doi:10.1111/j.1365-2591.2008.01386.x

Ex vivo evaluation of the ability of the ROOT ZX II to locate the apical foramen and to control the apical extent of rotary canal instrumentation

W. T. Felippe, M. C. S. Felippe, J. Reyes Carmona, F. C. I. Crozoé & B. B. Alvisi
School of Dentistry, Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil

Abstract

Felippe WT, Felippe MCS, Reyes Carmona J, Crozoé FCI, Alvisi BB. *Ex vivo* evaluation of the ability of the ROOT ZX II to locate the apical foramen and to control the apical extent of rotary canal instrumentation. *International Endodontic Journal*, **41**, 502–507, 2008.

Aim To evaluate the capacity of the ROOT ZX II to locate the apical foramen and to control the apical extent of rotary instrumentation.

Methodology Sixty-five extracted human single rooted teeth were selected and measured directly using a size 15 K-Flexofile introduced in the canal until the tip was visible at the major foramen (direct length, DL). The teeth were then measured electronically (EL1) with the ROOT ZX II when used passively, that is without rotation. To test the auto reverse function, the root canals were instrumented with nickel titanium rotary instruments. Instrumentation was carried out apically until rotation was reversed by the automatic apical reverse (AAR) function at different levels (2, 1 and 0.5). The instrumented length at each level was measured and registered as AAR2, AAR1 and AAR0.5, respectively. After instrumentation, a second passive electronic measurement was conducted and noted as electronic length 2 (EL2). All measurements were expressed in millimetres with accuracy set to 0.5 mm. Percentages of acceptable measurements for each electronic reading were calculated and compared using the proportions test. The Wilcoxon's signed rank test was used to compare the differences between DL/EL1 and DL/EL2, and to compare EL2 with the different AAR measurements. The critical value of statistical significance was 5%.

Results EL1 and EL2 measurements were coincident to DL in 56 (86%) and 54 (83%) of the cases, respectively. The proportions test showed no statistically significant difference between these percentages ($P > 0.05$). The Wilcoxon's signed rank test did not show any differences ($P > 0.05$) when comparing the mean difference between DL with EL1 (0.03) and DL with EL2 (0.10). Statistically significant differences were observed when comparing EL2 with AAR2 and with AAR1.

Conclusions The ROOT ZX II reliably located the major apical foramen, but was not an accurate method for controlling the apical extent of rotary instrumentation. Rotary instrumentation with the automatic apical reverse feature was always closer to the foramen than expected.

Keywords: apex locator, root canal length, ROOT ZX II, rotary instrumentation.

Received 22 May 2007; accepted 27 November 2007

Introduction

The establishment of the apical limit of canal preparation is an important phase of root canal treatment. It is generally accepted that canal preparation and filling should be limited to within the root canal (Holland *et al.* 1993, Ricucci 1998). Indeed, an *in vivo* histological study found that the most favourable histological conditions were observed when preparation and filling remained short of the apical constriction (Ricucci & Langeland 1998).

Displacement and disruption of the apical foramen may occur as a result of incorrect determination of

Correspondence: Wilson Tadeu Felippe, Rua: Presidente Coutinho, 179/702 Centro Florianópolis, CEP: 88.015-230 Santa Catarina, Brazil (Tel.: +55 (0) 48 3324 0417; e-mail: wtfelippe@hotmail.com).

working length, along with straightening of curved root canals and over-extension of root filling material. As a consequence, irritation of the periradicular tissues by extruded irrigants or filling materials may occur because of the loss of an apical stop (Hülsmann *et al.* 2005).

No individual technique is truly reliable in determining endodontic working length. Electronic apex locators offer a possible method for endodontic working length determination and localization of the foramen (Felippe & Soares 1994, Felippe *et al.* 1997, Plotino *et al.* 2006, Williams *et al.* 2006, Nekoofar *et al.* 2006), including retreatment cases (Alves *et al.* 2005).

