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ORIGINAL ARTICLE

Accuracy of Working Length Determination - Electronic Apex Locator *Versus* Cone Beam Computed Tomography

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ABSTRACT

Objective: To compare the accuracy of working length determination between cone beam computed tomography (CBCT) and electronic apex locator by measuring the actual working length of teeth. **Material and Methods:** A total of 150 single-rooted tooth assessed by radiograph undergoing root canal therapy were selected. The process was repeated to obtain a buccolingual and mesiodistal section of all teeth. The measurement line was considered from the reference occlusal plane following the center of the canal to the terminus. All information regarding the accuracy of cone-beam computed tomography and apex locator was noted in a pre-designed proforma. **Results:** CBCT consistently demonstrated high accuracy across all tooth types in both jaws. The electronic apex locator exhibited varying precision, with greater accuracy observed in the mandible. Statistical analyses revealed significant differences in electronic apex locator accuracy among tooth types in the maxilla (p=0.042), emphasizing the importance of specific clinical considerations. **Conclusion:** Cone beam computed tomography emerges as a reliable diagnostic tool for accurate working length determination, especially in complex cases, while the electronic apex locator remains valuable with careful consideration of potential variations in accuracy. An individualized approach, considering tooth type, jaw location, and clinical context, is crucial for precise working length determination in endodontic practice.

Keywords: Electronics; Endodontics; Mandible; Maxilla.

Introduction

In the realm of endodontics, the critical role of accurate working length determination cannot be overstated; it serves as the guiding compass for root canal procedures, preventing potential pulpal pathologies and ensuring the enduring success of treatments, particularly in the complex landscape of curved canals. This precision extends beyond procedural formality, playing a pivotal role in pain management and post-treatment comfort [1]. The apical constriction is recommended as the ideal end-point for the instrumentation and filling of the root canal system. It is shown to be located 0.5-1 mm from the major foramen on the root surface [2].

Traditional methods of working length measurement encompass various approaches, including paper point bleeding, apex locators, direct digital radiography, endodontic rulers with files, and electronic methods like electronic foramen locators [3]. The most widely used method for working length determination is the radiographic method. Radiographs are not as reliable as other methods and lead to inaccuracies because radiographs only provide a two-dimensional representation of the three-dimensional object [3]. Electronic measurement of root canal length precisely determines the working lengths for root canal procedures, and this method has become requisite in endodontics [4]. Current electronic apex locators are reliable and exhibit high accuracy and reproducibility in locating the major apical foramen [5]. In addition to this, the use of electronic apex locators reduces patient exposure to ionizing radiation by reducing the number of radiographs to determine the working length (WL) [6-8]. However apical anatomical complexities may affect electronic apex locator performance, resulting in unstable readings and inappropriate measurements [5].

While studies indicate the accuracy of electronic apex locators in determining working length, the necessity for radiographic verification still persists [4]. Cone beam computed tomography (CBCT) imaging is a contemporary radiologic imaging system that is useful before endodontic therapy in providing reliable anatomic information in 3 dimensions for diagnosis and treatment planning. The pre-operative working length might be estimated by a pre-existing CBCT scan for any indication in dentistry [9-12]. CBCT is used in the detection of apical periodontitis, endodontic surgery, dental trauma, root resorption, diagnosis of vertical root fracture and assessment of the outcome of endodontic treatment [13]. Studies suggest CBCT's accuracy is often comparable to electronic apex locators, though some variations exist. Notably, some studies propose electronic apex locators superiority in certain situations, while others indicate CBCT's precision, particularly in cases involving periapical lesions [5].

The significance of future research in working length measurement methods lies in their potential to address critical gaps. Enhanced precision in curved canals, comprehensive comparative analyses of electronic apex locator types, longitudinal assessments of treatment outcomes, patient-centric approaches, exploration of technological advancements, standardization of protocols, and interdisciplinary collaboration between endodontists, radiologists, and engineers are essential avenues to refine understanding and benefit endodontic practice. These efforts can contribute valuable insights, guide practitioners, and ultimately advance the precision and efficacy of working length determination in endodontics.

Against this background, this study aimed to compare the accuracy of working length between CBCT and electronic apex locator by measuring actual root canal length clinically.

