Research article

ISSN 2234-7658 (print) / ISSN 2234-7666 (online)
http://dx.doi.org/10.5395/rde.2012.37.3.149

RDE
Restorative Dentistry & Endodontics

Accuracy of Root ZX in teeth with simulated root perforation in the presence of gel or liquid type endodontic irrigant

Hyeong-Soon Shin[1], Won-Kyung Yang[1], Mi-Ri Kim[1], Hyun-Jung Ko[1], Kyung-Mo Cho[2], Se-Hee Park[2], Jin-Woo Kim[2]*

[1]Department of Conservative Dentistry, Ulsan University Asan Medical Center, Seoul, Korea
[2]Department of Conservative Dentistry, Gangneung-Wonju National University College of Dentistry, Gangneung, Korea

Objectives: To evaluate the accuracy of the Root ZX in teeth with simulated root perforation in the presence of gel or liquid type endodontic irrigants, such as saline, 5.25% sodium hypochlorite (NaOCl), 2% chlorhexidine liquid, 2% chlorhexidine gel, and RC-Prep, and also to determine the electrical conductivities of these endodontic irrigants. ***Materials and Methods:*** A root perforation was simulated on twenty freshly extracted teeth by means of a small perforation made on the proximal surface of the root at 4 mm from the anatomic apex. Root ZX was used to locate root perforation and measure the electronic working lengths. The results obtained were compared with the actual working length (AWL) and the actual location of perforations (AP), allowing tolerances of 0.5 or 1.0 mm. Measurements within these limits were considered as acceptable. Chi-square test or the Fisher's exact test was used to evaluate significance. Electrical conductivities of each irrigant were also measured with an electrical conductivity tester. ***Results:*** The accuracies of the Root ZX in perforated teeth were significantly different between liquid types (saline, NaOCl) and gel types (chlorhexidine gel, RC-Prep). The accuracies of electronic working lengths in perforated teeth were higher in gel types than in liquid types. The accuracy in locating root perforation was higher in liquid types than gel types. 5.25% NaOCl had the highest electrical conductivity, whereas 2% chlorhexidine gel and RC-Prep gel had the lowest electrical conductivities among the five irrigants. ***Conclusions:*** Different canal irrigants with different electrical conductivities may affect the accuracy of the Root ZX in perforated teeth. (*Restor Dent Endod* 2012;37(3):149-154)

Key words: Electrical conductivity; Root canal irrigants; Root perforation; Root ZX

Received February 22, 2012;
Last Revised June 22, 2012;
Accepted July 9, 2012.

[1]Shin HS; Yang WK; Kim MR; Ko HJ, Department of Conservative Dentistry, Ulsan University Asan Medical Center, Seoul, Korea
[2]Cho KM; Park SH; Kim JW, Department of Conservative Dentistry, Gangneung-Wonju National University College of Dentistry, Gangneung, Korea

***Correspondence to**
Jin-Woo Kim, DDS, PhD
Professor, Department of Conservative Dentistry, Gangneung-Wonju National University College of Dentistry, 7 Jukheon-gil, Gangneung, Korea 210-702
TEL, +82-33-640-3189; FAX, +82-33-640-3102; E-mail, mendo7@gwnu.ac.kr

Introduction

Root perforations that result in a communication of the root space with the periodontal tissues occasionally occur during endodontic procedures. They may be induced iatrogenically, by resorptive process, or by caries.[1] Identification of root perforations is possible by direct observation of bleeding, indirect bleeding assessment using a paper point, radiography, and an electronic apex locator (EAL).[2] The EAL's principle was initially introduced to clinical practice by Sunada.[3] The EALs are considered as accurate tools for determining canal working lengths, and are valuable aids in clinical endodontics.[4] EALs may detect root fracture that reaches the pulpal chamber and should detect the fracture as an 'apex' from the beginning of the periodontal communication at the fracture site.[5] The accuracies of EALs in fractured or resorpted root cases have been evaluated in a few studies, but confusing results have been reported.[6-8] In case of perforation, some authors recommended the use of EALs, but there were some difficulties in measuring the exact working length under different irrigation solutions in perforated roots.[2,9,10]

