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ORIGINAL RESEARCH

Accuracy of different electronic apex locators in determination of minimum Root perforation diameter

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Abstract

This study aims to evaluate the ability of Raypex 6, Propex Pixi, Dentaport ZX, Apex ID, Propex II and Dr.'s Finder NEO to detect minimum root canal perforation diameter. One hundred single-rooted, extracted human teeth were artificially perforated by 5 burs in different diameters (0.25–1.25 mm) in 5 mm above the apex. Twenty teeth were assigned to each group. The actual canal lengths (AL) were measured under stereomicroscope followed by a measurement of electronic canal length (EL) using each electronic apex locator (EAL). None of the EALs were able to detect the perforation at diameters of 0.50 and 0.25 mm. Although all EALs used in our study were unable to detect perforations at diameters of 0.5 mm and 0.25 mm, they were highly successful in the determination of simulated root perforations at diameters of 1.25, 1 and 0.75 mm.

KEYWORDS

apex locator, EAL, perforation, root canal

INTRODUCTION

Electronic apex locators (EALs) are used as a reliable device in determining the working length during endodontic treatment. They are also used in cases of retreatment with apical resection, localisation of horizontal and oblique root fractures and the detection of root canal perforations [1].

The unnatural pathway between the root canal system and periodontal tissue is defined as a root perforation [2]. Iatrogenic perforations are the most common cause of root perforations, with a range of 3% to as high as 10%. Deep caries and various resorptive processes may also cause these perforations [3]. Accurate detection of perforation is of utmost importance for the long-term prognosis, as it prevents over-instrumentation during the root canal treatment and minimises the risks of extrusion of irritating materials, including irrigation solutions, sealers or debris, into the surrounding tissues [4].

These perforations can be detected by various methods. Direct observation of bleeding during instrumentation from the root canal and indirect assessment of bleeding using paper points, radiographic methods using different angulations, and electronic apex locators (EALs) are among these methods [4]. The limitation of a radiograph is the possible incorrect localisation of perforation in which the perforation area is located on the buccal or palatal surface or superimposed situations due to the anatomical structures or radiopaque materials [2]. Recently, cone-beam computed tomography (CBCT) images were suggested, as they provide a three-dimensional imaging for endodontic cases where the conventional radiographs are not sufficient [5]. However, there are also some limitations of CBCT imaging. The quality of images is affected by voxel size and the artefacts as result of movement of patient during scanning or radiopaque materials, such as root canal filling materials, metal posts and restorations [6].

As the file reaches the perforation area, the signal is received from EAL as if the endodontic file tip is in contact with periodontal tissue. The perforation area can therefore be easily localised. Modern EALs use two or more

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different frequencies in order to measure alternating current impedances. Unlike previous EALs, they give accurate results under various conditions with different irrigation solutions [7]. Raypex 6, Propex Pixi, Propex II and Dr.'s Finder NEO are the new generation multi-frequency apex locators [8]. Propex Pixi measures the square root of the impedances of two different frequencies to determine the working length [8]. Propex II measures the capacitance and resistance of the circuit separately. It determines the energy of a signal with multiple frequencies instead of using the amplitude of the signal [9]. Dr.'s Finder NEO uses 3 different frequencies for exact accuracy. The accuracy of Dentaport ZX has been assessed in previous studies [8, 9]. This EAL uses two different frequencies simultaneously in the same canal to calculate the ratio of impedance value [10, 11]. Apex ID has the same mechanism of action as Root ZX but uses the different frequencies [12].

To our knowledge, there are many studies about the accuracy of different EALs in locating root canal perforations; however, there is no published study evaluating the detection of minimum root canal perforation size with EALs. This study aims to demonstrate the accuracy of different EALs (Raypex 6 [VDW], Propex Pixi [Dentsply Maillefer], Dentaport ZX [J. Morita], Apex ID [SybronEndo], Propex II [PRO; Dentsply Maillefer], Dr.'s Finder NEO [Good Doctors]) in determining minimum root perforation diameter.

The null hypothesis was that the perforation diameter does not affect the accuracy of aforementioned six EALs in the determination of root canal perforations.