Material and Methods

Study Design and Sampling

This *in-vitro* study was conducted in the Department of Operative Dentistry and Radiology, LUMHS, Hyderabad, Pakistan, from March to August 2023. The sample size for the study was determined using OpenEpi online software, considering an assumed accuracy of the apex locator to be 40% from the study [6], a margin of error of 10%, and a confidence interval of 95%. The initial calculated sample size was 93 samples. However, to enhance the power of the study, the sample size was increased to 150 samples. A total of 150 single-rooted tooth assessed by radiograph undergoing root canal therapy were selected for this study.

Inclusion and Exclusion Criteria

The inclusion criteria comprised sound teeth without carious lesions in both maxillary and mandibular jaws, extracted for orthodontic or periodontic reasons. Exclusion criteria encompassed teeth with immature or wide apices, fractured roots, root resorption, metallic restorations, calcified canals, and those with previous endodontic treatment assessed by radiograph.

Procedure

The selected teeth were stored in 10% formalin solution after extraction. Pre-operative periapical radiographs of all extracted teeth were taken. Endodontic access cavities were created with a high-speed handpiece, and a straight-line access was achieved with a #3 Gates-Glidden bur. The canal was irrigated with sodium hypochlorite solution and the canal patency was verified using a size #10 K-file inserted into the apex. After that, the working length measurements were performed as follows:

1. To measure the actual length as a standard, size #15K-file was inserted into the canal until visible through the major foramen. Then it was seen under a magnifying glass, at the level of the coronal-most boundary of the major foramen. The rubber stopper was set at occlusal reference and the distance was determined, with a digital caliper and detected as the actual length.
2. Alginate impression material was used to create molds for all teeth, and an electrode connected to J. Morita apex locator was inserted into the alginate. A #15 K-file was connected to the apex locator, and inserted into the root canal until the 3rd green bar of apex locator was reached. After that rubber stopper was adjusted and distance between reference point and tip of file was measured with digital caliper in millimeters.
3. A mold was prepared using polyvinyl siloxane impression material, and CBCT images were obtained with a small voxel size of 0.080 mm^3 and a field of view of 40X40 mm. The working model was positioned on a camera tripod in a reproducible position. The root canal of each selected tooth was placed in a vertical position to visualize the whole length in a single slice. The process was repeated to obtain a buccolingual and mesiodistal section of all teeth. The measurement line was established from the reference occlusal plane following the center of the canal to the terminus.

All information regarding the accuracy of CBCT and apex locator was noted by two well-experienced endodontists in a pre-designed proforma. The examiners were blinded to patient information to minimize bias during the analysis. Prior to analyzing the study materials, these examiners evaluated 10 CBCT images, and their assessments were compared based on their analysis of the CBCT images. If there was any disagreement between the examiners, they discussed the case until a consensus was reached. To assess intra- and inter-examiner reliability, a follow-up session took place four weeks after the initial evaluation.

Statistical Analysis

Data was analyzed using Statistical Package for Social Sciences version 20.0 (IBM Corp, Armonk, NY, USA). Mean and standard deviation were computed for quantitative variables like length with the electronic apex locator, CBCT and actual length. Frequency and percentages were calculated for the accuracy of the apex locator and CBCT of the maxilla and mandibular teeth. A comparison of accuracy was done by applying the chi-square test. The level of statistical significance was set at p≤0.05.

Results

The sample comprised 32 (21.3%) central incisors, 32 (21.3%) lateral incisors, 34 (22.7%) canines, 13 (8.7%), and 39 (26.0%) second bicuspids (Table 1).

Table 1. Association between tooth type and location in the jaw.

Tooth Type	Jaw Maxilla N (%)	 Mandible N (%)	Total N (%)	p-value
Central Incisor	10 (6.7)	22 (14.7)	32 (21.3)	0.018
Lateral Incisor	21 (14.0)	11 (7.3)	32 (21.3)	
Canine	11 (7.3)	23 (15.3)	34 (22.7)	
1st Premolar	6 (4.0)	7 (4.7)	13 (8.7)	
2nd Premolar	22 (14.7)	17 (11.3)	39 (26.0)	
Total	70 (46.7)	80 (53.3)	150 (100.0)	

The average actual working length was 20.40±1.64 mm for maxillary teeth and 20.86±1.72 for mandibular teeth. The mean working length by electronic apex locator was 20.25±2.13 mm for maxillary teeth and 20.72±2.05 mm for mandibular teeth whereas for CBCT, the mean working length for maxillary teeth was found to be 20.39±1.62 mm and for mandibular teeth, it was 20.82±1.68 mm as shown in Table 2.