The Tri Auto ZX (J. Morita Corp., Kioto, Japan) is a cordless handpiece designed for rotary canal preparation, with a built-in electronic apex locator (Kobayashi *et al.* 1997). The apical automatic reverse function reverses the rotation when the instrument tip reaches the length previously set by the operator, i.e. Apex, 0.5, 1, 1.5 and 2. Laboratory studies (Campbell *et al.* 1998, Pasternak Jr. 2000, Grimberg *et al.* 2002, Carneiro *et al.* 2006) have demonstrated that the Tri Auto ZX can accurately measure the root canal length and trigger reversal of file rotation when the instrument reaches a predetermined level.

ROOT ZX II (J. Morita Co.) is an apex locator that can be linked to a low-speed handpiece. The handpiece module is interchangeable and snaps onto the back of the unit. This allows the clinician to choose between the use of an apex locator, a low-speed handpiece or a combination of both. When the auto apical reverse/stop function is triggered, the motor can be set to reverse its rotation or stop when the instrument tip reaches a level preset by the clinician. The purpose of this laboratory study was to evaluate the ability of the ROOT ZX II to locate the apical foramen and to control the apical extent of rotary instrumentation during root canal treatment.

Material and methods

After approval by the Committee of Ethics of the Federal University of Santa Catarina, written informed consent was obtained from each patient before extraction.

Teeth preparation

Sixty-five maxillary and mandibular human anterior teeth with a single, straight canal and completely formed roots were used. The teeth were stored in 10% buffered formalin after extraction and were rinsed in saline solution before use.

After preparation of the endodontic access cavity, canal patency was checked with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) introduced to the anatomical apical foramen. The incisal edge of each tooth was adjusted to produce a regular, flat reference point and to obtain teeth ranging from 12 to 17 mm in length.

Direct length between the coronal reference point and apical foramen (DL)

The teeth were measured using a size 15 K-Flexofile introduced in the canal so that its tip was just visualized with the help of a magnifying glass (×2.5) at the cervical border of the major foramen. The file was held using a needle-holder perpendicular to the incisal edge and was laid against a millimetre ruler, to determine the length of each canal. All measurements were recorded in mm and the accuracy was set to 0.5 mm.

Electronic length between the coronal reference point and apical foramen before rotary canal instrumentation (EL1)

To conduct the electronic measurements, the ROOT ZX II unit was used according to the manufacturer's instructions (J. Morita MFG Corp. 2005). Measurements were obtained using the Apex LED. Each of the teeth was fixed at the level of cement–enamel junction to a perforation made in the lid of an opaque plastic cylinder to ensure that the root was submersed in saline. The labial clip, connected to the indifferent electrode of the device, was fixed to one hole made on the top of the container's surface. The file holder was connected to the different electrode, which was attached to a 31-mm size 15 K-Flexofile. The file was introduced in the canal, which had been previously filled with saline, until the 'Apex' reading was obtained. The stopper was placed against the reference point and the instrument was removed from the canal and measured with the millimetre ruler. These measurements were recorded as electronic length 1 (EL1).

Apical extent of the rotary canal instrumentation

To test the auto reverse function of the ROOT ZX II low-speed handpiece, the root canals were instrumented with nickel titanium rotary instruments (ProTaper;

Dentsply Maillefer) under irrigation with 2 mL of 1% sodium hypochlorite (Miyako, São Paulo, Brazil) between each instrument. According to the manufacturer's instructions and with the automatic apical reverse mechanism set at level 2, the preparation was performed in a crown-down technique, ending with a Finishing 2 file in every canal. Once the level was reached, the device emitted a sound and the reverse function was activated. Then, the stopper was placed against the reference point and the instrument was removed from the canal and measured with the millimetre ruler. These measurements were noted as automatic apical reverse 2 (AAR2).

Using the same teeth and instruments and also ending with a Finishing 2 file, the procedure was repeated twice to test the automatic apical reverse at level 1 (AAR1) and level 0.5 (AAR0.5).

