International Endodontic Journal

doi:10.1111/j.1365-2591.2008.01533.x

Ex-vivo area-metric analysis of root canal obturation using gutta-percha cones of different taper

C. Romania, P. Beltes, C. Boutsioukis & C. Dandakis

Department of Endodontology, Dental School, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract

Romania C, Beltes P, Boutsioukis C, Dandakis C. *Ex-vivo* area-metric analysis of root canal obturation using gutta-percha cones of different taper. *International Endodontic Journal*, **42**, 491–498, 2009.

Aim To evaluate the percentage of gutta-percha and sealer-filled canal area when four different types of master gutta-percha cones were used.

Methodology Sixty mandibular premolars with straight canals were instrumented using System ProTaper rotary instruments with a crown-down technique and assigned to four groups. Canals were obturated with AH-26 sealer either using lateral condensation and 0.02 taper gutta-percha cones (group A), 0.04 taper gutta-percha cones (group B), nonstandardized F- medium (group C) master gutta-percha cones, or a single System ProTaper gutta-percha cone (group D). The percentage of gutta-percha and sealer-filled area was calculated in horizontal sections of the apical portion of each canal, using image analysis software. The data was statistically analysed using Kruskal–Wallis test.

Results The distribution of filling materials amongst groups was not significantly different at each level of sectioning ($P > 0.05$).

Conclusion The percentage of gutta-percha and sealer-filled canal area was similar when canals were filled with different master cones using lateral condensation or single cone techniques.

Keywords: area-metric analysis, gutta-percha, sealing quality, single cone.

Received 17 June 2008; accepted 1 December 2008

Introduction

Lateral condensation of gutta-percha cones remains widely accepted as a benchmark for other root filling techniques (Dummer 2004), as it is a simple, reliable technique that can be applied to most cases (Qualtrough *et al.* 1999). However, it may be responsible for gaps between gutta-percha cones, sealer and canal walls (Peters 1986) and there is a risk of vertical root fractures during compaction (Lertchirakarn *et al.* 1999). The use of nonstandardized gutta-percha cones with increased taper either as master or as secondary cones has been suggested as an alternative to standardized 0.02 taper cones, in order to improve the homogeneity of the mass of gutta-percha inside the canal (Spangberg 2002).

Rotary Ni–Ti instruments employing the crown-down technique have emerged during the last decade as a possibly superior option to hand instruments (Hülsmann *et al.* 2005). They appear to provide a more uniform root canal shape with a predictable taper in the apical region (Glosson *et al.* 1995, Schafer 1997) whilst retaining the original shape and patency of the canal (Peters *et al.* 2001). Use of Ni–Ti rotary instruments led to the development of greater taper standardized gutta-percha cones in order to match more closely the prepared shape of the canal (Bal *et al.* 2001). However, these 0.04 and 0.06 taper cones do not appear to provide improved sealing ability when compared with standardized 0.02 cones in root canals prepared with rotary instruments (Bal *et al.* 2001, Hembrough *et al.* 2002, Gordon *et al.* 2005). Greater

Correspondence: Christina Romania, 3, Agias Varvaras Street, Glyfada, 166 74 Athens, Greece (Tel.: 302109601729; fax: 302108993662; e-mail: romania@edoeap.gr).

taper cones have also been used clinically as master cones during lateral condensation in canals prepared with increased taper in the hope of reducing the number of secondary cones, although documentation is lacking on the efficacy of this technique.

Recently, gutta-percha cones matching the taper of some rotary Ni–Ti instruments have been introduced. These combinations of instruments and cones attempt to prepare a root canal to a certain shape and then fill the canal using a single gutta-percha cone. This procedure might be less complicated and time-consuming. Moreover manufacturers claim that these combinations can provide an effective seal even in curved root canals without the use of secondary cones. However, these claims have not been thoroughly tested.

The aim of this study was to evaluate the percentage of gutta-percha and sealer-filled canal area when canals were prepared with ProTaper rotary instruments and filled with four different types of master cones.

