# Percentage of canals filled in apical cross sections – an *in vitro* study of seven obturation techniques

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## Abstract

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**Aim** To compare the apical density of several obturation techniques when used in palatal roots of extracted maxillary molars.

**Methodology** Seventy extracted molars were randomly divided into seven groups with 10 teeth each. The palatal root canals were instrumented to size 60 MAF, coated with Kerr's Pulp Canal Sealer, and obturated using one of seven techniques. The palatal roots were separated from the crowns, decalcified, and sectioned horizontally at 2 and 4 mm from the apex. The cross-sections were photographed through a microscope, the photos were analysed, and the amount of area in the canal that was obturated with gutta-percha was measured. The means for the 20 sections per group were calculated and the means were compared using mixed analysis of variance test.

**Results** Simplifill used in accordance with the manufacturer's directions and Thermafil had the greatest mean obturated area, but neither were statistically better than mechanical lateral or warm vertical compaction (WVC; Schilder Technique). Simplifill as recommended and Thermafil were statistically better than cold lateral ($P = 0.0210$ and 0.0433, respectively), WVC (continuous wave) ($P = 0.0006$ and 0.0015), and the modified Simplifill group ($P = 0.0010$ and 0.0012). In addition, mechanical lateral and WVC (Schilder) had statistically more obturated area than WVC (continuous wave) ($P = 0.0054$ and 0.0073) and modified Simplifill ($P = 0.0015$ and 0.0016). Cold lateral and WVC (continuous wave) had significantly more obturated area than modified Simplifill ($P = 0.0040$ and 0.0087).

**Conclusions** Simplifill as recommended, Thermafil, mechanical lateral and WVC (Schilder) obturation techniques created more complete obturation using gutta-percha at the 2 and 4 mm levels than cold lateral, WVC (continuous wave), and Simplifill not used as directed.

**Keywords:** apical cross-sections, obturation techniques, root canal filling.

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## Introduction

The goal of root canal filling is to completely obliterate the canal space with a stable, nontoxic material whilst at the same time creating an hermetic seal to prevent the movement of tissue fluids, bacteria or bacterial by-products through the filled canal. To date the material most used in endodontics is gutta-percha in combination with a root canal sealer. The sealer provides the seal, not the gutta-percha, yet it has been reported that some sealers shrink upon setting whilst others are susceptible to breakdown (Peters 1986, Kontakiotis *et al.* 1997). Therefore, the amount of sealer should be kept to a minimum and should only be found in a thin layer between the gutta-percha and the wall of the canal (Wu *et al.* 2000). To accomplish this task, the

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amount of gutta-percha packed into the canal must be maximized.

Lateral condensation is the obturation technique most widely taught in dental schools and used by practitioners, and is still the standard to which all other techniques are compared (Ingle & Bakland 2002). However, the technique can result in the creation of voids, spreader tracts, excessive amounts of sealer, and lack of surface adaptation to canal walls (Brayton *et al.* 1973, Eguchi *et al.* 1985). Alternative techniques have been introduced which incorporate the use of thermal or frictional heat to plasticize the gutta-percha, allowing for better adaptation to canal walls and a higher degree of homogeneity (Schilder 1967).

Several techniques utilize heat applied to gutta-percha in the canal. One of the first to be described was warm vertical compaction (WVC) of gutta-percha (Schilder 1967). This technique utilized heated spreaders and a series of specially designed pluggers. The WVC technique was later modified by incorporating the use of the System B spreader/plugger, the so-called 'Continuous Wave Technique' (Buchanan 1996).

Another method is to combine gutta-percha with an integrated, nonremovable carrier. These coated carriers are heated before being inserted into the canal. The first of these, Thermafil (Tulsa Dental, Tulsa, OK, USA), was introduced in 1978 (Johnson 1978). It involves the use of α-phase gutta-percha on a metal or plastic carrier that is heated prior to insertion (Thermafil Plus Instructional Manual 2002). Conversely, Simplifill (Lightspeed Technology Inc., San Antonio, TX, USA) is a system in which cold gutta-percha is placed into the canal using a removable carrier (Senia & Wildey 2000).

