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Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location

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Abstract

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Aim To present a novel method utilizing 3D printed templates to gain guided access to root canals and to evaluate its accuracy *in vitro*.

Methodology Sixty extracted human teeth were placed into six maxillary jaw models. Preoperative CBCT scans were matched with intra-oral scans using the coDiagnostix™ software. Access cavities, sleeves and templates for guidance were virtually planned. Templates were produced by a 3D printer. After access cavity preparation by two operators, a postoperative CBCT scan was superimposed on the virtual planning. Accuracy was measured by calculating the deviation of planned and prepared cavities in three dimensions and angle. Ninety-five per cent confidence intervals were calculated for both operators.

Results All root canals were accessible after cavity preparation with 'Guided Endodontics'. Deviations of planned and prepared access cavities were low with means ranging from 0.16 to 0.21 mm for different aspects at the base of the bur and 0.17–0.47 mm at the tip of the bur. Mean of angle deviation was 1.81°. Overlapping 95% confidence intervals revealed no significant difference between operators.

Conclusion 'Guided Endodontics' allowed an accurate access cavity preparation up to the apical third of the root utilizing printed templates for guidance. All root canals were accessible after preparation.

Keywords: accuracy, CBCT, guided technique, obliteration, printed templates, root canal treatment.

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Introduction

Treatment and prevention of apical periodontitis is still the major goal of root canal treatment (European Society of Endodontology 2006) and can be achieved by thorough cleaning and shaping of the root canal to eliminate microorganisms (Byström *et al.* 1987). Beforehand, a cavity has to be prepared to gain access to the root canals. This is the first invasive step of every root canal treatment and is thus crucial for the outcome, stability and longevity of the tooth (Trabert *et al.* 1978, Clark & Khademi 2010). To facilitate disinfection and complete debridement, straight line access to the orifices of the root canals is recommended (Mannan *et al.* 2001, Patel & Rhodes 2007, Johnson 2009), but there are also minimal invasive concepts to decrease fracture risk of root filled teeth (Krishan *et al.* 2014).

The number of elderly patients and their need for root canal treatment is increasing (Allen &

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Whitworth 2004, Cunha-Cruz *et al.* 2007, Dye *et al.* 2007, Wu *et al.* 2014). These patients can have teeth with totally calcified pulp cavities and root canals due to the lifelong apposition of dentine (Foreman & Soames 1988). Also young patients who suffered a dental trauma can present with partly or completely calcified root canals (Ranjitkar *et al.* 2002, Nikoui *et al.* 2003). Andreasen *et al.* (1987) found that 15% of traumatized permanent incisors had pulp canal obliteration, which is regarded as a sign of pulp healing and does not need endodontic intervention *per se*. However, there is a risk for the pulps of these teeth to become necrotic, ranging from 1 to 27% (Holcomb & Gregory 1967, Andreasen 1970, Stalhane & Hedegard 1975, Jacobsen & Kerekes 1977, Andreasen *et al.* 1987, Robertson *et al.* 1996, Oginni *et al.* 2009). In these cases, preparing an adequate access cavity and identifying the canal orifice can be challenging and may create a massive loss of tooth structure that is associated with a higher risk of fracture (Lang *et al.* 2006) and a high failure rate (Cvek *et al.* 1982). Therefore, preoperative planning is highly recommended and 3D imaging may be a useful tool.

Since its introduction into dentistry (Mozzo *et al.* 1998), CBCT offers new possibilities in diagnosis and treatment (European Society of Endodontology 2014). CBCT is often used in the field of oral implantology for three-dimensional planning, to quantify bone level or to visualize anatomic structures such as the mandibular nerve canal (Guerrero *et al.* 2006). Another application of CBCT is guided implant surgery using templates for implant site preparation and implant insertion according to the planning (Yatzkair *et al.* 2014). Nowadays, these templates can be produced by 3D-printing devices, based on matched 3D surface scans with CBCT data (Kühl *et al.* 2015).

