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Guided root canal preparation using cone-beam computed tomography and optical surface scans – an observational study of pulp space obliteration and drill path depth in 50 patients

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Abstract

Aim To report the precision of guided access cavity preparations in relation to demographic and dental variables in fifty patients.

Methodology This observational study was carried out during the period 2014-2017. The patients were consecutive referrals to a private endodontic practice. The inclusion criteria were: 1) pulp space obliteration associated with signs of apical periodontitis (PAI score >3 or sensitive to percussion, 2) teeth with pulp space obliteration in need of a post, where the referring dentist had attempted or failed to negotiate the obliterated root canal (and it was not possible to negotiate using the operating microscope within a reasonable time frame), 3) a surgical intervention was not justified. A published methodology for guided endodontics was used. Measures on demographical and previous dental history were analyzed and related to drill path precision, being evaluated on radiographs as optimal (centre of the root canal) or acceptable (peripheral/ tangential). The Chi-square test was used for analyses of correlation between predictor variables and Binary logistic regression analysis using backward elimination with degree of obliteration, guided access cavity preparation depth and precision as dependent variables. Significance level was 0.05%.

Results Thirty one female (median age 65 yr) and 19 males (median age 69 yr) were enrolled. Overall, 88% (n = 44) of the teeth had pulp space obliteration associated with signs of apical periodontitis, whereas the remaining teeth were in need of a post. The pulp space obliterations were longer in maxillary compared with mandibular teeth (P = 0.024). The performance of the drill path in mandibular teeth versus maxillary teeth resulted in a significantly greater number of optimal precision scores (P = 0.033), and when a previous attempt at access and canal negotiation had occurred versus no attempt (P = 0.009). Even in cases with the worst outcome the technique was still successful clinically.

Conclusions The clinical implementation of guided root canal treatment in fifty serial cases of single-rooted teeth with pulp space obliteration was associated with a precision that in all cases led to the location and negotiation of the root canal and completion of the treatment.

Introduction

Root canal treatment of teeth with pulp chamber and root canal obliteration is challenging (McCabe & Dummer 2012, Andreasen & Kahler 2015). Obliteration of the pulp space may occur as a result of the formation of tertiary dentine, as seen during caries progression (Bjørndal & Darvann 1999), or following tooth restoration (Fleig *et al.* 2017). In addition, pulp space obliteration occurs in teeth with open apices following luxation injuries, particularly following lateral luxation, intrusion and avulsion (Andreasen *et al.* 1987, Flores *et al.* 2007b, 2007a). Even though it is recommended that prophylactic root canal treatment should not be performed on a routine basis of teeth with pulp space obliteration (Robertson *et al.* 1996), the frequency of apical periodontitis has been reported to increase to approximately 10 % after more than 15 years in such cases (Jacobsen & Kerekes 1977). As a consequence, root canal treatment in teeth with pulp space obliteration and apical pathosis in adults following a luxation injury may be necessary. Finally, in cases with severe loss of tooth structure endodontic intervention may be indicated for post retention (Naumann *et al.* 2017).

Gaining access to a root canal in a tooth with pulp space obliteration and subsequent canal preparation can be time-consuming and difficult, even when using an operating microscope (Kiefner *et al*. 2017). Complications may include creating an overextended access cavity, incorrect alignment of the access cavity with the risk of root perforation as well as fracture of root canal instruments during canal preparation.

Recently, proof of concept papers have in parallel introduced the combination of CBCT and surface scans for the construction of a guide to pilot the negotiation and preparation of partly or completely obliterated pulp chambers and canals in anterior teeth (Buchgreitz *et al.* 2016, Zehnder *et al.* 2016). A laboratory analysis of the computed drill path based on a human tooth model was reported before the concept was introduced clinically (Buchgreitz *et al*. 2016), and revealed that the accuracy of the virtual designed drill path was sufficient to reach a predefined target point when using the guide. This was later confirmed in extracted mandibular incisors (Connert *et al*. 2017). In addition, case reports have been published of incisor teeth that were accessed and their canals prepared using this guided technique (Krastl *et al.* 2016, Connert *et al*. 2018). Also, a guided access cavity of a tooth affected by dental malformations has been published, justifying a buccal access (Mena-Álvarez *et al.* 2017).

