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Short communication

3D Computer aided treatment planning in endodontics

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ABSTRACT

Objectives: Obliteration of the root canal system due to accelerated dentinogenesis and dystrophic calcification can challenge the achievement of root canal treatment goals. This paper describes the application of 3D digital mapping technology for predictable navigation of obliterated canal systems during root canal treatment to avoid iatrogenic damage of the root.
Methods: Digital endodontic treatment planning for anterior teeth with severely obliterated root canal systems was accomplished with the aid of computer software, based on cone beam computer tomography (CBCT) scans and intra-oral scans of the dentition. On the basis of these scans, endodontic guides were created for the planned treatment through digital designing and rapid prototyping fabrication.
Results: The custom-made guides allowed for an uncomplicated and predictable canal location and management.
Conclusion: The method of digital designing and rapid prototyping of endodontic guides allows for reliable and predictable location of root canals of teeth with calcifically metamorphosed root canal systems.
Clinical significance: The endodontic directional guide facilitates difficult endodontic treatments at little additional cost.

1. Introduction

The objective of root canal treatment is adequate control of the resident microbiota through proper shaping, disinfection and obturation of the root canal system to achieve periapical healing. Calcification of the pulp chamber and root canal system can compromise access and thus complicate the root canal treatment. The process of calcification is called obliteration or calcific metamorphosis and is associated with injury to the pulp. The injury is commonly through disease process (caries, tooth surface loss), dentoalveolar trauma, or operative procedures such as pulp capping, pulpotomy and rarely orthodontic treatment [1]. Although canal obliteration does not inevitably lead to pulp necrosis or periapical disease [2,3], when it does, canal location and negotiation are significantly more difficult. The degree of difficulty is dictated by natural tooth morphology, the nature and extent of superimposed calcific alteration, extent of dentinal sclerosis and access to the tooth in the mouth.

In most cases, the calcific metamorphosis appears to be severe coronally, tapering off towards the root apex, leaving the dentist with the tantalising technical prospect of reaching it through spatial and drilling skills. Many clinicians have fallen foul of the temptation to achieve apical patency in such cases, only to have been sobered by the complications of excessive and uncontrolled dentine destruction or worse: root perforation [4].

Access to such calcified teeth has traditionally relied on the ability to drill truly in the direction of the anticipated canal opening based on knowledge of anatomy, 3D mental visualisation and a steady hand able to hold bur orientation [5]. A contemporary aberration of this approach is to use an operating microscope, which requires experience with treating challenging cases as it can further compromise any loss of orientation. Another development, cone beam computer tomography (CBCT), has the potential to aid the operator in enhancing the information for 3D visualisation by providing 3D depiction of the radiographic data. Not only does the CBCT dataset give a clear 3D representation of the tooth involved, it also seems to provide the operator with a more reliable way to detect root canal anatomy [6]. When comparing measurements made on traditional radiographs and CBCT datasets the latter seem to be more accurate [7] and the errors seem to be small and clinically insignificant [8]. The mere availability of 3D information,

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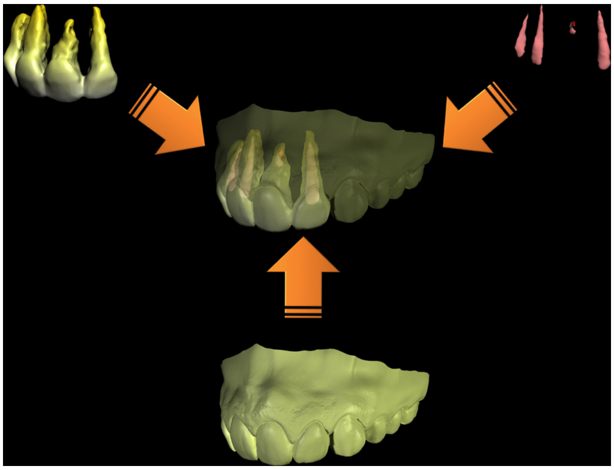

Fig. 1. 3D datasets of the teeth, pulp and digital impression of patient 3 combined in one 3D model.

however, still leaves the operator with the task of interpreting it, creating a *mental* 3D map along which to execute the practical task free-hand as before.

