ACTA
STOMATOLOGICA
CROATICA
www.ascro.net

Acta Stomatol Croat. 2007;41(1):49-56.

IZVORNI ZNANSTVENI RAD
ORIGINAL SCIENTIFIC PAPER

Lumnije Kqiku[1], Veton Hoxha[2], Peter Städtler[1]

Određivanje radne duljine s trima različitim endometrima

Determination of Working Length with Three Different Apex Locators

[1] Zavod za konzervativnu stomatologiju Sveučilišne stomatološke klinike, Graz, Austria
Department of Conservative Dentistry, University Dental Clinic, Graz, Austria
[2] Zavod za konzervativnu stomatologiju i endodonciju Sveučilišne stomatološke klinike, Priština, Kosovo
Department of Conservative Dentistry and Endodontics, University Dental Clinic, Prishtina, Kosova

Sažetak
Svrha je istraživanja ispitati točnosti triju različitih endometara. Za to se koristilo ukupno 20 ekstrahirnih jednokorijenskih ljudskih zuba. Svi su postavljeni u alginatni model (Alginate Plus, Henry Schein, Melville, NY SAD) za elektronično određivanje radne duljine endometrom. Elektronička duljina izmjerena je trima različitim endometrima: Propex Apex Locatorom (Dentsply/Maillefer, Montigny le Bretonneux, Švicarska), Root ZX-om (Morita Europe, Dietzenbach, Njemačka) i Elements Diagnostic Unit Apex Locatorom (Sybron Endo, Glendora, California, SAD) te uporabom endodontskog proširivača (K file) broj15 (VDW GmbH, Munich, Njemačka). Nakon toga određena je i radiografska radna duljina - u kanal je postavljen proširivač broj 15 te oduzet 1 mm od samog apeksa. Svaki je korijenski kanal pripremljen u apikalnoj trećini korijena i zatim je stereomikroskopom analizirana udaljenost između točaka na instrumentu i apikalnog foramena. Dobiveni rezultati statistički su analizirani metodom ANOVA na programu SPSS 11,0. Nije bilo znatnih razlika između različitih korištenih endometara i rendgenske kontrole. U ovom je istraživanju dokazano da elektroničko mjerenje radne duljine različitim endometrima daje iste rezultate kao i određivanje duljine kanala rendgenskom kontrolom.

Zaprimljen: 15. siječnja 2007.
Prihvaćen: 21. veljače 2007.

Adresa za dopisivanje
Univ. prof. dr. P. Städtler
University Dental Clinic
Department of Conservative Dentistry
Auenbruggerplatz 6a
A-8036 Graz
Tel.: ++43-316-385-2213
Fax: ++43-316-385-3375
peter.stadtler@meduni-graz.at

Ključne riječi
endodoncija; korijenski kanal; zubni instrumentarij

Uvod

Ispravno određivanje radne duljine važan je čimbenik koji utječe na ishod liječenja korijenskih kanala (1-3). Određivanje duljine korijenskog kanala često se obavlja rendgenskim metodama ili endometrima (4). Električni otpor između periodontnog ligamenta i membrane oralne sluznice opisao je Sunada godine 1962. (5).

Endometri bi trebali omogućiti precizno određivanje radne duljine ili fiziološkog foramena. Razmak između fiziološkog i anatomskog foramena korijenskih kanala varira između 0,5mm i 1 mm (6-8). Mjerenje kvocijenta impedencije dviju ili nekoliko

Introduction

Accurate working length determination is a crucial factor that influences the outcome of root canal therapy (1-3). Root canal length determination is commonly performed using radiographic methods or apex locators (4).The electrical resistance between the periodontal ligament and the oral mucous membrane was described by Sunada in 1962 (5).

Apex locators should facilitate accurate working length determination or physiological foramen location. The distance from physiologic foramen to anatomic foramen of the root canal ranges from 0.5 mm to 1 mm (6-8).By measuring the impedance quotient

