these cases into the high difficulty category (American Association of Endodontists 2010).

During cavity preparation, the location of the original (but obliterated) pulp canal may be detected as a

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grey, translucent area, fully embedded in darker tertiary dentine or bone-like matrix (Krasner & Rankow 2004). However, histologically, there is always a persistence of fine residual filaments of pulp tissue or tracts of organic material without the presence of inflammatory components (Malhotra & Mala 2013). The clinician may eventually expose a root canal for further instrumentation by preparing an access cavity parallel to the long axis of the root (Lovdahl & Gutmann 1997, Ngeow & Thong 1998), with the aid of an operating microscope, long neck burs and/or ultrasonic tips (da Cunha *et al.* 2009, Johnson 2009, Reis *et al.* 2009, McCabe & Dummer 2012). In some cases, the obliteration of the root canal is located apically, increasing the risk of jeopardizing the entire root, and if further attempts to reach the root canal are carried out, the use of additional radiographs, dye, or the so-called bubble tests with sodium hypochlorite have been advocated (McCabe & Dummer 2012). Apical surgery may eventually be indicated, but pulp remnants are still problematic in the residual calcified canal after root resection (Carrotte 2005).

Cone-beam computed tomography (CBCT) has been used as an aid in the planning of implant placements, and subsequently, in the production of acrylic guidance rails used for drilling into bone prior to the insertion of implants. However, the accuracy has been found to be deficient (Kalt & Gehrke 2008, Behneke *et al.* 2012). More recently, the combined use of CBCT and optical scans of the region of interest may have the potential to improve the precision of guided drilling procedures using computerized numerically controlled (CNC) technology for guide rail production. CBCT proved to be a valuable aid for selected diagnostic purposes prior to root canal treatment, such as diagnosing apical pathosis or revealing detailed root morphology (Abella *et al.* 2014, Patel *et al.* 2015). Recently, the European Society of Endodontology published a position paper comprising indications for the use of CBCT in endodontics (European Society of Endodontology 2014). No practical guidelines have been suggested for PCO and CBCT.

Since 2012, it has been possible to combine a CBCT scan and an optical surface scan of the same teeth. This means that preparation for an implant can be planned three-dimensionally (3D) and the optical surface scan allows the production of a guide rail. As a part of the guide rail, a metal sleeve is placed in the rail for controlling the position of the drill. The location and precision of the sleeve in the guide rail has not yet been tested for endodontic purposes.

The aim of this paper was to (i) evaluate the accuracy of a drilling procedure *ex vivo* using a guide rail based on a merged CBCT and an optical surface scan and (ii) present a new method for guided access cavity preparation in teeth with partial or complete PCO.

This study hypothesizes that the combined use of CBCT and optical surface scans for the precise construction of a guide rail will lead to the creation of a drill path that will reach an apical target point (apical root canal) within a mean distance (μ) lower than a well-defined threshold (based on estimates of the radius of the bur used and the diameter of a root canal (being visible on a radiograph). This approach may be a valuable tool for the negotiation and instrumentation of partial or complete PCO in endodontics.

Materials and methods

Macroscopical processing

The teeth used in this study were from a Danish population and had been extracted for reasons unrelated to this study. A total of 48 teeth were selected and kept in 0.5% aqueous chloramine. The teeth were embedded in 12 acrylic blocks, each containing 4–5 teeth (Fig. 1a), leaving both the crown and the apical region (1 mm) free of the acrylic resin. The canals in the apical regions were enlarged and half of the preparations were filled with gutta-percha with a diameter of 0.3 mm, to standardize an apical target

Figure 1 A test block with 4 resin embedded teeth (a, top) and the matching guide rail (a, bottom). With the guide in place, the entrance has been marked and enamel and filling material was cut with a high-speed bur exposing the entrance of the simulated access cavity. A commercially available twist bur with a diameter of 1.2 mm (b, left) and the same bur modified to be used through the guide sleeve (b, right).

point (Fig. 2a,b). It was the intention to examine whether the centre of a computer-based drill path could reach the centre of the circular target point confirming an optimal angulation of the drill rather than reaching all the way down to the target point *per se*. The bulk of the dentine was used as a model to reflect PCO; therefore in this set-up, the actual presence of the pulp cavity and the tooth type were not relevant and not taken into account.

