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COMPARATIVE EVALUATION OF ELECTRONIC APEX LOCATOR, CONVENTIONAL RADIOGRAPHY, AND RADIOVISIOGRAPHY FOR WORKING LENGTH DETERMINATION: AN IN VITRO STUDY

Dr. Annu Laxmi*[1], Dr. Amit Kumar[2], Dr. Sulaima Mehar[3], Dr. Raja Kumar[4], Dr. Mayank Chaudhary[5], Dr. Akanksha Abhilash[6]

[1*]MDS, Final year Postgraduate student, Department of Conservative Dentistry and Endodontics, Mithila Minority Dental College and Hospital, Darbhanga, Email id - annulaxmi57@gmail.com
[2]MDS, HOD and Professor, Department of Conservative Dentistry and Endodontics, Mithila Minority Dental College and Hospital, Darbhanga
[3]MDS, Senior Resident, Conservative Dentistry and Endodontics, PGIDER, I.G.I.M.S, Patna
[4]MDS, First year Postgraduate student, Department of Conservative Dentistry and Endodontics, Mithila Minority Dental College and Hospital , Darbhanga
[5]MDS, Senior Resident, Department of Conservative Dentistry and Endodontics, Mithila Minority Dental College and Hospital, Darbhanga
[6]MDS, Final year Postgraduate student, Department of Conservative Dentistry and Endodontics, Mithila Minority Dental College and Hospital, Darbhanga

ABSTRACT
Working length determination (WLD) is one of the most critical steps in endodontics to ensure successful outcomes including efficient cleaning, shaping and obturation of the root canal system and the avoidance of over and under-instrumentation. This in vitro study aimed to compare the precision of an electronic apex locator (EAL), conventional intraoral periapical radiography (IOPAR) and radio visiography (RVG) against the actual working length. 93 extracted permanent single-rooted mandibular premolars were evenly split into three groups (n = 31). Standardized access preparation and working length WL measurements were taken and the actual WL was stereo microscopically evaluated after longitudinal sectioning. One way ANOVA and Tukey's post hoc test were used for data analysis. There were considerable differences between the methods ($p < 0.001$). The electronic apex locator (EAL) gave measurements that were closest to the actual working length AWL and was not statistically substantially different from the reference standard. Both RVG and conventional radiography, on the other hand, significantly overestimated the working length, and there was no significant difference between the two radiographic techniques. With the constraint of this study, the electronic apex locator proved to be more accurate in determining the working length. Nonetheless, radiography techniques have their place in the measurement of root canal morphology and verification of the treatment protocols. Hence, it is advised that the combination of electronic apex locator and radiographic verification is necessary for accurate and predictable endodontic outcome.

KEYWORDS: Electronic apex locator; Working length; Radio visiography; Conventional radiography; Endodontics

INTRODUCTION
The critical factors for successful ED treatment are complete debridement, disinfection and three-dimensional obturation of the root canal system (RCS) within biologically acceptable limits. Of these procedures, one of the most important components that affect the consequence of treatment is the proper measurement of the WL. The goal of root canal treatment is to lower the number of microorganisms in the RCS to a point where they will not create or maintain apical periodontitis (Siqueira & Rôças, 2008). Failure to properly determine the working length can cause the extrusion of debris, irrigants, medicaments or filling materials outside the apical foramen, postoperative pain, delayed periapical healing or insufficient removal of infected tissues (Yusuf, 1982; Tuncer & Gerek, 2014).
The working length is the distance from a stable coronal reference point to the point where the cleaning, shaping and obturation should stop inside the canal (Tsesis et al., 2015). The most narrowed region of the root canal is termed as the apical constriction which is usually considered to be the most ideal end point for endodontic instrumentation and is considered as most ideal biological limit for the preparation of the root canal and obturation (Bhatt et al., 2015). If instrumentation is not maintained in this area, the results of treatment could be compromised because of the presence of infected tissue in the canal, or injury to the periapical tissues (Sheaffer et al., 2003).
Conventional intraoral periapical radiography has been the most common method used for working length determination due to its ease of use, accessibility and reliability to provide information regarding root morphology and periapical structures (Singh et al., 2015). But there are drawbacks to radiographic techniques. They only present a 2-D view of a 3-D anatomical structure, with the potential for magnification and distortion of the image and for anatomical superimposition and operator interpretation. Furthermore, the radiographic apex is often not related to the anatomic apex or the apex of the apical constriction, which means measurements are not always accurate (de Morais et al., 2016; Durack & Patel, 2012).

