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ORIGINAL ARTICLE/**ARTICOLO ORIGINALE**

Use of dynamic navigation with an educational interest for finding of root canals

Uso della navigazione dinamica per un'apertura della camera pulpare minimamente invasiva

KEYWORDS
Cone Beam Computer Tomography, Dynamic Navigation, Endodontics training, Minimal Invasive Endodontic, Pulp Chamber

PAROLE CHIAVE
Tomografia computerizzata a fascio conico, Navigazione dinamica, Pratica endodontica (Endodontics training), Endodonzia minimamente invasiva, Camera pulpare

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Received 2019, November 11
Accepted 2020, January 28

Abstract

Aim: *The aim of this technical note was to evaluate the potential application of dynamic navigation in teaching undergraduate students the opening of the access cavity.*
Methodology: *Extracted human teeth were fixed into a prefabricated phantom model in place of the correspondent teeth and pre-operatively scanned with the marker plate containing the fiducial markers with a cone beam computed tomography, imported on the ImplaNav software (ImplaNav, BresMedical, Sydney, Australia) and obtaining a 3D reconstruction. Open access cavity was performed with a diamond bur in using real-time navigation. This procedure was aimed to directly identify the pulp horns and the root canal entrances with a unique hole for each canal.*
Results: *All access cavities were prepared according to a minimally invasive endodontics approach with the dynamically guided ImplaNav software. No perforations occurred and all the canals were successfully located.*
Conclusions: *Present results demonstrated a possible application of this technology for educational purposes in finding root canals. This protocol may have potentialities in teaching dental students to start their approach in endodontic field.*

Obiettivo: *lo scopo di questa nota tecnica è valutare la potenziale applicazione della navigazione dinamica per un rilevamento minimamente invasivo dei canali radicolari.*
Metodologia: *i denti estratti sono stati fissati in un modello prefabbricato al posto dei rispettivi denti in resina e scansionati pre-operativamente con il marker plate e i rispettivi marcatori, attraverso una tomografia computerizzata a fascio conico, importata sul software ImplaNav (ImplaNav, BresMedical, Sydney, Australia) al fine di ottenere una ricostruzione 3D. La cavità di accesso è stata eseguita con una fresa diamantata utilizzando la navigazione dinamica in tempo reale. Questa procedura aveva lo scopo di identificare direttamente i cornetti pulpari e l'accesso a ogni canale radicolare con un'apertura minimamente invasiva.*
Risultati: *tutte le cavità d'accesso sono state preparate secondo un approccio endodontico minimamente invasivo con il software ImplaNav mediante una guida dinamica. Non si sono verificate perforazioni e tutti i canali sono stati localizzati correttamente.*
Conclusioni: *i nostri risultati hanno dimostrato una possibile applicazione di questa tecnologia nella ricerca dei canali radicolari. Questo protocollo può avere potenzialità nell'insegnamento agli studenti di odontoiatria per iniziare il loro approccio in campo endodontico.*

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Peer review under responsibility of Società Italiana di Endodonzia