Virtual design of the drill path

A CBCT scan (Orthophos XG 3D unit, Sirona Dental Systems, Bensheim, Germany) was made of each test specimen. Using specific software (Galaxis/Galileos Implant, Sirona Dental Systems), a drill path with a diameter of 1.2 mm was planned on a computer screen from an occlusal reference to the apical target point on each tooth and placed virtually in the bulk of dentine. The planned drill path was designed to reach the centre of the target point apically following specific alignment procedures (Fig. 2c). Superimposed on the drill path, a virtual sleeve was placed (inner diameter 1.2 mm, length 4 mm) for the guidance of the bur (Fig. 1b).

Guide rail construction

The teeth were surface scanned (CEREC, Sirona Dental Systems). The virtual surface models were merged with the CBCT image (Galaxis/Galileos Implant, Sirona Dental Systems), whereby a merged image was created comprising of a 3D volume of the tooth and the virtual drill path (Fig. 2c). A guide rail including the metal sleeve was produced by CNC technology as a SICAT optiguide (SICAT, Bonn, Germany) on the basis of the combined image. The sleeve guides the bur (1.2 mm) into the tooth. To obtain proper stability, the neighbouring teeth were included in the guide rail design (Fig. 1). The precision of the produced guide rail was analysed and measured by SICAT, and these data were forwarded to each rail. A margin was constructed to enable the bur to rotate without friction in the sleeve.

Test procedure on embedded teeth

A commercially available, cylindrical, stainless steel, spiral bur with a diameter of 1.2 mm (Busch, Engelskirchen, Germany) was modified to prepare a canal with a maximum working length of 22 mm from the top of the sleeve and into the tooth (Fig. 1b). The guide rail was placed covering the teeth and, through the sleeve, the drill entry point was marked by stained resin. A high-speed bur was used for the removal of enamel, exposing the dentine to such an extent that the spiral bur was not interfering when placed into the sleeve (Fig. 1a). The preparation of the drill path was performed with the spiral bur through the sleeve with the guide rail in place. Glyde (Dentsply Maillefer, Ballaigues, Switzerland) was used as lubrication and drilling was performed using 250 rpm in an endodontic hand piece.

Analysis of drill path

For the evaluation of the drill path, a new CBCT scan was carried out and the virtual drill path was superimposed on the performed drill path. Using this approach, the axis of the drill path could be extended to reach the apical target point in a blinded manner (Fig. 3c). The distance between the axis of this virtual

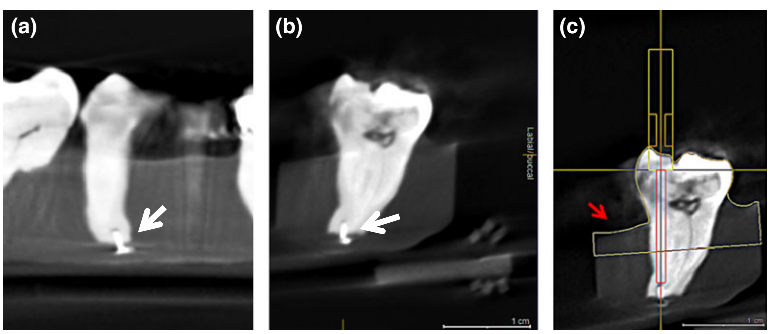

Figure 2 CBCT scan of specimen after preparation of a standardized apical target point (white arrows): (a) tangential (b) cross-sectional. The CBCT scan of the test block merged with the surface scan (red arrows). The planned drill path is virtually placed in the bulk of the dentine in order to reflect drilling through complete PCO: (c) cross-sectional.