frekvencija novim suvremenim uređajima za elektroničko mjerenje duljine korijenskih kanala, smanjilo je broj dijagnostičkih rendgenskih snimanja. Ako se primjenjivao endometar bez rendgena, nije bilo podataka o zakrivljenosti i usmjerenosti korijenskog kanala. Prva i druga generacija endometara izmjerile su otpor između dviju elektroda koristeći se jednom frekvencijom - bili su to endometri jednofrekvencijskog tipa impedencije (Tablica 1.). Nisu bili ni stabilni ni točni u kanalu napunjenom elektrolitom (9). Treća generacija endometara služi se višestrukim frekvencijama u određivanju radne duljine (Tablica 1.). Ti uređaji pokazali su da se precizna mjerenja mogu obaviti ako ima elektrolita, s točnošću između 85% i 95% (10-12). Te jedinice imaju snažne mikroprocesore i sposobni su obraditi matematički kvocijent i algoritamske izračune kako bi se dobila precizna očitanja (13). Endometri četvrte generacije potanko su ispitivani in vitro primjenom različitih sredstava, kao što su: agar, želatina, ili alginat te različitim kanalnim tekućinama (14-18).

U istraživanju se, za ispitivanje in vitro, koristio alginatni model. Svrha tog istraživanja ex vivo bila je odrediti radne duljine s trima različitim elektroničkim uređajima te usporediti dobivene podatke s iznosima radnih duljina izmjerenima rendgenskom metodom.

of two or several frequencies with modern new devices for electronic canal length measurement, the number of diagnostic radiographs is reduced. Apex locators used alone without the radiographic method cannot give any information about the curvature and direction of the root canal. The first and the second generation of apex locators measured resistance between the two electrodes used a single frequency; they were the single frequency impedance type (Table 1). They were not stable and accurate in a canal filled with a strong electrolyte (9).The third generation of apex locators used multiple frequencies to determine the working length determination (Table 1). Third-generation devices have shown that accurate measurements could be obtained even in the presence of electrolytes, and with accuracy between 85% and 95% (10-12). These units have more powerful microprocessors and are able to process the mathematical quotient and algorithm calculations required to give accurate readings (13). The fourth-generation apex locators are based on the new multi-frequency principle and measured directly and independently during use (Table 1). Apex locators have been widely studied in vitro using different mediums, such as agar, gelatin, or alginate and in the presence of various canal fluids (14-18).

In this study alginat model was used for testing of apex locators in vitro. The purpose of the present ex vivo study was the determination of working length with three different electronic devices and then compared with radiological measurements of root canal length.

Tablica 1. Generacija endometara
Table 1 Generation of apex locators

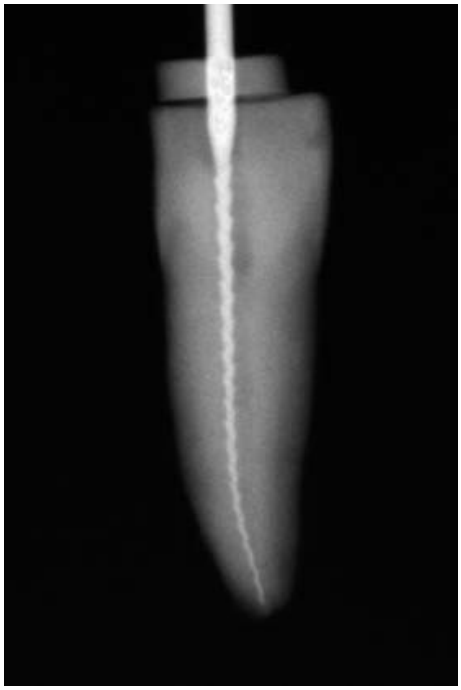
Generacija • Generation	Endometar • Apex locator	Tvrtka • Firma
Prva generacija • The first generation	Root Canal Meter Dentometer Endo Radar	Onuki Medical Co, Tokyo Japan Dahlin Electromedicine, Copenhagen, Danska • Denmark Eletronica Liarre, Imola, Italija • Italy
Druga generacija • The second generation	Sono Explorer Endocater Endo Analyzer Formatron IV	Hayashi Dental Supply, Tokyo, Japan Yamaura Seisokushu, Tokyo, Japan Analytic/Endo, Orange,CA, SAD • USA Parkell Dental,Farmingdale, NY, SAD • USA
Treća generacija • The third generation	Endex Apit Justy II Root ZX Neosono UltimaEZ AFA Apex Finder	Osada Electric Co., Los Angeles, CA, SAD • USA Osada Electric Co., Ltd., Tokyo, Japan Yoshida Co., Tokyo, Japan J Morita Corp., Tokyo, Japan Satelec Inc.,Mount Laurel, NJ, SAD • USA Analytic Technology, Orange, CA, SAD • USA
Četvrta generacija • The fourth generation	Bingo 1020 ProPex Raypex Elements Diagnostic Unit	Forum Engineering Technologies, Rishon Lezion, Izrael • Israel Densply Maillefer, Ballaigues, Švicarska • Switzerland VDW GmbH, Munich, Njemačka • Germany Sybron Endo, Glendora, California, SAD • USA

