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Full Length Research Paper

Accuracy of working length determination with root ZX apex locator and radiography: An *in vivo* and *ex vivo* study

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The purpose of this study was to clinically compare working length (WL) determination with root ZX apex locator and radiography, and then compare them with direct visualization method *ex vivo*. A total of 75 maxillary central and lateral incisors were selected. Working length determination was carried out using radiographic and electronic apex locator methods. Subsequently, the tooth under study was extracted and actual working length was determined directly under a stereomicroscope. Data were analyzed by Wilcoxon signed-rank, Spearman's correlation coefficient and intra-class correlation tests. All the statistical analyses were set with a significance level of α = 0.05. The absolute measurement errors of the two methods were compared using Wilcoxon signed test, exhibiting no statistically significant difference in measurement errors between the two methods. Descriptive evaluation revealed that in 72% (n = 54) of the specimens, both methods had errors in the same direction and in 28% (n = 21) of the specimens, the two methods had errors in opposite directions. Intra-class correlation coefficient test demonstrated a high degree of agreement between the two methods. In conclusion, this study did not show any difference between radiography, root ZX and direct visualization in WL determination.

Key words: Working length, electronic apex locator, root ZX, radiography.

INTRODUCTION

Correct and precise determination of working length is an important factor in endodontic treatment success (Ricucci and Langeland, 1998). The ideal spot for working length determination in endodontic treatment is the apical constriction (Kuttler, 1955). The apical constriction is the narrowest spot in the root canal with the lowest diameter of blood vessels; therefore, the smallest wound is created due to instrumentation in the area with a proper healing process (Ricucci and Langeland, 1998). This anatomic landmark is also called "minor diameter of the canal", where the pulpal and periodontal tissues coalesce (Grove, 1928). Microscopic studies indicate that there is a distance of 0.5 to 1 mm between the apical constriction and the external foramen or the major diameter (Green, 1960; Kuttler, 1955).

Radiography and electronic apex locator are two common methods for working length determination (Gordon and Chandler, 2004). Given the distance between the minor foramen and the radiographic apex, most clinicians confine instrumentation to 1 mm short of the radiographic apex. This technique works well in most cases; however, in the teeth in which the foramen is not located within the average distance from the radiographic apex, this technique will result in over- or under-instrumentation of the root canal and if the major foramen deviates in the lingual or buccal plane, it is difficult to locate its position using radiographs alone, even with multiplane angles (Schaeffer et al., 2005). In addition, radiographic interpretation of some teeth, such as

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maxillary molars, is difficult for working length determination (Tamse et al., 1980). Custer (1918) introduced the electronic method to locate the apical foramen for the first time; then Suzuki (1942) showed that the electrical resistance of PDL fiber and the oral mucosa is 6.5 kΩ, which led to the invention of apex locator by Sunada (1962). Initial apex locators had low accuracy since they were influenced by intra-canal fluids or tissues. Technological advances in the manufacture of apex locators led to the introduction of new generations of apex locators with high accuracy in the presence of electrolytes (Pilot and Pitts, 1997).

Kobayashi and Sunada (1994) introduced a new generation of electronic apex locators (EALs), called root ZX (J. Morita Co., Tustin, CA, USA), that is based on the radio based ERCLMD for measuring canal length. In the impedance ratio-based ERCLMDs, the AC source is again a two-frequency source, that is, it comprises two sine waves with a high and a low frequency (Nekoofar et al., 2006). This method simultaneously measures impedance values at two frequencies of 8 and 0.4 kHz and calculates a quotient of impedances. This quotient is expressed as a position of the file in the canal. When the minor diameter of the canal is reached, the quotient approaches a value of 0.67, which is a constant value, which is reliable in the presence of electrolytes or pulp tissue.

Although, a lot of studies have evaluated the accuracy of working length determination by radiography or apex locators, no study has to date attempted to simultaneously compare these two methods *in vivo* and *ex vivo*. Such a study should clinically compare these two methods and then compare them *ex vivo* with direct visualization method. It should also minimize the role of confounding factors. Therefore, the aim of this study was to clinically compare working length determination with root ZX apex locator and radiography, and then compared them with direct visualization method *ex vivo*.