MATERIALS AND METHODS

The Clinical Research Ethics Committee of Akdeniz University in Antalya, Turkey reviewed and approved the study design (decision number 2012-KAEK-20). The G*Power 3.1.9.7 program was used in determining the sample size. The minimum number of samples for each group in the 6x5 two-way ANOVA design was 12, with 80% power, 0.25 effect size and 0.05 alpha value. Due to possible experimental errors that may occur, the number of samples for each group was determined as 20. One hundred single-rooted, extracted human mandibular premolars that contained only a single canal were chosen for the study. Roots with open apices, fractures, resorption or previous endodontic treatment were excluded. Removal of soft tissue remnants and calculus from the root surfaces was performed using periodontal curettes. The teeth were submerged in 2.5% sodium hypochlorite (NaOCl) solution for 2 h before being stored in 0.9% sterile saline solution to prevent dehydration until further use.

To ensure easier access to the canal orifice and to obtain a fixed point of reference during all measurements, each tooth was decoronated at the cementoenamel junction with 15 mm working length by a diamond fissure bur. A proper barbed broach (VDW GmbH) was used for the removal of the canal contents. A size 10 K-file was advanced into the root canal system to ensure the patency and presence of the apical foramen opening, and apical preparation was made up to a size 15 K-file (Dentsply Maillefer). For standardisation of root canal width, the canals were irrigated with 2.5 ml 2.5% NaOCl solution before their preparation with ProTaper X1 (PTN, Dentsply, Maillefer). Subsequently, 2.5 ml 2.5% NaOCl was used to remove dentin debris, and 2.5 ml sterile 0.9% saline was used to eliminate the prolonged effect of NaOCl. After the external root surfaces were marked with an acetate pen in order to determine the localisation of perforation area, which was placed at 5 mm above the apex, the teeth were randomly divided into 5 groups according to perforation diameter ($n = 20$).

The diameters of the diamond burs used for creation of perforations were checked with a digital calliper. Afterwards, artificial perforation of the roots was performed in the areas marked on the external lateral root surfaces with diamond burs, which were perpendicularly directed to the long axis of the root under water cooling. An attempt was made to prevent differences in perforation size due to attrition in diamond burs by using a new bur every 5 samples. Perforation diameters were determined as 1.25 mm for Group 1, 1.00 mm for Group 2, 0.75 mm for Group 3, 0.50 mm for Group 4 and 0.25 mm for Group 5.

The actual lengths (ALs) were measured from the cementoenamel junction to the coronal margin of the perforation site. To calculate the ALs, the distances from the rubber stop to the tip of a size 20 K-file (Dentsply Maillefer), which had been detected with a stereomicroscope (Stemi DV4; Carl Zeiss) with a 15X magnification at the perforation area, were measured. Then, according to the model formed by Katz et al.[13], plastic boxes that were filled with freshly mixed alginate were used to embed the perforated roots up to the cervical region (Figure 1). Subsequently, EALs were operated in the presence of sterile 0.9% saline solution to measure the perforation sites electronically. A size 40 K-file was held with the file holder of the EAL, and the lip clip was placed in contact with alginate mould. The size 40 K-file was advanced through each root canal until the '0.0' signal for Dentaport ZX, Apex ID, Propex Pixi and Dr.'s Finder NEO, the 'red bar' for Raypex 6 and the 'Apex' signal for Propex II were seen on the screens of the devices. After these signals had remained constant for 5 s, electronic lengths (ELs) were recorded. This process was repeated 3 times for all teeth with each EAL. The same operator, who was experienced in using EALs were performed the measurements for all the teeth.

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After calculations were made by subtracting AL from EL to determine the differences, negative and positive values highlighted that measurements made by EALs were short and long of the AL, respectively. A value of 0 indicated a coinciding measurement. SPSS 20.0 (SPSS Inc) was used to perform the statistical evaluations. A two-way ANOVA test was used for the analysis of the data with a significance level of 0.05. Bonferroni correction was used in pairwise comparisons using standard statistical software.