Electronic length between the coronal reference point and apical foramen after rotary canal instrumentation (EL2)

After rotary instrumentation, the canal was irrigated with saline and the second electronic measurement was conducted as described previously (EL1). The measurements obtained were recorded as electronic length 2 (EL2).

Evaluation criteria

Measurements obtained with the ROOT ZX II before and after rotary instrumentation (EL1 and EL2) were compared with the direct measurements (DL). Differences were computed and considered to be acceptable when less than or equal to 0.5 mm. Percentages of acceptable measurements for each electronic reading were calculated and compared using the proportions test. Wilcoxon's signed rank test was used to compare the differences between DL/EL1 and DL/EL2, and to compare EL2 with the different AAR measurements. The critical value of statistical significance was 5%.

Results

Measurements obtained directly (DL), and with the ROOT ZX II before (EL1) and after rotary instrumentation (EL2, AAR 2, AAR 1, AAR 0.5) are shown in Table 1.

Within the adopted tolerance limits (±0.5 mm), measurements obtained using the device before root canal instrumentation (EL1) were considered

Table 1 Measurements obtained directly (DL), and with the ROOT ZX II before (EL1) and after rotary instrumentation (EL2, AAR 2, AAR 1, AAR 0.5)

Tooth	DL	EL1	EL2	AAR2	AAR1	AAR0.5
1	13.0	13.0	13.0	12.0	13.0	13.0
2	15.0	15.0	15.5	14.0	15.0	15.0
3	16.0	16.0	16.0	15.5	15.5	16.0
4	15.0	15.0	15.5	14.0	15.0	15.0
5	14.0	14.0	14.0	13.0	13.5	13.0
6	14.0	14.0	14.0	13.0	13.5	13.5
7	14.0	13.0	14.0	13.0	13.5	13.0
8	14.0	14.5	15.0	14.0	14.5	15.0
9	14.5	14.0	14.0	13.0	13.0	13.5
10	15.0	14.5	14.5	13.5	14.0	14.0
11	16.0	16.0	15.5	14.5	15.0	15.5
12	17.0	16.0	16.0	16.0	16.0	16.0
13	14.0	14.0	14.0	13.0	13.0	13.5
14	14.0	13.5	13.0	13.0	13.0	13.5
15	14.5	15.0	14.5	14.0	14.0	15.0
16	14.0	14.0	14.0	13.0	13.5	14.0
17	13.0	13.0	12.0	12.0	12.0	12.5
18	14.0	14.0	14.0	13.5	13.0	14.0
19	14.0	14.0	13.0	13.5	12.5	14.0
20	13.0	13.0	13.0	13.5	13.0	13.5
21	14.0	14.0	14.0	13.0	13.0	14.0
22	14.0	14.0	14.0	13.0	14.0	14.0
23	15.0	15.0	15.0	14.5	15.0	15.0
24	12.0	12.0	12.0	12.0	12.5	12.5
25	13.0	13.0	13.0	12.0	13.0	13.0
26	13.0	13.0	13.0	13.0	12.0	13.0
27	16.0	16.0	15.5	15.0	15.5	15.5
28	12.5	12.5	12.5	12.0	12.0	12.0
29	16.0	15.0	15.0	14.5	15.0	15.0
30	16.0	16.0	16.0	15.0	16.0	16.0
31	16.0	15.5	15.5	15.0	15.0	15.5
32	15.0	15.5	15.0	15.0	15.0	15.0
33	15.0	16.0	15.5	15.0	15.0	15.5
34	15.0	15.0	15.0	15.0	14.5	15.0
35	15.0	15.0	15.0	15.0	15.0	15.0
36	15.0	15.0	15.0	15.0	15.0	15.0
37	14.0	15.0	15.0	14.0	14.0	15.0
38	16.0	16.0	16.0	15.0	15.0	15.0
39	15.0	16.0	16.0	15.0	15.0	15.5
40	15.0	15.0	15.5	15.0	15.5	15.5
41	15.0	15.0	15.0	14.5	14.5	15.0
42	16.0	16.0	16.0	15.0	15.0	15.5
43	15.0	14.0	14.0	13.0	13.0	14.0
44	15.0	15.0	15.0	13.0	14.0	15.0
45	14.0	14.0	14.0	13.5	13.5	14.0
46	15.0	15.0	15.0	14.5	15.0	15.0
47	14.0	14.5	14.5	14.0	14.0	15.0
48	15.0	15.0	15.0	12.0	15.0	15.0
49	15.0	15.5	15.5	14.0	14.5	16.0
50	16.0	15.0	15.5	14.5	15.0	15.0
51	16.0	16.0	16.0	15.0	15.0	15.0
52	16.0	16.0	15.5	14.5	15.5	15.0
53	16.0	15.0	15.0	14.0	15.0	15.0
54	15.0	15.0	15.0	15.0	15.0	15.0
55	16.0	16.0	15.5	15.5	15.0	15.0