Effects of various irrigants, such as saline, hydrogen peroxide, sodium hypochlorite (NaOCl) solution, RC-Prep (Premier Dental Products, Plymouth Meeting, PA, USA), and ethylenediaminetetraacetic acid (EDTA) solution, on EALs' performance have been investigated.[11-13] Chlorhexidine is a potent antimicrobial agent that has been used in endodontic treatment as both a root canal irrigant and an intracanal medicament.[14-16] Because of the good biocompatibility of chlorhexidine, it has been recommended as a useful alternative to NaOCl, especially in patients allergic to NaOCl, or in patients with open apices.[14,17] Recently, chlorhexidine gel has been introduced as an endodontic lubricant.[18] Chlorhexidine gel has several advantages: it is biocompatible, water-soluble, and viscous, thereby facilitating instrumentation. The material acts like a lubricant, allowing increased mechanical removal of organic tissues and decreased smear layer formation as other irrigants.[19] The antimicrobial ability of 2% gel chlorhexidine gluconate was either no different from, or better than, 5.25% NaOCl in limiting *Enterococcus faecalis* counts 7-day after biomechanical instrumentation.[20]

RC-Prep, which is composed of glycol, urea peroxide and EDTA in a special water soluble base helps to remove calcifications and lubricates the canal to permit more efficient instrumentation. RC-Prep is also excellent for use with apex locators as it permits consistently reliable readings.[12]

Electrical conductivity is the ability of different types of matter to conduct an electric current. The electrical conductivity of a material is defined as the ratio of the current per unit cross-sectional area to the electric field producing the current.[21] It is an intrinsic property of a substance, which is dependent not on the amount or shape, but on the temperature and chemical composition.

To date, a few studies have examined the accuracy of EAL in perforated roots in the presence of gel or liquid type endodontic irrigants. In addition, electrical conductivities of each irrigant are not yet fully determined. The purpose of this study was to evaluate the accuracy of the Root ZX (J Morita Corp, Tokyo, Japan) in the presence of various gel or liquid type endodontic irrigants in perforated teeth and also to determine the electrical conductivities of these endodontic irrigants.

Materials and Methods

1. Sample preparation

A total of 20 extracted single-rooted human teeth with complete root formations were used. 'Informed Consent' was obtained from the patients whose tooth was extracted at the Department of Dentistry, Asan Medical Center, Seoul, Korea (2007-0404). After visual and radiographic examinations, teeth with fractures, resorption, and open apices were excluded. Teeth were soaked in 5.25% NaOCl for approximately 15 minutes and then stored in 0.2% thymol in normal saline solution. Each tooth was decoronated and flattened using steel discs (Brasseler, Savannah, GA, USA) to provide stable reference points for measurement of lengths. A perforation was simulated by means of a hole (1 mm diameter) made on the proximal root plane at 4 mm from the anatomic apex. Access cavities were made, and a coronal preparation of each canal was performed using Orifice Shapers (Dentsply Tulsa Dental, Tulsa, OK, USA). The patency of each root canal was confirmed with a #10 K-file (Kerr, Romulus, MI, USA). To determine the actual working length (AWL), a metal spatula was placed against the root apex. A #15 K-file was introduced until a firm contact with the spatula made. The AWL was confirmed again by visualization of the tip of #15 K-file at the apical foramen. The actual location of perforation (AP) was determined by visualization of the tip of a #15 K-file at the perforation hole. AWL and AP were measured with digital calipers (Mitutoyo, Tokyo, Japan) to the nearest 0.1 mm.

2. Measurement of working length and location of root perforation

Root ZX and five irrigants such as normal saline (JW Pharmaceutical, Seoul, Korea), 1% [w/v] NaOCl (Daemyung Chemical, Seoul, Korea), 2% [w/v] chlorhexidine liquid (Sungkwang Co., Cheonan, Korea), 2% [w/v] chlorhexidine gel (Sungkwang Co.) and RC-Prep gel were used. Electronic working length was measured at the display level '0.5 bar' of Root ZX, using digital calipers, to the nearest 0.1 mm.

Donnelly's *in vitro* gelatin technique was used for model measurements.[22] One 0.3 ounce package of sugar-free Jell-O (Kraft General Foods Inc., White Plains, NY, USA) was mixed, according to package directions, with 0.9% sodium chloride solution (irrigation grade) as a substitute for tap water. The warmed solution was poured into 100 mL plastic specimen cups and refrigerated for at least 2 hours to allow change from the liquid to gel.