drill path and the target point was measured. The measurements were taken at 3x magnification using the system software. Intravariability measurements were repeated twice with 1 week in between, and for testing intervariability a second examiner repeated all the measurements. The maximum radius between the drill path and our target point was defined as approximately 0.7 mm, based on estimates on the radius of the bur (Bur_{radius} = 0.6 mm) and of the root canal being visible on a radiograph ($Root\ canal_{radius}$ ~0.1 mm). The guide rail and the metal sleeve was produced (SICAT) and forwarded with technical specifications for each rail. To test the precision of the guide rail, including the position of the metal sleeve, between 2 and 4 metal sleeves were made in each guide rail (Fig. 1a).

Statistical analysis

The following hypothesis was examined using *t*-test: H_0: $\mu = 0.7$, where μ is the mean distance between the centre of the drill path and the centre of the target point. Data were log-transformed to obtain a normal distribution, using a Q-Q (quantile–quantile) plot. The mean distance (μ) was presented with 95% confidence interval (CI). The level of significance was set to 0.05. Inter- and intra-examiner reproducibility was expressed as intraclass correlation coefficients (ICC) (Altman 1991). Statistical analysis was performed with SAS Enterprise guide 7.1. (SAS Institute Inc., Cary, NC, USA).

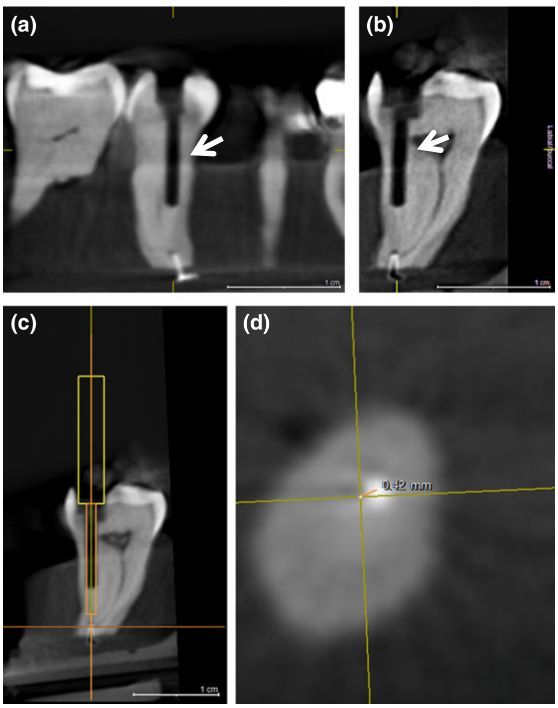

Figure 3 The CBCT scan of the test block after guided drill path preparation: (a) tangential (b) cross-sectional. A virtual drill path is superimposed on the performed drilling path: (c) cross-sectional. The distance between the axis of the drill path and the centre of the target point can be measured on the axial view. The distance was in this example 0.42 mm: (d) axial detail.

Results

Of the 48 teeth, it was possible to perform drill paths in 38 teeth. Due to the presence of the natural pulp cavity, a drill path only involving dentine could not be made in 10 teeth.

Qualitative and quantitative analysis

The combined use of CBCT and surface scan technology and the result of a guided access cavity preparation using the guide rail are shown in Fig. 3a,b. An example of measurements is shown (Fig. 3d), following the specific alignment of the virtual drill path. The intra-examiner reproducibility expressed as mean ICC was 0.84 (CI 95%; 0.69–0.92) confirming very good agreement between the repeated measurements. Inter-examiner reproducibility as mean ICC was 0.80 (CI 95%; 0.61–0.89) and was 0.94 (CI 95%; 0.89–0.97) when repeated, also confirming very good agreement between the examiners. Based on log-transformed data, it was possible to reject H_0: $\mu = 0.7$ mm disclosing a mean of μ being 0.46 mm. ($P < 0.001$ (CI 95%; 0.31–0.49)). This suggests that μ could be considerably lower. No systematic error could be detected between the rails (data not shown) when matching the drill paths made from the same guide rails.

