Comparison of two vertical condensation obturation techniques: Touch 'n Heat modified and System B

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Abstract

Silver GK, Love RM and Purton DG. Comparison of two vertical condensation obturation techniques: Touch 'n Heat modified and System B. *International Endodontic Journal,* **32,** 287–295, 1999.

Aim The aims of this study were firstly to compare the area of canal occupied by gutta-percha, sealer or voids using the System B heating device with that obtained by a modified vertical condensation technique using the Touch 'n Heat; and secondly to compare the temperature changes at the root canal wall and external root surface during obturation with the above techniques.

Methodology Forty-five resin blocks, each with a standardized, simulated, prepared main root canal and five lateral canals, were assigned to three equal experimental groups. The canals were obturated using either the System B technique at two different temperature settings, or vertical condensation with a Touch 'n Heat instrument as the heat source. A heat transfer model was used to simultaneously record internal and external root surface temperature elevations during obturation by the three techniques. Data were analysed using unpaired Student's *t*-test and Mann–Whitney *U*-test.

Results Both obturation techniques produced root fillings consisting of over 90% gutta-percha at most levels, although the percentages of sealer and voids 2–3 mm from the working length following System B obturation were higher than those found following modified vertical condensation. Modified vertical condensation resulted in more gutta-percha in lateral canals. Obturation was accomplished more quickly using the System B, and temperature elevations produced during obturation with the System B were significantly less ($P < 0.001$) than with vertical condensation. An elevation of external root surface temperature by more than 10°C occurred during vertical condensation.

Conclusions The results suggest that the System B may produce an acceptable obturation and that the use of a Touch 'n Heat source during vertical condensation may result in damage to the periodontium.

Keywords: System B, Touch 'n Heat, vertical condensation.

Introduction

Complete obturation of the root canal system, with a dimensionally stable material, is a goal in conventional root canal therapy. A root filling comprised primarily of gutta-percha can satisfy this goal and Schilder (1967) reported that vertical condensation of thermoplasticized gutta-percha can achieve this. Subsequent studies demonstrated that vertically condensed gutta-percha produced a seal similar to that produced by lateral condensation (Rhome *et al.* 1981, Dalat & Spångberg 1994), and that replication of the canal morphology was superior to that achieved by lateral condensation (Wong *et al.* 1981, Reader *et al.* 1993). Modifications to Schilder's technique have been advocated to improve its efficacy and efficiency. For example, the Touch 'n Heat endodontic heat source (EIE/Analytic, Redmond, WA, USA) has been used to thermoplasticize gutta-percha (Blum *et al.* 1997),

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supplanting a flame-heated spreader/carrier as originally advocated by Schilder. The System B endodontic heat source unit (EIE/Analytic) was designed to modify Schilder's technique by obturating the root canal system with a single continuous wave of thermoplasticized gutta-percha (Buchanan 1996). Numerous investigators have expressed concern that the use of an uncontrolled heat source within the root canal may have a deleterious effect on the periodontium. A temperature rise of 10°C above normal body temperature is regarded as a critical level at which periodontal tissues could be adversely affected (Fors *et al.* 1985, Hardie 1986, Gutmann *et al.* 1987, Saunders 1990b).

Scientific research regarding the efficacy and safety of the System B is lacking. Similarly, the Touch 'n Heat, used to modify Schilder's vertical condensation technique, has received little investigation, having been assumed to produce root fillings and root surface temperature elevations similar to those produced with a flame-heated spreader. The aims of this study were firstly to compare the area of canal occupied by gutta-percha, sealer or voids using the System B heating device with obturation by a modified vertical condensation technique using the Touch 'n Heat; and secondly to compare the temperature changes at the root canal wall and external root surface during obturation with the above techniques.

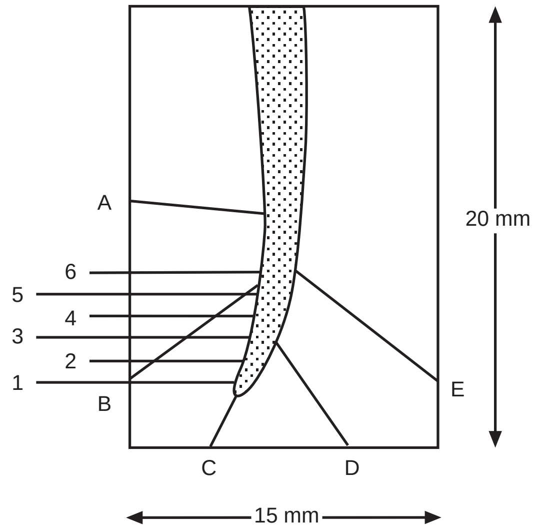

Figure 1 Diagram of artificial root canal model. A–E, lateral canals; 1–6, sectioning levels.