Table 2. Mean working length with electronic apex locator, cone beam computed tomography (CBCT) and actual length.

Working Length	Maxilla (Mean±SD in mm)	Mandible (Mean±SD in mm)
Electronic Apex Locator	20.25±2.13	20.72±2.05
CBCT	20.39±1.62	20.82±1.68
Actual	20.40±1.64	20.86±1.72

The accuracy of CBCT in determining working length was found to be consistently high across all tooth types in both the maxilla and mandible. The statistical analysis suggests no significant difference in CBCT accuracy across tooth types within each jaw (Table 3).

Table 3. Accuracy of CBCT in assessing the working length.

Tooth Type	Accurate N (%)	Not Accurate N (%)	Total N (%)	p-value
Maxilla				0.669
Central Incisor	10 (14.3)	0 (0.0)	10 (14.3)	
Lateral Incisor	20 (28.6)	1 (1.4)	21 (30.0)	
Canine	11 (15.7)	0 (0.0)	11 (15.7)	
1st Premolar	6 (8.6)	0 (0.0)	6 (8.6)	
2nd Premolar	22 (31.4)	0 (0.0)	22 (31.4)	
Total	69 (98.6)	1 (1.4)	70 (100.0)	
Mandible				0.470
Central Incisor	20 (25.0)	2 (2.5)	22 (27.5)	
Lateral Incisor	11 (13.8)	0 (0.0)	11 (13.8)	
Canine	23 (28.7)	0 (0.0)	23 (28.7)	
1st Premolar	7 (8.8)	0 (0.0)	7 (8.8)	
2nd Premolar	16 (20.0)	1 (1.2)	17 (21.2)	
Total	77 (96.2)	3 (3.8)	80 (100.0)	

Table 4 shows the accuracy of the electronic apex locator in assessing the working length. The overall accuracy of the electronic apex locator was higher in the mandible compared to the maxilla. Within maxilla, there was statistically significant differences in electronic apex locator accuracy among different tooth types (p=0.042). Mandible also exhibited variation in electronic apex locator accuracy across tooth types, but statistical significance was not explicitly established (p=0.740).

Table 4. Accuracy of electronic apex locator in assessing the working length.

Tooth Type	Accurate N (%)	Not Accurate N (%)	Total N (%)	p-value
Maxilla				0.042*
Central Incisor	9 (12.9)	1 (1.4)	10 (14.3)	
Lateral Incisor	12 (17.1)	9 (12.9)	21 (30.0)	
Canine	9 (12.9)	2 (2.9)	11 (15.7)	
1st Premolar	3 (4.3)	3 (4.3)	6 (8.6)	
2nd Premolar	19 (27.1)	3 (4.3)	22 (31.40)	
Total	52 (74.3)	18 (25.7)	70 (100.0)	
Mandible				0.740
Central Incisor	19 (23.8)	3 (3.8)	22 (27.5)	
Lateral Incisor	8 (10.0)	3 (3.8)	11 (13.8)	
Canine	16 (20.0)	7 (8.8)	23 (28.7)	
1st Premolar	5 (6.2)	2 (2.5)	7 (8.8)	
2nd Premolar	13 (16.2)	4 (5.0)	17 (21.2)	
Total	61 (76.2)	19 (23.8)	80 (100.0)	

*Statistically significant.

Discussion

The efficacy of root canal procedures hinges on the precise determination of the working length, serving as a guiding criterion from the coronal reference point to the apical constriction. This precision ensures effective cleaning, shaping, and subsequent elimination of infected tissue, reducing the risk of postoperative discomfort and treatment failure. Accurate working length calculation also plays a crucial role in the optimal positioning of filling materials, preventing bacterial reintroduction and enhancing periapical healing [7,8]. Beyond practical utility, this precision contributes to improved patient quality of life, mitigating postoperative discomfort associated with root canal therapy and ensuring the predictability and success of endodontic treatments [2,9].