However, more clinical evidence and experience is required using guided access cavity preparation techniques in teeth with pulp space obliteration. Based on recent studies it is hypothesized that guided drill paths have sufficient precision irrespective of gender, age and/or tooth site, degree of obliteration, and previous attempts to find and negotiate the root canal.

The aim of this study was to analyze the length of the drill path needed for completion of instrumentation, the length of the drill path in relation to the length of canal obliteration, and to report the precision of guided access cavity preparations, taking into account demographical variables, previous dental treatment history, and status of attempted canal negotiation in patients referred with teeth in which pulp space obliteration was a complicating factor.

Material and Methods

This study was intended and realized according to the STROBE Statements when applicable (URL http//www.strobestatement-org 2018). The study was carried out during the period 2014-2017. The inclusion criteria for were: 1) consecutively referred patients with pulp space obliteration associated with signs of apical periodontitis (PAI score >3 or sensitive to percussion, Fig. 1A), 2) teeth with pulp space obliteration in need of a post, where the referring dentist had attempted or failed to negotiate the obliterated root canal (and it was not possible to negotiate using the operating microscope within a reasonable time frame), 3) a surgical intervention was not justified, 4) informed consent was given by the patient. Exclusion criteria: 1) neighbouring teeth with metal restorations leading to CBCT artefacts, 2) the tooth could not be retained in a stable and rigid position during the scanning procedure and access preparation. Thus, patients enrolled on the basis of all inclusion criteria defined the study size.

Apart from the obtained informed consent, further ethical considerations were deemed unnecessary, as the guide technique is a pre-existing system for implant therapy. It has been tested *in vitro* for the modified approach of negotiating partly or completely obliterated pulp chambers and canals (Buchgreitz *et al*. 2016, Zehnder *et al.* 2016). In addition, two clinical case reports have proven its immediate applicability (Krastl *et al*. 2016, Connert *et al*. 2018).

Demographical, biological and pre-operative status

The included patients were analyzed according to gender, age, tooth type, and length of canal obliteration. The pre-operative status of the selected teeth was defined in relation to: small or no existing restorations, large restorations involving proximal surfaces or fractured coronal tooth structure, presence of full crown restorations. The status of previously attempted root canal location, that is, being short of the radiographically visible root canal *versus* no treatment attempts.

Procedures for estimates of drill path working length

For all patients a CBCT scan (Orthophos XG 3D unit, Sirona Dental Systems, Bensheim, Germany) was made of the tooth. On the basis of software intended for implantology (Galaxis/Galileos Implant, Sirona Dental Systems) a virtual drill path with a diameter of 1.2 mm was planned on the computer screen from an occlusal reference to the beginning of the radiographically visible root canal lumen. The drill path was designed to reach the first visible part of the root canal using specific alignment procedures (Fig. 1B-C). By adjusting the angulation of the virtual drill path it was possible to avoid involving the incisal edge and still reach the lumen of the root canal. Superimposed on the virtual drill path a virtual sleeve was placed for the guidance of the bur (Fig. 1D). Axial and transversal tomographic slice data were used to estimate the location of the root canal. On this basis the virtual drill path was constructed.

Drill path and guide construction

The teeth were surface scanned (CEREC, Sirona Dental Systems). The virtual surface models where merged with the CBCT volume (Galaxis/ Galileos Implant, Sirona Dental Systems), whereby a combination image was created comprising a 3D volume of the tooth including the virtual drill path. The guide including the metal sleeve was produced by CNC technology as a SICAT optiguide (SICAT, Bonn, Germany) on the basis of the combination image (Fig. 2). For further details see Buchgreitz *et al.* (2016).

Clinical procedure

The guides were tested by placing them over each tooth before rubber dam application (Fig. 3). Using a pin placed through the sleeve the point of entry of the drill on the tooth surface was marked by stained resin (Fig. 3D). The guide was removed and a high-speed bur was used for the removal of enamel so as to expose dentine (Fig. 3E) and so that a modified spiral bur (Busch, Engelskirchen, Germany) with a diameter of 1.2 mm was not interfering with enamel or a restoration when placed into the sleeve. The preparation of the drill path was achieved with the spiral bur through the sleeve with the guide in place. Glyde (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was used as a lubricant. Since cooling is difficult below the guide and in the drill path a low speed drilling was performed at 250 rpm in an endodontic handpiece (6:1) (VDW Silver, Munich, Germany). When the access was just below the enamel-cement junction a conventional radiograph was taken to ensure that the angulation of the preparation was correct.