Table 1 (*Continued*)

Tooth	DL	EL1	EL2	AAR2	AAR1	AAR0.5
56	16.0	16.0	16.0	14.0	15.0	15.0
57	15.0	15.0	14.5	14.0	16.0	16.0
58	16.0	16.0	16.0	15.5	14.0	15.0
59	15.0	15.0	15.0	14.0	15.5	16.0
60	16.0	16.0	16.0	14.0	14.5	15.0
61	15.0	15.0	15.0	15.0	16.0	15.5
62	15.0	15.0	14.0	14.0	15.0	15.0
63	16.0	16.0	15.5	13.5	14.0	14.0
64	16.0	16.0	16.0	15.0	16.0	15.0
65	15.0	15.5	15.5	15.0	16.0	15.0
Mean	14.84	14.81	14.74	14.00	14.36	14.62
(SD)	(1.05)	(1.04)	(1.05)	(1.02)	(1.09)	(0.97)

Table 2 Distribution of the differences between DL and electronic measurements obtained with the ROOT ZX II before (EL1) and after (EL2) rotary instrumentation

Difference from DL (mm)	*n* in EL1 (%)	*n* in EL2 (%)
−1[a]	6 (9.2%)	8 (12.3%)
−0.5 to +0.5	56 (86.2%)	54 (83.1%)
+1	3 (4.6%)	3 (4.6%)
Total	65 (100%)	65 (100%)

[a]When the DL was greater than the EL1 and/or EL2, the difference received a negative sign. When the DL was less than the EL1 and/or EL2, the difference was given a positive sign, indicating the file tip had passed beyond the foramen.

Table 3 Mean difference and results of Wilcoxon's signed rank test for comparisons between the direct length (DL) and the electronically measured length (EL1 and EL2)

Comparison	Mean difference	*Z*	*P*-value
DL vs. EL1	0.03	0.327	$P = 0.744$
DL vs. EL2	0.10	1.593	$P = 0.111$

Table 4 Distribution of the differences between EL2 and the different AAR measurements (AAR 2, AAR 1, AAR 0.5)

Difference from EL2 (mm)	*n* in AAR2	*n* in AAR1	*n* in AAR0.5
−3[a]	1	–	–
−2	04	01	–
−1.5	03	02	01
−1	25	14	08
−0.5	17	21	13
0	13	21	31
+0.5	02	03	08
+1	–	02	03
+1.5	–	01	01
Total	65	65	65

[a]When the DL was greater than the EL1 and/or EL2, the difference received a negative sign. When the DL was less than the EL1 and/or EL2, the difference was given a positive sign, indicating the file tip had passed beyond the foramen.

