
A new methodology for the comparative study of the root canal instrumentation techniques based on digital radiographic image processing and analysis

Georgios Mikrogeorgis, DDS, PhD,^a Ioannis Molyvdas, DDS, PhD,^b
Kleoniki Lyroudia, DDS, PhD,^c Nikolaos Nikolaidis, PhD,^d and Ioannis Pitas, PhD,^e
Thessaloniki, Greece
ARISTOTLE UNIVERSITY OF THESSALONIKI

Objective. The objective of this study was to evaluate the utility of digital image processing and analysis procedures for the study and comparison of the efficiency of 2 root canal instrumentation techniques.

Study Design. Forty mandibular incisors with a single canal were randomly divided into 2 groups of 20 teeth. A step-back technique was followed for the instrumentation of the root canals of Group 1 teeth using hand stainless steel Hedström files (Dentsply Maillefer, Switzerland), while a crown-down technique using ProFile engine-driven nickel-titanium instruments (Dentsply Maillefer) was followed for the instrumentation of the Group 2 root canals. Radiographs of each tooth were taken in bucco-lingual and mesio-distal projections, both before and after instrumentation, under constant conditions and by using a direct digital intraoral radiography system. The postoperative radiographs were digitally subtracted from their respective preoperative radiographs. A contrast enhancement process was applied to the resultant digital subtractive images. The enlargement of the root canals created by each instrumentation technique regarding the apical 6 mm was assessed through the application of region segmentation and area measurement processes.

Results. Using this methodology no significant difference between the 2 preparation techniques was found in terms of configuration and enlargement of the root canals.

Conclusions. The application of this methodology provided the ability to (1) visualize dentin lost during root canal instrumentation, (2) simultaneously compare root canal morphology before and after instrumentation, and (3) quantitatively evaluate the enlargement of the root canal area induced by each of the instrumentation techniques. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:e125–e131)

Root canal instrumentation is a significant step during an endodontic therapy. Root canal instrumentation is important because it determines the efficacy of all subsequent endodontic procedures and includes mechanical debridement, creation of space for medicament delivery, and optimization of root canal geometries for adequate obturation.¹ Many types of endodontic instruments and various preparation techniques have been proposed in order to achieve safe and efficient root

canal preparations without procedural errors. Consequently, the evaluation of the efficiency of all these instruments and techniques is very important in Endodontics. Many different experimental designs and methods have been used for this purpose

- Comparative analysis of radiographic images of root canals before and after their instrumentation by superimposing them using a double exposure system.²⁻⁴
- Use of simulated root canals of varying geometry in resin blocks.⁵⁻⁷
- Use of an analytical reassembly technique, which examined cross-sections of root canals before and after instrumentation, first described by Bramante et al.⁸ This methodology has subsequently been modified.⁹⁻¹²
- Use of silicone impressions of instrumented root canals.¹³
- Stereomicroscopic evaluation of cross or longitudinal sections of prepared root canals.¹⁴
- Scanning electron microscopic study of the walls of instrumented root canals.¹⁵

^aDentist, Department of Endodontology, Dental School, Aristotle University of Thessaloniki, Greece.

^bAssistant Professor, Department of Endodontology, Dental School, Aristotle University of Thessaloniki, Greece.

^cAssociate Professor, Department of Endodontology, Dental School, Aristotle University of Thessaloniki, Greece.

^dLecturer, Department of Informatics, Aristotle University of Thessaloniki, Greece.

^eChairman and Professor, Department of Informatics, Aristotle University of Thessaloniki, Greece.

Received for publication Nov 29, 2005; returned for revision Nov 29, 2005; accepted for publication Nov 30, 2005.

1079-2104/\$ - see front matter

© 2006 Mosby, Inc. All rights reserved.

doi:10.1016/j.tripleo.2005.11.023

- Computed tomography (CT)^{16,17} and the advanced microcomputed tomography (MCT),¹⁸⁻²³ that enable visualization and study in 3 dimensions and in a quantitative manner the morphology of the root canals before and after instrumentation.