Even though assumed pulp space obliteration was observed on the radiograph, all preparations were scouted clinically to determine if the canal had been exposed. Therefore halfway down the planned drill path a further radiograph was taken. If successful canal location was not achieved the preparation was continued and another radiograph taken at the expected start of the root canal (Fig. 4A). Concomitantly the base of the drill path was inspected using a microscope (Fig. 4B). The attempt to locate the root canal was made using sizes 6 to 10 C+ files (Dentsply Sirona Endodontics). In cases where the scouting was unsuccessful further preparation was performed without the guide in place as the already established drill path *per se* was acting as the guide. Finally, this was followed by an additional attempt to locate the root canal (Fig. 4C, D). The preparation of the canal was completed using reciprocating file sizes 25-50 (ReciProc, VDW, Munich, Germany) using an endodontic handpiece (Silver 6:1) (VDW) and a corresponding endodontic motor (VDW Silver motor). The size of the apical preparation was guided by the dimensions of the root canal. In principle, the root canal was enlarged to a file with a size two numbers higher than the size of the first file to bind at the full working length, following initial glide path instrumentation. However, in cases where size 6 to 10 C+

files was needed, the final reciprocating file was at least size 25. Canals were irrigated with 2.5-5% NaOCl during preparation.

Measurements of the length of the pulp space obliteration and length of the drill path on radiographs.
The length of the pulp space obliteration was measured from the proximal cervical enamel-cement junction to the level of the obliteration along the root canal relative to the tip of the root. The actual depths of the drill paths were measured from the same end-points that defined the pulp space obliteration. Therefore, both lengths were expressed on the basis of relative measures as the radiograph for the pulp space obliteration and the radiographs for the drill path were not the same, thus the projection either. The median value of the relative lengths of pulp space obliteration expressed in frequency was 43%. This threshold, was used to divide the patients in two equally-sized groups, one having the obliteration extending into the coronal region (length < 43% of the entire root length). The other group extended into the apical region (length > 43% of the entire root canal). Two scenarios were investigated in relation to the lengths of the drill path and the pulp space obliteration: Length of drill path $\leq$ length of pulp space obliteration (i.e. drill path was shorter or the same as the length of the pulp space obliteration); length of drill path > length of pulp space obliteration.

Accuracy of the drill path
The completion and accuracy of the drill path was evaluated on conventional radiographs and qualitatively divided in two groups: drill path centered (optimal precision) and drill path peripherally or tangentially transported (acceptable precision). In principle, a catastrophic failure in terms of root perforation was a theoretical option but not incorporated in the analysis.

Statistical analysis
For the statistical analyses the degree of obliteration and length of the drill paths were merged into 2 categories based on their medians. Age was also divided in two groups for the statistical analyses (Table 1). To overcome the association between length of drill path and length of pulp space

obliteration, the variables, were defined, as described above. The Chi-square test was used for analyses of correlation between predictor variables. Binary logistic regression analysis was preformed using backward elimination with degree of obliteration, guided access cavity preparation depth and precision as dependent variables. Kappa analysis was used to test the interrater agreement of estimated length of pulp space obliteration. Analyses were conducted using SPSS version 25.0 (SPSS, Inc., Chicago, IL, USA). Level of significance was set to 0.05%. As all data was obtained immediately during treatment no addressing concerning missing data were needed.

Results

The patients are presented in Table 1. Two additional patients were referred within the study period, but the teeth were too mobile and would not have been able to be fixed rigidly during the scanning procedure and access preparation. Overall, 88% (n = 44) of the referred teeth had pulp space obliteration associated with signs of apical periodontitis, whereas the remaining 6 teeth required a post. Due to the nature and simplicity of this study a flow diagram has been omitted.

Kappa values for the estimates of the length of the pulp space obliteration revealed substantial intra-rater agreement, K = 0.73, and for the interrater agreement the values were moderate, K = 0.63.

