

Comparative Evaluation of Working Length Using Conventional Radiographic Method, Radiovisiography, and Apex Locator in Single-rooted Permanent Teeth

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ABSTRACT

Introduction: The success of any root canal treatment depends on the accurate determination of the working length, biomechanical preparation, and obturation. Radiographs (conventional and radiovisiographs) have remained the mainstay modality in the determination of working length, although they are associated with disadvantages of high radiation exposure and increased treatment time. Apex locators are relatively regularly used equipment in working length determination, but their accuracy has been questioned time and again.

Aim and objective: The present study was done to evaluate and compare the accuracy of conventional radiographs, radiovisiographs (RVGs), and apex locators for the determination of working length.

Materials and methods: The present *in vitro* study was carried on 60 extracted single-rooted permanent teeth, and the working length was determined using three methods viz. conventional radiography, RVG, and apex locators. The three methods used were intercompared, and in addition comparison with actual working length of the tooth was also made.

Results: Among the three methods, the conventional radiographic method was found to be closest to the actual root canal length followed in order by RVG and electronic apex locator. Intercomparison between all three methods and actual root canal working length was found to be statistically significant except between conventional radiography and actual root canal working length. The difference between the mean values of root canal working length for conventional radiography and actual root canal working length was 0.01 mm, for RVG and actual root canal working length was 0.13 mm, and for electronic apex locator and actual root canal working length was 0.70 mm.

Conclusion: All the three methods for the determination of working length used in the study are clinically acceptable and are associated with advantages and disadvantages. Further research and advances may make electronic apex locator the technique of choice in working length determination, or a combination of the RVG and apex locator may be the future in endodontic therapy.

Keywords: India, Oral, Oral health.

Journal of Oral Health and Community Dentistry (2021): 10.5005/jp-journals-10062-0103

INTRODUCTION

Determining the “working” length is one of the earliest and crucial steps in root canal treatment. If calculated within correct limits, it will play an important role in determining the success of the treatment, and conversely, if calculated incorrectly may doom the treatment to failure. It establishes the apical limit of the canal preparation and demarcates the creation of the apical stop.^{1,2}

It is believed that the foramen is located at the limit of the cementum-dentin junction, where the periodontal ligament begins and the dental pulp ends. Several studies have determined that the limit is 0.5 or 1.0 mm short of the radiographic apex, but the ideal limits for instrumentation and obturation of the root canal may range from 0.0 to 2.0 mm.¹⁻⁴ The accuracy of the working length is also essential to avoid any injury or damage to the periapical tissues during instrumentation and obturation procedures.

Various methods have been developed to determine the working length viz. Tactile sense, conventional radiography, RVG, and apex locators—all with some advantages and disadvantages and different levels of accuracies.³⁻⁵ The purpose of the *in vitro* present study is to compare the root canal length determined by conventional radiography, RVG, and electronic apex locator with that of the actual root canal length for the assessment of accuracy.

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How to cite this article: Goel T, Indushekar KR, Saraf BG, *et al.* Comparative Evaluation of Working Length Using Conventional Radiographic Method, Radiovisiography, and Apex Locator in Single-rooted Permanent Teeth. *J Oral Health Comm Dent* 2021;15(2):49–54.

Source of support: Nil

Conflict of interest: None

MATERIALS AND METHODS

The materials and techniques tested in this study were apex locator, RVG unit, X-ray unit, and X-ray films.

Collection of Sample

Sixty freshly extracted single-rooted human permanent teeth were collected from the Department of Oral and Maxillofacial Surgery, SR Dental College, Faridabad. The teeth were screened and X-rays were taken. The inclusion and exclusion criteria were well-defined.