All the above methods have been used successfully for many years. However, a number of inherent limitations have been identified. Furthermore, as of today, digital subtraction radiography (DSR) and digital radiographic image processing and analysis procedures in general, have become established modalities in endodontic research.²⁴

The main goal of this study was to evaluate the utility of a new computerized methodology based on digital radiographic image processing and analysis for the study and comparison of the efficiency of root canal instrumentation techniques. For this reason a step-back technique using hand stainless steel Hedström files and a crown-down technique using ProFile engine-driven nickel-titanium instruments were comparatively studied by using the developed methodology.

MATERIAL AND METHODS

Fifty recently extracted mandibular incisors that had been stored in 0.1% thymol were used in this study. The teeth were free of caries and any restoration. Preoperative radiographs showed that 10 of them had 2 root canals. These teeth were excluded from the study. The remaining 40 teeth were randomly divided into 2 groups of 20 teeth. The root canals' instrumentation in Group 1 was done according to a step-back technique using hand stainless steel Hedström files (Dentsply-Maillefer, Maillefer Instruments SA, Ballaigues, Switzerland), while in Group 2 a crown-down technique using ProFile engine-driven nickel-titanium instruments (Dentsply-Maillefer) was followed. All instrumentations were performed by one experienced endodontist. The working length was determined for all teeth by subtracting 0.5 mm from the length of a #10 file when its tip was just visible at the apical foramina; NaOCl (2.5%) was used as an irrigation solution after each instrument size with a final irrigation of 5 mL NaOCl (2.5%). Glyde (Dentsply-Maillefer) was used as a lubricant with each instrument. Master Apical File (MAF) was an instrument #30; all root canals were controlled for apical patency with a #10 file after their instrumentation. Instruments were replaced after the preparation of just 1 root canal.

In group 1, Hedström files were used in an in and out filing motion to the apex with pressure along the canal walls to achieve circumferential filing. Each instrument size following MAF was used 0.5 mm shorter than the preceding one. The largest file used was #60.

ProFile engine-driven nickel-titanium instruments

were used in group 2 with Tecnika Motor (ATR Srl, Pistola, Italy) following the manufacturer's instructions. This micromotor device precisely controls the rotary speed/torque of the instruments. The sequence of instruments used was in accordance with the crown-down technique proposed by the manufacturer: coronal preflaring, where each instrument was used without force into the canals and when its progression became difficult was replaced by the next one: orifice shaper (O.S.) #3, O.S. #2, 0.06 #25, 0.06 #20, 0.04 #25; determination of the working length; apical preparation to the exact working length: 0.04 #20, 0.04 #25, 0.04 #30 (MAF); final flaring to the exact working length: 0.06 #20, 0.06 #25.

Radiographs of each tooth were exposed before and after instrumentation in bucco-lingual and mesio-distal direction. The radiographs were exposed under constant conditions by using the RadioVisioGraphy (RVG) direct digital intraoral radiography system (Trophy Radiology S.A., Paris, France) and an Oralix AC Denso-mat x-ray machine (Gendex Dental System, Milano, Italy, 65 kV peak and 7.5 mA mean) with an exposure time of 0.08 seconds. To standardize the position of teeth in relation to the sensor and the tubehead, molds were made using the Express vinyl polysiloxane impression putty material (3M ESPE, St. Paul, MN) in which the teeth were embedded buccolingually, and other similar molds in which the teeth were embedded mesiodistally. The molds were placed on top of the sensor, which was stabilized on a fixed horizontal block and the tubehead was set perpendicular to the block and in contact with the molds.

The postoperative radiographs were digitally subtracted from their respective preoperative radiographs by using a new digital radiograph registration, normalization, and subtraction software (EIKONA Subtraction Radiography, Alpha-Tec Ltd., Thessaloniki, Greece).²⁵ The software runs on a Pentium PC under a Windows 2000/XP operating system and it has been used successfully for the sensitive and reliable assessment of the progress of chronic apical periodontitis in a previous work.²⁶ In order to register the 2 input digital radiographic images, i.e., to correct the geometrical distortions (rotation, scaling, translation), prior to their subtraction, several pairs of user-defined landmark points were selected on them. The pairs of the selected landmark points must correspond to identical anatomical elements on the 2 digital radiographs. The selection of each landmark point was made by clicking with the mouse on the desired point of the corresponding digital radiographic image. A magnification window helps the user to accurately select the desired landmark points on the 2 digital radiographs. The registration procedure was based both on those landmark points as well as on

a refinement step that aimed at improving the initial registration results using image intensity information. Registration was accompanied by a normalization step that eliminates brightness and contrast differences between the 2 images. Finally, the 2 images were superimposed and subtracted. A contrast enhancement process was applied to the resultant digital subtractive images.