The advent of digital radiography and especially radio visiography (RVG) was a big step in the imaging of endodontics. The benefits of RVG compared to traditional radiography using film are that exposure to radiation is less, images are acquired in real time, images can be enhanced digitally, images can be stored and software is available to measure the images and aid in clinical interpretation (Bansal, 2006; Ilic & Stojanović, 2012). However, the disadvantages with the use of RVG are that it is a two-dimensional imaging modality and cannot overcome the anatomical limitations involved in radiographic working-length determination (Shanmugaraj et al., 2007).

To address many limitations of radiographic methods, electronic apex locators were developed to measure canal length by the electrical properties of the RCS instead of the use of radiographs. With the development of electronic technology, there is an evolution of multiple generations of apex locators which have enhanced accuracy and reliability under different canal conditions (Khadse et al., 2017). The 5th generation electronic apex locators are very accurate in determining the apex and have proven to be useful in the present endodontics (Bueno et al., 2013). However, other factors as canal contents, irrigating solutions, apical anatomy and operator technique may still affect their performance (Carneiro et al., 2016).

There are several studies that have evaluated the radiographic versus electronic methods of working-length determination but due to different methodology, study design, and reference standards, the reported results show varying degrees of relative accuracy (Amin et al., 2019; Paterson et al., 2020). Thus, more comparative studies with the genuine WL as the reference standard is clinically relevant. Therefore, the intent of the current in vitro study was to compare the WLD correctness of an EAL, intraoral periapical radiography (IPR), and radio visiography (RV). The null hypothesis was that there was no substantial difference in the three methods of determining the WL of the root canals.

Objectives of the Study:

- To compare the accuracy of working length determination using an electronic apex locator, conventional intraoral periapical radiography (IOPAR), and radio visiography (RVG) in extracted single-rooted mandibular premolars.
- To evaluate the agreement between the working lengths obtained by the three methods and the actual working length determined by stereomicroscopic examination.
- To identify the most accurate and reliable method for working length determination for potential application in endodontic practice.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

The study was a comparative study carried out in the “Department of Conservative Dentistry and Endodontics” in Mithila Minority Dental College, Darbhanga, Bihar, India in vitro. The study was done after receiving the ethical consent from the Institutional Ethics Committee. The aim of this study was to evaluate precision of three different processes of WL purpose of the extracted permanent mandibular premolars by evaluating with the actual working length.

2.2 Sample Size Calculation

Sample size was concluded using the G*Power software v3.1.9.7 with an effect size of 0.724, alpha error probability of 0.05, power of 80% and a distribution ratio of 1:1. Through analysis it was determined that there should be at least 31 specimens per group. Because the study involved three treatment groups, 93 extracted teeth were involved in this study. The methodology of sample size estimation was based upon the methodology reported by Malik et al. (2015).

2.3 Sample Collection and Selection

The number of freshly isolated permanent single-rooted mandibular premolars accumulated from the Department of Oral and Maxillofacial Surgery was 93. Upon removal the teeth were cleaned under running tap water, and all blood, saliva and soft tissue debris was removed. To avoid dehydration and maintaining the physical properties of the dental tissues during the study period the cleaned specimens were preserved in normal saline at room temperature until the next use. Those teeth with a single root with a single canal which were fully developed with closed apices and without any confirmation of root fracture were involved in the study. Teeth with gross caries, severe root curve/dilaceration, root resorption (internal and external) and open apices were excluded.

2.4 Materials and Instruments

Mandibular permanent premolars were used in the study, as well as 3% sodium hypochlorite solution, EDTA gel, modelling wax, an Endo-access bur, an Endo-Z bur, a high-speed airotor handpiece, #15 K-files, an endodontic gauge, disposable syringes, normal saline, a Coltene CanalPro electronic apex locator, an intraoral periapical radiographic unit and a stereomicroscope for direct view of the apical area. All of the standard diagnostic instruments and accessories used for preparing and handling the specimen during the study were also used. The materials and instruments used for specimen preparation are presented in Figure 1.