10.32067/GIE.2020.34.01.02

Introduction

New strategies are being implemented in clinical practice to overcome traditional difficulties in endodontics (1).
Endodontic cavities' design concerning different tooth types have remained unchanged for decades with only negligible modifications (2). Access cavity preparation is one of the most important factors that influences the quantity of the residual dental substance (3) and, consequently, the fracture strength of treated teeth (4). Indeed, root fracture is one of the most significative events which lead to tooth extraction in the long term (5, 6).
In 2010, Clark and Khademi (7) modified the endodontic cavity design to minimize tooth structure removal.
Inspired by the minimally invasive dentistry concept (8), conservative endodontic access cavity (CEC) preparation was proposed by these authors to preserve maximum tooth structure, while partially maintaining the chamber roof and peri cervical dentin.
Some endodontists have taken this concept a step further, designing "ninja" and "truss" endodontic access cavities (NECs and TRECs, respectively).
A NEC consists of a small occlusal entry that should allow the clinician to find and access all of the root canal orifices (3). On the other hand, a TREC consists of direct access from the occlusal surface to each canal orifice, avoiding removal of the whole pulp chamber roof (9).
One of the most critical aspect in endodontic procedures is the detection of root canal orifices in the pulp chamber. The opening of the pulp chamber is the first invasive step of every root canal treatment and is thus crucial for the outcome, stability and longevity of the tooth (1).
Students' perceptions of the difficulties of endodontic treatment are mainly focused on this first step, thus tutors and teachers are usually involved in trying to simplify the clinical approach to improve pulp chamber preparation and the location of the root canal orifices preventing the destruction of dentinal walls and the perforation of pulp chamber floor (10).
The use of phantoms and other plastic/resin devices to train students is therefore necessary. Unfortunately, some clinical conditions are extremely complex and require an innovative approach to avoid unnecessary risks and damages. Traditionally, a manual approach is required to remove residual dentin-enamel structure and to place the bur close or inside pulp chamber and close to the root orifices. For this reason, studies on new protocols for teaching endodontics are necessary in order to assess the effectiveness of dental care and help with the planning of future dental training (10).
Cone beam computed tomography (CBCT) has been introduced to detect not only periapical (undiagnosed) lesions and anatomy discrepancies, but also to guide the operator in clinical approach when considered difficult (11).
A dynamic navigation system, working on CBCT data and a computer assisted software, able to guide the high-speed handpiece (and bur) to the exact position of orifices may represent a challenging approach. This kind of technology has already been used for dental implantology for several years using the standard drill (12) and it has recently been proposed also with the aid of ultrasonic instruments (13).
The aim of the present research is to evaluate the feasibility of using a dynamic navigation system for minimally invasive Endodontics in addition to presenting an innovative didactical method for the opening of the pulp chamber cavity in order to find the root canal orifices before the endodontic treatment, thus preventing unnecessary alterations of crown morphology.

Materials and Methods

Step 1. Preparation of the tooth model
Three human teeth extracted for orthodontic reasons were selected, cleaned and stored in distilled water at 4° C for 10 days. Samples were fixed with a light cur-

Figure 1
Preparation of phantom tooth model: the marker plate was positioned on the anterior teeth using a silicone mold. The three metal pins were used as reference points to calibrate the dynamic navigation system.

ing resin composite into a prefabricated mouth plastic model (Phantom model) in place of the correspondent resin tooth (figure 1). Out of the extracted teeth, two were lower molars and one was a lower premolar; no one presented previous root canal treatment. A preoperative periapical radiograph of each sample was obtained to verify the dimension of the pulp chamber and the absence of root filling material.

Step 2. CT scan of the custom model
A dental-supported marker plate tray, provided by the Company, was fixed onto the model, before undergoing a cone-beam computed tomography (CBCT scanning). The markers plate tray (MPT), for dental supported procedure, was manufactured with a base similar to an impression tray and contain on the occlusal side the fiducial markers for calibrating the navigation system. The MPT was placed in situ by the use of Putty impression material (Ramitec, 3M ESPE, USA), according to the protocol of the navigation system manufacturer (ImplaNav, BresMedical, Sydney, Australia). A pre-operative CBCT (VGi, NewTom, Verona, Italy) scan (110 kv, 3.00 mA, 0.15 mm, FOV [10×5] HiRes) of the model was taken with the markers plate containing the fiducial markers, in place. CBCT scan of the model was then imported on the ImplaNav software and a 3D reconstruction model was then obtained.

Step 3. ImplaNav Navigation System
The ImplaNav Navigation System was used for this step (figure 2). ImplaNav consists of a software interface running in Microsoft Windows (Microsoft), which processes positional data obtained from a stereoscopic infrared camera. In each frame, the firmware of the camera (NDI Polaris Vicra; Northern Digital) identifies the 3D coordinates of a predefined geometric pattern of reflective spheres, which are segmented on-the-fly in the two-dimensional (2D) image obtained from the frame. Therefore, the reflective spheres are located onto two reference tools (RT) which position is identified in real-time by the camera.
The first reference tool is fixed on the model (patient reference tool: RTp) through a spherical connection present on a prominence on the anterior part of the MPT. This allows the navigation system to know in real time the position of the phantom patient.
In the same way, the position of the handpiece and consequently of the drill is identified via the second reference tool fixed on the handle (handpiece reference tool: RTh) through a screwable connection.
Image-to-world registration of the phantom patient was performed using radiopaque markers embedded in the tooth-supported MPT manufactured in biocompatible plastic.
In the lateral sides of the markers plate tray (MPT) are two definite points and via the touching one of these, on the left or on the right side, the handpiece calibration was done.
The calibration was completed with the patient (model) registration by touching three marker points placed on the MPT directly with the bur tip mounted on the handpiece.
This procedure allowed the system to identify in real time the position of the model.

