REVIEW ARTICLE

Comparison of Accuracy and Reliability of Working Length Determination Using Cone Beam Computed Tomography and Electronic Apex Locator: A Systematic Review

Janki Amin[1], Jordan Lines[2], Maxim P Milosevic[3], Andrew Park[4], Amar Sholapurkar[5]

Abstract

Aim: To compare the accuracy and reliability of cone beam computed tomography (CBCT) and electronic apex locator (EAL) in determining the working length (WL).

Background: A comprehensive literature search was conducted across several databases and gray literature. A total of 1,358 potentially relevant journal articles were identified with publication dates ranging from 1996 to 2017. After screening and applying the inclusion and exclusion criteria, five studies were identified as eligible for review. Data extraction was completed in two blinded pairs, cross-referenced and subsequently merged. Discrepancies were resolved through collaborator mediation. Meta-analysis was not undertaken due to heterogeneity between included studies.

Review results: In all five studies, no statistically significant difference was found between CBCT and EAL measurements of WL. The reliability of CBCT compared with EAL was not determined.

Conclusion: Due to significant heterogeneity between the included studies, the accuracy of CBCT compared to EAL couldn't be determined. Based on limited evidence, CBCT appeared to be as accurate as EAL. There was weak evidence suggesting that CBCT was reliable. Also the superiority of one method over the other could not be determined. These results should be interpreted judiciously. Further research is required to conclusively evaluate the accuracy and reliability of CBCT compared with EAL.

Clinical significance: Preexisting CBCT scans may be appropriate for WL determination but acquiring a new CBCT for endodontic treatment is inadvisable due to cost and the as low as reasonably achievable (ALARA) principle.

Keywords: Cone beam computed tomography, Endodontics, Odontometry, Root canal therapy.

The Journal of Contemporary Dental Practice (2019): 10.5005/jp-journals-10024-2651

Introduction

Clinicians generally agree that the successful endodontic treatment is dependent on the complete removal of diseased pulpal tissues and the total sealing of the root canal system[1,2] and reliable determination of the root canal working length (WL).[2,3] Accuracy is the degree to which a measurement conforms to the correct value, and reliability is the ability to repeatedly obtain precise measurements. Until the introduction of contemporary methods such as the electronic apex locators (EALs) and cone beam computed tomography (CBCT), WL determination was traditionally achieved through conventional radiography.[3]

According to Pratten and McDonald, the ideal end point of instrumentation is the cementodentinal junction, which is defined as the beginning of the periodontal ligament and the end of the pulpal tissue.[4,5] Its location varies between 0.50 and 0.75 millimeters (mm) coronal from the true anatomical foramen of the root canal. In accordance with these average measurements and higher rates of clinical success, clinicians have attempted to terminate their instrumentation 1–2 mm coronal to the radiographic apex.[2,4–6]

Conventional radiographic determination in conjunction with tactile sensation can be limited by anatomic variation and errors in projection; CBCT may overcome some of these problems.[2,4] Cone beam computed tomography produces three-dimensional images using divergent X-rays that form a cone and allow for increased image quality with decreased distortion, magnification, and superimposition of the targeted structures.[7] As a result, CBCT is being considered for several novel applications in endodontics including WL determination.[8] The Joint American Association of Endodontists/American Academy of Oral and Maxillofacial Radiology (AAE/AAOMR) recommend the of use the smallest possible voxel size and field of view (FOV) in their position statement on CBCT.[9] Aktan et al. determined that voxel size between 0.5 and 1 mm allowed reliable endodontic length measurement.[10] The higher radiation dosage of CBCT compared to conventional radiography limits its routine use. In particular, the as low as reasonably practicable (ALARP) principle often precludes the use of CBCT except in situations where it is of exceptional diagnostic value.[11]

Electronic apex locators determine the location of the major foramen by measuring resistance to electric current and are useful in determining the WL in more than 90% of cases.[5] However, factors such as intact vital tissue, inflammatory exudate, canal