Analyses of the lengths of pulp space obliteration and drill path and related precision

The length of pulp space obliteration was greater in maxillary compared with mandibular teeth (Table 1, P = 0.024). In the present study group the performance of the drill path in mandibular teeth versus maxillary teeth resulted in a significantly greater number of optimal precision scores (Table 2, P = 0.033). Also, the precision of the drill path resulted in significantly more optimal scores when a previous attempt at access and canal negotiation had occurred versus no attempt (P = 0.009) and when performed in patients aged 65 and beyond versus (Table 2). Gender (P = 0.083), tooth type (P = 0.849), and side of the jaw (P = 0.412) had no significant impact on the precision of the drill path. The length of pulp space obliteration (P= 0.613) as well as length of the drill path (P = 0.992) had no significant relation to precision *per se*. However, if the pulp space obliteration was below 20% of the root length (N = 9), the drill path was always located more deeply. When the pulp space obliteration was more than 50% of the root canal length (N = 11) the drill path was deeper in 45%.

Taken together, when the length of the drill path extended beyond the degree of pulp space obliteration (P = 0.068), a slight tendency toward more optimal precision score of the drill path, was noted. The regression analysis did not provide additional information not already provided by the Chi-square test.

A treated mandibular tooth with completed root filling and optimal precision score for the drill path is illustrated in Fig. 5A. An acceptable precision score for the drill path in the maxilla is illustrated in Fig. 5B; the drill path was peripherally transported. Working-length radiographs as well as postoperative and 1-yr follow-up radiographs are illustrated of an acceptable precision case (Fig. 6A-C).

Discussion

In fifty consecutive clinical cases it was possible to demonstrate that guided access cavity preparation and canal location and negotiation using CBCT in combination with optical surface scans provided an overall optimal or acceptable precision in single-rooted anterior teeth with pulp space obliteration. The findings confirm the hypothesis, with no significant influence from demographical variables such as anterior tooth type and previous dental treatment.

A more critical assessment of the drill path technique revealed that the worst outcome was still acceptable clinically. The optimal precision of the drill path was defined as being centrally located in relation to the root canal, whereas a peripheral or tangential transported drill path was categorized as having acceptable precision. The term ‘acceptable’ was used because location and preparation of the root canals were possible, and furthermore, follow-up in such cases demonstrated healing of the apical lesion (Fig. 4). This supports the hypothesis that the outcome is not impaired when a tooth has an obliteration that can be passed, compared to teeth without obliterations (Cvek et *al*. 1982). No catastrophic failure in terms of iatrogenic root perforation or root fracture was neither anticipated nor experienced following the fifty treatments.

Even though the length of pulp space obliteration in itself was not significantly associated with optimal precision of the drill path, the data revealed that optimal precision occurred most often in mandibular teeth, where the length of pulp space obliteration was smaller compared with maxillary teeth. Also, a tendency was noted that if the drill path length was longer than the pulp space obliteration, optimal precision was achieved more often, and most often occurred when the length of pulp space obliteration was relatively short. Any previous attempt to negotiate the root canal led to the greatest number of optimal precision scores following drill path preparation. It can be speculated that the resistance to the bur is less when previous attempts have been performed, also when the drill path passes the pulp space obliteration, less resistance may be expected, and therefore less transportation of the drill path is noted. In mandibular teeth where optimal precision was noted more often, a bur with a smaller diameter (0.8 mm) is recommended as the root thickness in the incisors in particular is more limited (Connert *et al.* 2017).

The median age of the referred patient population was 65 years for females and 69 years for males, and as expected for similar age groups there was no significant difference found for the degree of pulp space obliteration. The median value of 43% was only used to divide the material in two equal sized groups for the statistical analysis. The analysis showed that, irrespectively of gender and age, the length of the pulp space obliteration was more deeply extended in maxillary teeth, indicating in this patient group that other causes besides aging and operative procedures were associated with pulp space obliteration. If the presence of pulp space obliteration is interpreted as a delayed healing complication following luxations, a deeper extend of pulp space obliteration may correspond with the fact that trauma most often occurs in the maxilla, in particularly following lateral luxation, intrusion and avulsions injuries (Andreasen *et al.* 1987, Flores *et al*. 2007a, 2007b). Some well-documented episodes of trauma were reported by the patients (Figs. 1), however, unfortunately the patients were not able to report all potential episodes of previous tooth trauma. Considering the age of the referred patients, pulp space obliteration associated with apical periodontitis is an event that can be expected as time passes, confirming previous long-term observational data on this topic (Jacobsen & Kerekes 1977).