Inclusion Criteria

- Teeth with close apex

Exclusion Criteria

- Teeth with visible root fracture
- Calcification in the pulp chamber or root canal
- Resorbed apex
- Incompletely formed apex
- Dilacerated roots

Method of Collection of Data

Sixty extracted single-rooted human permanent teeth were selected and cleaned of debris, soft tissues, and calculus. The incisal or occlusal surface of each tooth was flattened using a diamond disc

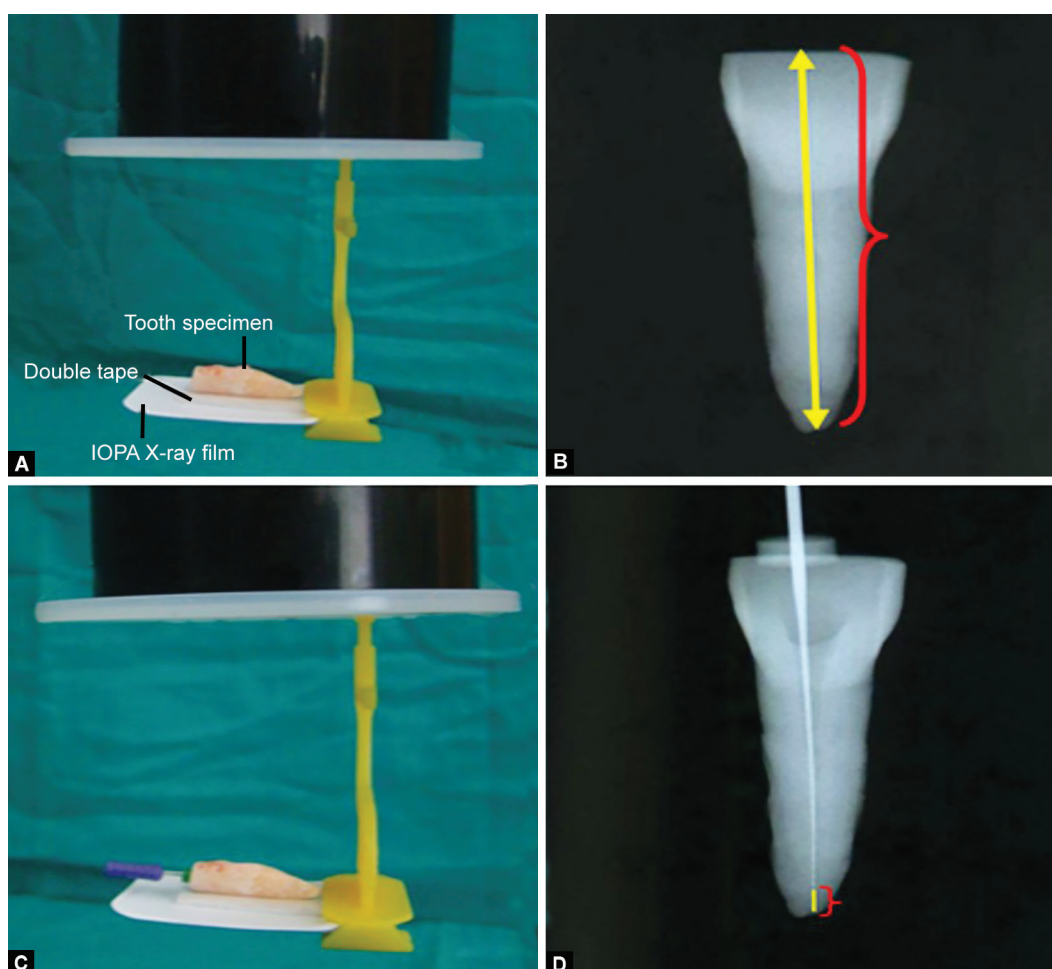
to have a stable incisal or occlusal reference point and then stored in distilled water until further use.

Access cavity was prepared on each tooth using air rotor handpiece and diamond bur. The root canal was traced and debrided, but no attempt was made to enlarge the canal, and the estimation of root canal working length was done using:

- Conventional radiography (Ingle's method)¹
- Radiovisiography (RVG) (Dr. Suniplus®, United States)
- Electronic apex locator (Ipx, NSK Ltd®, Tokyo, Japan)

Estimation of Root Canal Working Length Using Conventional Radiography (Fig. 1)

The radiographic measurement was taken by using the paralleling technique using an E-speed film. For this, the IOPA X-ray film was positioned parallel to the long axis of the tooth specimen, and the X-ray tube head was aimed at right angles to both the tooth specimen and IOPA X-ray film. The exposure factors and the distances between the source and the tooth specimen, and the tooth specimen and the film were standardized. A diagnostic radiograph was taken by stabilizing the tooth specimen on IOPA