Another alternative is to use frictional heat to thermoplasticize gutta-percha in the canal. One of these methods, mechanical lateral condensation (Gound *et al.* 2000), involves placing a master cone in the canal, followed by a nickel-titanium spreader activated with a reciprocating-action handpiece (Kerr Co., Orange, CA, USA).

The aim of this study was to compare the percentage of gutta-percha (PGP) in the apical extent of palatal roots of maxillary molar teeth after obturation using cold lateral condensation, mechanical lateral condensation, WVC (continuous wave), WVC (Schilder technique), Thermafil, or two techniques using Simplifill (to a standard size and to a custom size as per manufacturer's recommendations). This was accomplished by calculating the area of gutta-percha in cross-section and comparing that area with the overall area of the canal.

## Materials and methods

Seventy maxillary molars with nonfused, well-developed roots were randomly collected from the UNMC College of Dentistry Oral Surgery Department. Soft tissue tags, attached bone, and calculus were removed and the teeth were stored in a 2% solution of sodium hypochlorite. Seventy teeth were randomly divided into seven groups of 10 teeth each.

Access cavities were prepared using a cross-cut fissure bur, then a size 15 file was inserted into the palatal canal until it was just visible at the apical foramen. Working length was determined by subtracting 1 mm from this length. Patency was established and confirmed by passing a size 20 file through the apex before and after instrumentation.

Groups 1–5 were prepared in a crown down fashion. Briefly, Gates Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) sizes 5-2 were used in decreasing succession to flare the coronal portion of the canals to a depth of 8 mm from the working length. Next, a size 8 ProFile Series 29 nickel-titanium file (Tulsa Dental) with a taper of 0.04 was introduced into the canals in the presence of RC Prep (Premier Dental, Plymouth Meeting, PA, USA). Sequentially smaller ProFiles were then introduced until working length was reached. At this point, the preparation was enlarged with sequentially larger ProFiles to a standard size 8 ProFile (ISO size 60 at the working length). The files were advanced with only light apical pressure utilizing an Aseptico Endo ITR 8 : 1 minihead reduction contra-angle attached to an Aseptico Endo ITR Electric Torque Control Motor (Aseptico International, Woodinville, WA, USA) set at 350 r.p.m., torque level 2.

Groups 6 and 7 were also coronally flared using Gates Glidden drills, but Lightspeed rotary instruments were utilized instead of ProFiles. The reason for this is that the Simplifill system is designed to be used exclusively with Lightspeed instruments (Lightspeed Technology Inc.). In short, Lightspeed instruments were inserted into the canal by hand with no rotation (Simplifill Obturation Technique Guide 2002). The first rotary to bind short of working length indicated the size of the apex and signalled the initiation of rotary instrumentation. A Taskal 7 cordless handpiece (NSK Nakanishi Inc., Tochigi-ken, Japan) set at 2000 r.p.m. was used with sequentially larger instruments until it took 12 light pecks for the rotary to get to working length, which establishes the master apical rotary size. A step back preparation was created 4 mm from the working length. Simplifill obturators are designed to fill these parallel preparations. Instead of using manufacturers recommendations, canals in group 6 was prepared to a Lightspeed size 60, to be consistent with the standard experimental size for groups 1–5. The 12 pecks rule was followed for group 7 resulting in a variable master apical rotary size (between size 60 and 100).

One millilitre of 5.25% sodium hypochlorite was used to irrigate the canals between each change of instrument using a syringe and 27-gauge needle. After instrumentation, the teeth were stored in a 2% solution of sodium hypochlorite until obturation was accomplished.

*Group 1* was obturated using cold lateral condensation. The canals were dried using paper points. Freshly mixed Kerr Pulp Canal Sealer (Kerr, Romulus, MI, USA) was applied to the canals using a size 60 hand file rotating counterclockwise. A size 60 .04 taper primary gutta-percha cone coated with sealer was then placed to working length. A size 'fine' nickel-titanium spreader was inserted to 1 mm from working length and size 'fine–fine' accessory points were placed into the void left by the spreader upon its removal. This process was repeated until the spreader would not penetrate past mid-root with a reasonable amount of force (1–1.5 kg). The gutta-percha was seared off at the orifice using a System B heat source (EIE/Analytic Technology, Richmond, WA, USA) set at 230 °C and vertical pressure was applied with a plugger until cooling had occurred.