This paper describes a novel way to create a directional guide for anterior teeth with obliterated root systems on the basis of CBCT data, which guides the clinician while removing dentin to locate the canal opening.

2. Materials and methods

A small field CBCT data set (3D exam, KAVO, Amersfoort, The Netherlands) is made of the patient's upper or lower jaw, depending on the tooth to be treated. The patient is asked to open their mouth slightly to ensure that the maxillary and mandibular teeth are separated. The CBCT machine is set to a voxel size of 0.3 mm. This resolution surpasses the 0.5 mm resolution prescribed for planning implants using Nobelguide (Nobelbioresearch, Gothenburg, Sweden) or Simplant (Materialise, Leuven Belgium). These settings are chosen to obtain the lowest dose possible for the patient while maintaining the best imaging result to accomplish optimal planning. The CBCT dataset is converted to a surface model with "Devide" freeware (TU Delft Graphics group, Technical University of Delft, The Netherlands) using an optimal threshold to depict bone, teeth or the pulp. In addition, digital registration of the dentition is performed with the aid of the Lava COS intra oral scanner (3 M Espe Zoeterwoude, The Netherlands). Three separate entities, viz., bone, pulp and teeth are imported into 3ds Max software (Autodesk, San Rafael, California, USA) (Fig 1). As the planning requires a 3D model of the roots of the teeth (the CBCT dataset) and a precise 3D model of the crowns of the teeth (the digital impression), these two models are aligned and registered in GOM inspect free software (GOM mbH, Braunschweig, Germany).

In 3ds Max software, a virtual cylinder is created, which is aligned with the line between the centre of the remaining root canal and the centre of the palatal surface of the crown of the tooth. Around this central cylinder, a second 3D cylinder is designed with a diameter 2 mm larger than the central cylinder, by cloning the first cylinder and then increasing the diameter. This cylindrical zone depicts the safety zone around the central shaft within which drilling can be performed safely. A third cylinder is then created with a diameter similar to that of the consuetudinary drills used for the purpose. This cylinder is used to construct a hole for the metal

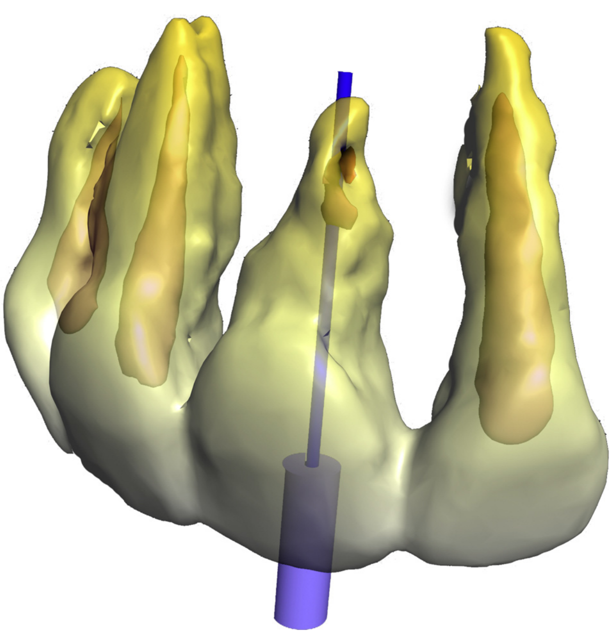

Fig. 2. Planning of the directional guide for patient 3. A cylinder is used to depict the direction of the drill necessary to locate the root canal system. Other cylinders are automatically aligned with the directional cylinder. Those cylinders are used for the design of the directional guide.