Figure 1. Materials used for specimen preparation

2.5 Group Allocation

All the 93 teeth were equally distributed into 3 groups with 31 teeth in each group based on working length determination technique used. Group I consisted of specimens that had the WL verified with an EAL. Specimens in Group II were evaluated by conventional intraoral periapical radiography (IOPAR) and in Group III, specimens were evaluated by radiovisiography (RVG).

2.6 Specimen Preparation

All specimens were organized with Endo-access and Endo-Z burs in the high-speed handpiece with copious water irrigation and standardized endodontic access cavities. After complete deroofing of the pulp chamber the location of the canal orifices were determined and negotiated with a #15 K-file. Root canals were flushed with 3% sodium hypochlorite solution to clean the root canals, and to open the root canals. Each specimen was stabilized with modelling wax and placed in a specially made tooth holder to ensure that the teeth were in a standardized position during the entire experiment. All radiographic exposures were made with a constant (3-inch) distance between the source and the object. The intraoral periapical radiographs were obtained using the paralleling technique with identical angulation and exposure parameters both for conventional radiographs and RVG images for uniformity among all the specimens.

2.7 Working Length Determination Using Electronic Apex Locator

Each tooth of the Group I specimens was placed in a container containing normal saline to replicate the electrical conductivity of periodontal tissues. The saline medium was placed in the lip clip of the EAL and a #15 K-file tied to the file holder was deliberately advanced in the canal until the EAL showed that the file tip had accessed the apical foramen. The silicone stopper was then moved to the pre-determined coronal reference point and working length was determined with an endodontic gauge. The measurement obtained was noted down for further analysis.

2.8 Working Length Determination Using Conventional Intraoral Periapical Radiography

A #15 K-file was implanted into the root canal of Group II to the estimated WL, and the silicone stopper was regulated to the selected reference point. Standard intraoral periapical radiographs were taken in standardized exposure conditions with the paralleling technique. After radiographic processing the WL was established by determining the distance from the coronal reference point on the radiographs to a point 1 mm short of the RA. The value measured was noted and compared with other techniques. The stepwise specimen preparation and working length resolve procedures using the EAL, Conventional Intraoral Periapical Radiography, and Radio visiography are illustrated in Figure 2.

