Original Article

Clinical Evaluation of Apex Locators and Cone-Beam Computed Tomographic for Working Length Determination in Pulp Canal Obliterated Traumatized Maxillary Incisors

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ABSTRACT

Aim: This clinical study evaluated pre- and intra-operative working length (WL) determination in incisors presenting with pulp canal obliteration (PCO), with cone beam computed tomography (CBCT) images measured by three softwares (3D Endo, SICAT and Horos), five electronic apex locators (EALs) (Apex ID, Canal Pro, E-Pex Pro, iPex II, and Root ZX Mini), and periapical radiographs. **Materials and Methods:** 24 maxillary incisors with history of trauma and PCO were included. Pre-operative CBCT WL measurements were performed using the softwares. Five EALs according to manufacturer's instructions, followed by the radiographic method. **Results:** Pre-operative CBCT measurements (n=16) were similar among the different software (*P*>.05). Radiographic WL strongly correlated with CBCT measurements (*P*<.001). Multiple regression analysis showed significant association between all the pre and intra-operative WL methods (P<.001). **Conclusions:** EAL measurements were adequate regardless the type of device, but restricted to the cases presenting foraminal patency. CBCT measurements might be useful for working length determination in PCO incisors.

Key words: Cone beam computed tomography, Electronic apex locator, Pulp canal obliteration, Three-dimensional software

Pulp canal obliteration (PCO) also known as calcific metamorphosis is one of the sequelae following tooth trauma, which is often reported in teeth after concussion or subluxation injury [1]. This entity features deposition of reparative dentin deposition inside the root canal space and yellow discoloration of the clinical crown [2]. Although the accurate pathogenesis of PCO is unknown, it has been related to damages to neurovascular supply of the pulp at the time of trauma [3, 4]. PCO has been reported more often in the anterior teeth, ranging from 4 to 64% of concussed and subluxated teeth [2].

Several studies have pointed out that even a complete radiographic obliteration does not signify absence of pulp or canal space [5, 6]. Specific clinical challenges faced by the operator in root canal treatment of PCO incisors are the access, canal negotiation and penetration [7, 8]. According to the statements of both American Association of Endodontics/American Association of Oral and Maxillofacial Radiology (AAE/AAOMR) [9] and European Association of Endodontology [10], a limited field of view (FOV) cone beam computed tomography (CBCT) scan might be considered as the imaging modality of choice for diagnosis and treatment planning of traumatic injuries to tooth if additional information can be gained from the three-dimensional reconstruction. A case series report on management strategies for PCO incisors emphasized about the importance of CBCT for detection and negotiation of the calcified root canals [11]. Moreover, it is known that diagnostic CBCT for any indication in dentistry might be potentially used for preoperative estimation of the endodontic working length (WL) [12-14].

Recently, different options of software have been introduced into the market for the specific treatment planning of endodontic procedures. 3D Endo™ software (Dentsply/Sirona, Wels bei Salzburg, Austria) presents an intuitive interface in which the clinician can follow steps for the identification and measurement of the canals, as well as the virtual planning of the access cavity, apical limit, and file selection for shaping procedures [15, 16]. Previous laboratory studies have shown that this enhances the three-dimensional visualization and provides reliable estimation of the pre-operative WL [15, 16]. Similarly, SICAT Endo™ software (SICAT GmbH and Co, Bonn, Germany) also dedicated to the endodontic planning of access and WL determination by using specific 3D rendering filters and tools for semi-automated detection of the canal trajectory [17]; however, its accuracy for WL determination has not been yet assessed.

Changes in the estimated preoperative WL are expected to occur after access [15, 18], requiring the confirmation of the apical limit by means of electronic or radiographic methods. Although electronic apex locators (EAL) are considered more precise and reliable than radiographs [19, 20], canal obliterations or lack of patency might negatively affect their accuracy [21 – 23]. However, the interference of canals obstructions also depends on the operating principles of the EALs [23]. Root ZX (J MoritaMfgCorp, Tokyo, Japan) is an EAL that operates using the ratio method of two simultaneous frequencies (8 and 0.4 KHz), and it has become the benchmark to which other devices are compared [24].