[1–5]Clinical Dentistry and Oral Radiology, College of Medicine and Dentistry, James Cook University, Cairns, Queensland, Australia

Corresponding Author: Amar Sholapurkar, Clinical Dentistry and Oral Radiology, College of Medicine and Dentistry, James Cook University, Cairns, Queensland, Australia, Phone: +61 455254361, e-mail: amar.sholapurkar@jcu.edu.au

How to cite this article: Amin J, Lines J, *et al.* Comparison of Accuracy and Reliability of Working Length Determination Using Cone Beam Computed Tomography and Electronic Apex Locator: A Systematic Review. J Contemp Dent Pract 2019;20(9):1118–1123.

Source of support: Nil

Conflict of interest: None

patency, metallic restorations, size of apical constriction, and cardiac pacemakers may affect the electrical current of the EAL and consequently the accuracy and reliability of the readings.[5]

The purpose of this systematic review was to screen and analyze the literature comparing CBCT with EAL in order to establish which is more accurate and reliable in determining the WL of permanent teeth of adults. This review question was developed according to the population, intervention, comparison, outcome, and study design (PICOS) format. To the best of the authors' knowledge, no previous attempts have been made to review the available literature for this purpose.

Review Proper

This review was registered in PROSPERO under number 2017:CRD42017056345. The review protocol was published as part of the proposal and in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines. This review was designed to answer the following research question: Which is more accurate and reliable in determining WL, CBCT or EAL?

Study Selection Criteria

The review included *in vivo* comparative human studies. *Ex vivo* studies on extracted teeth were excluded due to their lack of clinical relevance. Case series, case reports, reviews, ideas, editorials, and opinions were excluded. The population was defined as patients with permanent human teeth, as root canal obturation is infrequently undertaken in primary teeth. Studies on animals were excluded due to their limited clinical relevance. Patients with various pathologies were included as there are several reasons why teeth may require root canal treatment (RCT).[12] The interventions were defined as measurements taken with EAL and CBCT, and only articles that compared both were included. The outcomes were defined as accuracy and reliability of measurements. No restrictions were set on how these outcomes were quantified. Due to the variability in outcome measurements, meta-analysis was not feasible. No studies were excluded based on differences in time between intervention and outcome measurements across studies. No limitations were applied based on the study location, language, or sample size.

Information Sources

Search terms were developed using medical subject headings and words related to CBCT, EAL, and WL. An electronic search was undertaken in the databases, including PubMed (NCBI interface, 1946 onward), ProQuest (Health and Medicine Collection, 1946 onward), CINAHL (EBSCO-host interface, 1999 onward), MEDLINE (OvidSP interface, 1946 onward), Science Direct (Elsevier interface, 1946 onward), Scopus (Elsevier interface, 1946 onward), and Web of Science (Thomson Reuters interface, 1965 onward). Gray literature databases including TROVE, Worldcat, Google Scholar, and AHRQ were searched without publication date restrictions. The date of the last search was July 11, 2017.

Search Strategy

PROSPERO was searched for ongoing or completed systematic reviews on this topic to ensure the necessity and relevance of this review. Databases were searched using the James Cook University registry. One author developed the Medline search strategy, which was then peer reviewed by the remaining authors and a librarian with experience in systematic review search strategies. This was subsequently adapted to the syntax and subject headings of the other databases, including gray literature databases. Finally, the reviewers manually searched the reference lists of eligible articles for additional relevant citations. Search results were uploaded to EndNote X8, and duplicates were deleted. Training in this program was undertaken beforehand. The program allowed review authors to collaborate and be blinded to the other authors' decisions, when necessary.