Materijali i metode

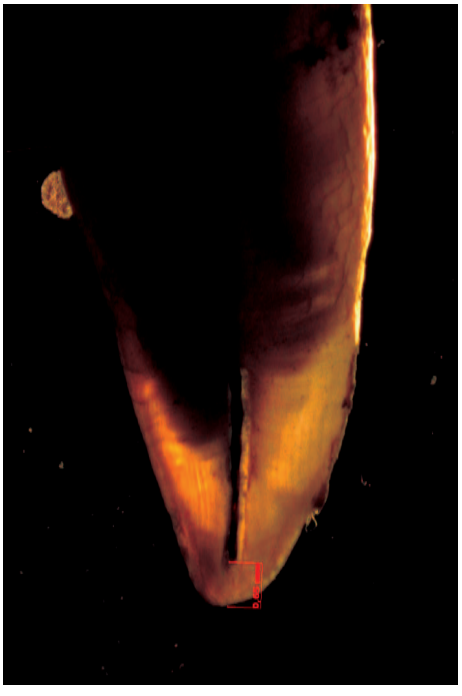
Ekstrahirano je ukupno 20 jednokorijenskih trajnih zuba sa zrelim korijenskim vrhovima. Prije ispitivanja zubi su bili pohranjeni u 10-postotnoj formalinskoj otopini, zatim dva tjedna u 3-postotnom natrijevu hipokloritu, kako bi ih se očistilo od suvišnih tkiva i kalkulsa. Stardardan je pristupni kavitet prepariran fisurnim svrdlom ()()()() velike brzine i vodom. Pulpno je tkivo uklonjeno žičanom strugalicom. Zubi su položeni u alginatni model (Alginate Plus, Henry Schein, Melville, NY SAD) kako bi se endometar ispitivao in vitro (19). Alginat je pretočen u plastičnu kutiju, zubi su položeni u nju te je u materijal umetnuta kvačica elektrode. Kod svih je endometara kanalni proširivač (K file) prikopčan kvačicom veličine 15 prema ISO sustavu. Prije nego što su se koristili elektronički uređaji kanali su isprani 3-postotnom otopinom natrijeva hipoklorita te dobro osušeni papirnatim stošcem - paper pointom (VDW GmbH, Munich, Njemačka). Nakon elektroničkih mjerenja duljine kanala, instrument je obilježen silikonskim stopom i zatim je obavljeno mjerenje milimetarskom ljestvicom. U rendgenskoj kontroli radne duljine koristio se digitalni rendgenski sustav (Sirona Dental Systems GmbH, Bensheim, Njemačka) – postavio se proširivač broj 15 u kanal do apeksa te oduzeo 1mm od izmjerene vrijednosti te se zatim sve proučavalo na zaslonu računala (Slika 1.).

Materials and methods

A total of 20 extracted single rooted permanent teeth with mature apices were selected. Before the tests, the teeth were stored in a formalin solution 10% then stored in 3% sodium hypochlorite for 2 weeks, to clean off extraneous tissue and calculus. A standard access cavity was prepared with a high - speed fissure bur and water. The pulp tissue was removed with a barbed broach. The teeth were embedded in an alginate (Alginate Plus, Henry Schein, Melville, NY USA) model to test apex locator in vitro (19). The alginate was poured into a plastic box, the teeth were embedded and the lip clip electrode was inserted into the material. All the electronic apex locators were clipped to an ISO 15 K-file. Before using the electronic devices, the canals were rinsed with 3% NaOCL and relatively dried with a paper point (VDW GmbH, Munich, Germany). After the electronic measurement of the canal length, the instrument was marked with a silicon stop and measured using a millimetre scale. As control the working length was determined radiographically with a digital radiographic system (Sirona Dental Systems GmbH, Bensheim, Germany) by placing a size 15 file to the apex, then subtracting 1 mm from this measurement, and then studying this image on a computer screen (Fig 1).