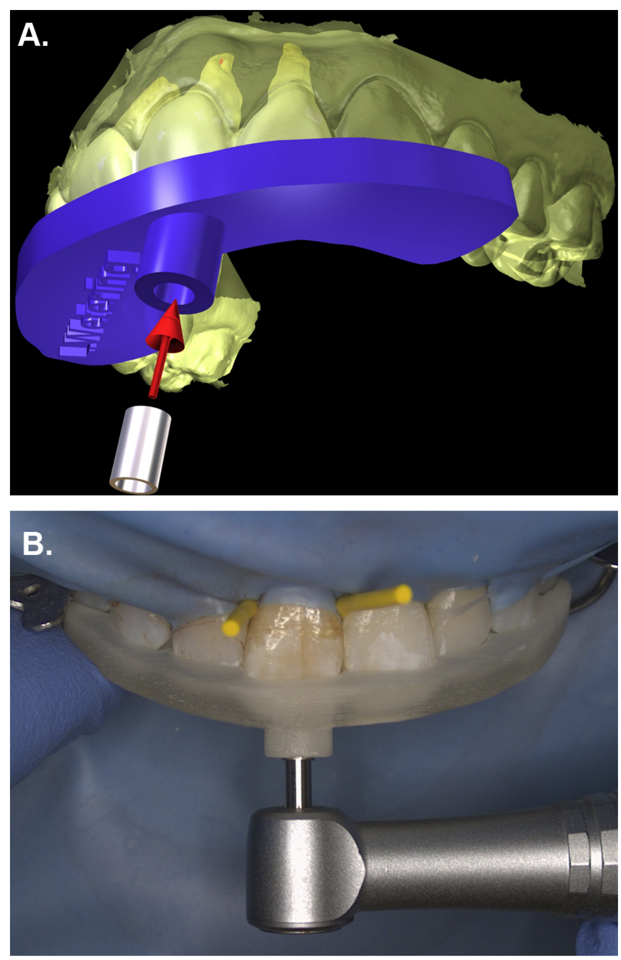

Fig. 3. The final directional guide design. (A) After the rapid prototyping of the guide a metal tube is placed in the corresponding hole. The metal tube has an inner diameter that is slightly larger than the bur used during the location of the root canal system. (B) The directional guide in place, while a bur is used to gain access to the canal system. As can be seen the direction of the bur is not exactly parallel to the long axis of the tooth during preparation. This coincides with the 3D planning.