Study Selection, Data Extraction, and Analysis

The search results were screened systematically to reduce the chance of excluding relevant studies. The inclusion and exclusion criteria were clarified between four authors. Title screening was completed by two pairs of authors and discrepancies reviewed with both pairs present. Abstract screening was carried out individually by three authors and discrepancies were resolved by the fourth author. Full-text screening was completed in pairs and a decision was made as to whether the studies met the criteria. Disagreements were resolved through discussion, and reasons for exclusion were recorded. No review authors were blinded to journal titles, study authors, or institutions. All authors were blinded to the other pair's or individual author's decisions until arbitration.

Using a standardized, preformatted form, data were extracted from each eligible study in pairs. To ensure consistency, all four reviewers undertook a calibration process prior to data extraction. Sample characteristics, methodology, intervention details, and all reported outcomes regarding the interventions of relevance were included in data extraction. The independently completed duplicate forms were merged and compared for inconsistencies, which were resolved by discussion between all authors. Any unresolved disagreements were arbitrated by a collaborator with experience in dental radiology and research.

Some eligible studies evaluated additional techniques for WL determination, such as intraoral periapical (IOPA).[13,14] However, only data relevant to the research question were extracted. Differences between the variety of EAL and CBCT systems used by eligible studies were not considered in this review.

Evaluation of accuracy was determined by the agreement between CBCT and EAL measurements. Reliability was quantified through assessment of differences between repeat measurements. A variety of statistical methods were employed across all studies in outcome measurement. Both accuracy and reliability were considered with equal priority, and no secondary outcomes were considered.

Risk of Bias in Individual Studies

The risk of bias in individual studies was assessed using a modified version of the criteria proposed by Hadorn et al.[15] These criteria were adapted to facilitate bias assessment for the experimental designs included in the review. Using the extracted data, studies were screened for major and minor flaws independently by two pairs of authors. To reach agreement, pairs discussed any inconsistencies between assessments. Arbitration by the collaborator was sought when this failed. Three minor flaws were equal to one major flaw, allowing the generation of a score of bias for each study. Based on the scores, studies were divided into three levels of evidence. Level I comprised well-conducted studies. Level II comprised moderately well-conducted studies with some flaws, while level III comprised studies with significant flaws affecting their validity and reliability.

Review Results

The initial search from the databases produced 4,361 articles, with an additional 55 articles sourced from gray literature. After duplicates were removed, 1,358 articles remained. Of these studies, all but 129 were excluded based on titles. Six articles met the inclusion criteria upon abstract screening. On full-text assessment, one study was excluded as it did not include CBCT as a method of measurement and thus failed to meet the inclusion criteria.[16] Reference lists from the eligible articles were manually searched with no additional relevant studies found. A total of five studies were selected (Flowchart 1).

Study Characteristics

Publication years ranged from 2011 to 2016 (Table 1). The brands and models of the CBCT and EAL varied depending on the study. Equipment operators were appropriately trained within the fields of dental radiology and endodontics.

Risk of Bias

Of the five included studies, two were found to be well-conducted with minimal risk of bias,[17,18] and three studies were moderately well-conducted with some flaws affecting study validity and reliability[13,14,19] (Table 2).

Results of Individual Studies

In all five studies, no significant difference was found between measurements taken with CBCT and EAL (Table 3).[13,14,17–19] Three studies evaluated the reliability of CBCT, finding it to be reliable based on Pearson correlation coefficient calculations of repeated measurements.[17–19] No studies evaluated the reliability of EAL, thus it could not be compared with CBCT in this context. Due to their comparative nature, no studies favored one method for accuracy of WL determination over another. Rather, each study confirmed that CBCT is at least as accurate as EAL in WL determination.

Discussion

Accurate WL determination is required to achieve total removal of the pulpal tissue and complete sealing of the canals, ensuring successful endodontic outcomes for the patient.[1,2] Currently, EAL with adjunctive IOPA radiography is the preferred method of WL determination.[4] This systematic review was conducted to assess whether CBCT is able to determine WL more accurately and reliably than EAL based on the current literature. Overall, there was a lack of evidence and a lack of high-quality evidence. As such, it was not possible to conclude which measurement technique was more accurate or reliable.