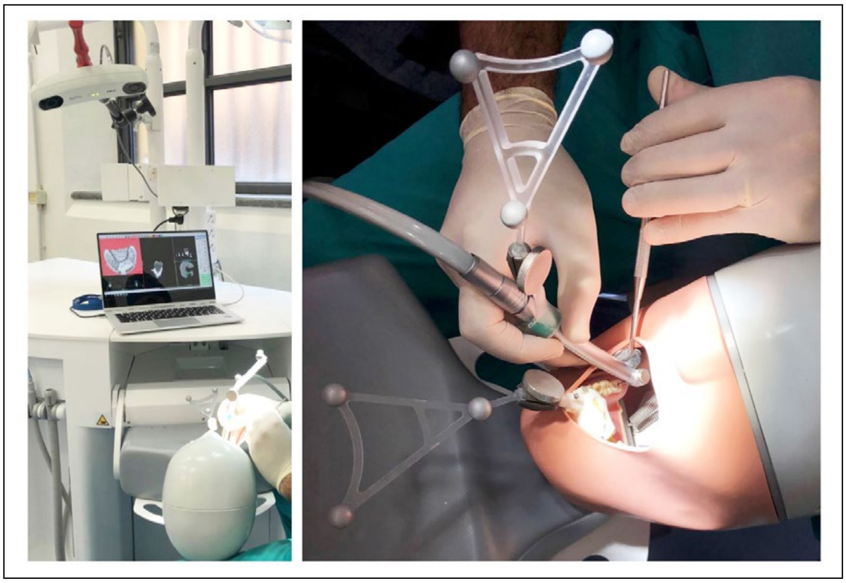


Figure 2
Dynamic guided navigation technique used in the present report.

Step 4. Cavity Preparation and Cavity Navigation

The preparation of the pulp chamber cavity was performed under the supervision of tutors from a Master's Program, by undergraduate students with a diamond bur in a dynamical way by real-time navigation. Rubber dam isolation (Hygienic Dental Dam, Coltène Whaledent, Cuyahoga Falls, USA) was followed before creating the straight-line access.

The image-guided procedure aimed to directly identify the pulp horns and the root canal entrances with a unique hole for each canal. The bur position was virtually followed by the operator on the navigation system screen during all the procedure.

Further preparation was not necessary as the access to the root canals was immediately obtained and verified via the insertion of an endodontic manual instrument. Finally, a postoperative CBCT was taken to radiographically prove the presence of a unique hole for each orifice, from the enamel to the root canal. Different samples were prepared and tested.

Sample 1. A lower premolar was used to create a minimally invasive access cavity by using a diamond bur mounted on a high-speed handpiece.

Operative information (drilling entry point, depth and angulation of bur insertion) of the precise position of tip bur were indicated by a green dot and checked in real-time on the navigation system display (figure 3).