In some cases the root canal was not visible on the CBCT because the spatial resolution of the system was 0.5 mm, which exceeded the diameters of these root canals. This could reflect imprecision, which according to the STROBE checklist needs reflection. In those cases the target point was established as the centre of the root as seen on the axial view of the apical one third of the root. Since the root canal of single-rooted teeth is placed in the centre of the root, localizing the periphery of the root was sufficient to appreciate where the canal was likely to be. When using conventional x-rays during the evaluation of the drill path, the bucco-lingual direction may cause an underestimation of the actual path, as previous laboratory studies have shown, (Zehner *et al.* 2016, Connert *et al.* 2017). Yet, to perform a drill path control using CBCT was not indicated, when reviewing previous data on precision (Buchgreitz *et al.* 2016). Similarly, 4 radiographs controlling the drill path perhaps may be redundant, but at the onset of this study only a few accuracy studies had been published. Therefore, the study commenced with every caution being taken and later the study design could not be changed. However, as a consequence of this study the number of radiographs most likely can be reduced by limiting them to a pre- and post- drill path radiographs.

It could be argued that treatment by specialist endodontists for several of the cases with pulp space obliteration was not necessary, and that the drill path approach should never replace the initial conventional approach of negotiating the pulp space obliteration. However, the drill path concept represents a robust strategy with an acceptable precision, irrespective of the degree of obliteration. Even though the precision of the drill path was categorised, the less optimal outcomes still allowed root canal treatment to be completed. Factors such as time taken for conventional negotiation using the operating microscope has previously been debated (Kiefner *et al*. 2017). The time spent performing the drill path *per se* was not measured systemmatically, however, a rough estimate would be less than 2 min, which could correspond well with the entire mean treatment time including the preliminary planning being approximately 10 min. (Connert *et al.* 2017). With regard to guided root canal treatment it should be remembered that the vast majority of the time used is associated with the non-chairside analysis that takes place in the digital laboratory, nevertheless, the concept does represent an additional cost for the patient.

Conclusion

The clinical implementation of guided root canal treatment in fifty serial cases of single-rooted teeth with pulp space obliteration was associated with a precision that in all cases led to the location and negotiation of the root canal and completion of treatment.

The hypothesis was confirmed that guided drill paths have sufficient precision regardless of age, gender, previous treatment status, length of pulp space obliteration as well as previous attempts to negotiate the root canal. Further studies involving cost-benefit analyses as well as time studies should be carried out.

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Conflict of Interest statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

References

Andreasen FM, Kahler B (2015) Diagnosis of acute dental trauma: the importance of standardized documentation: a review. *Dental Traumatology* **31**, 340-9.

Andreasen FM, Zhijie Y, Thomsen BL, Andersen PK (1987) Occurrence of pulp canal obliteration after luxation injuries in the permanent dentition. *Endodontics and Dental Traumatology* **3**, 103-15.

Bjørndal L, Darvann T (1999) A light microscopic study of odontoblastic and non-odontoblastic cells involved in tertiary dentinogenesis in well-defined cavitated carious lesions. *Caries Research* **33**, 50-60.

Buchgreitz J, Buchgreitz M, Mortensen D, Bjørndal L (2016) Guided access cavity preparation using cone-beam computed tomography and optical surface scans - an ex vivo study. *International Endodontic Journal* **49**, 790-5.

Connert T, Zehnder MS, Weiger R, Kühl S, Krastl G (2017) Accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. *Journal of Endodontics* **43,** 787-90.

Connert T, Zehnder MS, Amato M, Weiger R, Kuhl S, Krastl G (2018) Microguided Endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique. *International Endodontic Journal* **51**, 247-55.

Cvek M, Granath L, Lundberg L (1982). Failures and healingen endodontically treated non vital anterior teeth with post traumatically reduced plural lumen. *Acta Odontologica Scandinavia* **40**, 223-8.

Fleig S, Attin T, Jungbluth H (2017) Narrowing of the radicular pulp space in coronally restored teeth. *Clinical Oral Investigations* **21**, 1251-7.

Flores MT, Andersson L, Andreasen JO *et al.* (2007a) Guidelines for the management of traumatic dental injuries. I. Fractures and luxations of permanent teeth. *DentalTraumatology* **23**, 66-71.