The enlargement of the area of the root canals created by each instrumentation technique in the apical 6 mm of the teeth was assessed through the application of region segmentation and area measurement processes by using the digital image processing software EIKONA for Windows (EIKONA, Alpha-Tec Ltd.).²⁷ The area of the root canals was automatically segmented on the radiographic images of the apical 6 mm of the teeth, both before and after instrumentation. The automatic segmentation was based on characteristics of the radiographic image, such as area brightness and its fluctuations, which were defined by the user. Then, the segmented area was measured by using an appropriate algorithm. For each instrumentation technique, the percentage of enlargement of the area of the apical 6 mm of the root canals of each tooth, the minimum and maximum values, the sample mean, sample median, and sample standard deviation of the enlargement percentages both buccolingually and mesiodistally were calculated.

RESULTS

The results of the 2 instrumentation techniques were efficiently visualized through the digital subtractive images. On these images (Fig. 1, *c* and *c'*, and Fig. 2, *c* and *c'*), areas where both radiographic images had the same intensity were shown as grey, whereas areas where the postoperative radiographs (Fig. 1, *b* and *b'*, and Fig. 2, *b* and *b'*) were more radiolucent than their respective preoperative ones (Fig. 1, *a* and *a'*, and Fig. 2, *a* and *a'*) were demonstrated as dark. Therefore, the areas that corresponded to the enlargement of the root canals were demonstrated as dark elongated regions over a grey background on the digital subtractive images (Fig. 1, *c* and *c'*, and Fig. 2, *c* and *c'*). The depiction of the root canals before their instrumentation as grey areas placed between 2 dark elongated regions that demonstrate their enlargement can be clearly seen on Fig. 1, *c*, and Fig. 2, *c*. By applying contrast enhancement methods on the digital subtractive images, the areas that demonstrated the enlargement of the root canals were made more distinguishable as black elongated regions over a bright background (Fig. 1, *d* and *d'*, and Fig. 2, *d* and *d'*).

Furthermore, the results of the automatic segmentation on the radiographic images of the apical 6 mm of

the teeth before the instrumentation are depicted on Fig. 1, *e* and *e'*, and Fig. 2, *e* and *e'*. The corresponding segmentation results on the radiographic images after the instrumentation can be seen on Fig. 1, *f* and *f'*, and Fig. 2, *f* and *f'*. Using these results we were able to obtain measurements regarding the enlargement of the area corresponding to the apical 6 mm of the root canal of each tooth. The numerical results are shown on Table I. For each instrumentation technique, the percentage of enlargement of this area, as well as the minimum and maximum values, the sample mean, sample median, and sample standard deviation of the enlargement percentages both in bucco-lingual and mesio-distal directions are reported in this table.

Results showed no significant difference between the 2 instrumentation techniques in terms of the configuration and the enlargement of root canals. The fact that the difference in the enlargement of the root canal area induced by the 2 instrumentation techniques was not statistically significant was verified by applying the Student *t* test and the Mann-Whitney and Kolomogorov-Smirnov nonparametric tests on the enlargement percentage data both in bucco-lingual and mesio-distal directions.

DISCUSSION

Conventional computed tomography (CT) has inadequate resolution to detect subtle changes in root canal morphology.^{28,29} The advanced microcomputed tomography (MCT), proved to be a noninvasive method that provides the ability to accurately visualize the root canal morphology without resulting in teeth destruction. MCT allows the comparative evaluation of the morphology of the root canals before and after their preparation and provides the means for their 3-dimensional reconstruction and the formation of virtual cross sections in any desired orientation.¹⁸⁻²³ Furthermore, quantitative study and geometrical measurements of the changes in root canal volumes and surface areas before and after instrumentation can be performed.¹⁸⁻²³ Nevertheless, early studies using MCT were hampered by insufficient quality and resolution¹⁶ and projection errors.¹⁸ The prolonged scanning and reconstruction time—up to 4 hours per specimen^{18,19}—is another factor that limits the efficiency of this method. Moreover, this method requires costly and sophisticated hardware and software that has to be supported and serviced by experienced personnel. Such conditions can be met only in well-equipped and organized research centers.^{17,19,29}