*Group 2* was filled using mechanical lateral condensation. The same procedures were used as for group 1 except that the spreader was introduced into the canal using a reciprocating-action handpiece (Endo-Gripper, EndoSolutions, York, PA, USA).

*Group 3* was obturated using WVC (continuous wave). The canal was coated with sealer as before and a size sixty .04 taper gutta-percha cone coated with sealer was placed to working length. A medium-large System B insert tip bound at 3–4 mm from the working length and was used for condensation. The System B was preset to 230 °C during apical condensation of the primary cone. The tip was inserted to the predetermined length of 3–4 mm from the working length using steady pressure. Once at the proper depth, the heat was removed and apical pressure was maintained for 10 s. At this point, a short 1-s burst of heat was used to separate the tip from the apical gutta-percha plug and the tip was removed. The canal was coated again with a thin layer of sealer, backfilled with gutta-percha expressed from an Obtura II gun (Obtura Corp., Fenton, MO, USA) set at 200 °C, and down-packed with a plugger.

*Group 4* was obturated using the WVC Schilder technique. The same procedures were used as for group 3 except that the condensation was performed in three steps using a graded series of pluggers. First the primary gutta-percha cone was seared off at the coronal orifice and a large plugger was used to apply apical pressure to the remaining gutta-percha. Next, a 4–5 mm increment of gutta-percha was removed using the medium-large System B plugger, then a medium plugger was used to apply apical pressure again. Finally, gutta-percha was removed to 3–4 mm from the apex and a small plugger was used to apply apical pressure until cooling had occurred. The Obtura II was used to backfill the canal in the same manner as group 3.

*Group 5* was filled with Thermafil obturators. The canals were coated with sealer as in the previous groups and size 60 Thermafil obturators with plastic carriers were introduced according to the manufacturer's recommendations (Thermafil Plus Instructional Manual 2002). After heating the obturators for 10 s in a Thermaprep oven (Tulsa Dental), they were slowly inserted into the canals to 0.5 mm from the working length. An inverted cone bur was used to separate the handle from the rest of the carrier after placement, and the coronal gutta-percha was vertically condensed with Schilder pluggers until cooling had occurred.

*Group 6* was filled using size 60 Simplifill obturators. After trial fitting the obturators to within 1–3 mm from the working length, the canals were coated with sealer using a size 40 hand file rotating counterclockwise, and size 60 Simplifill obturators were introduced according to the manufacturer's recommendations (Simplifill Obturation Technique Guide 2002). The obturator was coated with a thin film of sealer and pressed to working length with firm apical pressure. Once at working length, the handle was rotated counterclockwise four full turns to release the gutta-percha plug from the carrier. The Obtura II was used to backfill the canal in the same manner as previous groups.

*Group 7* was filled with custom-fitted Simplifill obturators used in the same manner as group 6. However, the apical preparation size was more variable because the 12 pecks rule suggested by the manufacturer was used. The obturator corresponding to the respective master apical rotary instrument for each tooth was employed rather than the standard size of 60.

After obturation the teeth were stored for 7 days at 37 °C and 100% humidity to ensure complete setting of sealer. On day 8 a cross-cut fissure bur in a high-speed handpiece was used to section off the palatal roots at the furcation. Next the roots were placed into 5% nitric acid for 36 h to achieve decalcification. The decalcified roots were sectioned perpendicular to the long axis at a level 2 and 4 mm from the apex using a new size 15 blade for each root. These sections were photographed using Nikon Coolpix 950 (Nikon, Melville, NY, USA) mounted to a Photomakroskop M400 microscope (Wild, Heerbrugg, Switzerland) at 40× magnification and these photos were recorded as tagged image file format (TIFF) images. The area of the root canal and of the gutta-percha (excluding sealer) in the coronal part of each section were measured using Sigma Scan Pro 5 (SPSS, Chicago, IL, USA), and the PGP in each canal was calculated. The measurements were repeated randomly in at least two sections per group to assure reproducibility of measurements, and all PGP measurements were within 0.30% of each other. The mean PGPs for each group were determined and then the groups were compared using analysis of variance. More specifically, a mixed model analysis of variance was run as a split plot with the main plot factor being obturation technique and the subplot factor being distance from the apex. In addition, the model allowed for different variances for each group.