Table 5 Mean difference and results of Wilcoxon's signed rank test for comparison between the electronically measured length after rotary instrumentation (EL2) and the instrumented length for each tooth at different levels (AAR2, AAR1 and AAR0.5)

Comparison	Mean difference	*Z*	*P*-value
EL2 vs. AAR2	0.74	−6.505	$P < 0.001$
EL2 vs. AAR1	0.38	−4.606	$P < 0.001$
EL2 vs. AAR0.5	0.12	−1.742	$P = 0.081$

acceptable on 86% of cases ($n = 56$). After instrumentation (EL2), the percentage was 83.1% ($n = 54$) (Table 2). Using the proportions test (Z) to compare the percentage of acceptable measurements given by the ROOT ZX II in different situations, no statistically significant differences were apparent ($Z = 0.48$; $P = 0.6268$).

Comparing DL with EL1, the mean difference was 0.03 mm; and DL with EL2, the mean difference was 0.10 mm. Wilcoxon's signed rank test did not reveal any significant differences ($P > 0.05$) (Table 3).

Distribution of the differences between EL2 and the different AAR measurements are given in Table 4. When the AAR mechanism's setting was 2, 1 and 0.5, the instrument tip was, respectively, 0.74, 0.38 and 0.12 mm shorter than EL2. Statistically significant differences were observed when comparing EL2 with AAR2 and with AAR1 (Table 5).

Discussion

The laboratory model used in this study was adapted from that used previously (Felippe & Soares 1994, Kobayashi & Suda 1994, Felippe *et al.* 1997, Alves *et al.* 2005). In the present study, EL measurements were obtained with the Apex LED; this device was set-up to detect the major foramen, which is a reference point that can be determined by direct inspection. In this way, there was no requirement to grind the root apex to visualize the tip of the instrument, as is the case when the constriction has to be located. Also, it was possible to use the same teeth to analyse the performance of the ROOT ZX II AAR function at different times, i.e. after root canal instrumentation and using different settings.

The tolerance limit of ±0.5 mm was employed because the relation between the needle-holder or rubber stop/reference point, rubber stop/ruler and file tip/ruler was difficult to control visually. In addition, the foramen has variable forms (Gutierrez & Aguayo 1995) and it was challenging to visualize the exact point where the tip of the file reached the cervical border of the foramen, even with magnification. In this way, differences of ±0.5 mm between DL and electronic measurements may have been caused by the experimental model, and not through lack of precision of the ROOT ZX II.

The results reveal no difference between tooth lengths obtained by direct and electronic methods. EL1 and EL2 measurements were coincident to DL in 86% and 83% of the cases, respectively. In previous studies, the ROOT ZX gave an 85–100% coincidence between direct and electronic measurements (Shabahang *et al.* 1996, Felippe *et al.* 1997, Pagavino *et al.* 1998, Ounsi & Naaman 1999). Campbell *et al.* (1998) when using the Tri Auto ZX reported that the average electronically measured length was 0.54 mm shorter than the visually measured length. Alves *et al.* (2005) evaluated the ability of Tri Auto ZX to locate the apical foramen during root canal retreatment and found that it was accurate to ± 0.5 mm in more than 80% of teeth.

The reliability of the ROOT ZX II to control the apical extent of rotary instrumentation was tested by its AAR function. In contrast to previous studies performed with Tri Auto ZX (Campbell *et al.* 1998, Pasternak Jr. 2000, Grimberg *et al.* 2002, Carneiro *et al.* 2006), the same teeth were used to test the AAR at different levels. In addition, the AAR measurements were compared with those obtained after rotary instrumentation (EL2).

Several studies have compared the Tri Auto ZX AAR length with electronic length obtained before rotary canal instrumentation (Campbell *et al.* 1998, Pasternak Jr. 2000, Grimberg *et al.* 2002). Carneiro *et al.* (2006) ground the last four apical millimetres of the roots, until exposure of the file, for measurement of the distance from instrument tip to the apical foramen.