Materials and methods

Obturation of canals

Forty-five clear epoxy blocks with a standardized, simulated single, prepared root canal that tapered in diameter from approximately 2.5 mm at the access to 0.5 mm at the canal terminus and five lateral canals (0.1 mm diameter) (Kilgore International Inc., Coldwater, MI, USA) (Fig. 1) were used in this study. The patency of all lateral canals was verified using a size 06 K-type file and then the blocks were masked with aluminium foil and tape, leaving the access to the root canal open. They were randomly assigned to three equal numbered experimental groups:

1 *Vertical condensation*. Root canals were obturated as described by Schilder (1967). The heat source for this group was standardized by the use of a Touch 'n Heat (model 5004) at a power setting of 7 (Instruction guidelines, Touch 'n Heat). The canal and apical 2 mm of a medium-large non-standardized gutta-percha cone was lightly coated with sealer (Kerr Pulp Canal Sealer EWT, Kerr, Romulus, MI, USA) and the cone placed to within 0.5 mm of the working length. Sequential removal of thermoplasticized gutta-percha and vertical condensation of the remaining gutta-percha were completed when a number 9 (0.9 mm diameter tip) vertical plugger was 4 mm from the working length. The remainder of the canal was then obturated with warmed segments of gutta-percha.

2 *System B 200/250°C*. Canals were obturated using the System B technique (model 1005, EIE/Analytic) as recommended by the manufacturer and by Buchanan (1996). Briefly, the canal walls were thinly coated with sealer (Kerr Pulp Canal Sealer), and a medium-large non-standardized gutta-percha cone was placed to within 0.5 mm of the working length. A medium-large insert tip, which bound in the canal 3 mm from the working length, was used in the obturation of the canal. The System B unit was preset to 200°C during apical condensation of the primary gutta-percha cone (down-pack), to 100°C when adapting and condensing the apical portion of the secondary (backfill) gutta-percha cone, and finally to 250°C to thermosoften the remainder of the secondary cone prior to vertical condensation.

3 *System B 250/300°C*. Canals were obturated as above, except that the System B unit was preset to 250°C during down-pack and to 300°C when thermosoftening the backfill cone prior to condensation. These temperature settings were selected because a pilot study revealed that a temperature reading of 250°C and 300°C on the unit's liquid crystal display produced 200°C and 250°C, respectively, 2 mm from the insert tip. Therefore, this group tested the System B unit at the correct temperatures recommended by the manufacturer. All canals were obturated with gutta-percha from one source (Dentsply, Milford, DE, USA). To ensure complete setting of the sealer, all blocks were stored at room temperature for 1 week on moistened gauze in a sealed container.

Comparison of areas of canal occupied by gutta-percha, sealer and voids

The length of gutta-percha in each of the lateral canals was measured from the main canal wall using a stereo microscope at magnification × 40 (SZ4045TR, Olympus, Tokyo, Japan). The image of the lateral canal was transferred, via a video camera (JVC-TK1281, Victory Company of Japan Ltd, Tokyo, Japan), to a colour video monitor with an *x–y* axis (PVM1440QM, Sony, Tokyo, Japan). Measurements were made to the nearest 0.1 mm using a digital counter (CM6S, Nikon, Tokyo, Japan). The blocks were then sectioned perpendicular to the axis of the main canal at 1, 2, 3, 4, 5 and 6 mm from the working length (Fig. 1) using a 0.2 mm thick diamond rotary blade with copious cold water irrigation (Isomet Saw, Buhler Ltd, Evanston, IL, USA). Corresponding sections from all the blocks were then grouped together. Each section was displayed on a colour video monitor, and a clear yellow acetate sheet (type A 3R96025, Rank Xerox, UK) was placed over the image. Tracings were made of the area of canal occupied by gutta-percha in yellow, sealer in red, and voids in black. The tracings were electronically scanned (300 dots inch^{-1}, automatic gain and exposure), digitized (Hewlett Packard ScanJet 4c/t, Greeley, CO, USA) and stored using Adobe Photoshop 3.0 (Adobe Systems Inc, San Jose, CA, USA). The pixel count for each area was analysed using Erdas Imagine 8.2 software (Erdas Inc, Atlanta, GA, USA) and areas representative of gutta-percha, sealer or voids were expressed as percentages of the total canal area. All results were analysed with unpaired Student's *t*-test and MannWhitney *U*-test at the 95% confidence level.