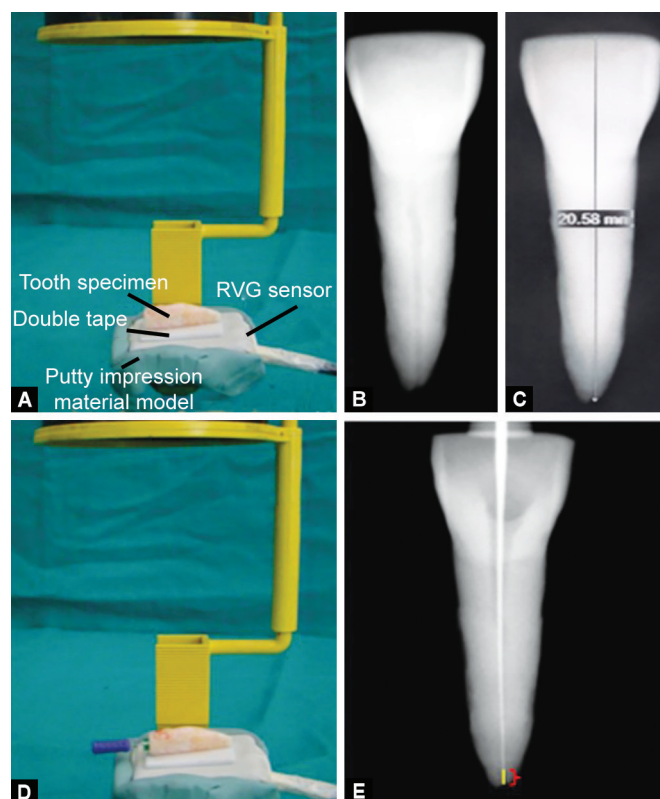
Figs 1A to D: Root canal working length measurement using conventional radiographic method. (A) Shooting diagnostic X-ray; (B) Total root canal length measured from diagnostic IOPA X-ray; (C) Shooting working length X-ray with No. 10 K-file; (D) Distance between file tip and radiographic apex measured from working length X-ray

X-ray film using double. Ingle's method was used to calculate the working length in the present study.

Ingle's method: The tooth was measured on a diagnostic radiograph from the incisal/occlusal reference point to the radiographic apex, and the measurement was taken as A1 in mm. As a safety factor, allowing for image distortion or magnification, at least 1 mm was subtracted from the initial measurement, that is, (A1) to obtain a tentative working length (A2). The instrument (No.10 K-file) was set with a rubber stop at this length (A2), inserted into the tooth to this length, and again a working length radiograph was taken. On the working length radiograph, the difference between the tip of the K-file inserted and the radiographic apex was measured. This difference was either added (if there is under extension) or subtracted (if there is overextension) from the tentative working length (A2), and this adjusted length (A3) was the total root canal length. From this adjusted length (A3), 1 mm was subtracted to obtain the representative radiographic root canal working length. For all measurements, digital vernier calipers were used.

Estimation of Root Canal Working Length Using RVG (Fig. 2)

After standardizing and stabilizing the sensor and tooth specimen, a diagnostic RVG image was taken. The sensor was stabilized by preparing a model with putty impression material. The sensor was positioned parallel to the long axis of the tooth specimen. The X-ray



Figs 2A to E: Root canal working length measurement using radiovisiography. (A) Shooting diagnostic RVG image; (B) Diagnostic radiovisiograph; (C) Total root canal length measured from diagnostic radiovisiograph; (D) Shooting working length radiovisiograph with No. 10 K-file; (E) Distance between file tip and apex measured from working length radiovisiograph

tube head was aimed at right angles to both the tooth specimen and sensor. After this, exposure was done and a diagnostic RVG was taken.

The tooth was measured on a diagnostic RVG from the incisal/occlusal reference point to the radiographic apex, and the measurement was taken as A1 in mm. The values A2 and A3 were calculated using Ingle's method as explained above; however, RVG was used instead of conventional films to take all the radiographs.