Although the mechanical properties of dentine compared to the alveolar bone are different (Oyen 2006) and may influence the accuracy, the transfer of this computer-aided technique from oral implantology to endodontics could be beneficial in producing a minimal invasive access cavity and locate calcified root canals.

A virtually planned and guided minimal invasive access cavity could help to preserve tooth structure and avoid perforations, which could lead to an improved long-term prognosis, especially for teeth with calcified root canals.

The aim of the present study was to present a novel 'Guided Endodontics' method utilizing 3D printed templates to gain minimal invasive access to root canals and to evaluate its accuracy.

The research hypotheses are that the 'Guided Endodontics' method.

- allows to locate root canals in the apical third of the root and
- shows an acceptable deviation compared with the virtual planning.

Material and methods

Six maxillary models were fabricated using 60 extracted, single rooted human teeth ($n = 10$ per model). Therefore, teeth (incisors, laterals, canines and premolars) extracted for periodontal reasons were fixed in a cast simulating a clinical situation. The study protocol conformed to the principles outlined in the German Ethics Committee's statement for the use of human body material in medical research (Zentrale Ethikkommission 2003).

Preoperative CBCT images (Morita Accuitomo 80, J.MORITA Mfg. Corp, Kyoto, Japan) of the models with a voxel size of 0.125 mm were stored as Digital Imaging and Communication (DICOM) files. Surface scans were performed using a 3D-intra-oral surface scanner (iTero, Align Technology Inc., San Jose, CA, USA), and data were stored as surface tessellation language (stl-) files.

CBCT data were uploaded into a planning software designed for guided implant surgery (coDiagnostiX™ version 9.2, Dental Wings Inc., Montreal, Canada). The software allowed the creation of a virtual image of a commercially available bur (Straumann Drill for Tempimplants, Ref.: 80381, Institut Straumann AG, Basel, Switzerland) with a total length of 37 mm, a working length of 18.5 mm and a diameter of 1.5 mm. In addition, a virtual sleeve for guidance with an inner diameter of 1.5 mm, an external diameter of 2.8 mm and a length of 6 mm was created for planning purposes. The virtual bur was superimposed on each tooth with the aim of creating a direct access to the apical third of the root canal (Fig. 1). To create a template for 'Guided Endodontics', the surface scans were uploaded to the implant planning software (coDiagnostiX™). Scans were matched with CBCT data by aligning the crowns of the teeth (Fig. 2). Finally, a virtual template was designed by applying a tool of the coDiagnostiX™ software. Information on sleeve's position was considered in the planning. Exported stl-files allowed a 3D printer (Objet Eden 260 V, Material: MED610, Stratasys Ltd., Minneapolis, MN, USA) to produce the templates. Computerized numerical control (CNC-) technology was used to fabricate the designed sleeves which were integrated into the printed templates.

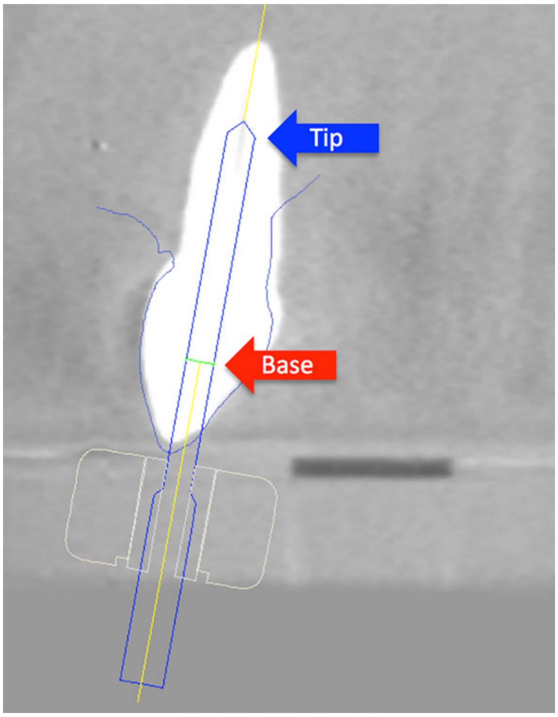

Figure 1 Superimposition of the virtual bur on the tooth to create straight line access to the apical third of the root canal. Red arrow indicates the base of the bur, blue arrow, the tip of the bur.