All included studies demonstrated that measurements based on CBCT were not significantly different to those taken with EAL.[13,14,17–19] As electronic measurements are currently considered a clinically acceptable means of determining WL,[5] these findings suggested that CBCT is at least as accurate as EAL. The clinical accuracy of either method cannot be established.

In most cases, the WL will have been already determined prior to the prescription of CBCT. However, the authors of four studies suggested that CBCT may be used for WL determination when there is a preexisting CBCT scan available.[14,17–19] Acquiring a new CBCT specifically for endodontic treatment is not advised due to costs and the high level of radiation exposure to the patient.[13,14] Ustun et al. suggested that prior to using a preexisting CBCT, clinicians should ensure that there have been no pathological changes. For example, external root resorption may result in a change to the reference point, root or root canal length.[18]

The eligible studies elicited less evidence for reliability when compared to accuracy. Studies by Jeger et al., Janner et al., and Ustun et al. suggested that CBCT was reliable but did not consider

Flowchart 1: PRISMA flowchart

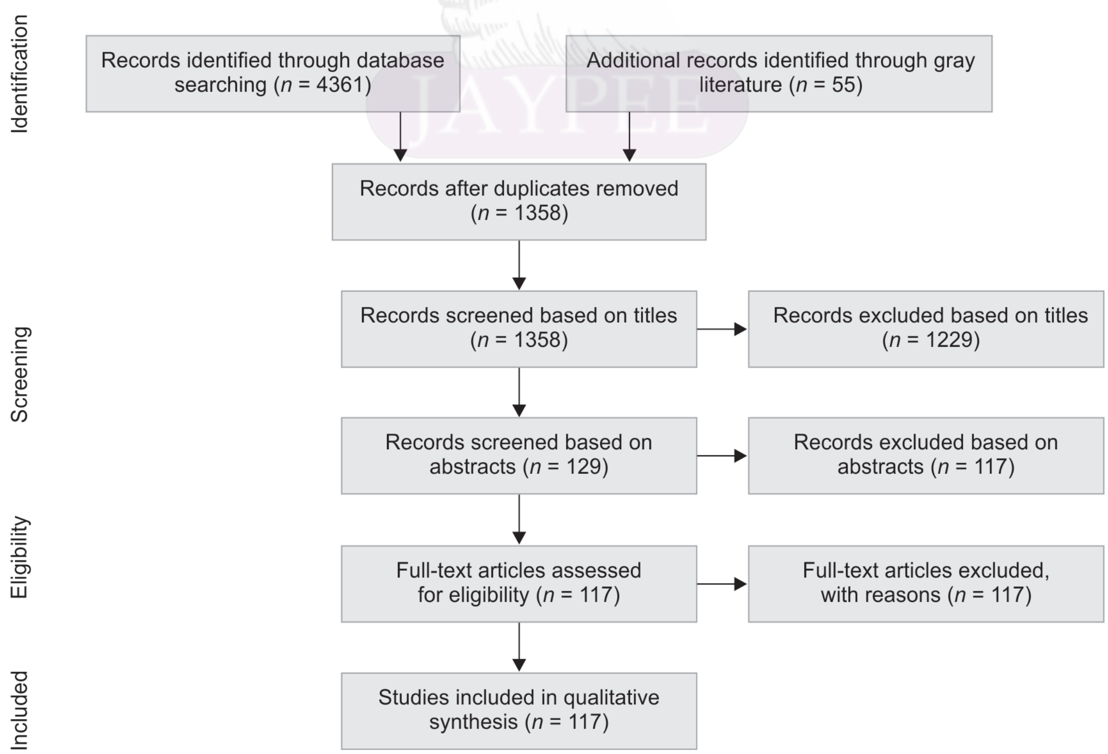

Table 1: Study characteristics

Study type/ authors, year	*Country*	*EAL brand*	*CBCT brand*	*Characteristics of teeth included*	*Sample size Patients/teeth/ canals*	*Method of accuracy measurement*	*Method of reliability measurement*
In vivo de Morais et al., 2016	Brazil	J. Morita USA	ICAT	Anterior, single canal teeth	19/30/30	The mean values of WL obtained with EAL, IOPA radiographs, and CBCT images were compared	None
Eslinger, 2012	USA	J. Morita USA	CareStream Health Inc.	Anterior and posterior, unspecified number of canals	nd/14/40	Paired sample *t* tests were conducted with measurements from coronal and sagittal CBCT images and compared to EAL measurements	None
Janner et al., 2011	Switzerland	J. Morita Japan	Morita Japan	Anterior and posterior, varying number of canals	3/9/10	The Pearson correlation coefficient was used to compare EAL with CBCT values to evaluate agreement	CBCT measurements of WL were repeated once and correlation with previous results measured