Comparison of temperature elevation

Tooth preparation. A fully formed, permanent, human, mandibular canine with a straight patent root canal was selected for this study. Adherent calculus and soft tissue were removed using periodontal scalers and 5.2% NaOCl and the root was examined for surface defects under magnification (× 3.5). The tooth was sectioned at the cemento-enamel junction using a water-cooled rotating diamond disc and the root canal was prepared chemomechanically using the step-back technique with Flex O Files (Maillefer, Ballaigues, Switzerland), Gates Glidden drills (Maillefer) and 2.6% NaOCl irrigation to an apical size 40, 0.5 mm short of the apical foramen. Preparation was considered complete when a number 9 vertical condensation plugger (Hu-Friedy, Chicago, IL, USA) could be placed to within 4 mm of the working length. The root was then sectioned longitudinally in a mesiodistal plane through the centre of the root canal using a rotary diamond saw. The sections were stored in a sealed container on moistened gauze until required.

Heat transfer model. The split tooth/computer temperature measurement system described by Weller & Koch (1995) was modified. Type K chromelalumel thermocouples (Omega Engineering Inc., Stamford, CT, USA) were fixed to the labial external root surface 4 mm (E-4) and 9 mm (E-9) from the anatomic apex with cyanoacrylate adhesive. Holes (1.6 mm in diameter) were cut through the dentine of the lingual section of the root at 4 and 9 mm from the apex and thermocouples I-4 and I-9 were secured flush with the root canal surface. The root halves, with thermocouples attached, were embedded in a two-part acrylic block.

Each thermocouple was linked to a MacLab/8e (AD Instruments Pty Ltd, Castle Hill, Australia) and computer (Apple Computer, Inc., Cupertino, CA, USA). The software program was configured to simultaneously record the input data from the four thermocouples at a continuous sampling rate for each thermocouple, with an accuracy of ± 0.1°C. The heat transfer model was maintained at room temperature during the study. All readings were recorded as temperature elevations, and commenced 1 min prior to obturation and finished 2 min after obturation. The heat transfer model was obturated 15 times, without sealer, for each technique. The time taken to obturate the canal using each technique was recorded. Unpaired Student's *t*-tests were used to compare the mean temperature elevations at each thermocouple.

Results

Length of gutta-percha in lateral canals

Significantly more gutta-percha was recorded in lateral canals A, B, C, D and E after vertical condensation

Table 1 Mean length (mm) of gutta-percha in lateral canals

Lateral canal	(1) Vertical condensation	(2) System B 200/250°C	(3) System B 250/300°C	Differences
A	0.8 ± 0.3	0.40 ± 0.2	0.50 ± 0.2	1–2 ($P < 0.001$)
B	1.1 ± 0.4	0.20 ± 0.2	0.30 ± 0.2	1–2, 1–3 ($P < 0.05$)
C	0	0	0	
D	0.8 ± 0.5	0.03 ± 0.01	0.07 ± 0.1	1–2, 1–3 ($P < 0.001$)
E	1.1 ± 0.4	0.50 ± 0.3	0.30 ± 0.2	1–2, 1–3 ($P < 0.001$)

than after either System B technique. No gutta-percha was found in canal C following any obturation technique. No differences were observed between the System B techniques (Table 1).

Cross-sectional area of canal occupied by gutta-percha, sealer or voids

At the 1 mm level, the percentages of gutta-percha, sealer and voids were not significantly different between the groups (Table 2). Vertical condensation produced a higher percentage of gutta-percha than did the System B 250/300°C technique at the 2 mm level, both System B techniques at levels 3 and 5 mm, and the System B 200/250°C technique at the 4 mm level. The System B 200/250°C technique produced a higher percentage of gutta-percha than did the System B 250/300°C technique at the 2 mm level, whilst at the 4 mm level the reverse was found. Vertical condensation resulted in less sealer than either System B technique at levels 5 and 6 mm, and less than the System B 250/300°C technique at the 2 mm level and the System B 200/250°C technique at the 3 and 4 mm levels. At the 2 mm level, the System B 200/250°C technique had less sealer than the System B 250/300°C technique, whereas at the 4 mm level the reverse was found. At the 3 mm level, the System B techniques resulted in a higher percentage of canal unfilled (voids) compared with vertical condensation. No other significant differences were found (Table 2).