Preparation of access cavity using 'Guided Endodontics'

Templates were attached to the models, and their correct and reproducible fitting was checked. Marks were set through the template sleeves to indicate the region of access cavity. Enamel was removed in this area using a diamond bur until dentine was exposed. Then, the specific bur was used to gain access to the root canal (Fig. 3). Rotational speed was set at 10 000/min, and pumping movements were applied. The bur was cleaned regularly during preparation. The final position was reached when the bur hit the mechanical stop of the sleeve.

Thereafter, access of each root canal was checked with a size 10 K-file (VDW, Munich, Germany) under a dental microscope (PROergo, Zeiss, Oberkochen, Germany).

Access cavity preparations were performed by two experienced operators.

Accuracy measurement

After access cavity preparation postoperative CBCT scans of the models were performed. Data were uploaded into the coDiagnostiX™- software to evaluate the deviation between planned and performed access cavity by matching the pre- and postoperative CBCT scans. After alignment of both scans, the virtual burs used for planning were superimposed on the access cavities of the postoperative scan. The software was able to automatically calculate the deviation between prepared cavity and the virtual planning at the level of the base (coronal end-point of bur's working length) and tip of the bur (Fig. 1). Deviations in mesial/distal and buccal/palatal aspect, depth and angle were determined at both levels.

A descriptive statistic was performed calculating the mean of absolute difference, median, minimum and maximum. Ninety-five per cent confidence intervals were calculated for each operator and parameter.

Two teeth were excluded because calculation of deviations was not possible due to loosening of the teeth in the cast.

Results

After preparation using 'Guided Endodontics', all root canals were accessible by a size 10 K-File.

Mean deviation of angle was 1.81° (median: 1.4°, min.: 0°, max. 5.6°).

At the base of the bur, the mean of absolute difference in mesial/distal direction was 0.21 mm (median: 0.19, min.: 0.0 mm, max: 0.75 mm) and 0.2 mm (median: 0.19 mm, min.: 0 mm, max.: 0.76 mm) for buccal/oral aspect. The mean of apical/coronal deviation was 0.16 mm (median 0.13 mm, min.: 0.0 mm, max.: 0.76 mm; Table 1).

Table 2 shows the results of the same parameters at the tip of the bur. Mean of mesial/distal deviation was 0.29 mm (median: 0.18 mm, min/max: 0–1.34 mm), and buccal/oral, 0.47 mm (median: 0.37 mm, min/max: 0–1.59 mm), and in apical/coronal direction, the mean difference was 0.17 mm (median: 0.13 mm, min/max: 0–0.75 mm).

Table 3 shows the 95% confidence interval and standard deviations of the same parameters differentiated by operators. Overlapping of all confidence intervals revealed no significant difference between operators.

Discussion

This study shows that the technique allowed preparation of an accurate access cavity *ex vivo*.

Deviations of planned and prepared access cavities were low, with means ranging from 0.16 to