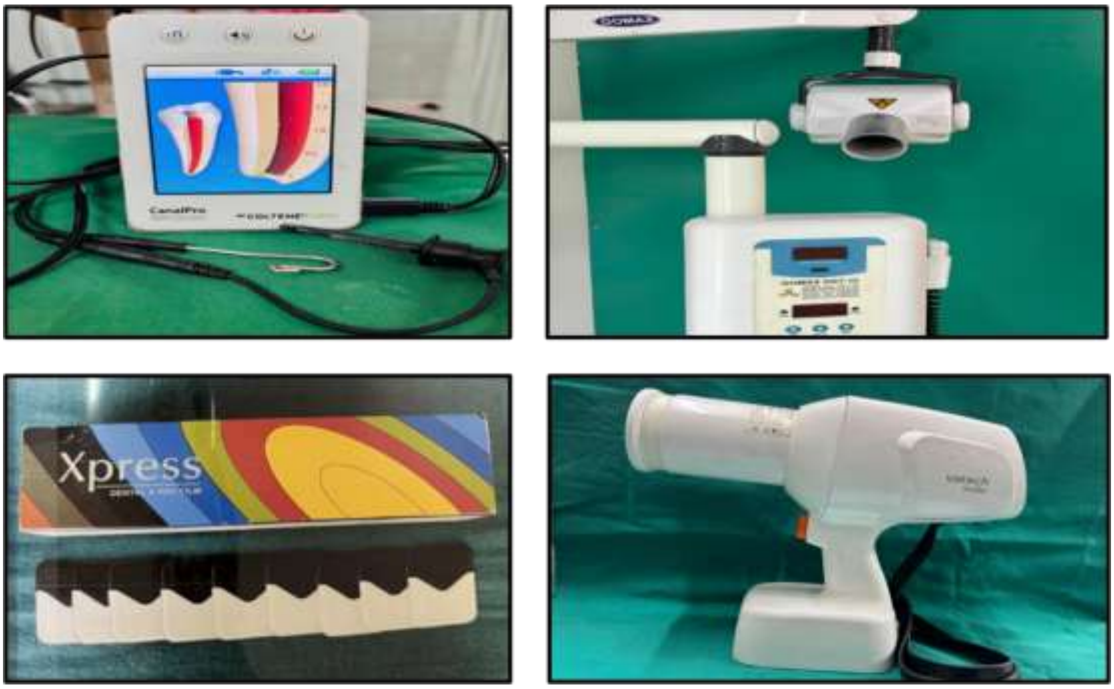

Figure 2. Specimen preparation and working length determination procedures

2.9 Working Length Determination Using Radiovisiography
In Group III, after making the same procedure as conventional radiography, a #15 K-file was injected in the canal. All the postures, exposure and angulations were standardized, and digital radiographs were taken with an RVG sensor. The digital images obtained were analysed using the measurement tools in the RVG software and the WL was determined as the separate from the coronal reference to a point 1 mm short of the RA. The measurements taken were recorded and were used for statistical analysis.

2.10 Determination of the Actual Working Length
All the specimens after WL determination by all the three experimental methods were longitudinally sectioned by selective grinding, to expose the root canal and apical region. The specimens were split in sections and analysed by stereomicroscope to enable the direct observation of the cemento-dentinal junction (CDJ). The #15 K-file was carefully inserted until the end of the file was at the same level as the CDJ, and the space between the coronal reference point and the file stopper was determined by an endodontic gauge. This measurement was deemed to be the true WL and compared with the values measured by the EAL, conventional intraoral periapical radiography and radio visiography.

2.11 Statistical Analysis
All the measurements were recorded and inputted into Microsoft Excel prior to statistical analysis. Normality of data was checked with the appropriate tests. One-way examination of variance (ANOVA) with Tukey's post hoc test for normally circulated data or Kruskal–Wallis test with the Mann–Whitney U test for data that was not normally dispersed were used to compare among the three groups according to the distribution of the data. A p value of < 0.05 was used as a cut-off for statistical significance.

3. RESULTS
Data was analysed using SPSS 26.0. A Kolmogorov–Smirnov test and a Shapiro–Wilk test was used as normality tests and established that the measurements of the working length were normally delivered. Hence, parametric statistical tests were used. (ANOVA) was conducted to compare the mean working lengths achieved by Actual Working Length, Electronic Apex Locator, Radio visiography (RVG) and Intraoral Periapical Radiography (IOPAR). Tukey's post hoc test was then concerned to make pairwise comparisons. P-values <0.01 were considered statistically highly important.

3.1 Comparison of Mean Working Lengths Among the Four Methods
Table 1 shows the evaluation of the WL measured with the four evaluation methods. There were 31 samples for each group. The mean value for the Actual Working Length was 19.45 ± 1.71 mm and the Apex Locator had a similar mean value of 19.23 ± 1.68 mm. By contrast, the mean working lengths of RVG and IOPAR were 20.76 ± 1.33 mm and 21.17 ± 1.47 mm, respectively. The difference between the four methods was highly substantial using one-way ANOVA ($F = 11.76$, $p < 0.001$), meaning that the method used had a substantial effect on the working length measured. IOPAR had the highest readings, RVG had the next highest and the Apex Locator had the next which was closest to the Actual Working Length overall. Figure 3 illustrates the comparison of mean WL measurements obtained using the Actual WL, Apex Locator, RVG, and IOPAR methods. Figure 4 shows the mean ± standard deviation of WL measurements obtained using the four evaluation methods.

Table 1. Comparison of Mean Working Lengths Obtained Using Different Measurement Methods

Method	n	Mean (mm)	Standard Deviation	F-value	p-value
Actual Working Length	31	19.45	1.71		
Apex Locator	31	19.23	1.68		
RVG	31	20.76	1.33	11.76	<0.001
IOPAR	31	21.17	1.47		