Estimation of Root Canal Working Length Using Apex Locator (Fig. 3)

Tooth specimen was mounted in alginate in such a way that the root was embedded completely in alginate exposing the crown portion. The alginate was used to simulate the periodontium. Alginate was moistened by 0.9% saline before taking the working length measurements, and the procedure was done immediately while the alginate was sufficiently humid or within 2 hours of mounting. The root canal was then flushed with 1 mL of 5.25% sodium hypochlorite and dried with paper points. The No. 10 K-file was attached to the file holder of the electronic apex locator, and the lip clip was embedded in the alginate to complete the circuit. The file was slowly inserted in the root canal until the beep sound was heard and the signal on the LCD screen of the electronic apex locator appeared 0 mm indicating that the tip of the file has reached the apex of the tooth. Now, the rubber stopper was adjusted to the incisal/occlusal reference point. The file was then removed from the canal, length was measured using a digital vernier caliper, and 1 mm was subtracted from this to obtain the electronic root canal working length. The device was used according to the manufacturer's instructions.

Estimation of Actual Working Length

Number 10 K-file was introduced into the root canal until its tip just appeared at the apical foramen that was visualized with the help of a magnifying glass, and the stopper was adjusted to the incisal/occlusal reference point. The file was withdrawn completely out of the root canal. The distance between the file tip and the stopper was measured using a digital vernier caliper and recorded as the actual total root canal length. From this recorded total root length, 1 mm was reduced as apical constriction is usually 0.5–1 mm short of the center of the apical foramen. This reading was registered as the actual root canal working length.

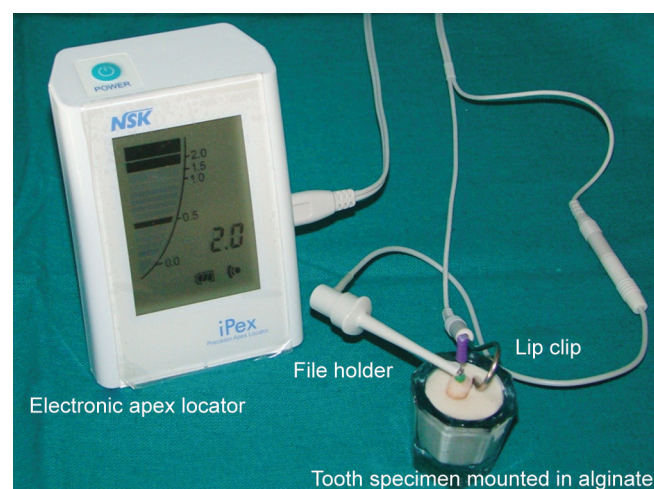


Fig. 3: Root canal working length measurement using electronic apex locator

Table 1: Root canal length determination using conventional radiography and RVG (Ingle's method)

Group	A1 (in mm)	A2 (in mm)	a (in mm)	A3 (in mm)	Final root canal working length (in mm)
Conventional radiographic method	20.71	19.71	0.72	20.35	19.35
RVG method	21.24	20.24	0.28	20.49	19.49

A1, total root canal length; A2, tentative working length; Difference between file tip and radiographic apex; A3, calculated as $A2 + a$ (if underextended) or $A2 - a$ (if overextended); Final root canal working length—calculated as $A3 - 1$ mm

Measurements were done three times at different time interval, and the average of the three readings was taken as a representative root canal working length for each method. All the 60 specimens were subjected for all the three methods (conventional radiographic method, RVG, and electronic apex locator) and were compared with actual root canal working length.

The result obtained was tabulated using SPSS and subjected to statistical analysis using analysis of variance to draw the conclusion.

RESULTS

Table 1 shows the root canal length calculation values for conventional radiography and RVG using Ingle's method. The difference between the mean tentative root canal working length (A2) and the mean final root canal length in both these groups was found to be statistically significant ($p < 0.05$). Using electronic apex locator, initially length E1 (in mm) was calculated when the LCD screen of the apex locator showed 0, and 1 mm was subtracted from this value to give final working length E2 (i.e., $E2 = E1 - 1$ mm). The mean value of E1 was calculated to be 19.66 mm, and the mean final working length (E2) using this method was 18.66 mm.