RESULTS

The mean difference between the EL and AL, with the standard deviation (SD) values for each EAL for each perforation diameter, are shown in Table 1. There was no significant difference among all EALs used in this study in Group 1 and Group 2 ($p > 0.05$). In Group 3, Apex ID was unable to localise the perforations, and Propex Pixi was significantly more successful than Dentaport ZX ($p < 0.05$). None of the

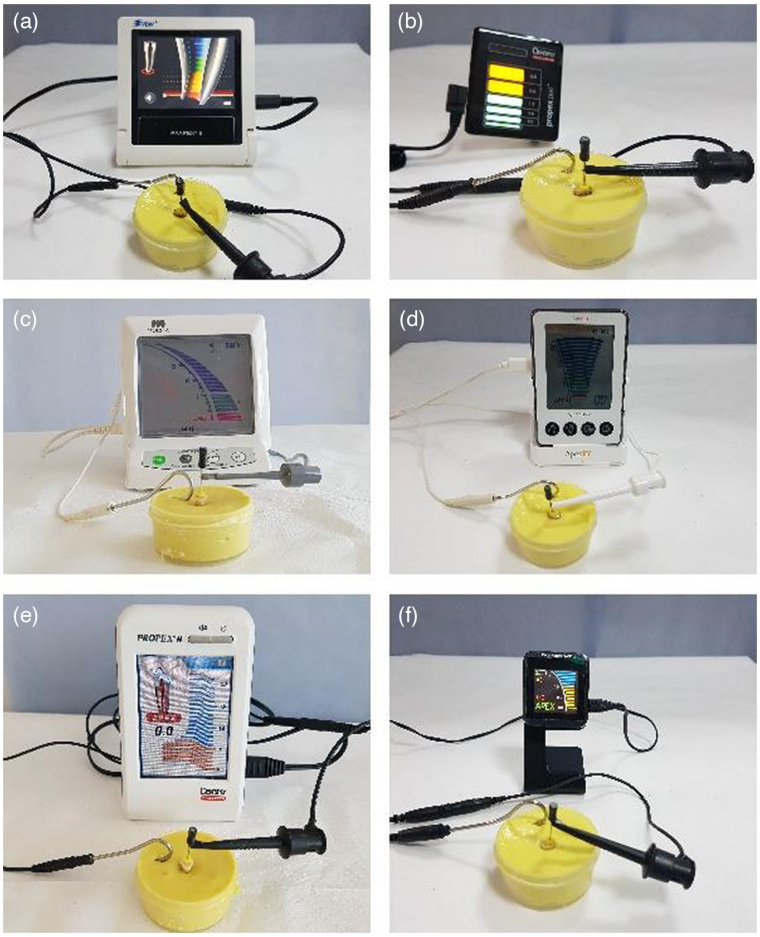


FIGURE 1 Number 40 K-file inserted into the canal during electronic measurement until (a) 'red area' on the screen of Raypex 6 (b) '0.0' reading on the screen of the Propex Pixi (c) 'apex' reading on the screen of Dentaport ZX (d) 'apex' reading on the screen of apex ID (e) 'apex' reading on the screen of Propex II (f) 'apex' reading on the screen of Dr.'s finder NEO were seen.

TABLE 1 Mean value with the standard deviation (SD) of the difference between EL and AL of the perforation for each EAL in different perforation diameters (mm)

	Perforation diameter		
EAL	**Group 1 (1.25 mm) (mean ± SD)**	**Group 2 (1.00 mm) (mean ± SD)**	**Group 3 (0.75 mm) (mean ± SD)**
Raypex 6	0.025 ± 0.34 Ba	0.1 ± 0.44 ABa	0.3 ± 0.47 Aab
Propex Pixi	0.05 ± 0.27 Aa	0.075 ± 0.43 Aa	0.25 ± 0.41 Ab
Dentaport ZX	0.05 ± 0.42 Ba	0.42 ± 0.29 Aa	0.62 ± 0.45 Aa
Apex ID	0.175 ± 0.43 Aa	0.15 ± 0.36 Aa	-
Propex II	0.175 ± 0.49 Ca	0.15 ± 0.28 Ba	0.47 ± 0.54 Aab
Dr.'s Finder NEO	0.075 ± 0.33 Ba	0.05 ± 0.22 Ba	0.45 ± 0.48 ABab

Note: Different uppercase letters in the same row indicate a statistically significant difference ($p < 0.05$).Different lowercase letters in the same column indicate a statistically significant difference ($p < 0.05$). Group 4 and Group 5 were not indicated in the table because none of the EALs were able to detect the perforation area in these groups according to the determined criteria.