Each root was mounted on an aluminum apparatus for convenience and stability, a file holder attached to a #15 K-file connected to the Root ZX was used in all cases. Test irrigants were introduced into the canal with 27-gauge needles until the canal was flooded and the irrigants extruded through the patent foramen and perforation site. Cotton pellets were used to dry the root surface and to eliminate excess irrigating solution. Each canal was irrigated with 20 mL of distilled water between measurements and then dried with paper points. A metal lip clip was placed into gelatin and stabilized with wax. Each measurement was conducted at a different gelatin position to prevent cross-

http://dx.doi.org/10.5395/rde.2012.37.3.149

contamination.

The silicone stop was adjusted and the distance from the base of the stop to the file tip was measured using digital calipers and repeated three times by the same operator blind to previous values. Average of these three values was compared with the AWL or AP, allowing tolerances of 0.5 or 1.0 mm. Measurements within these limits were considered as acceptable.

3. Electrical conductivity measurement

For measuring of electrical conductivities of irrigants, an electrical conductivity tester (EcoScan CON 6, Eutech Instruments Pte Ltd., Singapore) was used. 100 mL glass-beakers were half-filled with each irrigant, and the electrode probe of EcoScan CON 6 was immersed beyond upper steel band. In each step, electrode was washed with copious de-ionized water and tester was calibrated with appropriate range. Measurements were repeated ten times for each irrigant.

4. Statistics

Statistical analysis of data was performed with SPSS 13.0 (SPSS Inc, Chicago, IL, USA). The measurements recorded with each irrigant at the 0.5 and 1.0 mm tolerance levels were analyzed with a chi-square test or the Fisher's exact test ($\alpha = 0.05$).

Results

1. Working length measurement

The results obtained are summarized in Table 1 (0.5 or 1.0 mm tolerance). Acceptable results at a 0.5 mm tolerance were obtained with saline in five samples (25%), NaOCl in six samples (30%), chlorhexidine liquid in 12 samples (60%), chlorhexidine gel in 16 samples (80%), and RC-Prep in 13 samples (65%), repectively. At this tolerance level, liquid irrigants (saline, NaOCl, and chlorhexidine liquid) showed no measurements longer than AWL. Chlorhexidine gel showed four unacceptable measurement, two shorter and two longer than AWL and RC-Prep showed three measurements shorter and four longer than the AWL. There was a significant difference between chlorhexidine gel and saline ($p < 0.05$) and between chlorhexidine gel and NaOCl ($p < 0.05$) when chi-square test or the Fisher's exact test with Bonferroni's adjustment was applied for all pair of irrigants.

If a tolerance limit of 1.0 mm was allowed, the percentage of acceptable measurements were obtained with saline in seven samples (35%), NaOCl in eight samples (40%), chlorhexidine liquid in 14 samples (70%), chlorhexidine gel in 18 samples (90%), and RC-Prep in 17 samples (85%). At this tolerance level, liquid irrigants (saline, NaOCl, and chlorhexidine liquid) showed no measurements longer than AWL. Chlorhexidine gel and RC-Prep showed only one measurement shorter than AWL. There was also a significant difference between chlorhexidine gel and saline ($p < 0.05$), between chlorhexidine gel and NaOCl ($p < 0.05$), between RC-Prep and saline ($p < 0.05$), and between RC-Prep and NaOCl ($p < 0.05$).

2. The determination of location of root perforation

The results obtained are summarized in Table 2 (0.5 and 1.0 mm tolerance). Acceptable results at a 0.5 mm tolerance were obtained with saline and NaOCl in 6 samples (30%) each, chlorhexidine liquid in 3 samples (15%), RC-Prep in 1 sample (5%), and chlorhexidine gel in no sample (0%). At this tolerance level, chlorhexidine gel and RC-Prep showed no measurements shorter than AP. Saline showed fourteen unacceptable measurements, one shorter and thirteen longer than AP and NaOCl showed four mea-

Table 1. Accuracy of Root ZX in electronic working length measurement of perforated canals using different irrigants with 0.5 and 1.0 mm tolerances

Tolerances	Accuracy	Saline	NaOCl	CHX liquid	CHX gel	RC-Prep
0.5 mm	Accurate	5 (25)	6 (30)	12 (60)	16 (80)	13 (65)
	Long	0 (0)	0 (0)	0 (0)	2 (10)	3 (15)
	Short	15 (75)	14 (70)	8 (40)	2 (10)	4 (20)
1.0 mm	Accurate	7 (35)	8 (40)	14 (70)	18 (90)	17 (85)
	Long	0 (0)	0 (0)	0 (0)	1 (5)	1 (5)
	Short	13 (65)	12 (60)	6 (30)	1 (5)	2 (10)

Sample numbers are 20 for each irrigant and tolerance.
The numbers in the parentheses are percentages.
CHX, chlorhexidine.