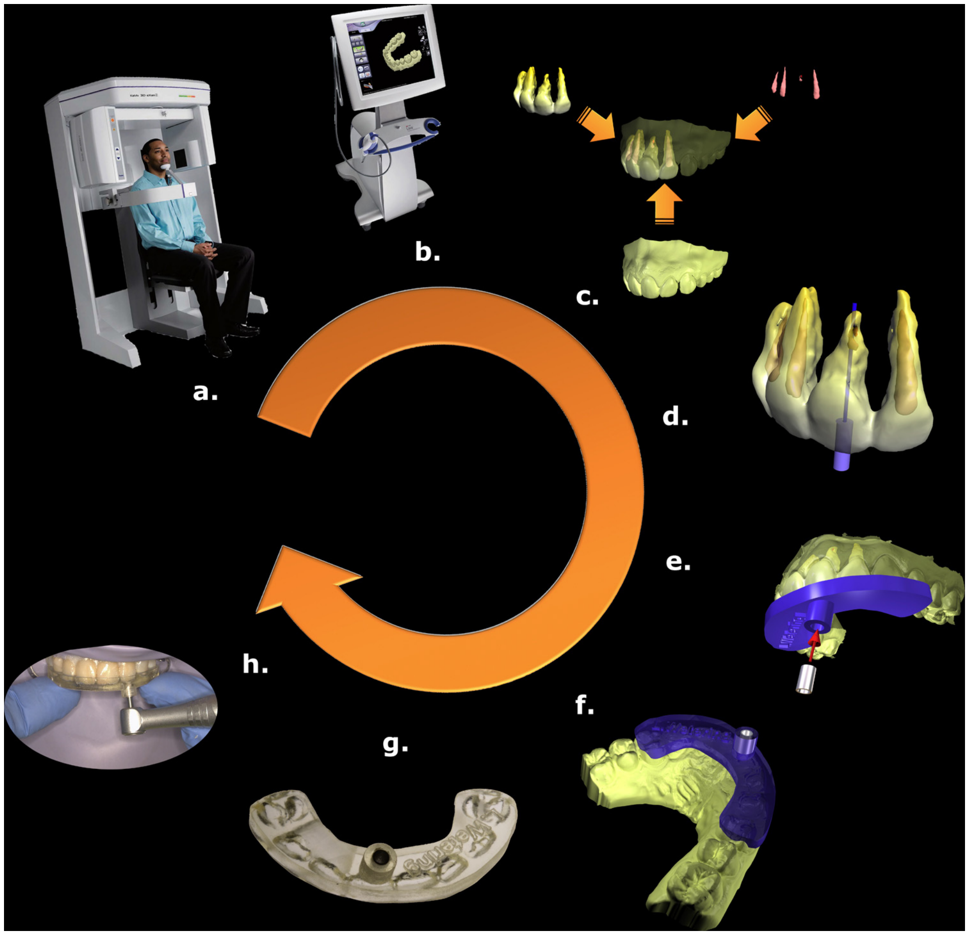

Fig. 4. An overview of the 3D planning for the endodontic directional guide and its application in the patient. A cone-beam CT is made (a) of the teeth involved in the planning. An impression of the dentition is made with an intra-oral scanner (b). In GOM inspect software the datasets of the teeth, pulp, bone and digital impression are registered (c). In 3D software the planning of the direction of the access is made (d) and a guide is designed with space dedicated for the metal guiding sleeve (e). When the final design is ready (f), it can be sent to a dental lab or a rapid prototyping facility. The printed guide (g) for use in the mouth of the patient (h). With this guide the root canal system is identified and prepared.

sleeve that will prospectively guide the drill. The aforementioned cylinder is aligned with the first cylinder using the "align"-tool available in the software (Fig 2).

Based on the planning, a surgical guide is digitally designed in the 3ds Max software. The guide will use the dentition for stable anatomical fixation and extends from the left first premolar to the right first premolar. The surgical guide is made to fit the dentition by first expanding the digital dentition by 0.1 mm using a "shell"-command and then digitally subtracting the dentition from the guide design using a Boolean operation. Expansion of the dentition is performed to compensate for the polymerization shrinkage that occurs in almost all 3D printing technologies, thus ensuring a proper fit. Similarly, a hole is modelled with an outside diameter of 3.0 mm in the surgical guide in which a metal tube with an inside diameter of 2.40 mm could be placed. This metal tube will eventually serve to guide the endodontic drill (Fig 3). The distance from the top of the guide to the beginning of the root canal system is measured and noted on the patient chart. The working length is also determined from the 3D dataset and noted on the patient chart. An overview of our digital planning process is given in Fig. 4.

The digitally designed surgical guide is prepared for export using the "stl check" command and exported as stl file and sent to a 3D printer. If a 3D printer is not available, the file can also be sent to a dental laboratory that is able to produce rapid prototyping models. With the aid of rapid prototyping the stl file is converted to a physical model.

The digital planning procedure and the directional guide were tested in three patients who required endodontic treatment on maxillary anterior teeth with obliteration of the root canal system. The patients were informed about the risk associated with endodontic treatment of calcified root canals and an informed consent form was signed by the patient. The Medical Ethics Review Board of the University medical Center, Groningen ascertained that the study was not deemed a clinical research project with test subjects as described in the Medical Research involving Human Subjects Act (WMO) and that formal ethics committee approval was not necessary as normal clinical procedures were followed with addition of an aid to increase the safety and decrease the risk of complications for the patients.