The Apex ID (Sybron Endo; Gendora, CA, USA) also employ the same impedance principles as the Root ZX but operates at frequencies of 0.5 and 5.0kHz, while CanalPro (Coltene-Endo; Cuyahoga Falls, OH, USA) measures the mean square root values for two different, alternating frequencies together with a filtering system [24. 25]. iPex II (NSK, Tochigi, Japan) uses two or more non-simultaneous frequencies and measures both capacitance and resistance [26], and E-Pex Pro (Eighteeth, Changzhou, China) uses advanced multi-frequency to assess the impedance [27]. It is unclear whether the different operating mechanisms can improve the WL determination. Moreover, little information is available in the scientific literature regarding the methods and accuracy in WL determination in traumatized PCO teeth.

Thus, the aim of this clinical study was to investigate different methods for pre- and intra-operative WL determination in traumatized PCO incisors, by means of CBCT images measured by three different software (3D Endo, SICAT and Horos), five different EALs (Apex ID,Canal Pro, E-Pex Pro, iPex II, and Root ZX Mini) and periapical radiographs.

MATERIALS AND METHODS

A total of 22 adult patients (15 males and 7 females) (mean age 37.79 years ± 12.87) referred to Department of Conservative Dentistry and Endodontics of the corresponding author institution requiring root canal treatment in the period between July 2017 to January 2020 were included in this investigation. A total of 24 maxillary incisors presenting with a history of trauma to maxillary incisors with pulp canal obliteration as evidenced from clinical and radiographic examinations and diagnostic of symptomatic irreversible pulpitis (with or without periapical symptoms) or pulp necrosis (accompanied of either symptomatic, asymptomatic apical periodontitis, chronic abscess or acute apical abscess) were included in this study. A written informed consent was obtained from each patient following the institutional ethical committee approval, and the Clinical Trial Registry of India Portal (CTRI/2020/02/023573). Teeth presenting with root fracture, extra canals or roots, internal resorption, and previous endodontic treatment were excluded of this study. This clinical trial adhered to protocols PRIRATE 2020 guidelines (Fig. 1) [28].

CBCT LENGTH MEASUREMENTS

Preoperative CBCT scans were acquired (Kodak CS 8100 3D,Carestream Dental, Atlanta, USA) with limited field of vision (FOV) to a maximum of 8 teeth with an exposure of 80 KV, 5 mA, 19.96 s and a voxel size of 90 µm. The presence of PCO was confirmed by analyzing the images in three-dimensions.