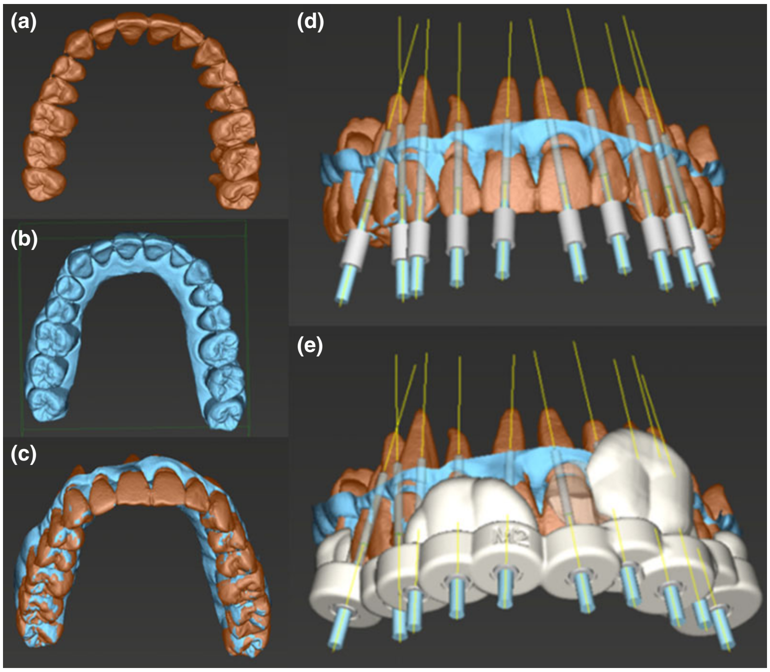

Figure 2 Matching of CBCT and surface scans: (a) CBCT scan (b) surface scan (c) matched scans (d) superimposition of virtual bur (e) designed template including sleeves and burs.

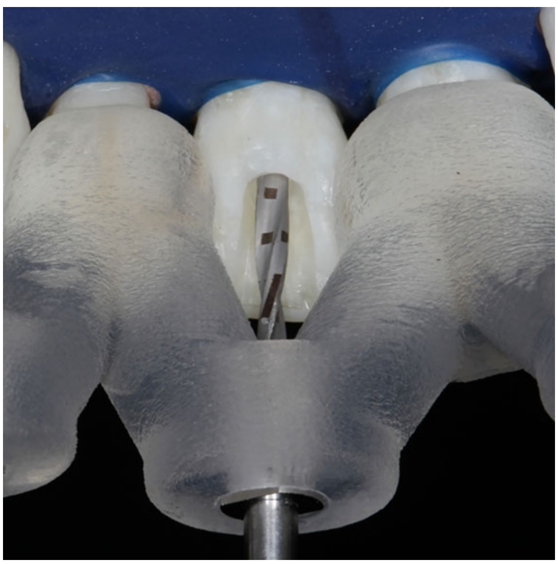

Figure 3 Clinical application: After the removal of enamel, the bur was guided through the sleeve to gain access to the apical third of the root canal. The sleeve's mechanical stop indicates that the bur reached the planned position.

0.21 mm for different aspects at the base of the bur and 0.17–0.47 mm at the tip of the bur. Mean of angle deviation was 1.81°. Overlapping 95% confidence intervals revealed no significant difference between operators. The results of the present study indicate a high accuracy of the 'Guided Endodontics' technique with a negligible influence of the operator.

Table 1 Mean of absolute difference, median, minimum and maximum of deviation at bur's base of planned and prepared access cavity in mesial/distal, buccal/palatal, apical/coronal [mm] aspect and angle [°]

	Angle [°]	Mesial/ distal [mm]	Buccal/ palatal [mm]	Apical/ coronal [mm]
Mean (abs. diff.)	1.81	0.21	0.2	0.16
Median	1.4	0.19	0.19	0.13
Min.	0.0	0.0	0.0	0.0
Max.	5.6	0.75	0.76	0.76

Compared with studies evaluating the accuracy of guided procedures in implantology, the results of this study were even more accurate. Jung *et al.* (2009) showed in a systematic review a mean error of 0.74 mm at the entrance point of the implant and 0.85 mm at the end-point. Another systematic review reported even higher values of mean error with 1.07 mm at entrance and 1.63 mm at the end-point.