Slika 1. Rendgensko određivanje radne duljine
Figure 1 Radiographic working length determination



Slika 2. Presjeci zuba u apikalnoj trećini. Razmak između proširivača i apeksa
Figure 2 Sectioned root teeth in the apical third. Distance between file and apex

Svaki je korijenski kanal bio prepariran u apikalnoj trećini te se stereomikroskopom (Carl Zeiss GmbH, Vienna, Austrija) proučavala udaljenost između vrha instrumenta i unutarnjeg foramena električnom i rendgenski određenom radnom duljinom (Slika 2.). Rezultati su nakon toga statistički analizirani metodom ANOVA uz program SPSS 11,0.

Rezultati

Slika 3. predstavlja smještaj endodontskog instrumenta u apikalnom foramenu tijekom elektroničkog linearnog mjerenja. Boxplot pokazuje (Slika 4. i 5.) rezultate određivanja radne duljine endometrima i rendgenskom kontrolom. Mjerila se preciznost slična u svim endometrima: s obzirom na postotak udaljenosti vrijednosti izmjerenih do apikalnog foramena nije dokazana znatna razlika među uređajima. Određivanje radne duljine obavljeno je ± 0,5 mm kod svakog slučaja: Root ZX-om u 78,8%, u 71,3% s endometrom Element Diagnostic Unit te u 74,4% Propexom (Slika 6.).

Elektroničko i rendgensko određivanje radne duljine

Elektonički određena radna duljina nije se znatno razlikovala od radne duljine dobivene rendgenskom kontrolom ($p > 0,05$). Stereomikroskopska analiza pokazala je da su radne duljine izmjerene elektroničkim endometrom u 74,8% slučajeva ± 0,5 mm od apikalnog foramena, a u 90% slučajeva ± 0,5 mm kod rendgenske kontrolne metode određivanja radne duljine (Slika7.).

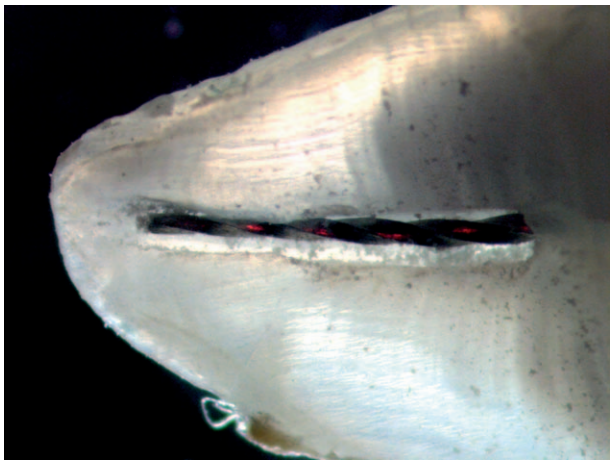
Each root canal was prepared in the apical third and the distance between instrument tip and internal apical foramen was examined under a stereomicroscope (Carl Zeiss GmbH, Vienna, Austria) followed by comparison with electric and radiographic working length determination (Fig. 2). The results were subjected to statistical analysis with ANOVA using the SPSS 11.0 program.

Results

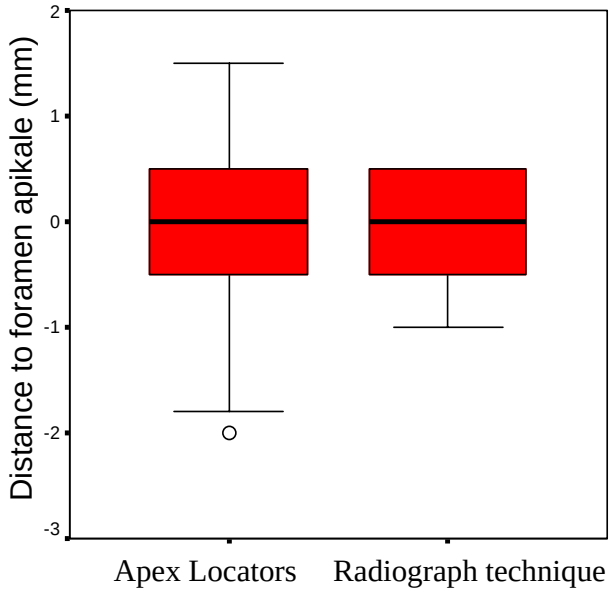
Fig. 3 represents the situation of the root canal instrument to the apical foramen during the electronic linear measurement. The Boxplot shows (Fig 4-5) the results of working length determination with apex locators and radiographic control. The measuring accuracy was similar in all apex locators: regarding the percentage of the measurements of the distance to the apical foramen, no significant differences between the devices were found. The working length determination was assessed within ± 0.5 mm of the apical foramen in all cases: with Root ZX in 78.8% of all cases, in 71.3% of all cases with Element Diagnostic Unit apex locator and in 74.4% of all cases using Propex (Fig.6).