Before the endodontic treatment, the anterior teeth were isolated by rubber dam from the right to left first premolar, to allow the endodontic directional guide to use these teeth for stability. The fit of the guide was confirmed using "fit checker" (GC Europe NV, B-3001 Leuven, Belgium). A standard endodontic opening was created in the involved tooth in each patient and the guide was placed in position. A Munce bur number 2 (CJM Engineering Inc., Santa Barbara, CA 93101, USA) was used to slowly gain access to the root canal system. The metal tube in the guide fitted tightly around the shaft of the bur, ensuring proper guidance in the right direction, while only the tip of the bur was able to cut the dentin. Once the full length of the shaft was reached, the bur was replaced with one with a longer shaft. After the root canal system had been

Fig. 5. The pre-operative radiograph (a) and working length radiograph of patient 1, after the root canal system had been located with the aid of the directional guide (b) and the preoperative (c) and immediate postoperative radiograph (d) of patient 2.

reached, it was negotiated with endodontic hand files with intracanal use of a lubricant to the working length as indicated by an apex locator while irrigating copiously. When the number 15 handfile was reached, a radiograph was taken to confirm the determined working length (Fig 5). The root canal system was further prepared using a WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) instrument. This phase was accomplished with the continuous intracanal use of a lubricant and a 2.5% solution of sodium hypochlorite. After a final rinse of 17% EDTA solution, the prepared canal was disinfected with a 2.5% solution of sodium hypochlorite and subsequently dried and prepared for obturation.

3. Results

Location of the root canal system proved straightforward in all three cases with the aforementioned directional guide. In the first case, after every millimetre advance of the bur, the guide was removed and the access cavity checked through the microscope to ensure that the proper angulation was maintained, by looking for traces of the original canal. The canal opening was reached as anticipated at the target length. In the subsequent cases, the microscope verification was abandoned without incurring any problems. Because the root canal systems could be rapidly located using the directional guide, the canal preparation of all cases could be finished in one visit.

4. Discussion

The digital planning procedure and the resulting directional guide simplified difficult root canal treatment in obliterated teeth meanwhile decreasing the risk of iatrogenic damage to the root due to excessive dentine destruction and/or root perforation.

In the traditional approach to calcified pulp chambers, if the canal orifice or pulp chamber has not been located after 3–4 mm of penetration into the teeth, it is recommended that the bucco-palatal orientation of the bur is rotated so that it is parallel to the long axis of the tooth. In most cases, the problem is that the long axis of the tooth had not been followed; the commonest error being that the bur is angled labially, leading to a perforation of the labial root surface below the gingival attachment [9]. To facilitate more predictable location of the root canal system, it has been suggested that the access cavity is prepared close to or through the incisal edge of the tooth [9,10]. This approach also facilitates better planing of the root canal system walls by the endodontic files [11]. Although this approach enables easier maintenance of bur alignment with that of the long axis of the tooth, it still requires the clinician to have an accurate mental map of the root canal system and the anatomy of the tooth. Even the availability of CBCT alone, merely enhances 3D visualisation, lacking the necessary coupling of the data set to clinical execution.

The developed method provides coupling between the CBCT dataset and physical execution of the task of drilling to the minerally-receded canal opening; it eliminates the unpredictability of drilling in the correct direction and makes a challenging clinical problem relatively simple to manage. The digitally designed directional guides worked in all respects to facilitate root canal treatment as anticipated and shortened treatment time considerably. The tentative sectional drilling and checking process is replaced by one that is uninterrupted and allows drilling directly to the receded canal. A major advantage of digital planning is that it is possible to preoperatively visualize the root canal location and plot the navigation in detail without having to mentally transfer the planning to the clinical situation. The described technique has the potential to substitute the 3D visualization skill, specialized training and/or clinical experience necessary to treat these difficult cases. This will enable many dentists to achieve predictable results without needing extensive endodontic skills.

The disadvantage of the method described is that multiple teeth have to be isolated during the procedure as the guide needs to rest on the teeth directly to ensure the stability of the guide. It is possible to use a smaller number of teeth for support of the guide, but still multiple teeth need to be isolated. Another disadvantage is that the guide restricts the visual access to the endodontic access cavity even though the guide is made of a transparent plastic, necessitating removal of the guide to ensure that the proper path is still being followed during the procedure. Modification of the guide to facilitate inspection of the access cavity is an issue for future developments. Moreover, an ultrasonic tip can be used with the guide in place, but this is not advised as the guide restricts the visual access. It is, therefore, advised to remove the guide before using an ultrasonic tip.