In this study, the digital subtraction radiography (DSR) and digital radiographic image processing and analysis procedures in general, were used for the first time for the comparative evaluation of the efficiency of

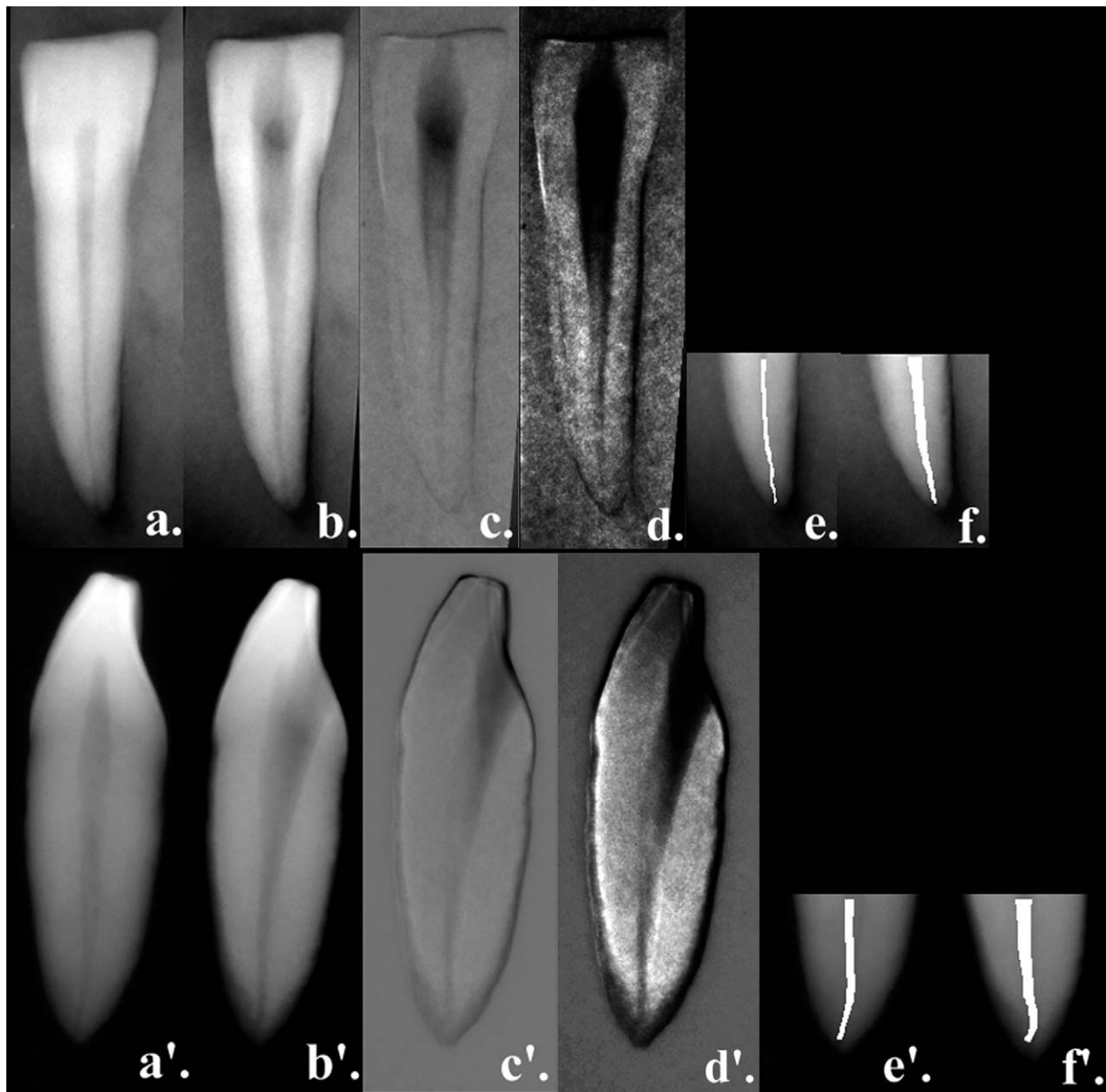


Fig. 1. **a.** Preoperative radiograph of the 13th tooth prepared with a step-back technique taken buccolingually. **a'**. Preoperative radiograph of the same tooth taken mesiodistally. **b.** Postoperative radiograph of the same tooth taken buccolingually. **b'**. Postoperative radiograph taken mesiodistally. **c.** Results of digital subtraction of **b.** from **a.** The root canal before its instrumentation is depicted as a grey area placed between 2 dark elongated regions that demonstrate its enlargement. **c'**. Results of digital subtraction of **b'**. from **a'**. The area that corresponds to the enlargement of the root canal is demonstrated as a dark elongated region over a grey background. **d.** Image resulting after the application of a contrast enhancement process on the subtractive image **c.** **d'**. Image resulting after the application of a contrast enhancement process on the subtractive image **c'**. **e.** Radiographic image of the apical 6 mm of the tooth before the instrumentation of its root canal taken buccolingually. The root canal has been digitally segmented. **e'**. Radiographic image of the apical 6 mm of the tooth before the instrumentation of its root canal taken mesiodistally. The root canal has been digitally segmented. **f.** Radiographic image of the apical 6 mm of the tooth after the instrumentation of its root canal taken buccolingually. The root canal has been digitally segmented. **f'**. Radiographic image of the apical 6 mm of the tooth after the instrumentation of its root canal taken mesiodistally. The root canal has been digitally segmented.

the root canal instrumentation techniques. This methodology is essentially a radiographic method for the study of the instrumentation techniques that is not par-

ticularly complex, time-consuming, and difficult to use. The inherent restriction of depicting 3-dimensional anatomical structures in 2 dimensions is partly dealt with



Fig. 2. **a**. Preoperative radiograph of the 19th tooth prepared with a crown-down technique taken buccolingually. **a'**. Preoperative radiograph of the same tooth taken mesiodistally. **b**. Postoperative radiograph of the same tooth taken buccolingually. **b'**. Postoperative radiograph taken mesiodistally. **c**. Results of digital subtraction of b. from a. The root canal before its instrumentation is depicted as a grey area placed between 2 dark elongated regions that demonstrate its enlargement. **c'**. Results of digital subtraction of b'. from a'. The area that corresponds to