Initial actual working length (F1 in mm) was calculated when the file just appeared at the apex, and the final working length (F2) was calculated by subtracting 1 mm from the initial actual working length (i.e., $F2 = F1 - 1$ mm). The mean values of F1 and F2 calculated were 20.36 and 19.36 mm, respectively.

Table 2 shows the final root canal working lengths using different methods. The mean values obtained indicate that the conventional radiographic method determines the working length nearly as accurately as the actual root canal working length followed by RVG, whereas the root canal working length determined by the electronic apex locator was significantly shorter than the actual root canal working length.

DISCUSSION

The complex anatomy of the apical area makes biomechanical preparation and obturation of the root canal as one of the most discussed issues in root canal therapy. For a successful root canal treatment, thorough removal of pulp, necrotic tissues, and microorganisms is essential from the canals before obturation which consequently is dependent on the determination of the exact working length.⁶⁻⁹ Hence, the procedure for the calculation of working length should be performed by the use of techniques that have been proven to give precise results and simultaneously being practical and efficacious. At the end of the 19th century, radiographs were not applied to dentistry and working length

Table 2: Final root canal working lengths using different methods

Groups	Final root canal working length (in mm)
Conventional radiographic method	$19.35 \pm 1.48a$
RVG method	$19.49 \pm 1.49b$
Electronic apex locator method	$18.66 \pm 1.70c$
Actual working length	$19.36 \pm 1.47d$
p-values	a vs b = 0.015*
	a vs c = 0.000*
	a vs d = 0.824
	b vs c = 0.000*
	b vs d = 0.029*
	c vs d = 0.000*

*Statistically significant at $p < 0.05$

was calculated till the point where the patient experienced feeling for an instrument placed into the canal which led to a multiplicity of errors.^{7,8,10}

In the early 1900s, the tactile method (the feeling of the patient as the apical position for the calculation of working length) of working length calculations was replaced by the radiographic method. The radiographic method is the still most common method of measuring working length in root canal treatment. The radiographic method described by Ingle is one of the most reliable methods that have been used in the present study.^{1-3,9} Although the radiographic method is a simple method, it has certain disadvantages like more radiation exposure, time-consuming, and in most cases the cementodentinal junction does not coincide with the point 1 mm short from the radiographic apex.^{5,7,8} Also, it has to be kept in mind that apical foramen does not coincide with the radiographical apex; therefore, positioning of the file within the latter may often lead to over- or under instrumentation.^{1,3,5,7} To add, the radiographic method has more potential chance of errors because of the observer bias and is prone to superimpositions by surrounding anatomical structures and distortions.⁸⁻¹⁰

The alternative for conventional radiography is RVG, a digital imaging system that utilizes an intraoral sensor in place of radiographic film. RVG has certain advantages over conventional radiographs, which include an instantaneous display of the image on a viewing screen that eliminates the time and equipment required for film processing. RVG also provides an additional ability to alter the displayed image that enhances the capability to identify details. The RVG image may be altered by varying the contrast in the grayscale, by reversal of the black and white aspects of the image (negative-to-positive conversion), and by selectively

enlarging the screen image (the zoom feature). However, original RVG images have been found to be significantly worse than the E-speed films.^{5,7,8} Another disadvantage with RVG is with the difficulty in the placement of sensors.^{6,10}

Due to such limitations, allow the location of the apical constriction with a substantial rate of success,^{7,8} as could be seen in this study. The speed and practicality of the method associated with the ease of establishing the working length at any operative step are significant advantages over the radiographic method.⁹⁻¹¹