In the present study, when the AAR function was activated, the instrument tip was shorter on average than the direct and electronically measured length. When the AAR mechanism was set to 0.5, 1.0 and 2.0, the instrument tip was, respectively, 0.12 mm, 0.38 mm and 0.74 mm shorter than EL2. These results are different from those obtained by other authors using the Tri Auto ZX (Table 6). Campbell *et al.* (1998) observed that when the AAR mechanism was set to 1.0, 1.5 and 2.0, the instrumented length was, respectively, 0.10 mm, 0.36 mm and 1.30 mm shorter than the electronically measured length. They found inconsistent results when it was set to 2.0. Pasternak Jr. (2000) demonstrated that the instrumented length at settings 0.5, 1.0, 1.5 and 2.0 were, respectively, 0.40 mm, 0.60 mm, 1.20 mm and 1.40 mm shorter than the electronically measured length. A study by Grimberg *et al.* (2002) reported that the electronic length measurements were coincident to AAR length in all instances. They observed that the AAR length provided by the Tri Auto ZX was shorter than the actual length in 60% of the treated cases (stereo microscope analysis). Carneiro *et al.* (2006) found that the mean distance from instrument tip to apical foramen at levels 1.0 and 2.0 was 0.67 mm and 1.38 mm, respectively.

Table 6 Results (mean in mm) obtained by authors using the AAR at different settings

	AAR2	AAR1.5	AAR1	AAR0.5
Present study	0.74	–	0.38	0.12
Campbell *et al.* (1998)	1.30	0.36	0.10	–
Pasternak Jr. (2000)	1.40	1.20	0.60	0.40
Grimberg *et al.* (2002)	–	–	–	0.50
Carneiro *et al.* (2006)	1.38	–	0.67	–

It is generally accepted that canal preparation and filling should be limited to the root canal (Holland *et al.* 1993, Ricucci 1998) remaining short of the apical constriction (Ricucci & Langeland 1998). Assuming that the distance between the apical constriction and the apical foramen ranges from 0.5 to 1 mm, the AAR feature set at 1 or 0.5 could in general consistently approximate and/or enlarge the apical constriction. Campbell *et al.* (1998) demonstrated that canal preparation with the AAR mechanism set at 1.0 frequently enlarged the constriction.

It seems that the AAR function should be used carefully as in this study, in 20 cases (30.8%), the AAR measurements were longer than EL2 (AAR2 = 2 cases, AAR1 = 6 cases and AAR0.5 = 12 cases) (Table 4).

The comparison of EL2 and AAR measurements indicated that they were more reliable when the reverse mechanism was set at 0.5 than when it was set at 1 and 2 (Table 5). This is in agreement with results of other authors (Campbell *et al.* 1998, Pasternak Jr. 2000). Carneiro *et al.* (2006) concluded that setting the reverse mechanism at 1 was more reliable than at 2.

According to the Tri Auto ZX operator's instructions, 'the handpiece automatically stops and reverses the rotation of the file when the tip reaches a distance from the apex preset by the clinician'. On the other hand, Kobayashi *et al.* (1997) stated that settings 1, 1.5 and 2 were arbitrary designations corresponding to increasing distances from the apical foramen, although not to particular millimetric values. Campbell *et al.* (1998) found that the 1, 1.5 and 2 settings corresponded to diverse distances from apical foramen. Considering that the device can use preset distances (in mm) from the apical foramen, Carneiro *et al.* (2006) concluded that the AAR mechanism was not sufficiently precise to reach the preset distance (1 and 2).

The present study corroborates the ROOT ZX II operator's instructions: 'the numbers 1, 2 and 3 do no represent length in millimeters'. Actually, it was observed that AAR2 and EL2 minus 2 mm were coincident only in four canals (6%); AAR1 and EL2 minus 1 mm were coincident in 14 canals (22%) and AAR0.5 and EL2 minus 0.5 mm were coincident in 13 canals (20%) (Table 4).

The position of the bar on the ROOT ZX II panel rather than the actual distance in millimetres of the file tip to the apical foramen indicates that the instrument tip is reaching the foramen. In this way, the apical extent of the instrumentation can be controlled avoiding overinstrumentation.