the enlargement of the root canal is demonstrated as a dark elongated region over a grey background. **d**. Image resulting after the application of a contrast enhancement process on the subtractive image c. **d'**. Image resulting after the application of a contrast enhancement process on the subtractive image c'. **e**. Radiographic image of the apical 6 mm of the tooth before the instrumentation of its root canal taken buccolingually. The root canal has been digitally segmented. **e'**. Radiographic image of the apical 6 mm of the tooth before the instrumentation of its root canal taken mesiodistally. The root canal has been digitally segmented. **f**. Radiographic image of the apical 6 mm of the tooth after the instrumentation of its root canal taken buccolingually. The root canal has been digitally segmented. **f'**. Radiographic image of the apical 6 mm of the tooth after the instrumentation of its root canal taken mesiodistally. The root canal has been digitally segmented.

Table I. Enlargement percentage of the area of the apical 6 mm of the root canals of each tooth, the minimum and maximum values, the sample mean, sample median and sample standard deviation of the enlargement percentages both buccolingually and mesiodistally for each instrumentation technique

	Enlargement of the area of the root canals buccolingually, %	Enlargement of the area of the root canals mesiodistally, %		Enlargement of the area of the root canals buccolingually, %	Enlargement of the area of the root canals mesiodistally, %
<i>A. Step-back</i>			<i>B. Crown-down</i>		
1st tooth	92.76	37.02	1st tooth	248.80	80.63
2nd tooth	69.03	36.67	2nd tooth	31.91	14.43
3rd tooth	76.55	47.89	3rd tooth	30.06	72.83
4th tooth	122.91	97.49	4th tooth	62.06	29.83
5th tooth	101.40	139.78	5th tooth	44.10	39.48
6th tooth	86.32	67.17	6th tooth	100.56	104.71
7th tooth	50.82	51.78	7th tooth	83.71	60.44
8th tooth	37.90	22.20	8th tooth	74.08	70.22
9th tooth	44.69	39.13	9th tooth	97.95	35.14
10th tooth	117.30	2.45	10th tooth	125.07	67.97
11th tooth	154.46	137.64	11th tooth	36.36	94.36
12th tooth	49.41	82.49	12th tooth	83.85	44.70
13th tooth	133.94	48.95	13th tooth	69.80	22.60
14th tooth	121.48	96.19	14th tooth	33.44	40.03
15th tooth	178.00	89.57	15th tooth	58.33	45.19
16th tooth	51.78	34.21	16th tooth	99.08	33.79
17th tooth	128.36	15.20	17th tooth	40.17	8.39
18th tooth	84.93	60.34	18th tooth	90.74	137.19
19th tooth	99.54	51.49	19th tooth	111.66	101.41
20th tooth	58.62	30.34	20th tooth	154.67	109.06
Minimum value	37.90%	2.45%	Minimum value	30.06%	8.39%
Maximum value	178.00%	139.78%	Maximum value	248.80%	137.19%
Sample mean	93.01%	59.40%	Sample mean	83.82%	60.62%
Sample median	89.54%	50.22%	Sample median	78.90%	52.82%
Sample standard deviation	39.22	37.52	Sample standard deviation	51.68	35.27