Materials and methods

Sixty freshly extracted human mandibular premolar teeth were used. Following extraction, the teeth were stored for 2 days at room temperature in 3% NaOCl to remove organic debris. Subsequently, they were debrided with ultrasonic scalers and washed with distilled water and then immersed in 10% formalin solution.

Criteria for tooth selection included: a single root canal, no visible root caries, fractures or cracks on examination with a 4× magnifying glass, no signs of internal or external resorption or calcification, a completely formed apex and curvature of $\leq 10^{o}$ (Schneider 1971). Preoperative radiographs were exposed to confirm the canal anatomy. The buccolingual to mesiodistal diameter ratio was selected to be <2 when examined at 5 mm from the apex (Wu *et al.* 2001).

After access cavities were prepared, a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the canal until it was visible at the apical foramen. The working length was determined by subtracting 0.5 mm from this measurement. This same file was used as a patency file during preparation. Only root canals in which the first file that fitted at working length was a maximum size 20 and the apical foramen was located ≤1 mm from the apex were included in this study.

A single operator instrumented all teeth. Root canals were prepared using ProTaper rotary Ni–Ti instruments (Dentsply Maillefer) on a 16 : 1 contra-angle handpiece (Weber & Haber, Burmoos, Austria) attached to an electric motor (ATR/Technika; Dentsply Tulsa Dental, Tulsa, OK, USA) at 250 rpm. Preparation was carried out according to the manufacturer's recommendations. Briefly, the S1 file was used to clean and shape the coronal part of the canal. Subsequently, the SX file was used to increase the taper of the coronal region and S1, S2, F1, F2 and F3 were used sequentially to full working length. A 15% EDTA gel (Glyde; Dentsply Maillefer) was used as a chelating agent and was introduced in the canal on the tip of each successive instrument. A new set of instruments was used for each group of teeth. Two instruments fractured during the preparation of the specimens. The instruments and specimens involved were replaced.

The canals were irrigated between instruments with 2 mL of 2.5% NaOCl. Irrigation was performed using 5 mL disposable plastic syringes with 27-gauge needle tips (Endo EZ; Ultradent Products Inc., South Jordan, UT, USA) placed passively into the canal, up to 3 mm from the apical foramen without binding. Finally, the root canal was irrigated with 5 mL of 2.5% NaOCl, followed by irrigation with 5 mL of 15% EDTA solution and a final rinse with 5 mL of 2.5% NaOCl. Irrigation was performed under the same conditions as in the instrumentation phase. The root canals of all teeth were dried with paper points.

Specimens were divided into sets of four teeth with similar working length. Each specimen from every set was randomly assigned to a study group (A, B, C, D). Canal filling was completed using AH-26 sealer (DeTrey Dentsply, Konstanz, Germany) and gutta-percha cones as described below:

Group A: 0.02 taper master gutta-percha cones size 30 (Dentsply Maillefer).

Group B: 0.04 taper master gutta-percha cones size 30 (Dentsply Maillefer).

Group C: Fine-Medium master gutta-percha cone (Hygenic Corporation, Akron, OH, USA) custom-fitted with the Gutta Gauge device (Dentsply Maillefer).

Group D: Single Protaper gutta-percha cone (Dentsply Mailleferd) matching the size of the F3 file used for final apical preparation.

Secondary gutta-percha cones size Medium-Fine (Hygenic Corporation) were laterally condensed in the root canals in groups A, B and C until the finger spreader size B (Dentsply Maillefer) could not penetrate further than the coronal third of the canals. Selection of spreader and the size of the secondary gutta-percha cones were performed during a preliminary study, according to penetration depth (unpublished data, C. Romania). No secondary gutta-percha cones or lateral condensation were applied in group D. Excess gutta-percha was removed with a heat-carrier and remaining gutta-percha was vertically compacted at the canal orifice. The access cavities were sealed with IRM. Teeth were stored at 37 ± 1 °C and 100% relative humidity for 7 days.

Specimens were embedded into transparent acrylic resin in order to permit horizontal sectioning of the apical portion. Following setting of the resin, the acrylic blocks were sectioned transversally using a hard tissue microtome (Isomet Low Speed Saw, $d = 0.3$ mm; Buehler Ltd, Evanston, IL, USA,) under copious irrigation with cold water, with gentle pressure of the saw disc on the root. Sections started 1.2 mm from the apex and six serial sections every 800 μm were made in total (Fig. 1). The first section from each specimen was discarded. Distinctive marks were added to each section to differentiate between the apical and coronal side.