Discussion

This *ex vitro* study has demonstrated a novel procedure for negotiating and treating partial or complete PCO in teeth with apical periodontitis using a guided access cavity preparation. The guided drill path was made on the basis of a CBCT scan and an optical surface scan allowing the production of a guide rail using CNC technology. In the guide rail, a metal sleeve is placed for controlling the drill. In this study, the location and precision placement of the guided drill path were reproducible with intraclass correlation coefficients disclosing very good agreement between repeated measurements. A threshold was determined ($\mu = 0.7$ mm) for the highest accepted distance between a well-defined apical target point and the centre of the drill path within the dentine. On the basis of the present measurements, a significant lower mean distance was shown, 0.46 mm ($P < 0.001$ (CI 95%; 0.31–0.49)). The guided drill paths were all performed short of the apical target point (for technical reasons), but the length of the drill path extended to 20 mm, reflecting a relevant clinical scenario. The variation noted may be explained as due to the necessary margin between the drill and the sleeve. The uncertainty of the guide rail positions on the test block were, in this study, shown to have no critical influence on suboptimal placement of a guided drill path in dentine. However, this may be more critical when testing on patients. A potential risk using this technique would be in curved root canals. Even if it is rare that a root canal is calcified until its apical third, as simulated in this study, the technique would destroy the root if the drill path was apically extended, without taking a curvature into account. For this reason, it must be underlined that the technique as presented may have anatomical limitations not only the curvature in severely curved roots, but also in the presence of radicular grooves, oval roots or isthmuses. In this study, the teeth were used as a model aiming to reflect partial or complete PCO using ortho-dentine and without taking the actual pulp cavity and tooth type into account. It could be speculated that in a real-life scenario, a drill path along the axis of a calcified canal may perform at least as well, due to a softer texture of the calcified tissue laid down in the root compared to ortho-dentine.

Several attempts have been suggested for gaining access through a calcified pulp chamber and the subjacent partial or complete PCO. This includes modified access cavity preparations (Lovdahl & Gutmann 1997), the use of an operating microscope, long neck burs and/or ultrasonic tips combined with periodic radiographs taken between each drilling (da Cunha *et al.* 2009, Johnson 2009, Reis *et al.* 2009, McCabe & Dummer 2012). Eventually, the PCO maybe so advanced that the concept of blind drilling is a reality, even when using magnification, giving rise to the risk of perforation. It could be speculated that using a guided access cavity preparation in the treatment of partial or complete PCO, these teeth may be successfully treated without jeopardizing the entire root, first and foremost in straight root canals, but perhaps also prior to a curvature in curved root canals. This would both have time and economic benefits, but the method needs to be tested further. The teeth to be selected would be traumatized or externally injured (by attrition, caries or operative procedures) and/or physiologically aged teeth (Andreasen & Kahler 2015, Qassem *et al.* 2015). The latter may be a more frequent occurrence, as population data show a marked decrease in the number of extracted teeth, indicating that people retain their teeth until an older age (Bjørndal 2011, Demant *et al.* 2012). Consequently, partial and complete PCO may be an increasing phenomenon in future.

Even though guided access is virtually controlled, periodic radiographs are a mandatory additional procedure to control the drill path. Moreover, a stepwise control of the needed depth of the drill path is suggested using a microscope, and as soon as a canal can be negotiated a shift towards conventional instrumentation can be carried out.

Conclusion

The hypothesis that the combined use of CBCT and optical scans for the precise construction of a guide rail leads to a drill path that will reach an apical target point (apical root canal) within a mean distance (μ) lower than 0.7 mm was confirmed. The presented technique may be a valuable tool for the negotiation and instrumentation of partial or complete PCO in endodontics.

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