Table 2 Percentage of main canal occupied by gutta-percha, sealer and voids

Level from the apex	(1) Vertical condensation	(2) System B 200/250°C	(3) System B 250/300°C	Differences
1				
Gutta-percha	96.9 ± 4.0	97.4 ± 4.0	92.6 ± 9.9	
Sealer	2.9 ± 4.1	2.1 ± 4.1	6.4 ± 8.6	
Voids	0.2 ± 0.4	0.5 ± 0.6	1.0 ± 1.5	
2				
Gutta-percha	94.5 ± 4.7	91.3 ± 7.3	84.5 ± 7.4	
Sealer	5.0 ± 4.7	7.9 ± 6.9	14.4 ± 7.3	1–3 ($P < 0.001$); 2–3 ($P < 0.05$)
Voids	0.5 ± 0.6	0.8 ± 0.9	1.1 ± 1.5	1–3 ($P < 0.001$); 2–3 ($P < 0.05$)
3				
Gutta-percha	97.5 ± 3.7	90.5 ± 8.5	87.2 ± 10.4	1–2 ($P < 0.05$); 1–3 ($P < 0.01$)
Sealer	2.2 ± 3.9	6.9 ± 8.2	10.5 ± 9.7	1–3 ($P < 0.05$)
Voids	0.3 ± 0.6	2.6 ± 3.6	2.3 ± 2.7	1–2, 1–3 ($P < 0.05$)
4				
Gutta-percha	97.8 ± 4.1	92.8 ± 5.9	96.9 ± 2.6	1–2, 2–3 ($P < 0.05$)
Sealer	1.6 ± 4.0	5.7 4.6	1.4 1.9	1–2, 2–3 ($P < 0.05$)
Voids	1.6 ± 4.0	1.5 ± 2.1	1.7 ± 2.5	
5				
Gutta-percha	98.7 ± 2.6	94.5 ± 4.4	95.0 ± 4.1	1–2, 1–3 ($P < 0.05$)
Sealer	0.3 ± 0.8	3.9 ± 4.1	2.8 ± 3.5	1–2, 1–3 ($P < 0.05$)
Voids	1.0 ± 2.6	1.6 ± 2.5	2.2 ± 2.8	
6				
Gutta-percha	98.1 ± 5.3	96.7 ± 2.9	97.0 ± 2.6	
Sealer	0.2 ± 0.5	2.0 ± 1.7	1.3 ± 1.7	1–2 ($P < 0.01$); 1–3 ($P < 0.05$)
Voids	1.7 ± 5.3	1.3 ± 1.7	1.7 ± 2.2	

Table 3 Mean root surface temperature elevation (°C) during obturation

Thermocouple[a]	(1) Vertical condensation	(2) System B 200/250°C	(3) System B 250/300°C	Differences
I-4	31.2 ± 5.2	8.6 ± 3.0	9.8 ± 1.5	1–2, 1–3 ($P < 0.001$)
I-9	57.4 ± 7.4	39.1 ± 11.2	41.2 ± 9.4	1–2, 1–3 ($P < 0.001$)
E-4	14.5 ± 2.3	4.0 ± 1.0	4.1 ± 1.0	1–2, 1–3 ($P < 0.001$)
E-9	12.3 ± 1.6	6.4 ± 1.2	6.2 ± 0.8	1–2, 1–3 ($P < 0.001$)

[a]Internal thermocouples: I-4, 4 mm from apex; I-9, 9 mm from apex. External thermocouples: E-4, 4 mm from apex; E-9, 9 mm from apex.

Temperature elevation during obturation

The mean temperature elevation during vertical condensation at all four thermocouples was significantly higher than with either System B technique, whilst there were no significant differences in temperature elevation between the System B techniques. The highest temperature elevation occurred at the I-9 thermocouple, and internal temperature elevations were always higher than external temperature elevations regardless of technique. Vertical condensation resulted in a root surface temperature elevation of more than 10°C at both thermocouples, with the E-4 thermocouple recording a significantly ($P < 0.05$) higher temperature elevation than the E-9 thermocouple (Table 3). The mean length of time that the root surface temperature was elevated by more than 10°C at the E-9 thermocouple was 3.27 ± 2.36 min, and at the E-4 thermocouple was 2.30 ± 1.40 min. These times were significantly different ($P < 0.05$).

Time required for obturation

The mean length of time required to obturate the heat transfer model by vertical condensation was 8.3 ± 1.8 min; that for the System B 200/250°C was 1.05 ± 0.03 min and that for the System B 250/300°C was 0.46 ± 0.01 min. The time required to obturate by vertical condensation was significantly ($P < 0.001$) longer than that found using either System B technique, and the System B 200/250°C technique took significantly longer than the System B 250/300°C technique ($P < 0.05$).