Jeger et al., 2012	Switzerland	J. Morita USA	J. Morita USA	Anterior, single canal teeth	30/40/40	Correlation between EAL and CBCT	CBCT measurements were repeated after 1 week to calculate an intraoperator reliability coefficient
Ustun et al., 2016	Turkey	Dentsply, VDW	QR Verona Italy	Anterior and posterior single canal teeth	30/73/73	Median values for CBCT, Raypex 6, and Propex Pixi measurements were compared	CBCT images were evaluated by a single expert radiologist twice and the intraoperator reliability was evaluated using the Pearson correlation coefficient

CBCT, cone beam computed tomography; EAL, electronic apex locator; nd, not described; IOPA, intraoral periapical

Table 2: Risk of bias within studies

Study type/authors, year	*Selection of samples*	*Allocation of samples to intervention groups*	*Measurement used*	*Study administration*	*Withdrawals from the study*	*Outcome measurement and blinding*	*Statistical analysis*	*Level of evidence*
In vivo de Morais et al, 2016	–	m	m	–	m	–	M + m	II
Eslinger, 2012	m	M	M + m	–	–	–	M	II
Janner et al., 2011	–	m	m	–	–	–	M	II
Jeger et al., 2012	M	–	–	–	–	–	M	I
Ustun et al., 2016	–	m	m	–	–	–	M	I

M, major flaw present; m, minor flaw present; –, no flaw present; III, level of evidence 3; II, level of evidence 2; I, level of evidence 1

Table 3: Results

Study type/authors, year	*Accuracy*	*Reliability*
In vivos de Morais et al., 2016	No difference ($p > 0.05$)	N/A
Eslinger, 2012	No difference ($p > 0.05$)	N/A
Janner et al., 2011	No difference (PCC = 0.968)	Repeated CBCT measurements were reliable (PCC = 0.998)
Jeger et al., 2012	No difference, mean discrepancy between CBCT and EAL was 0.51 mm (CI = 95%)	Repeated CBCT measurements were reliable (PCC = 0.99)
Ustun et al., 2016	No difference ($p > 0.05$)	Repeated CBCT measurements were reliable (PCC = 0.96)

CBCT, cone beam computed tomography; EAL, electronic apex locator; PCC, Pearson correlation coefficient; CI, confidence interval; N/A, not applicable

EAL reliability.[17–19] Existing literature and the widespread clinical application of EAL suggests that it is reliable; however, this cannot be confirmed within the boundaries of this review.[20] No definitive conclusion can be drawn with respect to which method is more reliable.