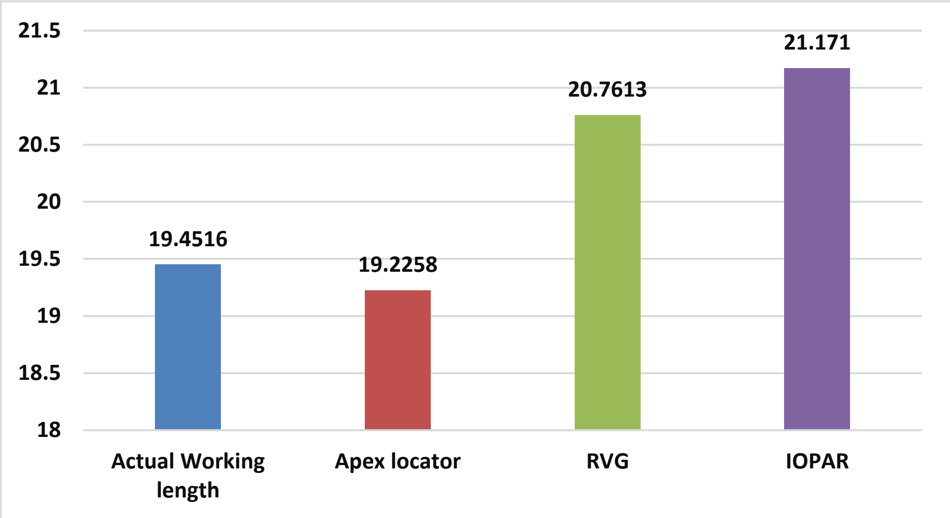

Figure 3. Mean working length measured using Actual Working Length, Apex Locator, RVG, and IOPAR

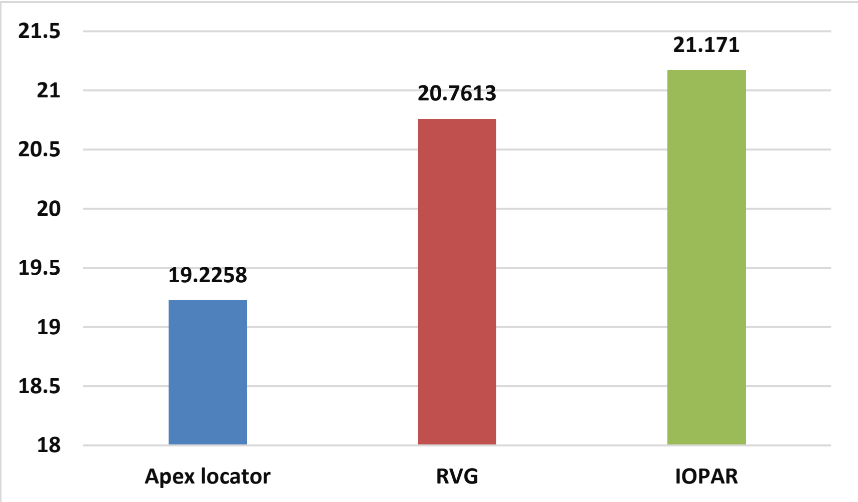

Figure 4. Mean ± standard deviation of working length measurements obtained using the four assessment methods

3.2 Pairwise Comparison of Working Length Measurements

Tukey's post hoc test was used for pairwise comparisons, and those results are given in Table 2. The results instructed that there was no statistically substantial difference between the Actual Working Length and Apex Locator measurements ($p = 0.940$); this indicates there is excellent agreement between the two methods. However, there was a substantial difference between the Actual WL and RVG ($p = 0.007$), and between the Actual WL and IOPAR ($p < 0.001$), which shows that both the radiographic methods resulted in longer WL than the actual WL. Likewise, the Apex Locator was also significantly different from RVG ($p = 0.001$) as well as IOPAR ($p < 0.001$). However, there was no significant difference between RVG and IOPAR ($p = 0.728$), indicating similar performances of these two radiographic techniques.

Table 2. Tukey's Post Hoc Pairwise Comparison of Working Length Measurements

Comparison	Mean Difference (mm)	p-value	Interpretation
Actual Working Length vs Apex Locator	0.226	0.940	Not significant
Actual Working Length vs RVG	-1.310	0.007	Highly significant
Actual Working Length vs IOPAR	-1.719	<0.001	Highly significant
Apex Locator vs RVG	-1.535	0.001	Highly significant
Apex Locator vs IOPAR	-1.945	<0.001	Highly significant
RVG vs IOPAR	0.410	0.728	Not significant

3.3 Agreement Between Actual Working Length and Apex Locator

Statistically, no substantial difference was found between the Actual WL and Apex Locator (mean difference = 0.226 mm, p = 0.940). These results show high clinical accuracy of the EAL in providing measurements that closely matched the actual working length. Figure 5 compares the Actual WL with the Apex Locator measurements.