When considering the accuracy of this 3D planning technique, a slight mismatch between the planning and execution may be expected. One reason for this is system error, i.e., a summation of all the errors present in the different phases, is accumulated in the final outcome. In the data acquisition phase, the resolution of the CBCT dataset should be taken into account even though the CBCT can be considered to be very accurate [7]. As the voxel size is 0.3 mm, the accuracy of the system as a whole is unlikely to surpass 0.3 mm. Then there is an error in the data acquisition of the dentition. The manufacturer of the Lava COS claims an accuracy of 11 μm, but this value has not yet been validated externally. Furthermore, the 3D model of the dentition was automatically registered with the dentition in the CBCT dataset to obtain a combined 3D model, which would give rise to registration errors [12]. During the final stage of rapid prototyping, the SLA or 3D printing material may show a slight dimensional change during polymerization. If the guide is not seated exactly as planned on the dentition, a small angulation of the Munce bur may occur resulting in magnified differences between the planned and final angulation of the bur. Furthermore, the bur used to remove the dentin is very thin and may show a slight bending under pressure.

A meta-regression analysis of Schneider et al. on computer-guided template-based implant dentistry [13] revealed a mean deviation of the implant of 1.07 mm at the entry point and 1.63 mm at the apex. However, some of the studies included in the meta-analysis involved edentulous subjects, in whom, the stability of the surgical guide may be less than optimal. Even though there is a difference between the procedures for placing implants and locating root canal systems, the procedure followed shows many similarities and a slight mismatch can be expected for the endodontic directional guide.

The proposed method has a number of advantages. It is a predictable technique that replaces mental visualisation and technical execution skills while it reduces treatment time. Furthermore, 3D planning can be relatively cost-effective and may be contracted out to a proficient 3D software operator with input from the clinician. Finally, the proposed method has flexibility of application to other teeth and for preparation of endodontic surgery (although not demonstrated in the presented cases).

The cost of the developed technique is potentially minimal. The 3D planning as described, may entirely be performed with expensive 3D software applications but to minimize the cost, we have used only one commercial software application, 3dsMax. To reduce the costs it is possible to perform the entire workflow using only freeware applications. The conversion of the CT data was already performed with the freeware application "Devide". The GOM inspect software, used to register the different 3D surface models, is also available free of charge. The 3D visualizations and designs were performed in 3ds Max software, but this can also be done in "Blender", a free 3D modelling and animation tool (www.blender.org). For the digitization of the dentition, the Lava COS intra-oral scanner was used, but a traditional impression poured in stone may also be used. Many dental laboratories offer the service of converting plaster models to digital models using 3D scanners at a small additional cost. The rapid prototyping of the directional guide may be performed with one of many available techniques. The SLA production of a directional guide costs currently around 130 euros, while the same guide design printed with a 3D polyjet printer ("Objet", Objet Ltd., Rehovot, Israel) costs around 30 euros. The guides produced with these technologies fit equally well. This means that the cost of the aforementioned method can be brought down to the cost of the production of the guide. With the prices of 3D printers reducing rapidly, the approach comes within reach for a clinician to print their own directional guide provided that the resolution of the printer is sufficient.

Future developments with regard to 3D computer aided treatment planning in endodontics include the use of the device for locating obliterated canals in posterior teeth. A limitation in this respect is the needed minimal thickness of the guide that might restrict its application in limited posterior spaces. Another development would be the fabrication of a set of sequential burs with a very small head with increasing lengths of the shaft. Such a design ensures a proper fit of the shaft in the metal cylinder and enables early use of the series of very thin burs. This approach would ensure preservation of coronal dentin and prevent unnecessary weakening of the root.

5. Conclusions

Endodontic treatment of an anterior tooth with severe pulp system obliteration requires experience and skills of the clinician and can be very challenging. By using a 3D digitally designed directional endodontic guide produced with computer-aided additive production techniques, the treatment of compromised cases can be performed by less specifically experienced or skilled clinicians. The cost of such 3D planning and the production of the directional guide are considered to be low and will further reduce in the future. In addition, use of the developed tool, may reduce the treatment time while increasing the predictability and success of the treatment of calcifically metamorphosed teeth.

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