Flores MT, Andersson L, Andreasen JO *et al.* (2007b) Guidelines for the management of traumatic dental injuries. II. Avulsion of permanent teeth. *Dental Traumatology* **23**, 130-6.

Jacobsen I, Kerekes K (1977) Long-term prognosis of traumatized permanent anterior teeth showing calcifying processes in the pulp cavity. *Scandinavien Journal of Dental Research* **85**, 588-98.

Kiefner P, Connert T, ElAyouti A, Weiger R (2017) Treatment of calcified root canals in elderly people: a clinical study about the accessibility, the time needed and the outcome with a three-year follow-up. *Gerodontology* **34**, 164-70.

Krastl G, Zehnder MS, Connert T, Weiger R, Kühl S (2016) Guided Endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. *Dental Traumatology* **32**, 240-6.

McCabe PS, Dummer PM (2012) Pulp canal obliteration: an endodontic diagnosis and treatment challenge. *International Endodontic Journal* **45**, 177-97.

Mena-Álvarez J, Rico-Romano C, Lobo-Galindo AB, Zubizarreta-Macho Á (2017) Endodontic treatment of dens evaginatus by performing a splint guided access cavity. J*ournal of Esthetic and Restorative Dentistry* **29**, 396-402.

Naumann M, Sterzenbach G, Dietrich T, Bitter K, Frankenberger R, von Stein-Lausnitz M (2017) Dentin-like versus rigid endodontic post: 11-year randomized controlled pilot trial on no-wall to 2-wall defects. *Journal of Endodontics* **43**,1770-5.

Robertson A, Andreasen FM, Bergenholtz G, Andreasen JO, Noren JG (1996) Incidence of pulp necrosis subsequent to pulp canal obliteration from trauma of permanent incisors. *Journal of Endodontics* **22**, 557-60.

URL http//www.strobe-statement.org/fileadmin/Strobe/uploads/checklists/STROBE_checklist_v4_combined.pdf.[accessed on 13 august 2018].

Zehnder MS, Connert T, Weiger R, Krastl G, Kuhl S (2016) Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location. *International Endodontic Journal* **49**, 966-72.

Figure Legends

Figure 1 A maxillary incisor traumatised in 1979 but with no subjective symptoms. The preoperative radiograph discloses a radiolucent area and a root canal treatment was planned (a). An attempt to localize the root canal failed (not shown in radiograph). An axial view of the CBCT scan 16 mm from the incisal edge. The canal is seen in the centre of the root surrounded by about 2 mm of dentine (b). The scan has been adjusted, whereby the drill path is noted along all three dimensions (c). The virtual drill path with a diameter of 1.2 mm is superimposed the axis of the root in both tangential and the cross-cut view. The actual drill path emerges from the visible root canal to the incisal edge. It is verified that the drill path is surrounded by dentine at both the tangential and the cross-sectional view. Also, the angulation of the drill path is changed in a way that the incisal edge is free and the virtual sleeve is placed free of the incisal edge (d).

Figure 2 A surface scan is made of the tooth arch (a). The surface and CBCT scans are then superimposed by marking 3 corresponding spots on each scan (a, b). The guide fits the occlusal surface of the tooth arch and the sleeve has the angulation which is defined by the virtual drill path (c). A guide is produced containing the metal sleeve with an internal diameter of 1.2 mm (d).

Figure 3 The clinical testing of the guide in the maxillary tooth with pulp space obliteration, associated with marked discoloration and apical radiolucency (a, b). Before application of the rubber dam the guide is tested for stability (c). A mark is made with a pin through the sleeve of the guide (d). The guide is removed and with a high-speed bur a plateau is prepared to ensure the spiral bur is not interfering with enamel when placed into the sleeve (e).

Figure 4 The clinical drill path procedure and root canal scouting involve the use of conventional radiographs. Related to the expected location of the root canal adjacent the obliteration a radiograph is taken (a). Periodically, the advancing front of the preparation is inspected using an operating

microscope (b). A C+ file (size 06) is used for scouting successfully the remnants of the canal in the apical portion of the root (c). The scouted orifice is visualized (d).

Figure 5 The two categories of precision are presented by the presence of the completed root fillings. A mandibular canine associated with optimal precision of the drill path located in the centre of the root canal (a). A maxillary central incisor associated with an acceptable precision of drill path peripherally or tangentially transported as evidenced by the root filling (b).