Custer (1918) was the first person to come with an idea of determining root canal length with an electronic method; however, the idea was revisited after nearly two decades by Suzuki who studied the flow of electric current in the teeth of dogs. Sunada (1962) refined these principles to construct a simple device that used direct current to measure the length of the root canal. This device worked on the principle that electrical resistance of the periodontium and mucous membrane registered 6.0 kilohms ($k\Omega$) in any part of the periodontium regardless of the person's age or the type and shape of the teeth. The accuracy of this method is not high enough to warrant the general replacement of radiographic methods by electronic methods.⁷⁻⁹ Despite its questionable usefulness in working length estimation, apex locator when used in combination with radiographs has proven to be a useful adjunct to radiographs in working length determination due to decreased chances of error compared to when radiographs are used alone. Apex locators are also potentially useful in cases of endodontic treatment during pregnancy to avoid radiation exposure and in patients where high gag reflex does not permit the placement of radiographs.¹⁰⁻¹²

In the present study, conventional radiography was found to be more accurate as its value was closer to the actual root canal working length followed by RVG. Intercomparison between both radiographic methods (conventional radiography and RVG) showed a statistically significant difference ($p > 0.05$) although this may not be clinically significant because this difference was very less (i.e., 0.14 mm). This minor difference between the two methods should not affect the clinical performance or instrumentation during the root canal therapy if an operator is either using conventional radiography or RVG. Also, this is supported by the fact that some studies have not even found any statistically significant difference between both these radiographic techniques.^{12,13} Another reason to justify the use of RVG over conventional radiography is the associated disadvantage of high radiation dose to the patient in conventional films and the time required for processing radiographs that may interrupt the treatment.³⁻⁶

When comparing radiographic methods with apex locators, conflicting results have been obtained in the studies,^{14,15} probably due to the differences in methodology, type, and generation of apex locator used in the study and difference in the definition of working length used. In the present study, the apex locator underestimated the working length of the root canal by 0.70 mm compared to the actual root canal length, and this difference was found to be statistically significant ($p < 0.05$). This difference could be because the present study is an *in vitro* study in which alginate was used as electroconductive materials to simulate the clinical situation. This media could have leaked through the apical foramen and caused premature readings.

The difference between the mean values of root canal working length for conventional radiography and actual root canal working length was 0.01 mm, for RVG and actual root canal working length was 0.13 mm, and for electronic apex locator and actual root canal

working length was 0.70 mm. This difference was found to be statistically nonsignificant in the case of conventional radiography, whereas statistically significant difference ($p < 0.05$) was found for RVG and electronic apex locator, but it was of limited clinical significance as working length 1 mm short of apex is clinically acceptable,¹⁶ and all the values of the present study fall within this range.

The radiographic information like canal width, degree of canal curvature, and relationship of multiple canals within the same root cannot be appreciated with the use of an electronic apex locator as no images are formed.¹⁰⁻¹³

It has been demonstrated that when the canal exits through the apical foramen buccally or lingually, it tends to become superimposed over the structures making the exact working length determination difficult.¹⁶

Hence, in this regards, *in vitro* studies are better wherein the actual or exact working length can be evaluated directly by examining the apical foramen or the point when a small file exits through the opening. However, *in vitro* studies have the disadvantages that these studies do not take into account the influence of scattered radiation or differences in bony density that occurs in the clinical settings,^{15,16} and hence, the results may not be accurate when extended clinically. Hence, designing a study to determine the exact working length has to weigh the potential advantages and disadvantages of both *in vitro* and *in vivo* studies.^{17,18}

To balance this, future research should focus on longitudinal studies involving patients comparing the success of endodontic treatment wherein working length determination has been carried out using different methods.

CONCLUSION DRAWN AND TAKE AWAYS FROM THE STUDY

All the three methods determined the root canal length nearly as accurately as the actual root canal length obtained by visual method.

Among the three methods, the conventional radiographic method was found to be closest to the actual root canal length followed by RVG and electronic apex locator.

Intercomparison between all three methods and with actual root canal working length was found to be statistically significant except between conventional radiography and actual root canal working length.

The conventional X-ray, though accurate, has the disadvantages of increased radiation and being time-consuming. The RVG overcomes these by reducing the radiation and time requirement and also eliminating the processing variables. The apex locator, however, completely eliminates radiation and has the advantage of time and convenient chairside access.

SCOPE OF FURTHER RESEARCH

Further research and advances may make electronic apex locator the technique of choice in working length determination, or a combination of the RVG and apex locator may be the future in endodontic therapy.

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