Electronic vs. radiological working length measurement

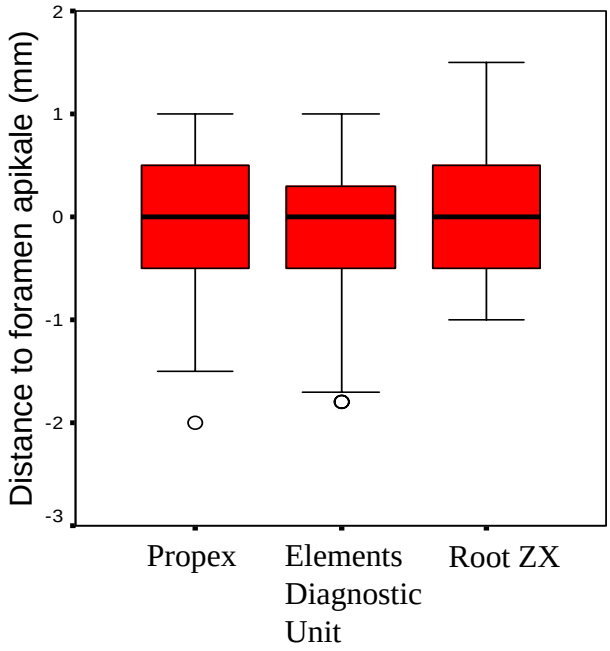
The electronically determined working length did not significantly differ from the radiographic control working length determination ($p > 0.05$). The stereomicroscope analysis showed that the working length measured with electronic apex locators was within ± 0.5 mm of the apical foramen in 74.8% of cases and within ± 0.5 mm of the radiological control length in 90% of all cases (Fig.7).



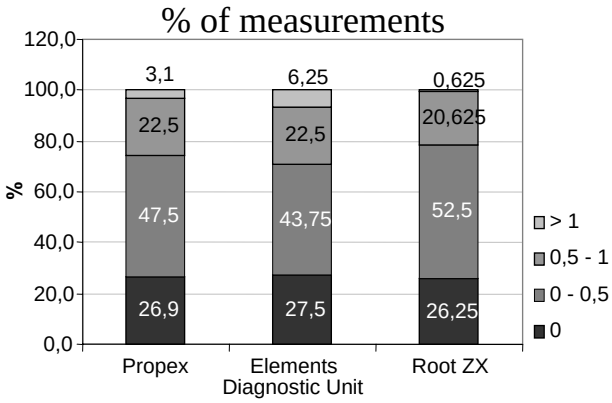
Slika 3. Pozicija vrha proširivača u apikalnoj regiji
Figure 3 Position of the file tip in the apical region



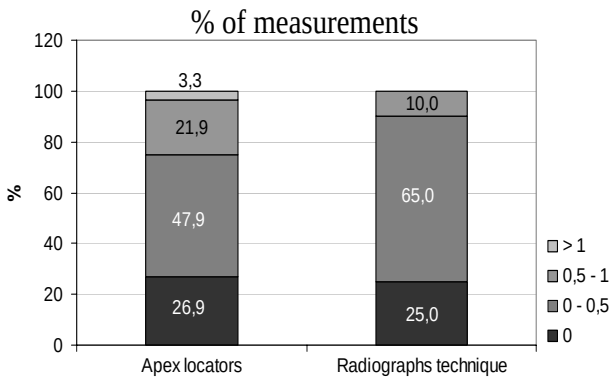
Slika 4. Rezultat određivanja radne duljine endometrima i rendgenskom metodom. Razmak između vrha instrumenta i apikalnog foramena. Vrijednost 0 pokazuje apikalni foramen.
Figure 4 Result of the working length determination with apex locators and radiographs method. Distance between instrument tip and apical foramen. The value 0 shows the apical foramen.



Slika 5. Rezultati elektroničkog određivanja radne duljine različitim endometrima. Razmak između vrha instrumenta i apikalnog foramena. Vrijednost 0 pokazuje apikalni foramen.
Figure 5 Result of the electronic working length determination with different apex locators. Distance between instrument tip and apical foramen. The value 0 shows the apical foramen.