Both sides of all sections were photographed using a CCD camera (JVC Ltd, Yokohama, Japan) attached on a Stereoscopic Microscope (Stemi SV8 Carl Zeiss, Göttingen, Germany) at 50× magnification. Therefore, 10 images were acquired per specimen, resulting in a total of 600 images. All images were recorded in a Tagged Image File (TIF) format with a resolution of 3937 ppi and were imported in Adobe Photoshop CS2 (Adobe Corporation, San Jose, CA, USA). The area of each section occupied by gutta-percha or sealer was calculated semi-automatically as a percentage of the total area. All calculations were performed by an independent operator blinded to the purpose of the study. Calculations were repeated in 10% of all images after a period of 3 months by the same operator to assess repeatability of the method.

As they were not normally distributed, the data were subjected to statistical interpretation using non parametric Kruskal–Wallis test. The null hypothesis was that there is no significant difference amongst the four groups regarding the area of each section occupied by gutta-percha or sealer. Furthermore, data from each group were analysed using Friedman's test to examine the possibility of pooling the results from different levels within each group, in order to increase the sample size. The null hypothesis was that there is no significant difference amongst the different levels within each group, regarding the area of each section occupied by gutta-percha or sealer. Correlation between initial and repeated calculations was examined with Spearman's coefficient. The level of significance was set at 95%. Statistical analysis was performed using SPSS 15.0 for Windows (SPSS Inc., Chicago, IL, USA).

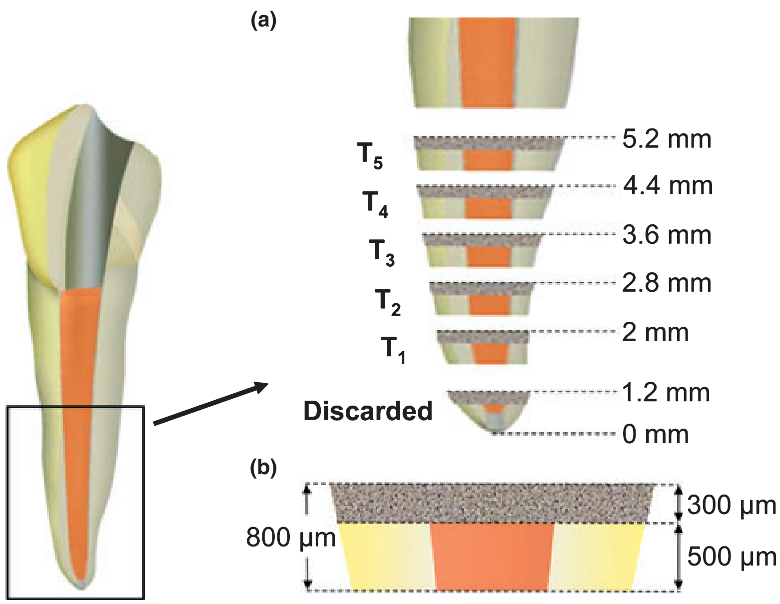

Figure 1 Schematic diagram of sectioning technique. (a). Sections started 1.2 mm from the apex and six serial sections every 800 μm were made in total. The first section from each specimen involving the apex was discarded. (b). Detail illustrating loss of tissue (stacked gray area) due to sectioning procedure.