Conclusions

In this laboratory study, the ROOT ZX II was reliable when locating the apical foramen, but was not an accurate method to control the apical extent of rotary instrumentation. Rotary instrumentation with the automatic apical reverse feature set at level 0.5 was more reliable than at level 1 and 2.

References

Alves AMH, Felippe MCS, Felippe WT, Rocha MJC (2005) Ex vivo evaluation of the capacity of the Tri Auto ZX to locate the apical foramen during root canal retreatment. *International Endodontic Journal* **38**, 718–24.

Campbell D, Friedman S, Nguyen HQ, Kaufman A, Keila S (1998) Apical extent of rotary canal instrumentation with an apex locator handpiece *in vitro*. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **85**, 319–24.

Carneiro E, Bramante CM, Picoli F, Letra A, da Silva Neto UX, Menezes R (2006) Accuracy of root length determination using Tri Auto ZX and Protaper instruments: an *in vitro* study. *Journal of Endodontics* **32**, 142–4.

Felippe MCS, Soares IJ (1994) *In vitro* evaluation of an audiometric device in locating the apical foramen of teeth. *Endodontics and Dental Traumatology* **10**, 220–2.

Felippe MCS, Lucena M, Soares IJ (1997) Avaliação da precisão de um aparelho audiométrico na determinação do comprimento dos dentes. *Revista Brasileira de Odontologia* **54**, 53–5.

Grimberg F, Banegas G, Chiacchio L, Zmener O (2002) *In vivo* determination of root canal length: a preliminary report using the Tri Auto ZX apex-locating handpiece. *International Endodontic Journal* **35**, 590–3.

Gutierrez GJH, Aguayo P (1995) Apical foraminal openings in human teeth. Number and location. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **79**, 769–77.

Holland R, Otoboni Filho JA, Bernabe PFE, de Souza V, Nery MJ (1993) Healing process of dogs' pulpless teeth after apicoectomy and root canal filling at different levels. *Endodontics & Dental Traumatology* **9**, 8–12.

Hülsmann M, Peters OA, Dummer PMH (2005) Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics* **10**, 30–76.

Kobayashi C, Suda H (1994) New electronic canal measuring device based on the ratio method. *Journal of Endodontics* **20**, 111–4.

Kobayashi C, Yoshioka T, Suda H (1997) A new engine-driven canal preparation system with electronic canal measuring capability. *Journal of Endodontics* **23**, 751–4.

Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PM (2006) The fundamental operating principles of electronic root canal length measurements devices. *International Endodontic Journal* **39**, 595–609.

Ounsi HF, Naaman A (1999) *In vitro* evaluation of the reliability of the Root ZX electronic apex locator. *International Endodontic Journal* **32**, 120–3.

Pagavino G, Pace R, Baccetti T (1998) A SEM study of *in vivo* accuracy of the Root ZX electronic apex locator. *Journal of Endodontics* **24**, 438–41.

Pasternak Jr. B (2000) Avaliação da capacidade do Tri Auto ZX determinar o comprimento dos dentes e manter o comprimento de trabalho de modelagem, Thesis. Florianópolis, Brazil: Universidade Federal de Santa Catarina.

Plotino G, Grande NM, Brigante L, Lesti B, Somma F (2006) Ex vivo accuracy of three electronic apex locators: ROOT ZX, Elements Diagnostic Unit and Apex Locator and Propex. *International Endodontic Journal* **39**, 408–14.

Ricucci D (1998) Apical limit of root canal instrumentation and obturation, part 1. Literature review. *International Endodontic Journal* **31**, 384–93.

Ricucci D, Langeland K (1998) Apical limit of root canal instrumentation and obturation, part 2. A histological study. *International Endodontic Journal* **31**, 394–409.

Shabahang S, Goon WWY, Gluskin AH (1996) An *in vivo* evaluation of Root ZX electronic apex locator. *Journal of Endodontics* **22**, 616–8.

Williams CB, Joyce AP, Roberts S (2006) A comparison between *in vivo* radiographic working length determination and measurement after extraction. *Journal of Endodontics* **32**, 624–7.