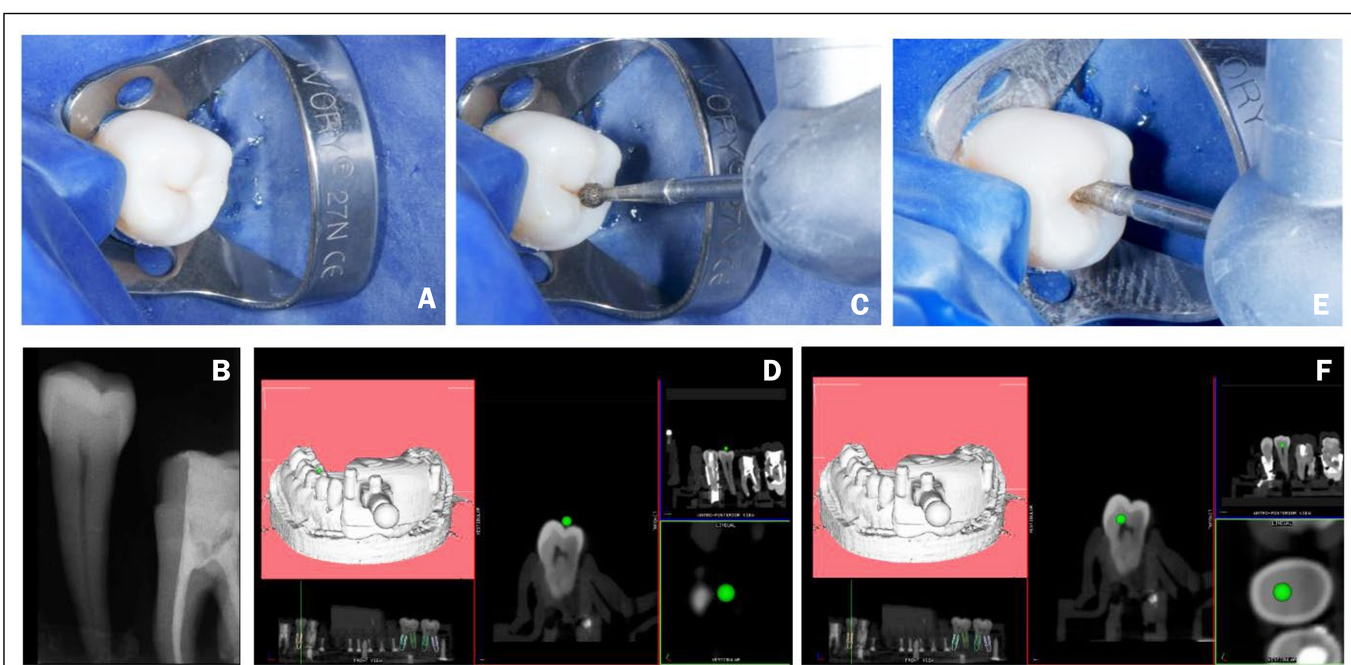
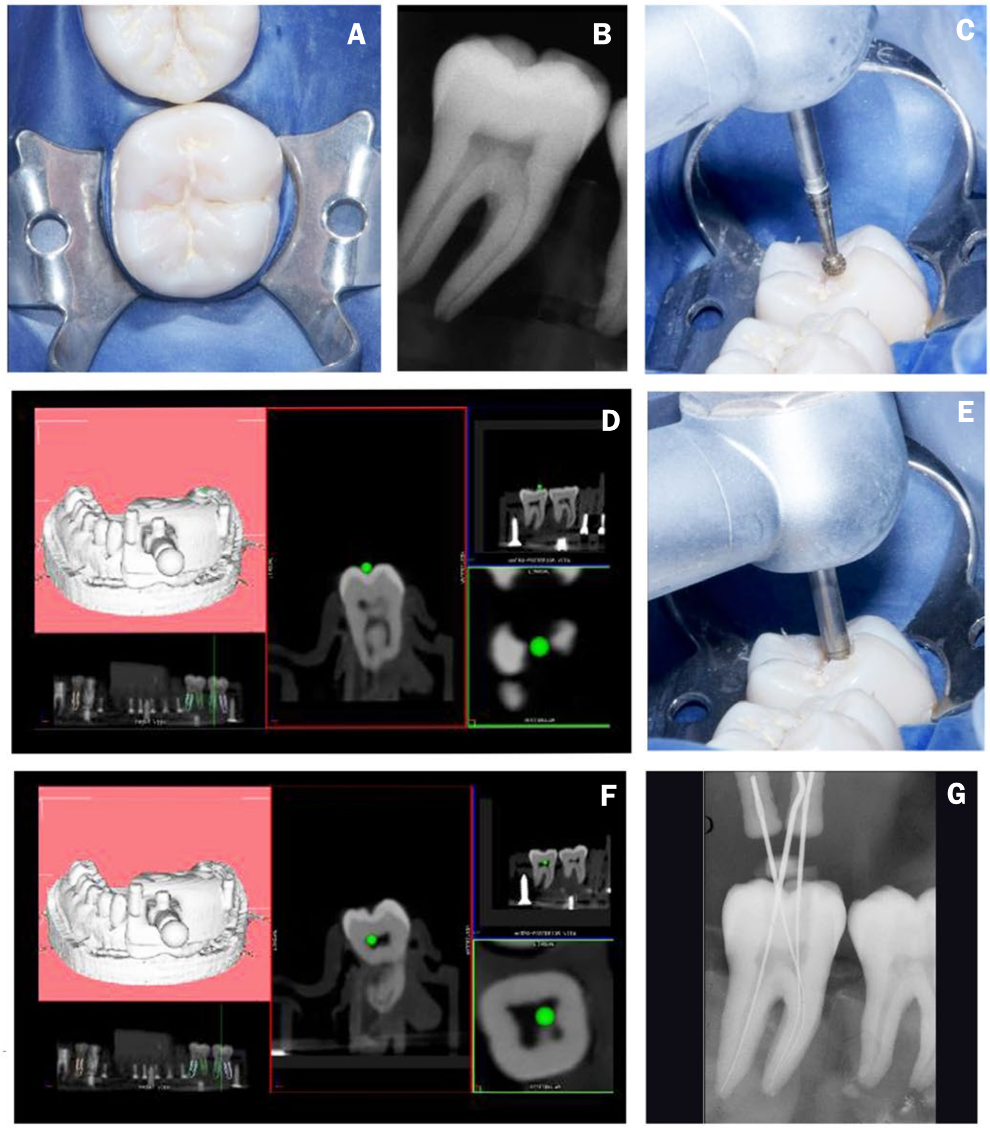