Table 1 Median values and range of the percentage of gutta-percha at each level of sectioning

Level		Group A (n = 15) %	Group B (n = 15) %	Group C (n = 15) %	Group D (n = 15) %	p_1
$T1^A$	median	62.10	73.90	75.65	77.90	0.504
	range	0–86.83	0–91.62	0–92.91	0–97.07	
$T1^B$	median	80.22	84.46	74.83	87.50	0.155
	range	0–88.29	67.52–86.68	66.46–88.89	0–89.48	
$T2^A$	median	78.91	83.24	80.58	83.90	0.205
	range	0–94.83	62.63–97.19	54.06–88.59	61.72–95.93	
$T2^B$	median	72.98	77.20	80.50	84.39	0.142
	range	49.48–92.63	62.08–88.99	61.42–89.67	56.92–89.18	
$T3^A$	median	76.20	77.91	81.53	84.66	0.099
	range	51.56–93.96	59.11–88.33	62.70–93.96	57.88–93.11	
$T3^B$	median	73.67	76.33	78.95	80.93	0.231
	range	52.17–92.85	63.47–91.63	66.01–89.47	56.50–92.32	
$T4^A$	median	80.13	74.02	78.79	77.06	0.471
	range	53.52–89.36	59.15–95.98	58.89–91.35	57.38–89.18	
$T4^B$	median	75.40	76.04	77.69	77.41	0.663
	range	56.28–95.91	66.13–92.27	70.01–92.76	64.57–91.76	
$T5^A$	median	76.27	76.02	75.00	74.45	0.950
	range	52.45–89.28	64.32–88.28	54.88–87.65	66.39–87.01	
$T5^B$	median	79.13	82.33	77.01	77.85	0.716
	range	47.64–93.53	69.45–92.87	59.69–91.28	62.92–93.17	
	p_2	0.014*	0.044*	0.543	0.003*	

$T1^A$–$T5^A$ depict the apical side of each section, $T1^B$–$T5^B$ depict the coronal side of each section. p_1 refers to comparisons amongst the four groups at each level, whilst p_2 refers to comparisons amongst the different levels within each group.
*statistically significant difference

Results

Spearman's coefficient for the initial and repeated calculations was 0.859, which indicated high repeatability of the calculation method.

Descriptive statistics for groups A, B, C and D is presented in Table 1. Comparison of the four groups at each level of sectioning ($n = 15$) did not result in any significant differences ($p_1 > 0.05$) regarding the area occupied by gutta-percha or sealer (Tables 1 and 2). Median values for the percentage of area of each section occupied by gutta-percha or sealer plotted against level of sectioning (Fig. 2) did not reveal any obvious trend concerning a possible change in the amount of gutta-percha or sealer from apical to coronal direction. Comparison of the different levels within each group ($n = 10$) revealed significant differences within groups A, B and D ($p_2 = 0.014$, $p_2 = 0.044$ and $p_2 = 0.003$, respectively) concerning gutta-percha area (Table 1) and B and D ($p_2 = 0.031$ and $p_2 < 0.001$, respectively) concerning sealer area (Table 2). Therefore, no pooling of the results from each level could be achieved.

Discussion

Despite the lack of evidence, it is generally accepted that the volume of gutta-percha should be maximized and the volume of sealer should be minimized within the root canal (Gound *et al.* 2000, Wu *et al.* 2002). This assumption is based on the fact that microleakage occurs along the intersurface between dentine and gutta-percha, dentine and sealer, or gutta-percha and sealer (Hovland & Dumsha 1985) and also through the mass of the sealer due to setting contraction and time-dependent dissolution (Kazemi *et al.* 1993, Kontakiotis *et al.* 1997), whilst it seems not to occur through the solid mass of gutta-percha (Wu *et al.* 2000).

In order to standardize root canal preparation the use of rotary Ni–Ti instruments was deemed necessary. ProTaper instruments (Dentsply, Maillefer), were selected as matching gutta-percha cones for the instruments used for final canal preparation (F1, F2 and F3) have been introduced recently by the manufacturer but not yet examined for the quality of root filling they provide.

The sealing of the apical third in order to achieve high success rates (Ingle & West 1994) led to the selection of this part of the canal for evaluation. Furthermore, the inability to create a standardized uniform round-shaped root canal in the middle and coronal third of the canal due to shape variability and presence of oval-shaped canals (Wu *et al.* 2001) was an additional reason that suggested the evaluation of the apical region.