Limitations

All studies included in this review had various flaws affecting their validity and reliability. Being *in vivo* in design, the included studies could not elicit the superiority of one measurement technique, despite their greater clinical relevance. All studies were likely underpowered due to small sample sizes and thus susceptible to type II error.[21] Therefore, the failure of all eligible studies to detect a significant difference between measurement methods should be interpreted with caution.[13,14,17–19]

All studies were assessed to be either well-conducted or moderately well-conducted with some flaws. As seen in Table 2, all studies had major inadequacies in their statistical analysis. All studies used the correlation coefficient to compare CBCT and EAL. However, differences between clinical measurement methods are more appropriately evaluated using a Bland–Altman plot.[22] Sample selection was generally well-described; however, two studies were assigned at least one major or minor flaw for sample selection.[13,17] Three of the study protocols failed to randomize the order of measurement methods.[14,18,19] The effect of this is unknown but may have increased bias. Jeger et al. was the only study to comprehensively describe CBCT, EAL, and repeat measurement techniques.[17] Three studies described repeated measurements, enhancing data reliability.[17–19]

The primary limitation of this review was its comparison of studies with variable sample sizes, equipment brands, inclusion criteria, and outcome measurement methods. Furthermore, various CBCT slices were used to obtain WL, reducing the inter-study comparability. Additionally, three studies failed to specify voxel size, potentially resulting in different spatial resolutions across studies. This review was restricted to comparing the accuracy and reliability of CBCT and EAL. As such, other, potentially more accurate methods of WL determination such as conventional radiography were not considered.

The accuracy and reliability of CBCT WL determination demands further enquiry. It is recommended that prospective researchers complete a power analysis to acquire an adequate sample size. Further research is required to evaluate the clinical utility of CBCT in WL determination. Future studies would also benefit from investigation into voxel size, jaw type, tooth type, canal number, and morphology and their effects on WL measurement.

It may also be beneficial to compare the outcomes of RCT based on the method of WL determination used. Teeth that have undergone occlusal shortening after the CBCT scan also require investigation, as this may alter the reference point and in turn affect WL.[17] It is also recommended that teeth with metallic restorations are studied in detail to determine the most effective method of establishing their WL. Metallic restorations can reduce the accuracy of CBCT through scatter and EAL through electrical short-circuiting.[13,18]

Finally, a combined *in vivo* and *ex vivo* study on patients with preexisting CBCTs would be beneficial. This could involve measuring WL *in vivo* using CBCT and EAL, extracting the hopeless tooth and establishing actual WL *ex vivo*. While such a study would require ethical consideration, it would allow actual WL to be measured as the control for accuracy and reliability comparisons.

Conclusion

Due to significant heterogeneity between the included studies, the accuracy of CBCT compared to EAL in WL determination could not be determined. However, based on the limited evidence available, CBCT appeared to be at least as accurate as EAL in determining WL. Consequently, WL determination using a preexisting CBCT scan may be a clinically appropriate method.[14,17–19] Despite this, there was inadequate evidence to justify acquisition of a new CBCT specifically for endodontic treatment due to cost and radiation exposure.[16] While preexisting scans are beneficial for WL determination, the ALARP principle should guide referral for new CBCT acquisition. There was a lack of high-level evidence comparing the reliability of CBCT with EAL. However, the eligible studies generally suggested that CBCT was reliable. These results should be interpreted judiciously. Further research is required to conclusively evaluate the accuracy and reliability of CBCT compared with EAL.

References

1. Fleming CH, Litaker MS, et al. Comparison of Classic Endodontic Techniques versus Contemporary Techniques on Endodontic Treatment Success. J Endod 2010;36:414–418. DOI: 10.1016/j.joen.2009.11.013.
2. Kqiku L, Städtler P. Radiographic versus electronic root canal working length determination. Indian J Dent Res 2011;22(6):777–780. DOI: 10.4103/0970-9290.94666.
3. Ounsi HF, Naaman A. *In vitro* evaluation of the reliability of the Root ZX electronic apex locator. Int Endod J 1999;32(2):120–123. DOI: 10.1046/j.1365-2591.1999.00202.x.
4. Pratten DH, McDonald NJ. Comparison of radiographic and electronic working lengths. J Endod 1996;22(4):173–176. DOI: 10.1016/S0099-2399(96)80095-1.
5. Gordon MPJ, Chandler NP. Electronic apex locators. Int Endod J 2004;37(7):425–437. DOI: 10.1111/j.1365-2591.2004.00835.x.
6. Sjögren U. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16:498–504. DOI: 10.1016/S0099-2399(07)80180-4.