Figure 6 A working length radiograph of a maxillary central incisor with acceptable precision, as the file reveals a peripheral transported drill path (a) followed by the completed root filling (b) and 1-yr follow-up (a).

Table 1 Summary of demographic and biological variables

Variables	Data	
	Median age (N)	
Female	65 yr (31)	
Male	69 yr (19)	
	Cause of referrel	
Pulp space obliteration and apical pathosis	44	
Pulp space obliteration in need of a post	6	
	Teeth	
1+1	17	
2+2	14	
3+3	5	
1-1	9	
2-2	4	
3-3	1	
	Preoperative status	
Small or no restoration	29	
Large restoration involving proximal surfaces	9	
Anatomical crown broken of	5	
Full crown restoration	7	
	Previous attempted root canal negotiation	
No attempts	24	
Short of the radiographical visible root canal	26	
	Extent of pulp space obliteration	Coronal Apical
Female	18	13
Male	7	12
	Extent of pulp space obliteration	
	Coronal	Apical
Upper jaw	15	22*
Lower jaw	10	3

* P = 0.024

Table 2 A summary of the drill path precision

Variables	Data	
	Length of drill path (DP) and pulp space obliteration (PSO)	
	DP ≤ PSO	DP > PSO
Female	6	25
Male	3	16
	Lengths of drill path (DP) and pulp space obliteration (PSO)	
	DP ≤ PSO	DP > PSO
Optimal precision	4	18
Acceptable precision	5	23
	Maxillary teeth	*Mandibular teeth*
Optimal precision	13	9 *
Acceptable precision	24	4
	Age 14-65	*Age 65+*
Optimal precision	5	17 **
Acceptable precision	14	14
	Previous attempted root canal negotiation	
	No attempt	Short of root canal
Optimal precision	6	16 ***
Acceptable precision	18	10

* P = 0.033
** P = 0.049
*** P = 0.009

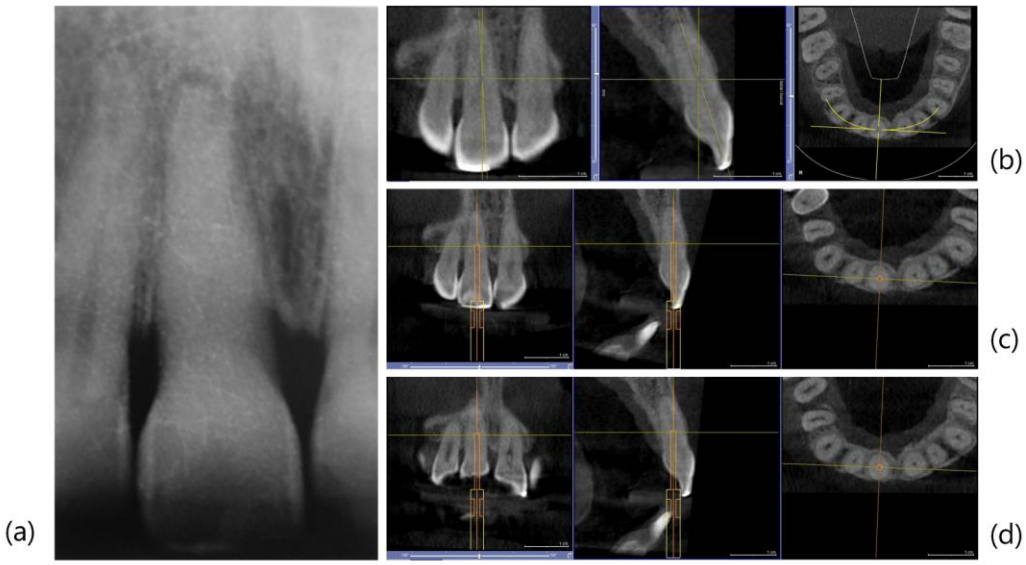
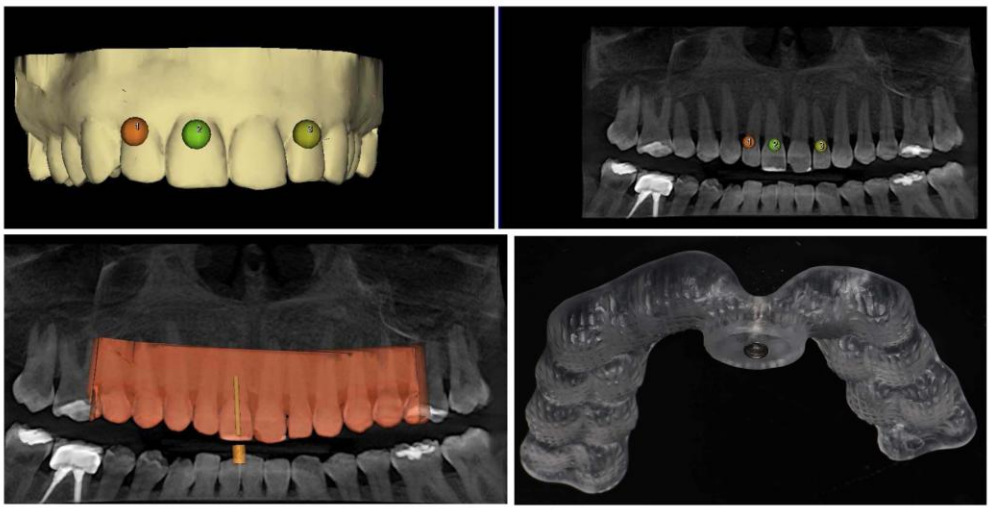