Table 2 Median values and range of the percentage of sealer at each level of sectioning

Level		Group A (*n* = 15) %	Group B (*n* = 15) %	Group C (*n* = 15) %	Group D (*n* = 15) %	p_1
T1^A	median	18.67	17.72	19.75	19.61	0.858
	range	0–97.48	0–95.33	2.80–98.87	2.73–97.91	
T1^B	median	13.60	14.25	16.02	10.73	0.392
	range	0–39.06	8.44–27.58	9.80–31.71	7.73–98.38	
T2^A	median	17.24	14.32	14.33	11.98	0.527
	range	2.28–60.77	1.62–32.30	8.57–25.79	2.74–33.56	
T2^B	median	22.22	21.29	15.29	13.01	0.383
	range	5.47–33.76	6.66–33.08	7.84–25.03	8.91–34.49	
T3^A	median	23.16	18.51	15.33	13.19	0.091
	range	2.76–38.93	7.33–38.56	3.78–36.13	5.49–33.99	
T3^B	median	21.27	19.59	18.98	14.91	0.200
	range	1.06–37.21	5.75–33.04	8.38–25.52	5.75–33.42	
T4^A	median	14.54	20.67	19.01	19.68	0.551
	range	6.53–38.33	2.89–35.41	6.60–27.57	9.10–35.61	
T4^B	median	20.30	20.69	18.79	20.67	0.818
	range	2.76–34.22	6.48–30.80	5.09–28.74	7.67–26.16	
T5^A	median	19.36	21.84	18.03	22.89	0.900
	range	4.87–46.11	8.32–33.47	8.70–43.87	10.93–30.54	
T5^B	median	16.68	15.03	18.25	19.37	0.649
	range	3.78–51.00	6.00–28.48	4.22–38.20	5.04–35.56	
	p_2	0.678	0.031*	0.409	<0.001*	

T1^A–T5^A depict the apical side of each section, T1^B–T5^B depict the coronal side of each section. p_1 refers to comparisons amongst the four groups at each level, whilst p_2 refers to comparisons amongst the different levels within each group.
*statistically significant difference

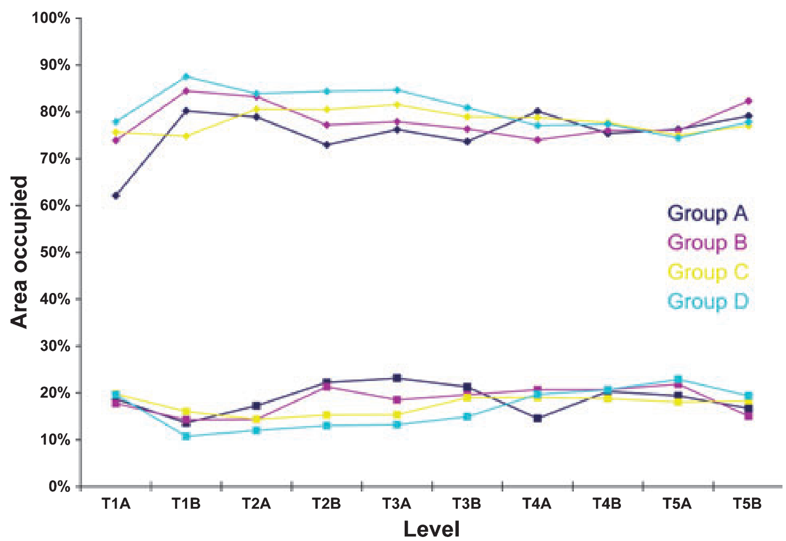

Figure 2 Median values for the percentage of area of each section occupied by gutta-percha or sealer plotted against level of sectioning. No consistent trends could be identified in any group.

An epoxy resin sealer (AE-26; DeTrey Dentsply) with significantly increased strength and hardness (Tagger *et al.* 2002) was used to ensure sectioning of the teeth without gutta-percha deformation, a possible problem with zinc-oxide sealers (Hembrough *et al.* 2002). The selection of a sealer with volumetric stability was justified by the significant amounts of sealer found within the canal during the present study. No gutta-percha transportation or transformation could be identified, in accordance with earlier studies (Wu & Wesselink 2001, Wu *et al.* 2001).