through the fact that the radiographs were taken both buccolingually and mesiodistally. The results showed that the digital radiograph registration, normalization, and subtraction software that was developed and used in this work provide the ability to visualize the dentin surfaces that were lost during root canal instrumentation, and allow the simultaneously comparative study of the root canal morphology before and after their preparation. Moreover, through the application of region segmentation and area measurement processes a quantitative evaluation of the root canal enlargement is accomplished. Such a quantitative calculation can be provided only through the MCT method.

The successful use of DSR depends directly on the radiographic image reproducibility. Reproducibility is associated with radiographic contrast, brightness, and geometrical distortions. It has been shown that radiographic contrast and brightness distortions can be corrected so long as they remain within certain limits.^{30,31} The digital image processing procedures implemented in the developed software seem to be able to correct effectively the radiographic contrast and brightness distortions.

The main problem associated with DSR is the radiographic geometrical distortion, which depends on the reproducibility of the relative position and orientation of the x-ray beam, the tooth, and the receptor.³¹⁻³⁴ Therefore, in this study molds of teeth were made using the vinyl polysiloxane impression putty material to standardize the position of teeth relative to the sensor and the tubehead. Furthermore, the registration algorithm that was developed has been proved to compensate effectively the planar rigid transforms (i.e., translations and rotations) and the vertical angulation changes of the 2 radiographs that were subtracted.

In conclusion, the application of this methodology provided the ability to:

1. visualize dentin lost during root canal instrumentation,
2. simultaneously compare root canal morphology before and after preparation,
3. quantitatively evaluate the enlargement of the root canal area induced by each of the instrumentation techniques.

However, in order to come up with concrete conclu-

sions regarding the merits of this methodology, a thorough and quantitative comparison with results provided by other methods (e.g., the MCT method) needs to be carried out.