Figure 1

(a) (b)



(c) (d)

Figure 2

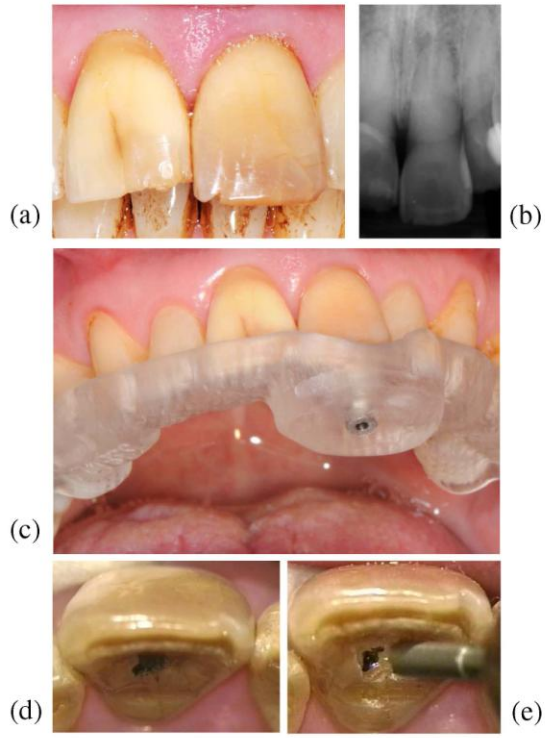


Figure 3

(a) (b) (c) (d) (e)

Figure 4

Figure 5

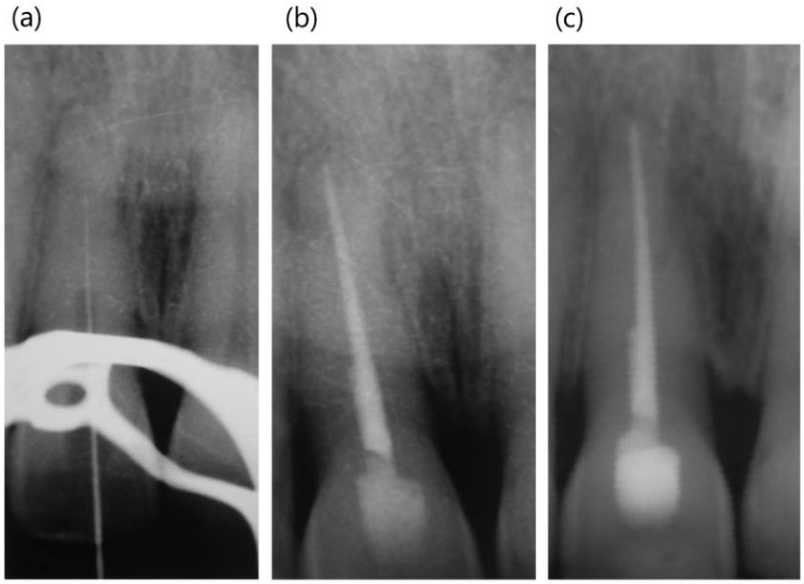


Figure 6