In order to examine the performance of master gutta-percha cones with different taper, the evaluation of the area occupied by materials in serial sections of the root canal was selected. Area-metric analysis has been applied previously to examine several materials and techniques (Dandakis *et al.* 2005, Kececi *et al.* 2005, De-Deus *et al.* 2006, Pagavino *et al.* 2006, Gulsahi *et al.* 2007). In order to improve accuracy, each section was evaluated from both aspects (apical and coronal). Nevertheless, loss of dental tissue due to the sectioning procedure could not be avoided, although results from histological examination (sections every 700 μm) have been found to be highly correlated to micro-CT results (scanning <10 μm) (Jung *et al.* 2005).

No significant correlation has been reported between the percentage of gutta-percha filled area and fluid transport leakage (van der Sluis *et al.* 2005), possibly due to detection of *cul de sac* voids by the former method, which do not contribute to the fluid transportation detected. However, the former is still considered as an acceptable method to evaluate the efficacy of a root canal filling (van der Sluis *et al.* 2005). Lack of correlation has also been reported in another study assessing the correlation between the percentage of gutta-percha and sealer filled area and bacterial leakage (De-Deus *et al.* 2008). However, in that study the entire filled area (gutta-percha and sealer) was evaluated, which could have masked an existing correlation.

Absolute numbers of the maximum distance between gutta-percha and canal walls (Hembrough *et al.* 2002) or surface area devoid of filling material (Epley *et al.* 2006) have been used to evaluate sealing quality. However, this requires extensive standardization of specimens, materials and methods, which is not always feasible when using human teeth. In the present study, absolute numbers of pixels representing areas of filling materials were converted to percentages of the total section area to avoid standardization issues, as in earlier studies (Wu & Wesselink 2001, Wu *et al.* 2003, Kececi *et al.* 2005).

A previous study failed to demonstrate significant differences amongst laterally condensed 0.02, 0.06 taper and nonstandardized medium master cones regarding the percentage of gutta-percha canal filled area in also 0.06 taper root canals (Hembrough *et al.* 2002). Similar results were also observed in a micro-leakage study examining laterally condensed 0.06 and 0.02 taper master cones in 0.06 taper root canals (Bal *et al.* 2001). No significant differences could be detected in the present study amongst laterally condensed 0.02, 0.04 taper and nonstandardized Fine-Medium master cones in ProTaper prepared root canals.

Similar percentages of gutta-percha filled canal area were found in 0.06 taper root canals filled either with laterally condensed 0.02 taper cones or with single 0.06 taper cones (Gordon *et al.* 2005). No significant differences could be detected in the present study between laterally condensed 0.02 master cones and single Protaper cones in ProTaper prepared root canals.

The median of the area occupied by gutta-percha in canals filled with lateral condensation, excluding the first section, ranged between 62.1% and 87.5% (Table 1). Similarly low findings have been reported in earlier studies using the same filling technique (Gencoglu *et al.* 2002, Kececi *et al.* 2005). Conversely, area occupation up to 93% has been reported in an earlier study (Jarrett *et al.* 2004), a finding that was attributed to the combined use of a Fine-sized spreader and Fine–Fine accessory cones (Gound *et al.* 2001), whilst the reported 70–100% values in other studies (Wu *et al.* 2001, 2002) can be attributed to root canal shape and operator variability. Multiple factors affecting results do not allow direct comparisons amongst different studies.

A reduced amount of gutta-percha was found in the first section compared with those more coronal regardless of group, possibly due to the distance between the apex and the apical foramen resulting in total absence of obturating materials in the first section of some specimens.

No obvious trend for increase of the amount of gutta-percha from apical to coronal direction could be observed (Fig. 2), in contrast to earlier studies (Gordon *et al.* 2005, Kececi *et al.* 2005). However, in these studies the evaluation was performed in the entire root canal. The present results are in agreement to other studies that evaluated the apical 4–5 mm (Wu *et al.* 2001, Gencoglu *et al.* 2002).

The amount of sealer on the perimeter of the root canal, identified in earlier studies (Hall *et al.* 1996, Wu *et al.* 2000), is not comparable with the amount of sealer identified within the root canal in the present study. This amount is probably influenced by the condensation process and the physical properties of the sealer rather than the amount inserted (Ørstavik 1982, Hall *et al.* 1996, Weis *et al.* 2004). Therefore, these studies cannot be directly compared with the present one due to differences in sealers and methodology employed.