Figure 3
Operative procedures for Sample 1 (premolar tooth). Occlusal pre-operative aspect **(A)** and periapical preoperative radiograph **(B)**. Intraoperative photograph **(C)** and CBCT before access cavity: the green dot represents the tip of the bur in contact with the premolar enamel crown **(D)**. Tip of the bur inside the canal orifices: photograph **(E)** and CBCT **(F)**, respectively.



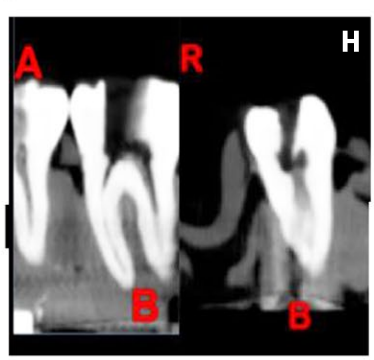


Figure 4
Operative procedures for Sample 2 (molar tooth). Occlusal pre-operative aspect **(A)** and periapical preoperative radiograph **(B).** Intraoperative photograph **(C)** and CBCT before access cavity: the green dot represents the tip of the bur in contact with the molar enamel crown **(D).** Tip of the bur inside the canal orifices: photograph **(E)** and CBCT **(F)**, respectively. Manual K-files used to confirm with a periapical radiograph the correct position inside the canal orifices **(G).** Coronal and sagittal views of postoperative CBCT **(H)** showing a straight access to the three root canal orifices without excessive tissue removal.

The applied movement was a vertical in and out motion to be as much conservative as possible. After achieving the correct depth in the pulp chamber, a manual K-file #10 (Dentsply Maillefer) was used to confirm with a periapical radiograph the correct position inside the canal orifice.