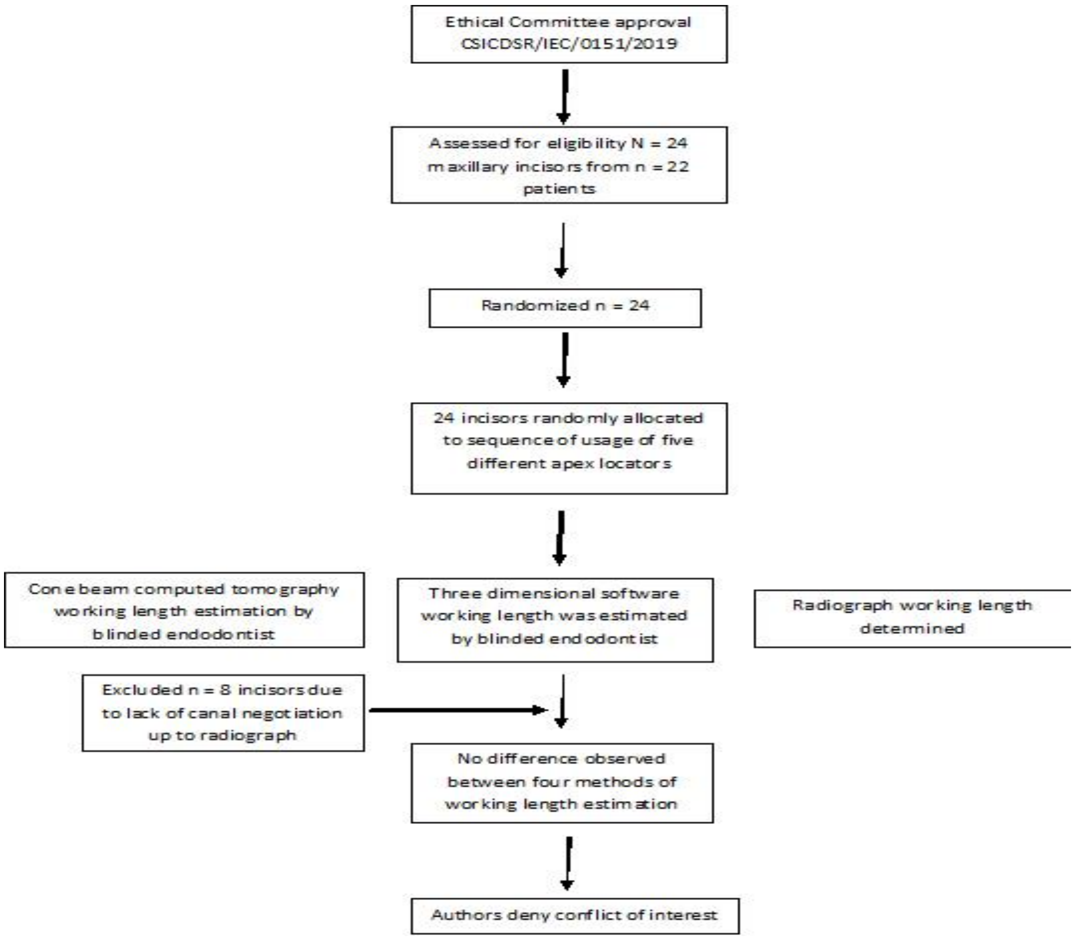

Figure 1: PRIRATE 2020 flowchart illustrating the flow of participants.

The CBCT scans were used for planning of the endodontic treatment as needed by the clinician; however the measurements used for the present study were not performed by the same operator to prevent bias.All CBCT measurements used for this study were performed by an Endodontist experienced with the tested software programs, who was blinded to clinical details related to the case, including the electronic or radiographic WL The images were manipulated using a PC running Microsoft© Windows XP Professional (Microsoft Corp, Redmond, WA, USA), in a 40” flat-screen monitor (resolution 1920 x1200 pixels) and dimmed lights.

In the first section, the DICOM files of the cases were imported in the Horos viewer (Horos project USA). The selected tooth was vertically positioned and slightly rotated to obtain a single sagittal slice that best represented the whole length of the canal, in both buccolingual (BL) and mesiodistal views (MD) [29]. A measuring line was traced from the occlusal reference to the apical foramen (AF), centered in the canal following any visible deviation. The average between BL and MD measurements was calculated and recorded as the CBCT working length (CWL).

In the second section, the DICOM files of the CBCT scans were imported to the software 3D Endo (Dentsply Sirona, Salzburg, Austria). Briefly, the images of the PCO tooth were individualized by cropping the surrounding tissues. Then, in the axial images it was located the transversal slices of the cemento-enamel junction (CEJ) and the AF, followed by an automatic line that was properly adjusted by the operator to follow the trajectory of the root canal on the three planes. In the last step, the software automatically inserts a virtual K-file into the canal trajectory; the apical position is set to Apical Foramen. The coronal angulation of the file was positioned according to the concept of a straight-line endodontic access and the virtual rubber stopper was manually adjusted to the coronal reference. The length of the virtual file was automatically calculated by the software and recorded as the 3D working length (3DWL).

Finally, the scans were imported to Sicat Endo software (SICAT GmbH and Co, Bonn, Germany). After the spatial adjustments of the dental arch, the tooth was selected and the long axis defined. The root canal was then manually marked from the AF to the coronal reference using the feature named "Endoline" [17]. The view was rotated around this Endoline to ensure it was centrally placed and all necessary corrections were made to follow the canal trajectory. The length of the Endoline was recorded as SICAT working length (SWL).

CLINICAL PROCEDURES AND ELECTRONIC APEX LOCATOR MEASUREMENTS

A preoperative periapical radiograph was taken for clinical purposes using a PSP scanner (VistaScan Mini Plus; Durr Dental, Bietigheim-Bissingen, Germany) and paralleling cone technique (Densmart X-ray film holder; Universal X-rays, New Delhi, India). The clinician was allowed to view the CBCT scans before and during the endodontic treatment, but it was blinded to the measurements used for this investigation. After administration of local anesthesia with 2% lignocaine with1:80 000 adrenaline (Lignox, Warren Pharmaceuticals, Mumbai, India), rubber dam was placed in position. Endodontic access was prepared using tapered diamond burs (Mani Co., Tochigi, Japan) under copious water irrigation. The canals were irrigated using sodium hypochlorite 3% and canals were negotiated to the radiographic estimated length using a manual size 10 K-file (Mani, Tochigi, Japan).