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EALs were able to detect the perforation area in Group 4 or Group 5 according to the determined criteria. The distributions of measurements obtained from the EALs at Group 1, Group 2 and Group 3 are presented in Tables 2–4.

The efficiency of each device in terms of perforation detection was examined according to the perforation diameters. Raypex 6 showed higher accuracy in Group 1 than in Group 3. There was no significant difference among Group 1, Group 2 and Group 3 for Propex Pixi ($p > 0.05$). Dentaport ZX had the highest accuracy level in Group 1, while no significant difference was found between Group 2 and Group 3 ($p < 0.05$). For Apex ID, there was no significant difference between Group 1 and Group 2 ($p > 0.05$). There were significant differences among Group 1, Group 2 and Group 3 for Propex II, and the success order was Group 1 > Group 2 > Group 3 ($p < 0.05$). The lowest precision values were observed in Group 3 for Dr.'s Finder NEO, and these values were significantly lower than in Groups 1 and 2 ($p < 0.05$). No statistically significant difference was found between Group 1 and Group 2 ($p > 0.05$).

The success rates of EALs were shown in detail in Tables 2–4. The following data was obtained for detection of a perforation area when the tolerance range was accepted as ±0.5 mm. For Raypex 6, the success rates were 100%, 90% and 80% for Group 1, Group 2 and Group 3, respectively. For Propex Pixi, the success rates were 100%, 90% and 90% for Group 1, Group 2 and Group 3, respectively. For Dentaport ZX, the success rates were 95%,

TABLE 2 Distribution of the difference between EL and AL for Group 1 (1.25 mm) according to different reference intervals

Distance between EL and AL (mm)	Raypex 6		Propex Pixi		Dentaport ZX		Apex ID		Propex II		Dr.'s finder NEO	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
<−0.51[a]	0	0	0	0	0	0	1	5	3	15	0	0
−0.5 to (−0.01)[a]	5	25	2	10	5	25	1	5	5	25	3	15
0.00	11	55	14	70	9	45	9	45	8	40	11	55
0.01 to 0.50	4	20	4	20	5	25	8	40	4	20	6	30
>0.51	0	0	0	0	1	5	1	5	0	0	0	0

[a]Negative value indicates short (or coronal) file position in relation to the apical foramen.

TABLE 3 Distribution of the difference between EL and AL for Group 2 (1.00 mm) according to different reference intervals

Distance between EL and AL (mm)	Raypex 6		Propex Pixi		Dentaport ZX		Apex ID		Propex II		Dr.'s Finder NEO	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
<−0.51[a]	0	0	0	0	0	0	0	0	0	0	0	0
−0.5 to (−0.01)[a]	4	20	4	20	0	0	1	5	0	0	1	5
0.00	10	50	11	55	5	25	13	65	15	75	16	80
0.01 to 0.50	4	20	3	15	13	65	3	15	4	20	3	15
>0.51	2	10	2	10	2	10	2	10	1	5	0	0

[a]Negative value indicates short (or coronal) file position in relation to the apical foramen.

TABLE 4 Distribution of the difference between EL and AL for Group 3 (0.75 mm) according to different reference intervals

Distance between EL and AL (mm)	Raypex 6		Propex Pixi		Dentaport ZX		Apex ID		Propex II		Dr.'s Finder NEO	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
<−0.51[a]	1	5	0	0	0	0	0	0	0	0	0	0
−0.5 to (−0.01)[a]	0	0	2	10	1	5	0	0	2	10	1	5
0.00	8	40	8	40	2	10	1	5	5	25	4	20
0.01 to 0.50	8	40	8	40	9	45	2	10	6	30	8	40
>0.51	3	15	2	10	8	40	0	0	7	35	6	30

[a]Negative value indicates short (or coronal) file position in relation to the apical foramen.