Although there is no definitive limit, the amount of gutta-percha within the canal cannot be considered satisfactory either for lateral condensation or single-cone technique employed in the present study. Therefore, doubt may be raised about the manufacturer's claims for close matching of instruments and cones shape.

Conclusions

The percentage of gutta-percha and sealer-filled canal area was similar when canals were filled with different master cones using lateral condensation or single cone techniques.

Acknowledgements

The authors are grateful to Associate Professor K. Lyroudia, Department of Endodontology, Dental School, Aristotle University of Thessaloniki, Greece, for allowing and supervising the use of the stereomicroscope and to Mr. D. Charaklias, computer engineer, for the lengthy procedure of image analysis.

This study was submitted as a Dissertation to the Department of Endodontology, Dental School, Aristotle University of Thessaloniki, in partial fulfilment of the requirements for the Postgraduate Degree of Specialization in Endodontology.

References

Bal AS, Hicks ML, Barnett F (2001) Comparison of laterally condensed .06 and .02 tapered gutta-percha and sealer in vitro. *Journal of Endodontics* **27**, 786–8.

Dandakis C, Kaliva M, Lambrianidis T, Kosti E (2005) An in vitro comparison of the sealing ability of three endodontic sealers used in canals with iatrogenic enlargement of the apical constriction. *Journal of Endodontics* **31**, 190–3.

De-Deus G, Murad C, Paciornik S, Reis C, Coutinho-Filho T (2006) A laboratory analysis of gutta-percha-filled area obtained using Thermafil, System B and lateral condensation. *International Endodontic Journal* **39**, 378–83.

De-Deus G, Murad C, Paciornik S, Reis C, Coutinho-Filho T (2008) The effect of the canal-filled area on the bacterial leakage of oval-shaped canals. *International Endodontic Journal* **41**, 183–90.

Dummer PMH (2004) Root canal filling. In: Pitt Ford TR, ed. *Harty's Endodontics In Clinical Practice*, 5th edn. Edinburgh, UK: Wright, pp. 113–36.

Epley S, Fleischman J, Hartwell G, Cicalese C (2006) Completeness of root canal obturations, Epiphany techniques versus gutta-percha techniques. *Journal of Endodontics* **32**, 541–4.

Gencoglu N, Garip Y, Bas M, Samani S (2002) Comparison of different gutta-percha root filling techniques, Thermafil, Quick-fill, System B, and lateral condensation. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **93**, 333–6.

Glosson C, Haller R, Dove S, Del Rio C (1995) A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-flex endodontic instruments. *Journal of Endodontics* **21**, 146–51.

Gordon M, Love R, Chandler N (2005) An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals. *International Endodontic Journal* **38**, 87–96.

Gound TG, Riehm RJ, Makkawy HA, Odgaard EC (2000) A description of an alternative method of lateral condensation and a comparison of the ability to obturate canals using mechanical or traditional lateral condensation. *Journal of Endodontics* **26**, 756–9.

Gound TG, Riehm RJ, Makkawy H (2001) Effect of spreader and accessory cone size on density of obturation using conventional or mechanical lateral condensation. *Journal of Endodontics* **27**, 358–61.

Gulsahi K, Cehreli Z, Kuraner T, Dagli F (2007) Sealer area associated with cold lateral condensation of gutta-percha and warm coated carrier filling systems in canals prepared with various rotary NiTi systems. *International Endodontic Journal* **40**, 275–81.

Hall MC, Clement DJ, Dove SB, Walker WA (1996) A comparison of sealer placement techniques in curved canals. *Journal of Endodontics* **22**, 638–42.

Hembrough M, Steiman R, Belanger K (2002) Lateral condensation in canals prepared with nickel titanium rotary instruments : an evaluation of the use of three different master cones. *Journal of Endodontics* **28**, 516–9.

Hovland E, Dumsha T (1985) Leakage evaluation in vitro of the root canal sealer cement Sealapex. *International Endodontic Journal* **18**, 179–82.