The electronic measurements were performed by a single operator using the five tested EALs. For each tooth, the sequence of usage of the devices was randomly allotted using Google spin wheel (https://tools-unite.com/tools/random-picker-wheel). The EALs were used following manufacturer's instructions. The lipclip was positioned in the patient's lip, and the first EAL measurement was taken using either a 10 or 15 size hand K-file that was able to achieve patency. The file was inserted into the root canal until the EAL displayed the "0.0 or APEX" mark, then slightly withdrawn until the display shows the mark of the apical constriction (0.5 mark for Apex ID, iPex II and CanalPro, and a midway point between the APEX and 1 mark for the Eighteeth and Root ZX devices).The rubber stopper in the file was moved and positioned to the incisal reference point and fixed using a cyanoacrylate resin after the display was stable for 5 seconds.

The length of the file was measured using a digital caliper to a precision of 0.01 mm and measurements were recorded as the electronic working length (EWL). When the EALs readings were not stable or absent, it was marked as "erratic" reading.

A confirmatory periapical radiograph was taken with a manual file inserted at the EWL provided by Root ZX, using a PSP scanner (VistaScan Mini Plus; Durr Dental, Bietigheim-Bissingen, Germany) and paralleling cone technique (Densmart X-ray film holder; Universal Xrays, New Delhi, India). The radiographic length (RWL) was calculated by adding the distance from the file tip to the radiographic apex of the root to the length of the inserted file, then 0.5 mm was reduced and recorded. For the cases in which the electronic readings were successful, the measurements provided by the Root ZX device were taken as the gold standard to complete the canal preparation (Fig. 2), unless the tip of the files was positioned more than 2 mm short or beyond the radiographic apex, the WL was adjusted following the radiographic method. For the cases with erratic EAL readings, the treatment was completed to the radiographic WL.

Cases in which the canal negotiation was unsuccessful up to the radiograph measurements were excluded for the statistical analysis. These teeth where obturated using Biodentine® (Septodont Healthcare Pvt Ltd., Raigod, India) and kept under observation (Fig. 3).One case presenting with large periapical lesion in which canal negotiation was unsuccessful, was managed by root end resection and periapical curettage.

All the rootcanal treatments were performed in two visits. Cleaning and shaping were performed using rotary files (Aurum Pro, Meta Biomed, Korea) activated by an endodontic motor Endomate DT (NSK, Tochigi, Japan), and irrigation was performed using 3% sodium hypochlorite (Septodont, Healthcare India, Raigad, India). Intra-canal medicament (Calcium hydroxide cement, Prime Dental, Thane, India) was placed at the end of first visit and tooth was temporarily sealed using zinc oxide eugenol cement (Prime Dental, Thane, India). At the second visit, root canal obturation was completed with single cone technique (Greater taper gutta-percha points, Diadent, Seoul, Korea) and zinc oxide eugenol sealer (Dental Products of India Ltd, Mumbai, India), followed by permanent coronal restoration with composite.

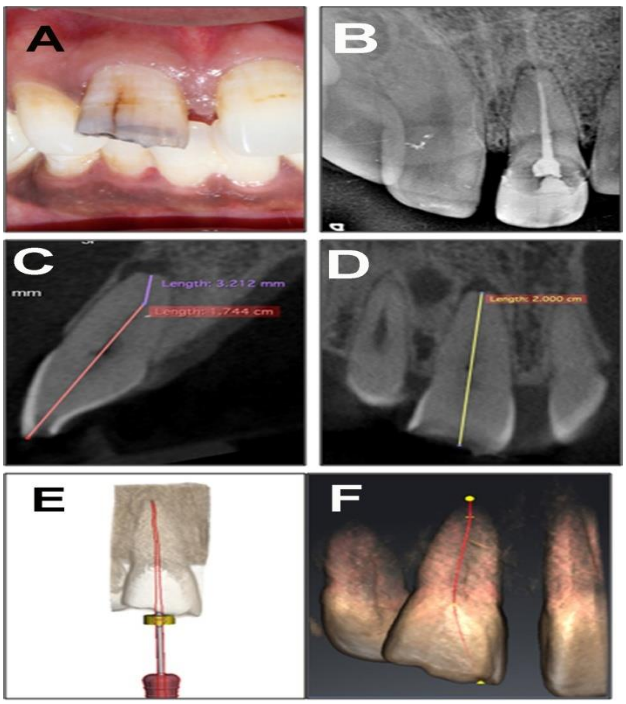

Figure 2: A. Preoperative photograph of the fractured right maxillary central incisor with PCO; B. Post obturation radiograph till the Root ZX working length measurement; C – F. CBCT preoperative measurements using Horos(C, D);3D Endo (E), and Sicat Endo software (F).