In this study, employing CBCT and electronic apex locator, the research aimed to evaluate the reliability of working length determination in 150 single-rooted teeth. CBCT consistently demonstrated high accuracy in working length estimation across various tooth types in both the maxilla and mandible. Its reliability and precision have positioned CBCT as a formidable tool in endodontics, providing distortion-free, three-dimensional images crucial for precise working length determination [10,11]. In contrast, the electronic apex locator exhibited varying precision, with greater accuracy in the mandible. Statistically significant variations in electronic apex locator precision among tooth types in the maxilla emphasize the importance of assessing accuracy based on specific clinical contexts [6,12].

The results highlight the significance of integrating CBCT and an electronic apex locator in working length determination, recognizing their distinct strengths and accuracy levels. CBCT's constant accuracy, especially in the mandible, contrasts with the variability observed with the electronic apex locator, particularly in the maxilla. The discussion underscores the need for clinicians to consider these trends when choosing between CBCT and electronic apex locator, emphasizing the advantages of CBCT's consistent accuracy against potential electronic apex locator variability, especially in specific clinical settings or tooth types.

Comparing our findings with existing literature reveals alignment with studies emphasizing CBCT's consistent and high accuracy across different tooth types [13,14]. Variability in electronic apex locator accuracy, especially in the maxilla, resonates with previous studies, emphasizing the influence of tooth type, canal morphology, or pathologies on EAL accuracy [14-16]. The collective evidence contributes to the evolving understanding of CBCT and electronic apex locator in endodontics, recognizing the need for continuous improvement in techniques and technologies.

Acknowledging the limitations of using extracted teeth, caution is advised in extrapolating findings to clinical scenarios. *In vivo* complexities, such as tissue elasticity and blood flow, may impact outcomes. The controlled environment may not fully capture the diverse conditions encountered clinically, emphasizing the need for validation in future clinical trials [17].

The clinical implications of this study underscore the importance of informed decision-making in working length determination. CBCT's consistently high accuracy positions it as a reliable diagnostic tool, especially in complex cases. Electronic apex locator, with its non-invasive nature, remains valuable, though clinicians must be mindful of potential variations in accuracy. An individualized approach, considering tooth type, jaw location, and clinical context, is crucial for accurate working length determination. Integrating CBCT and electronic apex locator into a comprehensive diagnostic strategy may enhance precision, contributing to predictable treatment outcomes and improved patient comfort.

CBCT and EAL offer valuable advantages in endodontics, but the financial implications should be carefully evaluated by practitioners before adoption. Consideration of initial investments, ongoing maintenance costs, training requirements, reimbursement issues, and the overall economic feasibility is crucial for making informed decisions that align with the practice's goals and resources. The potential long-term benefits in terms of improved patient care and practice efficiency may justify the initial costs for many endodontic practices.

The study has several limitations that warrant consideration. The *in-vitro* design using extracted teeth stored in formalin may not fully replicate the clinical environment, limiting the external validity of the findings. The exclusion criteria, sample characteristics, and artificial procedural conditions further restrict the generalizability, particularly to multi-rooted teeth and live patient scenarios. The use of formalin as a storage medium may impact the dental tissues' properties, potentially influencing working length measurements. Operator-dependent variables and a single-operator bias may introduce variability, affecting the reliability of the results. The study primarily focuses on single-rooted teeth, and the limited discussion on the radiographic method hinders a comprehensive comparison. Recognizing these limitations is crucial for interpreting the study's outcomes and guiding future research to enhance the applicability of working length determination techniques in diverse clinical contexts.

Conclusion

Cone beam computed tomography consistently demonstrated high accuracy in working length estimation across various tooth types in both the maxilla and mandible. The electronic apex locator exhibited varying precision, with greater accuracy observed in the mandible and statistically significant variations in electronic apex locator precision among tooth types in the maxilla. Future research in endodontics should strive to bridge existing knowledge gaps and contribute to the refinement of working length determination. Focusing on specific clinical scenarios, conducting longitudinal assessments, embracing technological advancements, standardizing protocols, prioritizing patient-centered approaches, and fostering interdisciplinary collaboration will collectively contribute to the evolution of endodontic practice and enhance patient outcomes.

Authors' Contributions

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All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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