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

Ingle JI, West JD (1994) Obturation of the radicular space. In: Ingle J, Bakland L, eds. *Endodontics*, 4th edn. Malvern, PA, USA: Williams & Wilkins, pp. 228–319.

Jarrett IS, Marx D, Covey D, Karmazin M, Lavin M, Gound T (2004) Percentage of canals filled in apical cross sections-an in vitro study of seven obturation techniques. *International Endodontic Journal* **37**, 392–8.

Jung M, Lommel D, Klimek J (2005) The imaging of root canal obturation using micro-CT. *International Endodontic Journal* **38**, 617–26.

Kazemi RB, Safavi KE, Spangberg LSW (1993) Dimensional changes of endodontic sealers. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **76**, 766–71.

Kececi A, Unal G, Sen B (2005) Comparison of cold lateral compaction and continuous wave of obturation techniques following manual or rotary instrumentation. *International Endodontic Journal* **38**, 381–8.

Kontakiotis EG, Wu M-K, Wesselink PR (1997) Effect of sealer thickness on long-term sealing ability: a 2-year follow-up study. *International Endodontic Journal* **30**, 307–12.

Lertchirakarn V, Palamara J, Messer H (1999) Load and strain during lateral condensation and vertical root fracture. *Journal of Endodontics* **25**, 99–104.

Ørstavik D (1982) Seating of GP points: effects of sealers with varying film thickness. *Journal of Endodontics* **8**, 213–8.

Pagavino G, Giachetti L, Nieri M, Giuliani V, Russo DS (2006) The percentage of gutta-percha-filled area in simulated curved canals when filled using EndoTwinn, a new heat device source. *International Endodontic Journal* **39**, 610–5.

Peters D (1986) Two-year in vitro solubility evaluation of four gutta-percha sealer obturation techniques. *Journal of Endodontics* **12**, 139–45.

Peters O, Schönenberger K, Laib A (2001) Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *International Endodontic Journal* **34**, 221–30.

Qualtrough AJ, Whitworth JM, Dummer PM (1999) Preclinical endodontology: an international comparison. *International Endodontic Journal* **32**, 406–14.

Schafer E (1997) Root canal instruments for manual use: a review. *Endodontics and Dental Traumatology* **13**, 51–64.

Schneider SW (1971) A comparison of canal preparation in straight and curved root canals. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **32**, 271–5.

Spangberg LSW (2002) Instruments, materials and devices. In: Cohen S, Burns RC, eds. *Pathways of the Pulp*, 8th edn. St Louis, USA: Mosby, pp. 543–4.

Tagger M, Tagger E, Tjin AH, Bakland LK (2002) Measurement of adhesion of endodontic sealers on dentin. *Journal of Endodontics* **28**, 351–4.

van der Sluis L, Wu M, Wesselink P (2005) An evaluation of the quality of root filings in mandibular incisors and maxillary and mandibular canines using different methodologies. *Journal of Dentistry* **33**, 683–8.

Weis M, Parashos P, Messer H (2004) Effect of obturation technique on sealer cement thickness and dentinal tubule penetration. *International Endodontic Journal* **37**, 653–63.

Wu MK, Wesselink PR (2001) A primary observation on the preparation and obturation of oval canals. *International Endodontic Journal* **34**, 137–41.

Wu MK, Ozok A, Wesselink P (2000) Sealer distribution in root canals obturated by three techniques. *International Endodontic Journal* **33**, 340–5.

Wu MK, Kastakova A, Wesselink P (2001) Quality of cold and warm gutta-percha fillings in oval canals in mandibular premolars. *International Endodontic Journal* **34**, 485–91.

Wu MK, van der Sluis L, Wesselink P (2002) A preliminary study of the percentage of gutta-percha filled in the apical canal filled with vertically compacted warm gutta-percha. *International Endodontic Journal* **35**, 527–35.

Wu MK, De Groot SD, van der Sluis LW, Wesselink PR (2003) The effect of using an inverted master cone in a lateral compaction technique on the density of the gutta-percha fill. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **96**, 345–50.