Table 2. Accuracy of Root ZX in locating root perforation of different irrigants with 0.5 and 1.0 mm tolerances

Tolerances	Accuracy	Saline	NaOCl	CHX liquid	CHX gel	RC-Prep
0.5 mm	Accurate	6 (30)	6 (30)	3 (15)	0 (0)	1 (5)
	Long	13 (65)	10 (50)	16 (80)	20 (100)	19 (95)
	Short	1 (5)	4 (20)	1 (5)	0 (0)	0 (0)
1.0 mm	Accurate	9 (45)	10 (50)	5 (25)	0 (0)	1 (5)
	Long	11 (55)	10 (50)	15 (75)	20 (100)	19 (95)
	Short	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Sample numbers are 20 for each irrigant and tolerance.
The numbers in the parentheses are percentages.
CHX, chlorhexidine.

surements shorter and ten longer than the AP. There was no significant difference for all pair of irrigants at this tolerance level.

If a tolerance limit of 1.0 mm was allowed, the percentage of acceptable measurements with saline in 9 samples (45%), NaOCl in 10 samples (50%), chlorhexidine liquid in 5 samples (25%) and others were same with 0.5 mm tolerance limit. At this tolerance level, all unacceptable measurements were longer than AP, that is, eleven with saline, ten with NaOCl, fifteen with chlorhexidine liquid and nineteen with RC-Prep, and all measurements with chlorhexidine gel.

There was also a significant difference between chlorhexidine gel and saline ($p < 0.05$, Fisher's exact test), between chlorhexidine gel and NaOCl ($p < 0.05$), between RC-Prep and saline ($p < 0.05$), and between RC-Prep and NaOCl ($p < 0.05$).

3. Electo-conductivity measurement

The data obtained are summarized in Table 3. The unit of electrical conductivity in the SI system is the siemens per meter, where the siemens is the reciprocal of the ohm, the unit of electrical resistance. Conductance derives from Ohms law, E = IR, and is defined as the reciprocal of the electric resistance of a solution.

Table 3. Electrical conductivities (μS/cm) of five irrigants

Groups	Electrical conductivities
Saline	44,940 ± 114.02
NaOCl (1%)	172,420 ± 356.37
CHX liquid (2%)	2,160 ± 35.36
CHX gel (2%)	655 ± 20.38
RC-Prep	27 ± 0.11

Values are means ± standard deviations in μS/cm, and sample numbers are 20.
CHX, chlorhexidine.

$$C = 1/R$$

Where C is conductance (siemens), R is resistance (ohms)

It was presented that 1% NaOCl had the highest electrical conductivity, whereas 2% chlorhexidine gel and RC-Prep gel had the lowest electrical conductivities among the five irrigants (Table 3).

Discussion

Post-treatment endodontic disease is often a result of root perforation.[23] In perforated cases, endodontists may face difficulties in measuring of working length with EALs. The prognosis of perforated teeth depends on the location, size, duration of perforation and feasibility of sealing the perforation, and an accurate detection of the location of root perforation is a key factor for successful treatment.[2,10,24]

In this study, the perforation situation was different from the previous study of Fuss *et al.*[10] The perforation was made by transportation in their study. However, in this study perforations were made by drilling from the external surface, like an external resorption or a big lateral canal, while original canal of apical third was remained. The shapes and positions of our simulated root perforations, which were created iatrogenically by round bur with an 1 mm diameter at 4 mm above apical foramen, may be unrealistic. In addition, dentin thickness from inner root canal to outer root surface may vary with each tooth. Although we made perforation on mesial or distal root surfaces instead of buccal or lingual root surfaces to minimize differences of dentin thickness between each tooth, varying dentin thickness could have influenced the detection of root perforation location.