Slika 6. Postotak određivanja radne duljine ± 0,5 mm od apeksa različitim endometrima.
Figure 6 Percentage of length determination ± 0.5 mm to the apex with different apex locators.



Slika 7. Postotak elektroničkog ili rendgenskog određivanja radne duljine ± 0,5 mm od apeksa.
Figure 7 Percentage of electronic or radiological length determination ± 0.5 mm to the apex.

Rasprava

O određivanju radne duljine već se raspravljalo, a rezultati su bili različiti. Istraživanje Martineza i Lozana te njihovih suradnika godine 2001.(20) upozorilo je na to da elektronička metoda zadovoljava u 67,8% slučajeva, prema 50,6% i 61,4% slučajeva kod konvencionalnih i digitalnih rendgenskih metoda. Nije bilo razlika između ispitivanih tehnika. Pommer je godine 2001.(21) uspoređivao radne

Discussion

Working length determination has been discussed in previous publications with various results. Martinez-Lozano et al 2001(20) found that the electronic method was satisfactory in 67.8% of cases, versus 50.6% and 61.4% for the conventional and digital radiological methods. None of the techniques were completely satisfactory in establishing the true working length. There were no differences

duljine određene endometrom AFA Apex Finder s rezultatima dobivenima rendgenskom tehnikom. U 77,2% procjenjenih rendgena, apikalni je vrh radne duljine pronađen ± 0,5 mm od apikalnog suženja. U 98,5% elektronički određenih radnih duljina, udaljenost između vrha endodontskog proširivača i apikalnog suženja bila je manja od 0,5 mm. Ovo je istraživanje pokazalo da je uređaj za elektroničko mjerenje duljine korijenskog kanala dao znatno točnije rezultate od rendgenskih snimki. Suprotno tome, ispitivanje in vitro pokazalo je da elektroničko određivanje radne duljine nije superiorno rendgenskoj kontroli. Ounsi i Naaman (22) uspoređivali su godine 1999. Root ZX s pravim izmjerenim vrijednostima koristeći se fiziološkom otopinom u gelu te su pronašli da daje u 84% slučajeva mjerenja unutar 0,5 mm od izmjerene duljine. Vrijednosti elektroničkih radnih duljina izmjerenih Root ZX-om smanjile su postotak do sada pretežno prihvaćene pretpostavke do 21% (23). Endometar Root ZX pokazao je znatno točnije ukupne vrijednosti -0,03 +/- 0,39 mm u usporedbi s endometrom Apex Finderom -0,31 +/- 0,46 mm. Na Apex Finder negativno utječe NaOCl u korijenskom kanalu. Root ZX češće je pokazivao ne tako stabilne rezultate kod kanala niske provodljivosti (24). Jenkins i suradnici (25) pokazali su 2001. da je endometar Root ZX pouzdan u mjerenju duljine kanala do 0,31mm te da nije bilo razlike u određivanju duljine kao funkcija sedam uporabljenih irigansa. U drugim su istraživanjima mjerenja radne duljine u zubima procijenjena indikacijama za ekstrakciju. Zato je apikalna trećina otvorena i proučena mikroskopom reflektirane svjetlosti - endometrom Root ZX precizno je određena duljina korijenskog kanala u 82,3% slučaja izmjerena 0,5 mm od apikalnog suženja (26) te je u drugom istraživanju u 90,7% slučajeva bila na ± 0,5 mm od apikalnog suženja (27). Regija između područja foramen major i foramen minor precizno je određena endometrom Justy II (Hager & works, Duisburg, Njemačka) u 82,4% i endometrom Endy 5000 (Loser, Leverkusen, Njemačka) u 81% i apikalno suženje u 51% Justy II i 64,3% endometrom Endy 5000 (28). Zaključili su da je moguće odrediti regije između područja foramen major i foramen minor elektroničkim uređajem za određivanje radne duljine, ali i to da se tim uređajima ne može točno odrediti apikalno suženje. U novim ispitivanjima preciznost radnih duljina postiže se različitim novim endometrima i rendgenskom kontrolom te se provjerava stereomikroskopom. Vrhovi endodontskih instrumenata locirani su u 71, 3 do 78,8%