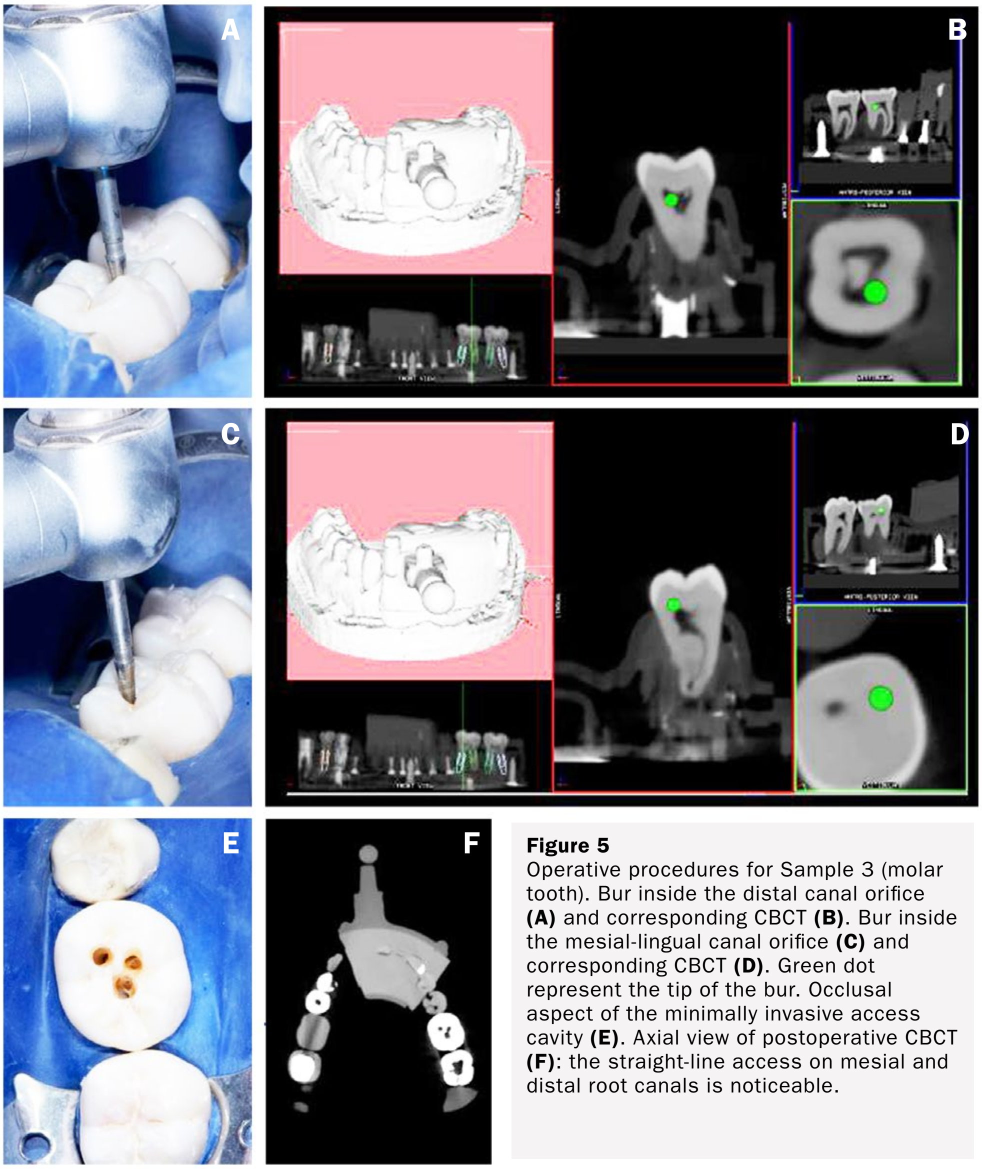


Figure 5
Operative procedures for Sample 3 (molar tooth). Bur inside the distal canal orifice **(A)** and corresponding CBCT **(B)**. Bur inside the mesial-lingual canal orifice **(C)** and corresponding CBCT **(D)**. Green dot represent the tip of the bur. Occlusal aspect of the minimally invasive access cavity **(E)**. Axial view of postoperative CBCT **(F)**: the straight-line access on mesial and distal root canals is noticeable.

Sample 2. A lower molar was used to create a minimally invasive access cavity by using a diamond bur mounted on a high-speed handpiece. The protocol of pulp chamber opening was the same as previously described for Sample 1, with the only difference that the standard cavity design satisfied the presence of three different orifices (mesiobuccal, mesiolingual and distal, figure 4).