The lubricants like RC-Prep or chlorhexidine gels have been used and also they may act as electric conductors in the root canal. Dual-frequency EAL, Root ZX, simultaneously uses two wave forms, a high (8 kHz) and a low (400 Hz) frequency wave forms.[25] Even though Root ZX was accurate in the presence of electrolytes, electrical conductivity of ir-

http://dx.doi.org/10.5395/rde.2012.37.3.149

rigant affected the determination of working length.[12] Electrical conductivity in the liquid state is generally due to the presence of ions. The conductivity of a one molar electrolyte is of the order of 0.01 siemens per meter, far less than that of a metal, but still very much larger than that of typical insulators. As might be expected, the conductivity of a dissolved electrolyte depends on its concentration.[21] It is well known that electric conductivity of tap water is 100 to 1,000 μS/cm and 5% sodium chloride solution is 70,000 μS/cm. Similarly, in this study, electrical conductivity of physiologic saline and 1% NaOCl solution were 44,940 μS/cm and 172,420 μS/cm, respectively. Therefore different concentration of endodontic preparations may present dissimilarities to another. Gel types were different from solution types. Gels are defined as a substantially dilute cross-linked system, which exhibits no flow when in the steady-state.[26] By weight, gels are mostly liquid, yet they behave like solids due to a three-dimensional cross-linked network within the liquid. Therefore, electrical conductivities in gel have complexities. They may be influenced by three-dimensional structure of gel, concentration of ions and water content.

In this study, RC-Prep had the lowest conductivity. It is composed of glycol, urea peroxide and EDTA in a special water soluble base. It might be different from hydrogel like chlorhexidine gel. Chlorhexidine gel is used as an endodontic lubricant, antiseptic agent and irrigation medicament of canal preparation.[18] Clinically, this agent is very useful for canal enlargement. However, further long-term studies are needed to determine its effectiveness as a canal irrigant or preparatory material.

Working length measurements tended to be slightly shorter in solutions of higher electrical conductivity, such as NaOCl solutions.[12] In our study, the electrical conductivity of the 1% NaOCl solution was four-fold higher than that of physiologic saline. In the previous study, the influence of chlorhexidine liquid on EALs' accuracies was tested, which was found to be similar to that of NaOCl.[27] However, in this study, resulting data with chlorhexidine liquid were very different from other liquid type irrigants such as saline and NaOCl. Electrical conductivity of chlorhexidine liquid was much lower than that of other liquid type irrigants and similar to that of gel type irrigants. It can be presumed to be main cause of our results.

Another study showed that the Root ZX reliably measured the canal lengths to within 0.31 mm under RC-Prep.[12] However, in the present study, we found that there were statistically significant differences between liquid type irrigants of saline and NaOCl and gel type irrigants of chlorhexidine gel and RC-Prep. Gel type irrigants were very stable in determining real working length in perforated teeth. Similarly, in the other study, the largest deviation from the actual canal length was reported with NaOCl.[28] Obviously, both type of irrigants can be extruded over the apical foramen excessively. However, the possibility and amount of excessive extrusion is greater in liquid types than in gel types. This excessive extrusion may explain why gel types showed higher accuracy than liquid types in case of measuring AWL. On the contrary, liquid types showed higher accuracy than gel types in case of locating root perforation. Because simulated perforation was made to proximal root plane, good flowing liquid types were advantageous to reach the outer proximal root surface. This could make liquid types more accurate than gel types when we located root perforation.

Shabahang *et al.* suggested that a 1.0 mm tolerance can be considered clinically acceptable.[28] This tolerance level would be considered acceptable, especially when the determination of the apical limit becomes more difficult because of the existence of perforation.[7] Most of the results obtained were between perforation length (AP) and real working length (AWL), and there was no unacceptable data more than 1 mm shorter from perforation.

Further evaluation of the accuracy of the Root ZX in perforated tooth in clinical conditions is indicated and should be needed in future *in vivo* studies.

Conclusions

Different canal irrigants with different electrical conductivities may affect the accuracy of the Root ZX in perforated teeth. In AWL measurement, gel type irrigants showed higher accuracy than liquid type irrigants such as saline and NaOCl. On the contrary, liquid type irrigants such as saline and NaOCl showed higher accuracy than gel type irrigants when locating root perforation. Chlorhexidine gel and RC-Prep gel had the lowest electrical conductivities.

Conflict of Interest: No potential conflict of interest relevant to this article was reported.

References

1. Cohen S, Hargreaves KM. Pathways of the pulp. 9th ed. St Louis: Mosby Elsevier Co.; 2006. p996.
2. Alhadainy HA. Root perforations. A review of literature. *Oral Surg Oral Med Oral Pathol* 1994;78:368-374.
3. Sunada I. New method for measuring the length of the root canal. *J Dent Res* 1962;41:375–387.
4. Trope M, Rabie G, Tronstad L. Accuracy of an electronic apex locator under controlled clinical conditions. *Endod Dent Traumatol* 1985;1:142-145.
5. Topuz O, Uzun O, Tinaz AC, Bodrumlu E, Görgül G. Accuracy of two apex-locating handpieces in detecting simulated vertical and horizontal root fractures. *J Endod* 2008;34:310-313.
6. Angwaravong O, Panitvisai P. Accuracy of an electronic

apex locator in primary teeth with root resorption. *Int Endod J* 2009;42:115-121.