between the techniques investigated. In 2001 Pommer (21) compared working lengths determined with AFA Apex Finder to results obtained by using the radiographic technique. In 77.2% of the evaluated radiographs the determined apical point of working length was found within ± 0.5 mm of the apical constriction. In 98.5% of the electronic working length determination attempts, the distance between file tip and the apical constriction was less than 0.5 mm. This study showed that electronic root canal length measuring device provided significantly more accurate results than the radiographs. In contrast to this, the present in vitro study showed that electronic working length determination is not superior to radiological control. In 1999 Ounsi and Naaman (22) compared the Root ZX with the actual measurement using a saline gel, and found that Root ZX gave measurements within 0.5mm of the measured length in 84.7% of the cases. Electronic working length measurements with the Root ZX reduced the percentage of overestimation to 21% (23).The Root ZX showed overall significantly more precise measurements: -0.03 +/- 0.39 mm compared with the Apex Finder measurements : -0.31 +/- 0.46 mm. The Apex Finder was negatively influenced by the presence of NaOCl in the root canal. The Root ZX was more frequently unable to reveal stable measurements in canals with low conductivity (24). In 2001 Jenkins et al. (25) showed that the Root ZX electronic apex locator measured canal lengths reliably to within 0.31 mm and that there were no differences in the length determination as a function of the seven different irrigants used. In other studies working length measurements were evaluated in teeth indicated for extraction. Subsequently, the apical thirds were opened and examined under a reflected-light microscope: with the Root ZX apex locator the root canal length was 82.3% within 0.5mm of the precisely determined apical constriction (26), and in another study in 90.7% within ± 0.5 mm of the apical foramen (27).The region between Foramen major and minor was determined correctly with Justy II (Hager & works, Duisburg, Germany) in 82,4% and Endy 5000 (Loser, Leverkusen, Germany) in 81% and the apical constriction in 51% Justy II and 64.3% Endy 5000 (28). They concluded that determining the region between the minor and major apical foramen is possible with electronic length measuring devices, however, use of these devices does not result in precise determination of the apical constriction. In the present study the accuracy of the working length was determined with var-

slučajeva ± 0,5 mm od apikalnog foramena kod svih endometara te u 90% slučajeva ± 0,5 mm od apikalnog foramena kod rendgenskog određivanja radne duljine.

Zaključak

Kod zajedničke primjene endometara i rendgena, smanjen je broj potrebnih rendgenskih snimki. Elektronička mjerenja mogu se ponoviti tijekom preparacije korijenskoga kanala, bez dodatnog izlaganja rendgenskom zračenju. Nema razlika u preciznosti ispitanih suvremenih endometara u ovom istraživačkom izlaganju. Odabir prikladnog uređaja ovisi o razlikama u prikazu ili cijeni.

ious newer apex locators and radiographic control, and then verified under stereomicroscope. The tips of root canal instruments in 71, 3 - 78.8% of cases were located within ± 0.5 mm to the apical foramen for all apex locators and 90% within ± 0.5 mm to the apical foramen for radiological length determination.

Conclusion

When apex locators are used in conjuction with radiographs, there is reduction in the number of radiographs required. Electronic measurements can be repeated during root canal preparation without additional x-ray exposure. There are no differences in the accuracy of modern apex locators investigated in this study exposure. The choice of the appropriate device relies on the differences in display or price.

Abstract
The purpose of this study was to test the accuracy three different apex locators. A total of 20 extracted single - rooted human teeth were used for this study. The teeth were embedded in an alginate (Alginate Plus, Henry Schein, Melville, NY, USA) model developed for electric working length determination with apex locators. Electronic length measurement was achieved with three different apex locators: Propex Apex Locator (Dentsply/Maillefer, Montigny le Bretonneux, Switzerland), Root ZX (Morita Europe, Dietzenbach, Germany), Elements Diagnostic Unit Apex Locator (Sybron Endo, Glendora, California, USA) using a size 15 K file (VDW GmbH, Munich, Germany). After that the working length was determined radiographically by placing a size 15 file to the root canal, then subtracting 1 mm from apex. Each root canal was prepared in the apical third and the distance between the instrument's tip to the apical foramen was analyzed under stereomicroscope. The results were subjected to statistical analysis with ANOVA using the SPSS 11.0 program. There were no significant differences between the different apex locators used and the radiographic control in determining working lengths. Electronic working length measurement with different apex locators used in this study proved the same results as the radiological control of canal length determination.