Sample 3. A lower molar was used to create a truss access cavity by using a diamond bur mounted on a high-speed handpiece. In this sample, the access to the canal orifices was achieved by removing enamel and dentin in three different points, and creating three different holes on the occlusal surface in correspondence of the three orifices (mesiobuccal, mesiolingual and distal, figure 5).

After gaining the access to the canal orifices, postoperative CBCT scans were acquired for each of the included samples.

Results

A reduced dentinal destruction was noted by observing axial, coronal and sagittal frames.
No perforations were recorded and all the canals were successfully located, by resulting accessible to a K-file. This approach seemed to simplify the pulp chamber opening when the operators were undergraduate students.

Discussion

The present report describes a new method to identify the root orifices via the use of a dynamic navigation system confirming its applicability for educational purposes. The minimal access cavity allowed to preserve the structure integrity and to localize the root canal orifices with a simplified technique. All access cavities were prepared according to a minimally invasive endodontics approach with the dynamically guided ImplaNav software.
Reduction of the pulp chamber due to the formation of physiological or pathological secondary dentine, presence of blood, tissues, tooth rotation and inclination in the mouth may prevent the localization of the root canals. Straight line access to the root canals is preferable in order to preserve tooth structure and prevent instrument fractures. Peculiar root canal anatomies could be present in teeth, especially in molars where variations in the number and shape of root canals are frequent.
A virtually planned and guided minimal invasive access cavity could enhance the preservation of the tooth structure avoiding perforations, which could lead to an improved long-term prognosis, especially for teeth with calcified root canals (14).
Periapical radiographs do not show the real morphology of the root canal system and several studies have identified CBCT as a superior aid in the detection of various endodontic complications (15).
CBCT enables three-dimensional evaluation of teeth and related structures, and therefore could be considered a preferred imaging modality. CBCT is often used in the field of oral surgery for 3D planning of implant cases, to quantify bone level or to visualize anatomic structures such as the mandibular nerve canal (16).
However, CBCT offers a static view of the anatomy system and consequently could not provide immediate advantages during the preparation of the access cavity. Although mechanical properties of dentine compared to the alveolar bone are different and may influence accuracy, the use of this computer-aided technique from oral implantology applied to endodontics could be beneficial in producing a minimally invasive access cavity, locating calcified root canals and in endodontic surgery.
Several new approaches have been designed and tested regarding the minimally invasive approach in complex root canal treatments, using guided implantology software (1, 17, 18).
However, these experimental procedures were designed in a static model, creating a resin template which should be adapted first to a dental model, then in the oral cavity and the overall dimension of the template has yet to be considered. Dynamic navigation is the most recent free-hand method for computer-aided surgery via an image-guided procedure. New dynamic three-dimensional technology has already occurred in the dental implantology field (19) and could be now applied to Endodontics in order to reduce the treatment invasiveness and avoiding the use of a bulky resin template. A navigation system could give significant aid when scouting the root canal system intraoperatively.
Dynamic guided endodontics may be challenging in clinical practice because it allows a maximum preservation of the dental structure (20), by reducing the encumbrance to the minimum. The dynamic navigation seems to be a useful device to help students to identify the root canal orifices through a fast moving image guided procedure. Up to date, this kind of technology presents some limits for a full application in the Endodontic field.
First, the accuracy declared by the manufacturer companies of about 0.5 mm needs further evaluation to determine whether or not it is sufficient. Secondly, the possible presence of a metal crown could represent another problem due to the radiographic

artifacts. Our initial evaluation of using dynamic navigation for Endodontics seems promising and a worthy method to be further investigated.
The present report seems to show that the system can be useful to identify the coronal third of the root.

Conclusions

The use of CBCT and the software assisted ImplaNav Navigation System has been tested for the first time in Endodontics at the University of Bologna.
The potentialities of this technique can be identified in teaching the pulp chamber opening and access to the canal orifices in teeth with a modified position (orthodontic reasons) and an altered anatomy.

Clinical Relevance

Utilization of a dynamic navigation in the endodontic field may provide significant advantages in endodontic training as a didactic tool to find the root canals. In addition, this technology would be useful in complex retreatment cases or in presence of sclerotic root canals.

Conflict of Interest

The authors deny any conflicts of interest related to this report.

Acknowledgments

The report was self-funded.

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