7. Goldberg F, Frajlich S, Kuttler S, Manzur E, Briseño-Marroquín B. The evaluation of four electronic apex locators in teeth with simulated horizontal oblique root fractures. *J Endod* 2008;34:1497-1499.
8. Gordon MP, Chandler NP. Electronic apex locators. *Int Endod J* 2004;37:425-437.
9. Nahmias Y, Aurelio JA, Gerstein H. Expanded use of the electronic canal length measuring devices. *J Endod* 1983;9:347-349.
10. Fuss Z, Assooline LS, Kaufman AY. Determination of location of root perforations by electronic apex locators. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996;82:324–329.
11. Kim DW, Nam KC, Lee SJ. Development of a frequency-dependent-type apex locator with automatic compensation. *Crit Rev Biomed Eng* 2000;28:473-479.
12. Jenkins JA, Walker WA 3rd, Schindler WG, Flores CM. An *in vitro* evaluation of the accuracy of the root ZX in the presence of various irrigants. *J Endod* 2001;27:209-211.
13. Kaufman AY, Keila S, Yoshpe M. Accuracy of a new apex locator: an *in vitro* study. *Int Endod J* 2002;35:186-192.
14. Jeansonne MJ, White RR. A comparison of 2.0% chlorhexidine gluconate and 5.25% sodium hypochlorite as antimicrobial endodontic irrigants. *J Endod* 1994;20:276-278.
15. Siqueira JF Jr, de Uzeda M. Intracanal medicaments: evaluation of the antibacterial effects of chlorhexidine, metronidazole, and calcium hydroxide associated with three vehicles. *J Endod* 1997;23:167-169.
16. Mohammadi Z, Abbott PV. The properties and applications of chlorhexidine in endodontics. *Int Endod J* 2009;42:288-302.
17. Kaufman AY, Keila S. Hypersensitivity to sodium hypochlorite. *J Endod* 1989;15:224-226.
18. Dametto FR, Ferraz CC, Gomes BP, Zaia AA, Teixeira FB, de Souza-Filho FJ. *In vitro* assessment of the immediate and prolonged antimicrobial action of chlorhexidine gel as an endodontic irrigant against *Enterococcus faecalis*. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005;99:768-772.
19. Mônika CM, Fröner IC. A scaning electron microscopic evaluation of different root canal irrigation regimens. *Braz Oral Res* 2006;20:235-240.
20. Vianna ME, Gomes BP, Berber VB, Zaia AA, Ferraz CC, de Souza-Filho FJ. *In vitro* evaluation of the antimicrobial activity of chlorhexidine and sodium hypochlorite. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004;97:79-84.
21. Joesten MD, Hogg JL, Castellion ME. The world of chemistry: essentials. 4th ed. Belmont, CA: Brooks Cole; 2004. p461.
22. Donnelly JC. A simplified model to demonstrate the operation of electronic root canal measuring devices. *J Endod* 1993;19:579-580.
23. Ingle JI, Bakland LK. Endodontics. 5th ed. Hamilton, London: Williams & Wilkins; 2002. Chapter 13, Outcome of endodontic treatment and retreatment; p747.
24. Kim M, Kim B, Yoon S. Effect on the healing of periapical perforations in dogs of the addition of growth factors to calcium hydroxide. *J Endod* 2001;27:734-737.
25. Ingle JI, Backland LK, Baumgartner JC. Ingle's endodontics. 6th ed. Hamilton: Decker; 2008. p852-853.
26. Ferry JD. Viscoelastic Properties of Polymers. 3rd ed. New York: Wiley; 1980. p529.
27. Erdemir A, Eldeniz AU, Ari H, Belli S, Esener T. The influence of irrigating solutions on the accuracy of the electronic apex locator facility in the Tri Auto ZX handpiece. *Int Endod J* 2007;40:391-397.
28. Shabahang S, Goon WW, Gluskin AH. An *in vivo* evaluation of Root ZX electronic apex locator. *J Endod* 1996;22:616–618.

http://dx.doi.org/10.5395/rde.2012.37.3.149