## Results

In a preliminary statistical analysis, there was no statistically significant difference between PGP at 2 and 4 mm; therefore, only treatment differences were compared. In addition, the modified Simplifill group (group 6) had a much larger variance than the other groups, and for that reason a separate variance was used for group 6 in the final analysis to improve the validity of the statistics and to elicit differences between the other groups.

Because the 2 or 4 mm sections were combined there were 20 samples for each group. A significant treatment effect was discovered and the mean PGP values for each group are shown in Table 1. Analysis of variance for independent groups indicates that the mean PGPs for Simplifill used according to manufacturer's recommendations, Thermafil, mechanical lateral condensation and WVC (Schilder) techniques were not statistically different ($P > 0.05$). Simplifill as recommended and Thermafil had mean PGPs that were significantly higher than cold lateral condensation ($P = 0.0210$ and $0.0433$, respectively), WVC (continuous wave) ($P = 0.0006$ and $0.0015$), and the modified Simplifill group ($P = 0.0010$ and $0.0012$).

**Table 1** Percent gutta-percha (PGP) filled area in palatal roots of maxillary molars obturated using different techniques. Means with no shared (x) are significantly different at a level of 0.05

| Group name (number) | PGP, % (mean ± SD) | | | | |
|---|---|---|---|---|---|
| Simplifill customized (7) | 97.4 ± 3.8 | x | | | |
| Thermafil (5) | 96.9 ± 3.1 | x | | | |
| Mechanical lateral condensation (2) | 96.2 ± 2.0 | x | x | | |
| Warm vertical Schilder (4) | 96.1 ± 4.1 | x | x | | |
| Lateral condensation (1) | 93.8 ± 4.7 | | x | x | |
| Warm vertical continuous wave (3) | 91.8 ± 7.0 | | | x | |
| Simplifill Modified (6) | 78.3 ± 15.4[a] | | | | x |

[a]Excessive standard deviation requiring separate variance in calculations of pairwise comparisons.

In addition, mechanical lateral and WVC (Schilder) were also statistically better than WVC (continuous wave) ($P = 0.0054$ and $0.0073$) and modified Simplifill ($P = 0.0015$ and $0.0016$). Cold lateral and WVC (continuous wave) were also significantly better than modified Simplifill ($P = 0.0040$ and $0.0087$).

## Discussion

Palatal canals of maxillary molars were used in this study because they are long, relatively straight canals which are usually oval, offering a better test of the ability of a technique to fill irregularities, compared with roots with round canals (Wu *et al.* 2001). Canals were enlarged to size 60 in all except the customized Simplifill group to standardize the canal shape as much as possible.

In two other studies (Gençoglu *et al.* 2002, Wu *et al.* 2001), similar research protocols were used including sectioning 2 and 4 mm or 1, 2, 3 and 4 mm from the apex. Unlike the present research, both of these authors did find some differences in PGP at different levels of sectioning.

There were some minor differences in the PGP values obtained in this study compared with those found in other studies: for cold lateral condensation, Gençoglu *et al.* (2002) reported a mean PGP of 81.2%, Wu *et al.* (2001) reported 93.6%, and in the present study it was 93.8%. For WVC, Gençoglu *et al.* (2002) used the System B and his PGP was 86.7% compared with 91.85% for WVC (continuous wave) in the present study. Wu *et al.* (2001) used the Touch n' Heat and different sized condensers and had a mean PGP of 96.9% compared with 96.1% in the present study using WVC (Schilder). Gençoglu *et al.* (2002) had more

 