Table 2 Mean of absolute difference, median, minimum and maximum of deviation at bur's tip of planned and prepared access cavity in mesial/palatal, buccal/palatal, apical/coronal [mm] aspect and angle [°]

	Mesial/distal [mm]	Buccal/palatal [mm]	Apical/coronal [mm]
Mean (abs. diff.)	0.29	0.47	0.17
Median	0.18	0.37	0.13
Min.	0.0	0.0	0.0
Max.	1.34	1.59	0.75

Table 3 Ninety-five per cent confidence interval (standard deviation) of all determined parameters differentiated by operators

	95% confidence interval	
Parameter	Operator 1	Operator 2
Angle [°]	1.50–2.49 (1.51)	0.94–1.92 (1.01)
Mesial/distal (base) [mm]	0.17–0.28 (0.17)	0.10–0.24 (0.15)
Buccal/palatal (base)	0.14–0.24 (0.15)	0.15–0.31 (0.16)
Apical/coronal (base)	0.10–0.20 (0.15)	0.10–0.29 (0.19)
Mesial/distal (tip)	0.20–0.38 (0.28)	0.13–0.46 (0.34)
Buccal/palatal (tip)	0.33–0.63 (0.45)	0.31–0.59 (0.29)
Apical/coronal (tip)	0.11–0.20 (0.15)	0.10–0.29 (0.19)

The mean error of angle deviation was also much higher with 5.73° (Schneider *et al.* 2009).

A more recent study utilizing printed templates for guided implantology and the same planning software reported an apical deviation of 0.49 mm and error of sleeve angulation of 1.5° (Kühl *et al.* 2015). This indicates a high accuracy of printed templates and the software (coDiagnostiX™ version 9.2), and therefore, this technique was applied in the present study. One reason for the even higher accuracy measurements of 'Guided Endodontics' may be related to the fact, that only a single bur was used in contrast to implant cavity preparation. The latter requires several burs with varying diameters, which could be an additional source of inaccuracy.

Inaccuracies are partly related to the loose fit between the drill and the sleeve, which is necessary to avoid heat development during access preparation. However, this gap leads to deviation in angulation due to reduced guidance. Reduction of the tolerance between drill and the slightly oversized sleeve may improve the accuracy of cavity preparation.

The presented method is based on matching surface scans with CBCT data.

CBCT is becoming more important in all parts of dentistry including endodontology (Patel 2009). Radiation doses associated with CBCT are still higher than that of conventional radiographs. Although new CBCT devices with a limited field of view may have a relatively low radiation dose of only 5 μSv, there is still a large range of radiation dose when comparing different devices (Ludlow *et al.* 2015). With respect to the 'ALARA'-principle ('as low as reasonably achievable'), the use of CBCT has to be carefully justified, especially when treating young patients, who have an increased biological risk after exposure to radiation (Dula *et al.* 2014). In cases with radiological signs of severe root canal calcification and apical periodontitis, a CBCT and 'Guided Endodontics' might be indicated to retain the tooth (European Society of Endodontology 2014). There is only limited data on the treatment of teeth with calcified canals. Cvek *et al.* (1982) assessed the frequency of technical failures of endodontically treated teeth with calcified canals. The total frequency of failure was high (20%) with mandibular incisors showing a failure rate of even 71%. Akerblom & Hasselgren (1988) found that endodontic treatment of teeth with calcified root canals had an overall success rate of 89% when performed by a specialist. They also found that the success rate of treating teeth with calcified canals and preoperative apical periodontitis was only 62.5%. Yet, there is no data on the treatment of teeth with calcified root canals in general practice and on the loss of hard tissue when accessing these root canals. 'Guided Endodontics' could be a helpful tool for practitioners to treat these complicated cases even without a dental microscope.

A drawback of this *ex vivo* study is the lack of calcified canals. It remains unknown to what extent, this aspect might have influenced the results of this study. In addition, the expenditure of time needed for 'Guided Endodontics' including CBCT acquisition, intra-oral scanning, virtual planning and printing was long when compared to conventional root canal treatment. However, accessing calcified root canals with or without a dental microscope might be even more time consuming than the present technique. This will be the focus of further studies.

Another critical aspect of 'Guided Endodontics', which also needs further investigation, is the additional cost including CBCT, intra-oral scan, software and fabrication of templates.

Conclusion

The 'Guided Endodontics' technique allowed accurate access cavity preparation utilizing printed templates by matching CBCT data with an intra-oral scan. It was possible to locate all root canals in the apical third. Therefore, the hypotheses of this study were confirmed.

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