7. Kapila S, Conley RS, et al. The current status of cone beam computed tomography imaging in orthodontics. Dentomaxillofac Radiol 2011;40(1):24–34. DOI: 10.1259/dmfr/12615645.
8. Hoer D, Attin T. The accuracy of electronic working length determination. Int Endod J 2004;37(2):125–131. DOI: 10.1111/j.0143-2885.2004.00764.x.
9. AAE and AAOMR Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Oral Surg Oral Med Oral Pathol Oral Radiol 2015;120(4):508–512. DOI: 10.1016/j.oooo.2015.07.033.
10. Aktan AM, Yildirim C, et al. Effects of voxel size and resolution on the accuracy of endodontic length measurement using cone beam computed tomography. Annals of anatomy = Anatomischer Anzeiger: official organ of the Anatomische Gesellschaft 2016;208:96–102. DOI: 10.1016/j.aanat.2016.05.005.
11. Patel S, Durack C, et al. European Society of Endodontology position statement: The use of CBCT in Endodontics. Int Endod J 2014;47(6):502–504. DOI: 10.1111/iej.12267.
12. Lee AHC, Cheung GSP, et al. Long-term outcome of primary non-surgical root canal treatment. Clin Oral Investig 2012;16(6):1607–1617. DOI: 10.1007/s00784-011-0664-2.
13. Eslinger BT. Accuracy of Cone-Beam Computed Tomography (CBCT) in Determining Root Canal Working Length. Chicago, IL: University of Illinois; 2012.
14. de Morais ALG, de Alencar AHG, et al. Working Length Determination Using Cone-Beam Computed Tomography, Periapical Radiography and Electronic Apex Locator in Teeth with Apical Periodontitis: A Clinical Study. Iran Endod J 2016;11(3):164–168.
15. Hadorn DC, Baker D, et al. Rating the quality of evidence for clinical practice guidelines. J Clin Epidemiol 1996;49(7):749–754. DOI: 10.1016/0895-4356(96)00019-4.
16. Connert T, Judenhofer MS, et al. Evaluation of the Accuracy of Nine Electronic Apex Locators by Using Micro-CT. Int Endod J 2014;47: 698–703. DOI: 10.1111/iej.12206.
17. Jeger FB, Janner SF, et al. Endodontic Working Length Measurement with Preexisting Cone-Beam Computed Tomography Scanning: A Prospective, Controlled Clinical Study. J Endod 2012;38(7):884–888. DOI: 10.1016/j.joen.2012.03.024.
18. Ustun Y, Aslan T, et al. Evaluation of the Reliability of Cone-beam Computed Tomography Scanning and Electronic Apex Locator Measurements in Working Length Determination of Teeth with Large Periapical Lesions. J Endod 2016;42(9):1334–1337. DOI: 10.1016/j.joen.2016.06.010.
19. Janner SF, Jeger FB, et al. Precision of Endodontic Working Length Measurements: a Pilot Investigation Comparing Cone-Beam Computed Tomography Scanning with Standard Measurement Techniques. J Endod 2011;37(8):1046–1051. DOI: 10.1016/j.joen.2011.05.005.
20. Elayouti A, Dima E, et al. Consistency of Apex Locator Function: A Clinical Study. J Endod 2009;35(2):179–181. DOI: 10.1016/j.joen.2008.10.017.
21. Banerjee A, Chitnis UB, et al. Hypothesis testing, type I and type II errors. Ind Psychiatry J 2009;18(2):127–131. DOI: 10.4103/0972-6748.62274.
22. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1(8476):307–310. DOI: 10.1016/S0140-6736(86)90837-8.