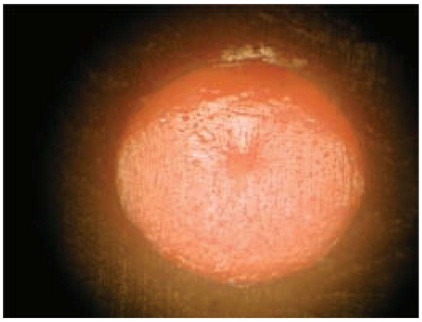

**Figure 1** Customized Simplifill obturator displaying excellent adaptation and homogenous obturation of the canal space.

obturated area with Thermafil (PGP 98.9%) than noted in the present study (PGP 96.9%).

The technique with the most obturated area, the recommended Simplifill technique (group 7) utilized a plug of cold gutta-percha that is wedged into an apical preparation very closely mimicking the size of the plug (Fig. 1). It can be equated to putting a cork in a bottle. Gutta-percha whilst not compressible (Schilder *et al.* 1974a), may be compactable to a certain degree and it may retain some memory after compaction causing it to exert internal pressure against the walls of the root canal (Marlin & Schilder 1973). The present research showed that it is essential to machine the apex using the '12 pecks rule' in the hope of achieving a close fit with the Simplifill obturators, as they will not adapt to anything but a round preparation. The group having the least obturated area (group 6) illustrates this fact, by not performing the obturation based upon the manufacturer's recommendations the resultant fillings had poor density and exhibited a high degree of variability (Fig. 2).

Three groups with the most obturated areas (groups 2, 4 and 5) utilized some form of heat to plasticize the gutta-percha. When gutta-percha is heated beyond 42–49 °C it undergoes a crystalline phase transition resulting in permanent volumetric changes (Schilder *et al.* 1974b). The net result is an increase in the volume of the gutta-percha as it changes from its beta to alpha phase (Lee *et al.* 1997). For this to be of any potential benefit however, the gutta-percha must be heated within the canal.

Thermafil uses oven-heated $\alpha$-phase gutta-percha on a carrier, which is introduced into the canal in one motion. Because it is heated outside the canal, it will only shrink within the canal after being introduced. The technique was time-efficient and obliterated the canals well, however there were two areas of potential concern; all of the Thermafil samples experienced gutta-percha overfills and many of the cross-sections revealed the carrier directly against the wall of the canal (Fig. 3). None of the other groups experienced gutta-percha overfills.

In theory, WVC techniques should result in the plasticizing of the gutta-percha apical to the heat carrier. Whether the heat is actually sufficient to induce phase change ahead of the instrument is still in question (Blum *et al.* 1997, Venturi *et al.* 2002). This method seems conducive to excellent canal adaptation due to flow and volume changes. The relatively poor results for WVC (continuous wave) in the present study were a surprise. It could be due to a less effective compaction resulting from inadequate hydraulic forces, stemming from the use of a single heater/plugger as opposed to the multiple pluggers used in the Schilder procedure. It is possible that the heated gutta-percha simply flows and expands around the plugger instead of being forced into irregularities as with Schilder's technique (Fig. 4).