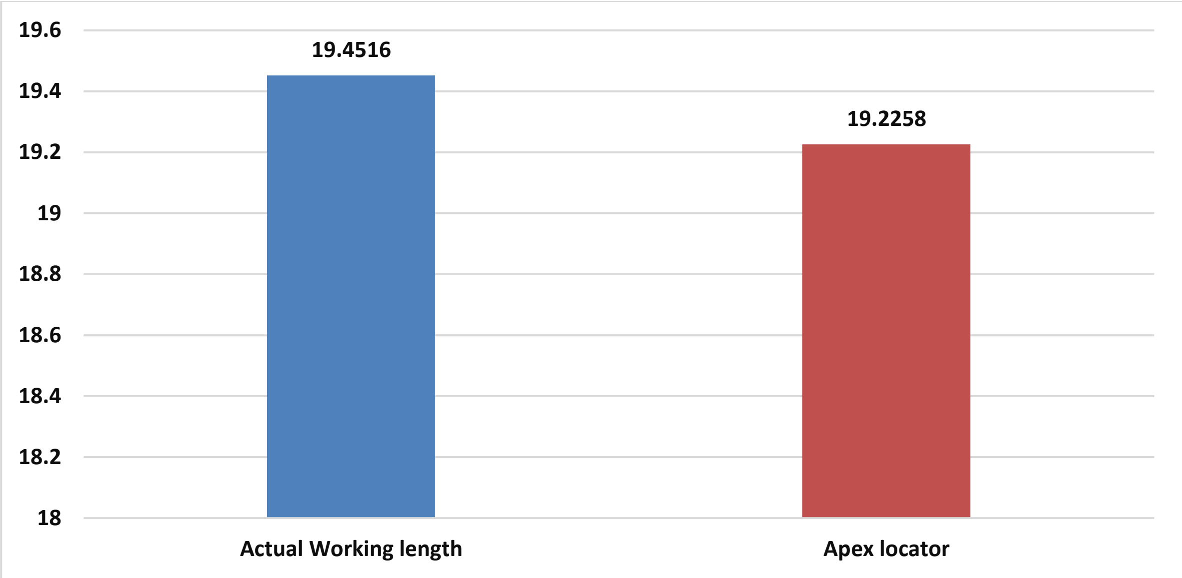

Figure 5. Comparison of Actual Working Length and Apex Locator measurements

3.4 Comparison of Actual Working Length with Radiographic Techniques

The measurements for working length by both radiographic techniques were found to have significantly higher values than the Actual WL. The mean difference for working length measured by RVG was 1.31 mm (p = 0.007) and even larger for IOPAR with a mean difference of 1.72 mm (p < 0.001). These results indicated that the working length as measured radiographically is likely to be longer than the actual working length. Figure 6 Comparison of Actual Working Length with (a) Radiovisiography (RVG) and (b) Conventional Intraoral Periapical Radiography (IOPAR)