Data was statistically analysed using IBM SPSS software version 23 (IBM, Armonk, NY) with significance set at 5%.Data acquired during the experimental procedure were normally distributed (Shapiro-Wilk test, $P > 0.05$) and homoscedastic (Levene's test, $P > 0.05$). Repeated-measures analysis of variance (ANOVA) with a Greenhouse-Geisser correction and post-hoc test using the Bonferroni correction was used to compare the average measurements, and Pearson's correlation and multiple regression analysis were used to compare the different measurement methods.

RESULTS

A total of 24 traumatized maxillary incisors (21 maxillary central incisors and 3 maxillary lateral incisors) presenting with PCO with and without periapical radiograph lesion were initially included in this study.Root canal negotiation to the radiographic apex was unsuccessful in eight cases, which were excluded from statistical analysis. Table 1 presents the descriptive for the CBCT measurements of the 16 remaining teeth. There was no significant difference ($P > 0.05$) in the mean measurements and a strong positive correlation ($P < 0.001$) for the pre-operative WL among the three tested software.

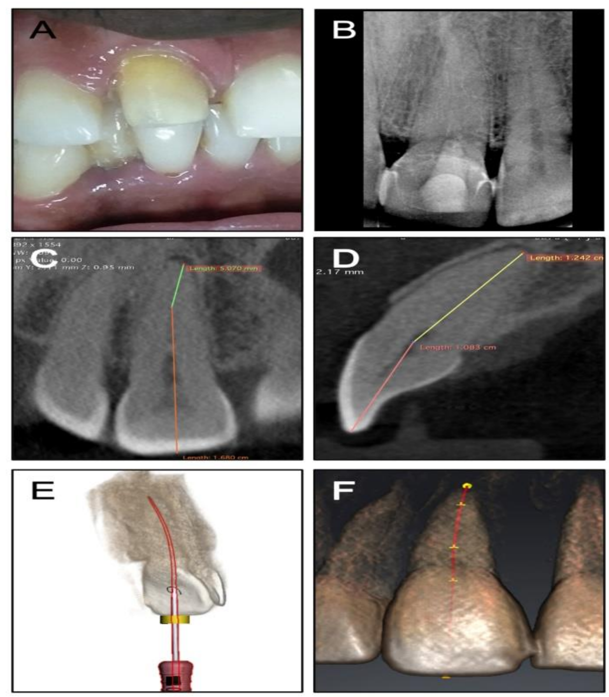

Figure 3: A. Preoperative photograph of the fractured right maxillary central incisor with PCO. B. Radiograph showing rootcanal obturation with Biodentine® after unsuccessful canal negotiation. (C – F) CBCT preoperative measurements using Horos (C, D); 3D Endo (E), and Sicat Endo software (F).

All the five EALs displayed error readings in 6 (37.5 %) teeth, thus, for these cases; the WL was established by the radiographic method. These 6 cases were not included for the statistical analysis of the intra-operative WL (Table 2). Nevertheless, a strong correlation ($P < 0.001$) was found between the radiographic WL and the CWL ($r = 0.977$), 3DWL ($r = 0.966$), and SWL ($r = 0.965$).

Table 2 shows the descriptive for the intra-operative WL obtained by the different methods for the 10 teeth in which the electronic readings were stable and recorded for all the tested devices. Repeated ANOVA measures did not observe any significant difference between the WL readings obtained from different methods (*P*> 0.05). Multiple regression analysis showed a significant association between all the pre and intra-operative WL methods for these 10 cases (P< 0.001).

DISCUSSION

The present study investigated the clinical use of different methods for WL estimation in traumatized PCO incisors. To the best of our knowledge, no previous studies have compared the accuracy of both electronic and CBCT methods in teeth presenting pulp canal calcifications *in vivo*.