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90% and 60% for Group 1, Group 2 and Group 3, respectively. For Apex ID, the success rates were 90% and 90% for Group 1 and Group 2, respectively. For Propex II, the success rates were 85%, 95% and 65% for Group 1, Group 2 and Group 3, respectively. For Dr.'s Finder NEO, the success rates were 100%, 100% and 70% for Group 1, Group 2 and Group 3, respectively.

DISCUSSION

Successful treatment of root canal perforations and prognoses for affected teeth depend on the location and size of the perforation area, the time between the onset of perforation and treatment, the determination of the exact location of the perforation and the ability to seal the perforation area with endodontic treatment [14]. The diagnosis of perforations that occur on lingual or buccal root surfaces can be quite difficult, even for experienced endodontists, due to reasons such as superposition of anatomical structures with 2D conventional radiographic methods [15].

Recently, clinicians have suggested that cone-beam computed tomography (CBCT) images already taken for other procedures can be used in determining the working length during root canal treatment. However, the deficiencies of CBCT images in teeth with endodontic treatment and the detection of root fractures constitute the limitations of CBCT [6, 16]. Given that these limitations have some unwanted effects on the prognosis of the tooth and bone tissue, immediate detection of root perforations is of utmost importance [16].

It has been previously suggested that the location of major and minor apical foramen, apical root resorption and horizontal root fractures can be determined with EAL [4, 17–19]. In addition, the accuracy of EALs in locating root canal perforations has been tested under in vitro conditions, and the results have shown that EALs are a clinically acceptable method to detect root canal perforations [16, 20, 21]. In our study, one hundred extracted lower premolar teeth were artificially perforated on the lateral root surfaces with different perforation diameters (1.25, 1.00, 0.75, 0.50 and 0.25 mm). All teeth were then embedded in the alginate model to evaluate the accuracy of EALs in the determination of minimum root perforation diameter.

In previous studies, various electro-conductive materials such as alginate, agar-agar, saline solution and gelatin were used for in vitro evaluation of EALs [16, 21–23]. In this study, alginate was used as an embedding mould because of its easy manipulation, proper electroconductivity, high elasticity and viscosity. It can wrap and adapt to the root surface tightly for simulating the periodontal tissue quite well [24].

Manufacturers recommend using the largest file that can reach apical constriction to measure working length. Herrera et al.[25] stated that although small files are routinely used to determine the working length, accuracy of EALs might be influenced by file size, as slim files leave empty space within root canals, especially in wider canals. On the other hand, the effects of hand file sizes (#8, #10 and #15) on the result of electronic measurement were investigated, and it was found that the file size did not affect the accuracy of EALs [26, 27]. In addition, it has been shown the use of nickel–titanium files or stainless-steel files does not affect the accuracy of EALs to determine the working length [9, 28]. In accordance with the manufacturer's instructions, a size 40 stainless-steel K-file, which has the best adaptation to the root canal when the perforation area is reached, was used in electronic measurements in this study.

Numerous studies investigating the accuracy of EALs in detecting apical foramen have been reported that large apical diameters may affect the measurements of EALs [29, 30]. Venturi et al.[31] indicated a clear relationship between apical foramen diameter and working length accuracy, showing that 11.3% of the measurements they obtained were ahead of apical foramen, and 85.3% of these results belonged to teeth with an apical foramen diameter of 0.40 and 0.60 mm. A study by Sübay et al.[32] highlighted that as the apical foramen diameter increased, the number of results obtained from the EALs beyond the apical foramen increased. They indicated that Propex II has higher accuracy than Raypex 6 and Root ZX in diameters of 0.15–0.60 mm [32]. In another study, it was shown that apical foramen diameter did not affect the accuracy of Root ZX II, while Propex II had more accurate results in diameters of 0.25 mm than wider foramen sizes [33]. Although there have been many studies evaluating the effect of apical foramen diameter on the success of EALs, there was only one study evaluating the accuracy of EALs in detecting different size of root perforations [20].