Received: January 15, 2007
Accepted: February 21, 2007

Address for correspondence
Univ.-Prof. Dr. P. Städtler
University Dental Clinic
Department of Conservative Dentistry
Auenbruggerplatz 6a
A-8036 Graz
Tel.: ++43-316-385-2213
Fax: ++43-316-385-3375
peter.stadtler@meduni-graz.at

Key words
endodontics; root canal therapy; dental equipment

References

1. Steffen H, Splieth CH, Behr K. Comparison of measurements obtained with hand files or the Canal Leader attached to electronic apex locators: an in vitro study. Int Endod J. 1999;32(2):103-7.
2. Ricucci D. Apical limit of root canal instrumentation and obturation, part 1. Literature review. Int Endod J. 1998;31(6):384-93.
3. Kaufman AY, Keila S, Yoshpe M. Accuracy of a new apex locator: an in vitro study. Int Endod J. 2002;35(2):186-92.
4. Bramante CM, Berbert A. A critical evaluation of some methods of determining tooth length. Oral Surg Oral Med Oral Pathol. 1974;37(3):463-73.
5. Sunada I. New method for measuring the length of the root canal. J Dent Res. 1962;41:375-87.
6. Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc. 1955;50(5):544-52.
7. Grove CJ. A new simple standardized technique producing perfect fitting impermeable root canal filings extended to the dentinocemento junction. Dent Items Interest. 1928;50:855-7.
8. Green D. Stereomicroscopic study of 700 root apices of maxillary and mandibular posterior teeth. Oral Surg Oral Med Oral Pathol. 1960;13:728-33.
9. Fouad AF, Krell KV, McKendry DJ, Koorbusch GF, Olson RA. Clinical evaluation of five electronic root canal length measuring instruments. J Endod. 1990;16(9):446-9.
10. Fouad AF, Rivera EM, Krell KV. Accuracy of the Endex with variations in canal irrigants and foramen size. J Endod. 1993;19(2):63-7.
11. Frank AL, Torabinejad M. An in vivo evaluation of Endex electronic apex locator. J Endod. 1993;19(4):177-9.
12. Kobayashi C. Electronic canal length measurement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995;79(2):226-31.
13. Gordon MP, Chandler NP. Electronic apex locators. Int Endod J. 2004;37(7):425-37.
14. Aurelio JA, Nahmias Y, Gerstein H. A model for demonstrating an electronic canal length measuring device. J Endod. 1983;9(12):568-9.

15. Donnelly JC. A simplified model to demonstrate the operation of electronic root canal measuring devices. J Endod. 1993;19(11):579-80.
16. Katz A, Kaufman AY, Szajkis S. An in vitro model for testing the accuracy of apex locators. Revue Francaise D´endodontie. 1992;11:67.
17. Tinaz AC, Alacam T, Topuz O. A simple model to demonstrate the electronic apex locator. Int Endod J. 2002;35(11):940-5.
18. Weiger R, John C, Geigle H, Lost C. An in vitro comparison of two modern apex locators. J Endod. 1999;25(11):765-8.
19. Kaufman AV, Katz A. Reliability of Root ZX apex locator tested by an in vitro model. J Endod. 1993;19:201.
20. Martinez-Lozano MA, Forner-Navarro L, Sanchez-Cortes JL, Llena-Puy C. Methodological considerations in the determination of working length. Int Endod J. 2001;34(5):371-6.
21. Pommer O. In vitro comparison of an electronic root canal length measuring device and the radiographic determination of working length. Schweiz Monatsschr Zahnmed. 2001;111(10):1165-70.
22. Ounsi HF, Naaman A. In vitro evaluation of the reliability of the Root ZX electronic apex locator. Int Endod J. 1999;32(2):120-3.
23. ElAyouti A, Weiger R, Lost C. The ability of root ZX apex locator to reduce the frequency of overestimated radiographic working length. J Endod. 2002;28(2):116-9.
24. Venturi M, Breschi L. A comparison between two electronic apex locators: an in vivo investigation. Int Endod J. 2005;38(1):36-45.
25. 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(3):209-11.
26. Dunlap CA, Remeikis NA, BeGole EA, Rauschenberger CR. An in vivo evaluation of an electronic apex locator that uses the ratio method in vital and necrotic canals. J Endod. 1998;24(1):48-50.
27. Welk AR, Baumgartner JC, Marshall JG. An in vivo comparison of two frequency-based electronic apex locators. J Endod. 2003;29(8):497-500.
28. Hoer D, Attin T. The accuracy of electronic working length determination. Int Endod J. 2004;37(2):125-31.