Table 1: Mean and standard deviation (mm) obtained for the CBCT root canal length

	n	Mean	SD
CBCT	16	21.08 [a]	2.21
3D Endo software	16	20.89[a]	2.34
SICAT software	16	20.94[a]	2.23
a = (*P*> 0.05)			

Table 2: Mean and standard deviation (mm) obtained for the working length according to the different measuring methods

	n	Mean	SD
Periapical radiograph	10	20.46[a]	2.18
Apex ID	10	20.59[a]	2.29
Canal Pro	10	20.55[a]	2.18
E-Pex Pro	10	20.51[a]	2.18
iPex II	10	20.53[a]	2.14
Root ZX	10	20.24[a]	2.10
a = (*P*> 0.05)			

The endodontic management of PCO cases is very complex. Even with the aid of three-dimensional images, accessing and negotiating the canals might not be possible. In the present study, in 8 teeth it was not possible to advance to the pre-operative WL. Clinically, un-negotiable canals might be a result of calcifications, accumulation of debris, iatrogenic ledges or even complex anatomies such as apical bifurcations, deltas, or sharp curvatures in the last millimetres of the root canal extension. The unintentional limitation of apical extension compromises the disinfection of the canals and negatively affects the prognosis of the endodontic treatment [30]. Thus, for these cases, cleaning and shaping was performed to the achieved length, followed by obturation with bioactive endodontic cement [Biodentine® (SeptodontHealthcare Pvt Ltd., Raigod, India)]. The patients were informed about the difficulty encountered during canal negotiation, prognostic and were requested for periodically return at every six months, for clinical and radiographic follow up and consider if necessary, treatment options such as apicoectomy or implants. Only one case with large periapical lesion became symptomatic after two years of treatment completion of this study, and it was managed with root end resection and periapical curettage.

For the remaining 16 cases, once the initial negotiation of the root canal was able to reach proximity to the pre-operative length was reached; both electronic and radiographic methods were used for the intra-operative WL. Electronic readings were unsuccessful in 6 cases (37.5%). Although for these cases an acceptable radiographic apical limit was achieved, the lack of foraminal patency is likely the reason for these erratic electronic readings. The disfunction of the EALs in obstructed canals has been related to the interruption of the electrical circuit and to the inability of analysing the resistive component of the impedances [21, 31]. This was corroborated by an in vitro study that showed that electronic measurements could be obtained only after the recapitulation of nonpatent canals [32].

In the present investigation, five brands of EALs were utilized, because it has been previously suggested that the effect of canal obliteration on the electronic accuracy could be related to the operating mechanism of the device [22, 23]. A previous in vitro study [22] showed that dentinal plugs blocking the AF of mesial root canals of inferior molars significantly reduced the accuracy of Root ZX, while Apex ID readings at 0.0 mark were not affected. Another study [23] also reported that foraminal obstructions affected the precision of electronic measurements at 0.5 mark, being more pronounced for Root ZX than Raypex6 (VDW, Munich, Germany).

Differently, present results showed that for the cases in which patency was not achieved, electronic measurements were not consistent, regardless the type of device or mark. The discrepancy compared to the previous studies is probably related to the different study designs (*in vitro* vs *in vivo*).

Vasconcelos *et al* [22]. Suggested that the methodologies employed to mimic the apical blockage in a laboratorial setting might present differences in density and humidity compared to a clinical situation, and might not reflect the same electrical interference. In a clinical study, El Ayouti *et al* [22]. concluded that obliteration of the root canals was the main factor resulting in inconsistent function of two different EALs, Root ZX and Raypex5 [VDW, Munich, Germany].Thus, for those cases, the authors recommended to use of radiographic method to determine the WL. Similarly, in the present study, in the 6 cases (37.5%) that was not possible to perform any electronic measurements, the apical limit was determined between 0.5 to 1 mm short to the radiographic apex [19, 21]. For the cases in which the electronic measurements were feasible, all measurements were considered adequate and no difference was found among the five tested devices. These positive results are in agreement with previous reports about the high accuracy of Root ZX [24, 26], CanalPro [24], Apex ID [24], iPex II [26], E-Pex Pro [27]. Previous clinical studies have considered as acceptable the electronic measurements which resulted in an apical limit 0.5 to 2mm short to the radiographic apex [19, 21]. In the present study, all the consistent electronical measurements were within the acceptable range, resulting in an intra-operative WL similar to the one obtained by the radiographic method. Additionally, no over-estimation of the WL was observed in this study, corroborating previous reports [19, 33].