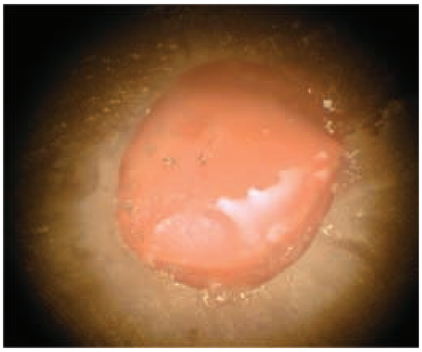

**Figure 2** Modified Simplifill showing a complete lack of canal wall adaptation.

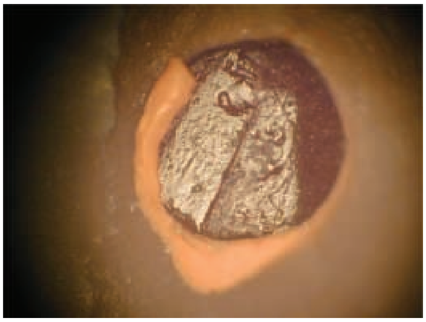

**Figure 3** Thermafil obturator with the carrier lying directly against the wall of the canal.

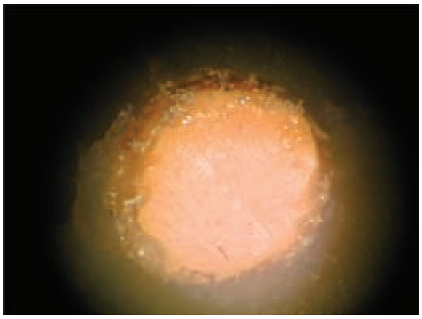

**Figure 4** Warm vertical continuous wave showing a lack of canal wall adaptation.

The mechanical lateral technique produces frictional heat via a reciprocating spreader placed deeply into the canal. Whilst the PGP was very similar for Mechanical Lateral and WVC (Schilder), the latter technique produced a more homogenous mass of gutta-percha at both 2 and 4 mm when judged qualitatively (Figs 5 and 6). The mechanical lateral groups displayed areas of swirled gutta-percha with small amounts of sealer between them. These findings compared with Wong *et al.* (1981), who found that a different mechanical condensation technique produced more density than cold lateral condensation, but the replication of canal irregularities was inferior to WVC.

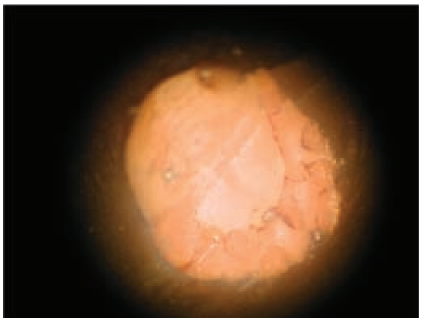

**Figure 5** Mechanical lateral compaction with swirls of gutta-percha indicating that the gutta-percha has been thermoplasticized.

Cold lateral condensation density was relatively good, but obvious voids and spreader tracts were apparent in cross-sections (Fig. 7). The improved PGP compared with the results of Gençoglu *et al.* (2002) could be due to the use of size 'fine' spreaders in conjunction with size 'fine–fine' accessory points. A fine spreader creates a larger space than is required for a fine–fine accessory cone and this combination may have allowed for deeper penetration and an increased number of accessory points placed into each canal (Gound *et al.* 2001).

This research protocol has several limitations. Only two areas of the obturated canal were evaluated, and different findings may have been present at other levels. Wu *et al.* (2001) also measured PGP at 2 and 4 mm levels and found no statistical difference at the 2 mm level between cold lateral and warm GP techniques. They also tested for apical leakage using a fluid transport model and again found no statistical difference between the two groups, suggesting that a correlation between PGP at the 2 mm level and leakage may exist. Further research is indicated to confirm that finding.

A final question to be discussed is whether the differences found in this and similar studies are clinically relevant. Recently, Friedman *et al.* (2003) compared clinical success rates for cold lateral condensation (78%) to the rate for WVC Schilder technique (86%) and reported no statistical difference ($P = 0.810$). The differences in PGPs in the present study were also not significant ($P = 0.1354$).

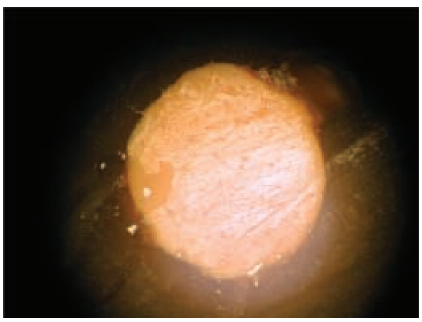

**Figure 6** Warm vertical Schilder technique also displaying excellent adaptation and homogenous obturation.

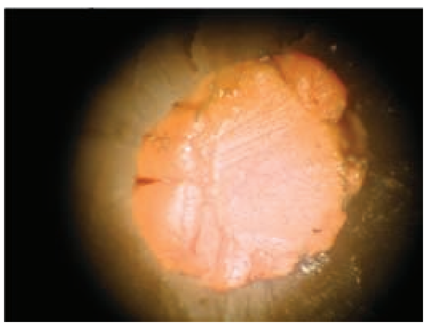

**Figure 7** Cold lateral condensation with numerous voids between primary and accessory points.

Additional clinical research is needed to determine if differences in other techniques exist.