In previous studies evaluating the detection of perforations with EALs, perforation sizes were 1, 0.60, 0.40, 0.30 and 0.27 mm. Fuss et al.[34] reported that the results were clinically acceptable for the Sono Explorer III and Apit (Endex) devices for a perforation diameter of 0.27 mm created by a #25 engine plugger. In another study [20], perforations with diameters of 0.55–0.6 mm and 0.25–0.4 mm were created with #25 and #30 spreaders, respectively. A significant difference was not indicated, but it was shown that Root ZX has a higher accuracy than Sono Explorer III ve Apit. On the contrary, EALs were not successful in determining the perforation size of 0.50 and 0.25 mm in the present study. These results, which are inconsistent with those of the present study, can be explained by the different tooth

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morphologies used in the experiment and by the use of transportation as the perforation technique. In these previous studies [20, 34] strip perforation was simulated. On the other hand, in this study it was aimed to simulate external root resorption with root canal perforation which caused to preferred different perforation technique. In our study, artificial perforations of the roots were performed in the areas marked on the external root surfaces with diamond burs perpendicularly directed to the long axis of roots to achieve an equal perforation diameter on both surfaces. In addition, we used a new bur in every five samples to prevent changes in diameter due to friction of burs. To avoid the differences in perforation diameter that may be caused by varying dentin thicknesses, we preferred to use the mesial or distal root surfaces instead of the buccal or lingual root surfaces to create perforation areas, as described in a previous study [23].

The effect of irrigation solutions on the accuracy of EALs has been evaluated in many studies, and the general belief is that root canal conditions affect accuracy of EALs [4, 23, 35]. Shin et al.[23] investigated the effects of liquid-form and gel-form irrigants on perforation detection with Root ZX. It was shown that the device's accuracy in locating root perforations was higher in liquid-form irrigants than in gel-form. Researchers explained this situation in the simulated perforation areas by the fact that the good flow of liquid-form irrigants better enabled them to reach the outer lateral surface of the root [23]. Altunbaş et al.[4] revealed that the most accurate result in determining perforation was obtained when the root canals were dry. Although the root canal perforations were detected by both devices within a clinically acceptable range in the presence of NaCl, NaOCl and EDTA, the Dentaport ZX provided more accurate results than the Rootor [4]. Another study by Khatri et al.[36] indicated that Vdw gold (GmbH) presented better results than iPex in locating root perforation in dry condition. They found that in the presence of 2% CHX, EALs were able to accurately determine the perforation area, but in the presence of 3% NaOCl, both EALs showed significantly different results than the actual length determined under the stereomicroscope [36]. Considering all these studies, we used saline solution during electronic measurements in order to ensure electro-conductivity between the alginate and the root canal.

Iatrogenic perforations often occur when preparing the post cavity or placing the post after root canal treatment. Traditional approaches on placing post restorations are centred around achieving good width and length for the post, which induces the risk of apical and strip perforation. Marroquin et al.[22] created perforation areas located at mesiolingual canals to place metal posts, and they connected EALs to metal posts to detect root perforations. They recommended the use of an EALs to diagnose root perforations occurring during metal post placement, with high specificity and sensitivity and inter-device agreements [22].

In the previous studies evaluating both the determination of working length or root perforation, ±0.5 mm tolerance was clinically accepted [4, 16, 23]. Thus, for perforation diameters <1 mm, it can be said that the success rate of the accuracy of EALs decreases as the perforation diameter gets narrower.

The study has some limitations that derive from its being an in vitro experiment, as the EALs were not in contact with living tissue, electro-conductive fluids such as blood and saliva were absent, and the electrical resistance of the periodontal ligament was different from that of the alginate impression material.

CONCLUSION

Considering the results from this study, it can be concluded that all devices used in this study detected root canal perforations within a clinically acceptable range in perforation diameters of 1.25 and 1.00 mm. Although Apex ID could not detect the perforation area in Group 3, the other devices had successful results, especially Propex Pixi. In Group 4 and Group 5, in which the perforation diameters were narrowest, none of the EALs could detect perforations within the criteria set in the study, indicating that the accuracy of EALs were affected by the diameter of perforation.

AUTHOR CONTRIBUTIONS

All authors have contributed the manuscript equally and are in agreement with the manuscript.

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CONFLICT OF INTEREST

The authors have no declared financial interest in any company manufacturing the types of products mentioned in this article.

ETHICAL APPROVAL

The Clinical Research Ethics Committee of Akdeniz University in Antalya, Turkey reviewed and approved the study design (decision number 2012-KAEK-20).

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