The traditional radiographic method for WL presents many limitations such as superimpositions, distortions and difficulties with landmark identification, which are mainly related to its two-dimensional nature [19, 21]. On the other hand, CBCT scans allow the assessment of the anatomy in three dimensions and it has proven to be more accurate than periapical radiographs for preoperative WL length estimation [14]. Earlier clinical investigations considered CBCT measurements for WL estimation a reliable method, in agreement with our present findings [12-14]. However, controversy in the literature is found when comparing the accuracy of CBCT and EALs to determine the WL [12 – 15, 29]. The key factor is to differentiate the goals and applications of such methods, because the WL is subjected to changes throughout the endodontic treatment [18], and the pre-operative length should be adjusted after access and pre-flaring procedures [15, 29]. Therefore, in the present study, pre- and intra-operative were evaluated separately. Additionally, the 6 cases in which canal patency failed were not included in the intra-operative WL evaluation, because electronic measurements could not be performed. Nevertheless, for these cases, an adequate radiographic WL was achieved (0.5 to 1 mm from the radiographic apex). A high statistical correlation was found between the radiographic WL and the CBCT measurements, regardless the software. The measuring tool provided by 3D Endo and Sicat software aims to increase the precision of the WL determination by following the trajectory of the root canal in three dimensions.

Previous studies have shown that 3D endo was accurate to provide accurate measurements when compared to the actual lengths measured up to the foramen of extracted or plastic teeth [15]. For the Sicat Endo, this appears to be the first investigation on its use for WL determination. Results showed no difference in the mean lengths provided by the three evaluated software programs. Present results corroborate the use of CBCT measurements for the preoperative WL estimation when a previous scan is available, regardless the software program [12 – 14]. Additionally, for the cases in which EALs readings are not possible, the CBCT scans represent an invaluable aid to locate the foraminal exit in three-dimensions, allowing the clinician to combine the anatomical information from both 3D and 2D radiographic methods to establish an adequate WL.

CBCT scans are an important aid for endodontics diagnosis and treatment planning, mainly for challenging situations such as calcifications of the pulp space [9 – 11]. 3D Endo is considered supplementary visualization software, which enables the rendering of the color-coded trajectories of the root canals in three-dimensions, as well the virtual placement of the access cavity and a selection of endodontic files of the same manufacturer [34]. These features highlight the presence of anatomical complexities [34], allowing a better understanding of the root canal system and reducing the stress levels while treating molar cases [35]. Besides the three-dimensional visualization, Sicat Endo also allows planning and ordering of surgical guides from the manufacturer for either ortho or retrograde access of the root canals. One clinical report showed the successful management of a PCO mandibular incisor using the Sicat Endo guided access [17]. In the present study, pre-operative CBCTs were taken as a part of the clinical routine of the dental clinic for the management of PCO cases. The clinician had complete access to the CBCT images during the treatment, by using only the regular visualization software available in his working station. For the purposes of this study, de-identified DICOM images were exported and evaluated by an Endodontist blinded to the clinical scenario of the case. Although in this study such protocol was followed to prevent bias, it is possible that the use of the three-dimensional tools of 3DEndo and Sicat Endo could have improved the clinical strategy to manage the cases; however, this assumption should be evaluated in further clinical studies.

A limitation of the present study was the difficulty in selecting cases that fit number of cases, which resulted in a small sample size. The development of PCO after trauma can result in different patterns, impairing a proper standardization of the cases, thus most of literature is comprised of case reports [8, 11] and laboratory studies [36]. Nevertheless, this investigation adds to the current literature, highlighting the challenges and options to determine the WL in PCO cases, which might be used as a reference for future clinical trials.

CONCLUSION

Within the limitations of this study, it can be concluded that preoperative measurements of 3D Endo and Sicat Endo were similar to conventional CBCT software, providing a reliable estimation of the extent of the root canals. EAL measurements were adequate regardless the type of the device, but restricted to the cases presenting foraminal patency. Since the complete negotiation of maxillary incisors with PCO after trauma might be challenging, the clinician should consider combining different methods aiming to optimize the working length determination in these cases.

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