MATERIALS AND METHODS

A total of 75 maxillary central and lateral incisors, planned to be extracted for prosthodontic reasons, were selected from the patients that were referred to the Department of Maxillofacial Surgery, Tabriz Faculty of Dentistry. The patients were 31 to 65 years old with a mean age of 49. Exclusion criteria included resorption, immature apex, severe root curvature, multiple roots, previous endodontic tenement and apical resection confirmed by a standard preliminary periapical (PA) radiograph. All the patients accepted the prosthetic treatment plan and the extraction of anterior teeth, and were briefed on the study plan and the way they were to participate in the study. All the patients signed informed written consent forms. All the patients were referred to the Department of Endodontics before extraction.

Magnitude of errors in both methods was compared by Wilcoxon signed-rank test, and Spearman's correlation coefficient was used to evaluate any relationship between actual root length and error magnitude. Reliability of two methods was evaluated by intra-class correlation test. All the statistical analyses were set with a significance level of α = 0.05.

Clinical determination of working length (*in vivo*)

Radiography

The teeth were isolated with rubber dam after anesthesia. Standard access cavity was prepared and the pulp chamber was irrigated with 1% sodium hypochlorite. After locating the canal orifice, the coronal part of the canal was enlarged with #2 to #4 Gates-Glidden drills (Mani, Tochigi, Japan) and #40 and #35 Race (FKG Dentaire, Switzerland) orifice shapers with 0.1 and 0.08 tapers, respectively. Each canal was irrigated with 1% sodium hypochlorite using a 27-guage endodontic needle. Working length was determined on the diagnostic radiography. Then, a suitable K-file was placed in the canal up to the estimated working length as the initial file; the file had a slight binding at the apical end of the canal. Then a PA radiograph was taken using the parallel technique, while the file had penetrated 1 mm short of the radiographic apex. The measured working length was confirmed by another operator using digital calipers with an accuracy of 0.001 mm. The same radiographic adjustments were used for all the teeth under the study.

Root ZX apex locator

The pulp chamber was dried up with a cotton pellet, but it was not necessary for the canals to be dried up. In order to determine the working length with root ZX (J. Morita Co., Tustin, CA, USA), the major apical foramen was located: The apex was located by solid audible tone of root ZX and then the file was removed from the canal; the length was then measured by another operator and 1 mm was subtracted from the measured length.

Working length determination on the extracted tooth (*ex vivo*)

The patients were again sent to the Department of Maxillofacial Surgery and the teeth were extracted. Then, the teeth were immersed in 5.25% sodium hypochlorite for 10 min. After cleaning the teeth from any residual tissues and rinsing them with water, the actual working length was determined by placing a #15 K-file inside the root canal in a way that the tip of the file was visible at the apical foremen. Subsequent to adjusting the silicon stop on the canal, a second operator measured the distance between the file tip and the stop and subtracted 1 mm from it. This way, the actual working length was measured. All these procedures were carried out under a stereomicroscope (Wild Makroskop M420, Heerbrugg, Switzerland) at a magnification of 20x.

RESULTS AND DISCUSSION

After the measurements were completed, the values obtained were subtracted from the actual values and measurement errors of both measuring methods were calculated (Table 1). The absolute measurement errors of the two methods were compared using Wilcoxon signed-rank test, exhibiting no statistically significant differences in measurement errors between the two methods (z = -1.632, $p = 0.103$).

Descriptive evaluation revealed that in 72% (n = 54) of the specimens, both methods had errors in the same direction and in 28% (n = 21) of the specimens, the two methods had errors in opposite directions (Table 2).

Intra-class correlation coefficient test demonstrated a high degree of agreement between the two methods (α =

Table 1. Summary of the actual working lengths and radiographic vs. root ZX errors.