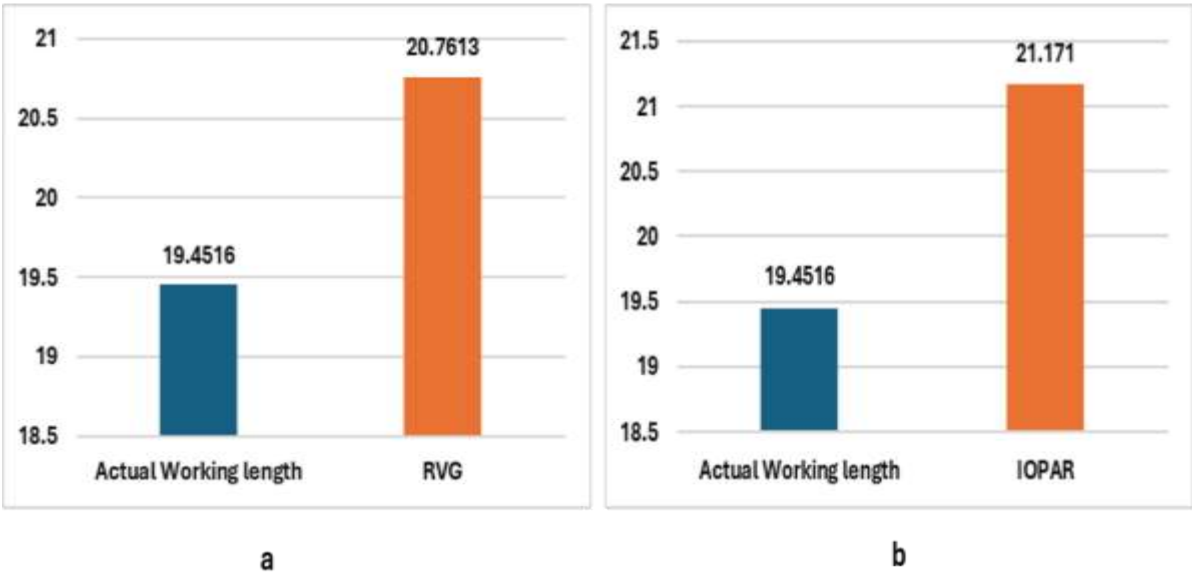

Figure 6. Comparison of Actual Working Length with (A) Radiovisiography (RVG) and (B) Conventional Intraoral Periapical Radiography (IOPAR)

3.5 Comparison Between Radiographic Methods

No statistically substantial difference was found between RVG and IOPAR (mean difference = 0.41 mm, p = 0.728), suggesting that the performance of the two radiographic techniques was comparable. However, both techniques resulted in significantly greater working lengths than did the Apex Locator. Figure 7 illustrates the comparison of working length measurements between RVG and IOPAR.

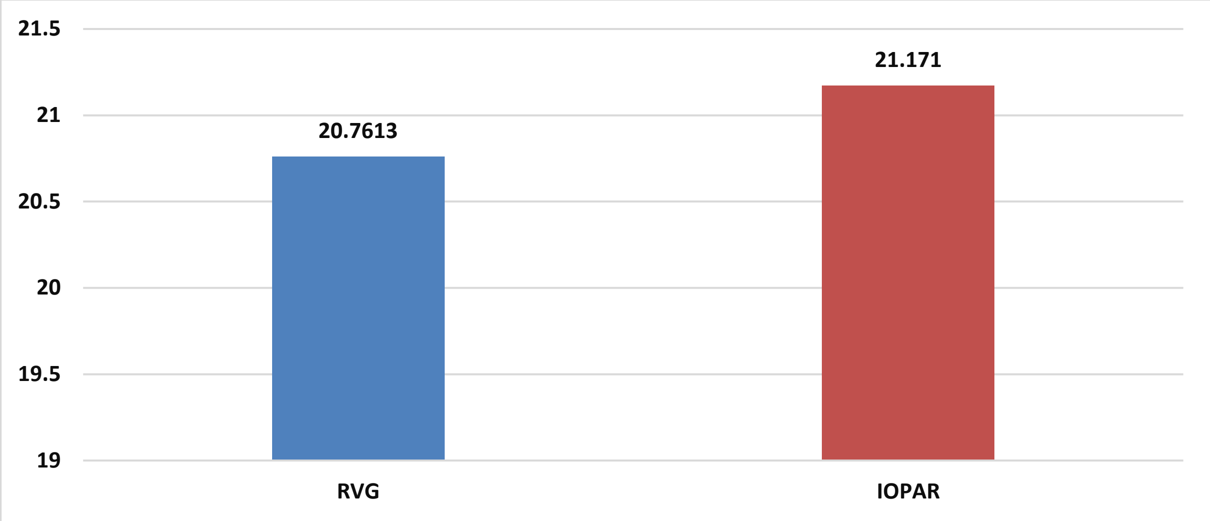

Figure 7. Pairwise comparison of RVG and IOPAR working length measurements

4. DISCUSSION

The purpose of WL in endodontics is essential to the success of endodontic treatment as it directly impacts the effective debridement, shaping and obturation of endodontic canals and minimizes the risk of over-instrumentation and under-instrumentation. In the current study, the four methods of WL determination were found to be significantly different. Both Radio visiography (RVG) and Intraoral Periapical Radiography (IOPAR) showed significantly longer working lengths than the Electronic Apex Locator EAL which showed measurements closest to Actual Working Length AWL. These results indicate that electronic measurement is more concordant to the real canal length when compared to radiographic methods.