## Conclusion

When used *in vitro* Simplifill (using the recommended technique), Thermafil, mechanical lateral and WVC (Schilder) obturation techniques created more complete obturation at the 2 and 4 mm levels than cold lateral, WVC (continuous wave) and a modified Simplifill technique.

## References


Blum J, Parahy E, Machtou P (1997) Warm vertical compaction sequences in relation to gutta-percha temperature. *Journal of Endodontics* **23**, 307–11.

Brayton SM, Davis SR, Goldman M (1973) Gutta-percha root canal fillings. *Oral Surgery, Oral Medicine, Oral Pathology* **35**, 226–31.

Buchanan LS (1996) Continuous wave of obturation technique. *Dentistry Today* **15**, 60–7.

Eguchi DS, Peters D, Hollinger JO, Lorton L (1985) A comparison of the area of the canal space occupied by gutta-percha following four gutta-percha obturation techniques using procosol sealer. *Journal of Endodontics* **11**, 66–75.

Friedman S, Abitbol S, Lawrence HP (2003) Treatment outcomes in endodontics: The Toronto Study Phase 1: Initial treatment. *Journal of Endodontics* **29**, 787–93.

Gençoglu 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 Endodontics* **92**, 333–6.

Gound TG, Riehm RJ, Odgaard EC, 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.

Gound TG, Riehm RJ, Makkawy H, 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.

Ingle JE, Bakland LK (2002) *Endodontics*, 5th edn. Hamilton, Ontario, Canada: BC Decker Inc.

Johnson WB (1978) A new gutta-percha filling technique. *Journal of Endodontics* **4**, 184–8.

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.

Lee C, Chang Y, Cobb C, Robinson S, Hellmuth E (1997) Dimensional stability of thermosensative gutta-percha. *Journal of Endodontics* **23**, 579–82.

Marlin J, Schilder H (1973) Physical properties of gutta-percha when subjected to heat and vertical condensation. *Oral Surgery, Oral Medicine, Oral Pathology* **36**, 872–9.

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

Schilder H (1967) Filling of the root canal in three dimensions. *Dental Clinics of North America* **11**, 723–44.

Schilder H, Goodman A, Aldrich W (1974a) The thermomechanical properties of gutta-percha I. The compressibility of gutta-percha. *Oral Surgery, Oral Medicine, Oral Pathology* **37**, 946–53.

Schilder H, Goodman A, Aldrich W (1974b) The thermomechanical properties of gutta-percha III. Determination of phase transition temperatures for gutta-percha. *Oral Surgery, Oral Medicine, Oral Pathology* **38**, 109–14.

Senia ES, Wildey WL (2000) *The Lightspeed Instructional Guide*. San Antonio, TX: Lightspeed Technology Inc.

Simplifill Obturation Technique Guide (2002) http://www.tulsadental.com/PDFs/TUD-2065_therfil+instr.pdf. Tulsa, OK: Tulsa Dental.

*Thermafil Plus Instructional Manual* (2002) http://www.tulsadental.com/PDFs/TUD-2065_therfil+instr.pdf. Tulsa, OK: Tulsa Dental.

Venturi M, Pasquantonio G, Falconi M, Breschi L (2002) Temperature change within gutta-percha induced by the System-B heat source. *International Endodontic Journal* **35**, 740–46.

Wong M, Peters DD, Lorton L (1981) Comparison of gutta-percha filling techniques, compaction (mechanical), vertical (warm), and lateral condensation techniques, Part 1. *Journal of Endodontics* **7**, 551–8.

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

Wu M-K, Kašt'áková A, Wesselink PR (2001) Quality of cold and warm gutta-percha fillings in oval canals in mandibular premolars. *International Endodontic Journal* **34**, 485–91.