Parameter	N	Minimum	Maximum	Mean	Standard deviation	Mean of absolute error
Actual working lengths	75	17.00	23.50	20.62	1.347	
Root ZX error	75	-0.70	1.00	0.029	0.358	0.298
Radiographic error	75	-0.80	0.90	0.106	0.373	0.342

Table 2. Cross-tabulation of error type of radiographic vs. root ZX errors.

Parameter	Radiographic error type			Total
	Under†	Over‡	No error	
Root ZX error type	22	13	0	35
	3	30	1	34
	2	4	0	6
Total	27	47	1	*75*

†Under-prediction; ‡over-prediction.

0.9864, df = 0.74, p<0.001). There was no significant correlation between the actual length and amount of error in both techniques [Spearman's rho = -0.099, p = 0.396 (root ZX error to actual length) and Spearman's rho = -0.088, p = 0.455 (radiographic error to actual length)].

In most studies carried out to date, the accuracy of working length determination by radiography or apex locator has been evaluated *in vitro*, which has been compared with the direct method. However, in extracted teeth, out of the oral cavity environment, precise simulation of working length determination with radiography or EALs is very difficult. In various *in vitro* studies carried out to date, various tooth embedding materials such as 2% agar (Nahmias et al., 1987; Nekoofar et al., 2002), gelatin (Donnelly, 1993) and alginate (Kaufman et al., 2002) have been used to simulate the impedance values of human tissues. The differences in the statistical results obtained by various authors, despite the use of similar procedure and instruments, might be attributed to differences in the tooth embedding materials used. The use of *in vivo* models in which PDL is present will help eliminate this confounding variable and increase accuracy of the results.

Root ZX was used in this study because studies have shown that it yields the best results (Goldberg, 1995; Shabahang et al., 1996). Shabahang et al. (1996) showed that root ZX can locate the apical foramen ±0.5 mm from its actual location in 96.2% cases. Dunlap et al. (1998) reported that root ZX can locate the apical constriction at a range of ±0.5 mm from its actual location in 82% cases. Ounsi and Naaman (1999) also showed that root ZX has an accuracy of 84.72% in locating the apical foramen at a range of ±0.5 mm.

In this study, apex locator was used to locate the major foramen because a study carried out by Mayeda et al. (1993), Lee et al. (2002) and Ounsi and Naaman (1999) have shown that EALs can only locate the major foramen. EAL manufacturers recommend that in order to locate the working length, the major foramen should be initially located by an EAL and then approximately 0.5 mm should be subtracted from the length (Elements, 2006; Precision, 2006; Root, 2005). However, Guise et al. (2010) suggested subtraction of 0.5 mm from the measured length results in overextended preparation in some instances; therefore, most practitioners believe that it is better to subtract 1 mm from the electronic readings of the apical foramen to determine the minor constriction. In this study, also, 1 mm was subtracted from the major foramen reading to locate the minor apical constriction.

Based on the results of previous studies (Ibarrola et al., 1999), in this study, pre-flaring of the canal was performed in order to increase the accuracy of measurements and hand instruments were used in EALs to determine the working length because studies have reported that hand instruments are more accurate than NiTi and rotary files in determining working length (Siu et al., 2009). Furthermore, a specific file size was not used for working length determination since the size of the primary file does not influence the accuracy of WL determination by EALs (Nguyen et al., 1996; Ricard et al., 1991). The results of this study from radiography and EAL were similar; intra-class correlation coefficient also showed that each of the two radiography and EAL methods are reliable and there is no need to use them together. It is probable that if maxillary molars had been used instead of maxillary single-rooted teeth in this study, superimposition of anatomic structures would have made WL determination difficult and different results would have been achieved, which emphasizes the importance of using EAL in such teeth. In addition, different root lengths were used in this study, demonstrating that root length does not increase or decrease the accuracy of radiography or EAL in working length determination.

Conclusion

This study did not show any significant differences between radiography, root ZX and direct visualization in WL determination, although, further studies are necessary.

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