The lack of significant difference between Actual WL and Apex Locator measurements shows that the electronic WL determination is very accurate. Electronic apex locators work by detecting the changes in electrical impedance that occur in the RCS, which helps to identify the apex of the root. Past studies have shown high success rates ranging from around 75% to 96.5% of accuracy in teeth with fully formed apices when using the modern electronic apex locators, and an accuracy of ±0.5 mm is considered highly accurate, whereas an accuracy of ±1.0 mm is regarded as clinically acceptable (Pagavino et al., 1998; Weiger et al., 1999). The present results are supported by the study conducted by Elshinawy (2017), who noted that electronic apex locators (EALs) gave measurements that were close to actual canal lengths in in vitro conditions.

The present study also found that both RVG and IOPAR were significantly overestimating the working length as compared to the Actual WL. This finding could be due to the intrinsic limitations of the radiographic methods. The radiographs only represent a two-dimensional image of a three-dimensional anatomical structure, and the apical foramen is often not in the same direction as the anatomical apex. Thus, the apical constriction is not always clearly visible on the radiographs and discrepancies arise in the estimation of working length (Martínez-Lozano et al., 2001; Vieyra et al., 2011). Different radiographic projection and anatomical variations at the apical level add to these measurement errors, and it may be a reason for the tendency of radiographic methods to record longer working lengths (Vasconcelos et al., 2013; Elshinawy, 2017).

Both RVG and IOPAR showed significantly higher working length values as compared to Actual WL, but there was no substantial difference between the two radiographic techniques. This discovery suggests there is no difference in the performance of digital and conventional radiography for working length determination even though they have different image acquisition and processing. Previous investigations have shown similar findings with conventional radiography and radio visiography, which were equally accurate for working length estimation (Shearer et al., 1990; Ong & Pitt Ford, 1995). Although RVG has the potential benefits of lower radiation exposure, instant image acquisition, image enhancement, and digital storage, these do not necessarily mean RVG will provide better measurement accuracy than traditional radiography (Griffiths et al., 1992; Brown et al., 1998).

The result of the current study confirms the clinical usefulness of EALs as a useful method for establishing WL. EALs also provide measurements that closely approximate the actual working length, which helps to reduce the need for repeated radiographic exposures and radiation exposure to patients and enhance the efficiency of the procedures (Brunton et al., 2002; Vieyra et al., 2011). However, electronic measurements are insufficient to give any indication of the shape of root canals, canal curvature or the presence of adjacent anatomical structures. Hence, radiography is still important for diagnosis, treatment planning and confirmation of master cone placement. Therefore, the association of electronic apex locator and radiography seems to be the most reliable and clinically predictable method for determining working length and achieving success in endodontics (Brunton et al., 2002; Martínez-Lozano et al., 2001).

5. CONCLUSION

Working length is a critical influence that helps to ensure the success of endodontic treatment because it directly affects how well the canals can be cleaned, shaped, disinfected, and obturated and how much risk there is for over- or under-instrumentation. This in vitro study directed to compare the precision of (EAL), conventional intraoral periapical radiography (IOPAR) and radio visiography (RVG) with the AWL as a reference standard. All three methods gave clinically acceptable results in establishing the WL, but there were statistically substantial differences between the methods. The (EAL) provided measurements that were closest to the actual working length and no statistically substantial difference from the reference standard, meaning that it was more accurate than the radiographic methods among the techniques evaluated. Working length was over-estimated with the RVG and conventional radiography, but there was no substantial difference between these two radiographic methods. The benefits of RVG are lower radiation exposure, instant image acquisition and digital image enhancement, but the accuracy is like conventional radiography. The results indicate that electronic apex locators may be considered a primary means of locating working lengths due to the high accuracy and radiation-free working. However, radiography is still essential to evaluate the root canal anatomy and the curve of the root canal and to assess treatment progress. Thus, the most reliable and clinically predictable means of working length determination and favourable endodontic outcomes is to use an (EAL) in conjunction with radiographic confirmation.

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