REFERENCES

- Ingle J, Bakland L, editors. Endodontics. 5th ed. Hamilton, London: BC Decker Inc; 2002. p. 470.
- Pertot WJ, Camps J, Damiani MG. Transportation of curved canals prepared with Canal Master-U, Canal Master-U-NiTi, and stainless steel K-type files. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;79:504-9.
- Jardine SJ, Gulabivala K. An in vitro comparison of canal preparation using two automated rotary nickel-titanium instrumentation techniques. *Int Endod J* 2000;33:381-91.
- Iqbal MK, Maggiore F, Suh B, Edwards KR, Kang J, Kim S. Comparison of apical transportation in four Ni-Ti rotary instrumentation techniques. *J Endod* 2003;29:587-91.
- Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. *J Endod* 1975;1:255-62.
- Smith RB, Edmunds DH. Comparison of two endodontic handpieces during the preparation of simulated root canals. *Int Endod J* 1997;30:369-80.
- Schafer E. Shaping ability of Hero 642 rotary nickel-titanium instruments and stainless steel hand K-Flexfiles in simulated curved root canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001;92:215-20.
- Bramante CM, Berbert A, Borges RP. A methodology for evaluation of root canal instrumentation. *J Endod* 1987;13:243-5.
- McCann JT, Keller DL, LaBounty GL. A modification of the muffle model system to study root canal morphology. *J Endod* 1990;16:114-5.
- Kuttler S, Garala M, Perez R, Dorn SO. The endodontic cube: a system designed for evaluation of root canal anatomy and canal preparation. *J Endod* 2001;27:533-6.
- Ponti TM, McDonald NJ, Kuttler S, Strassler HE, Dumsha TC. Canal-centering ability of two rotary file systems. *J Endod* 2002;28:283-6.
- Paque F, Musch U, Hulsmann M. Comparison of root canal preparation using RaCe and ProTaper rotary Ni-Ti instruments. *Int Endod J* 2005;38:8-16.
- Abou-Rass M, Jastrab RJ. The use of rotary instruments as auxiliary aids to root canal preparation of molars. *J Endod* 1982;8:78-82.
- Wu MK, Wesselink PR. Efficacy of three techniques in cleaning the apical portion of curved root canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995;79:492-6.
- Schafer E, Vlassis M. Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. *Int Endod J* 2004;37:239-48.
- Gambill JM, Alder M, Del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *J Endod* 1996;22:369-75.
- Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT files versus traditional instruments in canals shaped by novice operators. *Int Endod J* 2001;34:476-84.
- Nielsen R, Alyassin A, Peters D, Carnes D, Lancaster J. Micro-computed tomography: an advanced system for detailed endodontic research. *J Endod* 1995;21:561-8.
- Rhodes JS, Ford TR, Lynch JA, Liepins PJ, Curtis RV. A comparison of two nickel-titanium instrumentation techniques in teeth using microcomputed tomography. *Int Endod J* 2000;33:279-85.
- Peters OA, Laib A, Gohring TN, Barbakow F. Changes in root canal geometry after preparation assessed by high-resolution computed tomography. *J Endod* 2001;27:1-6.
- Peters OA, Schonenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *Int Endod J* 2001;34:221-30.
- Peters OA, Peters CI, Schönenberger K, Barbakow F. ProTaper rotary root canal preparation: assessment of torque and force in relation to canal anatomy. *Int Endod J* 2003;36:93-9.
- Hübscher W, Barbakow F, Peters OA. Root canal preparation with FlexMaster: canal shapes analysed by micro-computed tomography. *Int Endod J* 2003;36:740-7.
- van der Stelt PF. Research methods in dentistry. 8. Methods for longitudinally detecting differences in bone density: digital subtraction radiography. *Ned Tijdschr Tandheelkd* 2005;112:46-50.
- EIKONA Subtraction Radiography, Alpha-Tec Ltd. 2005. Available at: <http://www.alphatecltd.com/eikonasr/eikonasr.html>. Accessed Jan 22, 2006.
- Mikrogeorgis G, Lyroudia K, Molyvdas I, Nikolaidis N, Pitas I. Digital radiograph registration and subtraction: a useful tool for the evaluation of the progress of chronic apical periodontitis. *J Endod* 2004;30:513-7.
- EIKONA, Alpha-Tec Ltd. 2005. Available at: <http://www.alphatecltd.com/eikona/eikona.html>. Accessed Jan 22, 2006.
- Dowker S, Davis G, Elliott J. X-ray microtomography—nondestructive three-dimensional imaging for in vitro endodontic studies. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997;83:510-6.
- Stamm T, Kaup M, Hohoff A, Meier T, Meyer U. Validity of a three-dimensional public-domain system for contemporary endodontic research. *J Endod* 2003;29:801-5.
- Ruttimann UE, Webber RL, Schmidt E. A robust digital method for film contrast correction in subtraction radiography. *J Periodontol Res* 1986;21:486-95.
- Lehmann TM, Grondahl HG, Benn DK. Computer-based registration for digital subtraction in dental radiology. *Dentomaxillofac Radiol* 2000;29:323-46.
- Grondahl HG, Grondahl K, Webber RL. A digital subtraction technique for dental radiography. *Oral Surg Oral Med Oral Pathol* 1983;55:96-102.
- Rudolph DJ, White SC. Film-holding instruments for intraoral subtraction radiography. *Oral Surg Oral Med Oral Pathol* 1988;65:767-72.
- Orstavik D, Farrants G, Wahl T, Kerekes K. Image analysis of endodontic radiographs: digital subtraction and quantitative densitometry. *Endod Dent Traumatol* 1990;6:6-11.

Reprint requests:

Georgios Mikrogeorgis, DDS, PhD
11, Pindarou Str.
546 39 Thessaloniki
Greece
gmicro@dent.auth.gr