Discussion

The purpose of this study was to compare the areas of canal occupied by gutta-percha, sealer or voids and the root temperature elevations associated with warm vertical condensation and System B obturation techniques. These techniques use an electronically controlled heat source. Preliminary investigation demonstrated that the Touch 'n Heat and System B units used in this study failed to attain the temperatures claimed by the manufacturer at specified settings. Jurcak *et al.* (1992) and Blum *et al.* (1997) also reported a similar disparity with the Touch 'n Heat. Since the Touch 'n Heat was used as a thermosoftening device, and the temperature was sufficiently high to accomplish this, the unit setting was standardized at 7 (410 ± 39°C at 5 s and 505 ± 49°C at 10 s, compared with 600°C claimed by the manufacturer). The System B has been reported to be accurate to ± 10°C (Buchanan 1996). In the present study, it was found that temperature settings above 200°C, on three different units, produced insert-tip (medium-large) temperatures approximately 50°C below the LCD readout. In view of this, the unit was tested according to the LCD readings (200/250°C group), and a group (250/300°C) introduced where the insert-tip temperatures were at the recommended levels of 200°C during apical condensation, 100°C to adapt and apically condense the secondary gutta-percha cone into the backfilling space, and 250°C to thermosoften the secondary cone prior to vertically condensing warm gutta-percha into the coronal half of the backfilling space.

The incidence of lateral canals (Hess & Zürcher 1925, Meyer 1970) compared with the overall success of conventional endodontic treatment (Sjögren *et al.* 1990) would tend to indicate that the two are not strongly correlated. However, successful treatment has been reported following conventional retreatment resulting in the obturation of previously unfilled lateral canals (Weine 1984). Therefore, their significance should not be completely disregarded. Condensation of warm gutta-percha requires a minimum thermosoftening temperature of 39–42°C (Goodman *et al.* 1981) and sufficient vertical condensation pressure. In the present study, sealer was readily condensed into lateral canals during all three techniques, whilst gutta-percha was less so. Vertical condensation resulted in significantly ($P < 0.05$) more gutta-percha in lateral canals than did the System B techniques, although no gutta-percha was measured in canal C following any technique. Although canal C was classified as a lateral canal, it is more accurate to describe it as an extension of the main canal beyond the apical constriction. The results suggest that the three techniques did not overheat gutta-percha and/or produce excessive vertical condensation pressure in the apical region of the canal, and that extrusion of gutta-percha beyond the apical constriction should not occur clinically. Reader *et al.* (1993), using a similar model, reported comparable results following vertical condensation; however, they observed gutta-percha in canal C. The findings in the present study are in general agreement with those of Lugassy & Yee (1982) and Reader *et al.* (1993), who found that lateral canals are obturated primarily with sealer and not gutta-percha following vertical condensation. Whether obturation of a lateral canal primarily with sealer, rather than gutta-percha, significantly influences clinical success is not known.

To minimize variation due to instrumentation and the shape of the root canal, a standardized, prepared artificial root canal system was used which proved to be a convenient and reliable model. The diameter of the canal tapered from 2.5 mm at the coronal access to 0.5 mm at the canal terminus and, although large, was representative of a clinical situation where a vertical condensation technique would be preferable to lateral condensation. The digital imaging technique used to analyse the tracings of the obturated canal sections has been shown to be fast, precise and unbiased compared with other analogue techniques such as planimeter and dot-grid (Israel *et al.* 1996). Areas of interest were easily and accurately mapped by computer, and after counting the number of pixels in an area, percentage values were calculated.

A root filling comprised primarily of gutta-percha is regarded as ideal (Schilder 1967, Langeland 1974). Vertical condensation and the System B 200/250°C technique resulted in root fillings with a percentage of gutta-percha above 90.0% at all levels. Eguchi *et al.* (1985) found that the mean percentage of canal filled by gutta-percha following vertical condensation decreased from 90% at 1.5 mm from the apical foramen to approximately 86% at 7.2 mm from the apical foramen. This difference may be due to the fact that, in the present study, the lateral canals exited the acrylic block allowing sealer to escape from the root canal, whilst Eguchi *et al.* (1985) used natural teeth which limited drainage of excess sealer. The System B 250/300°C technique was able to produce root fillings consisting of greater than 90% gutta-percha at most levels examined; however, the technique failed to attain 90.0% gutta-percha at levels 2 and 3 mm. This may have been due to a more fluid gutta-percha mass which flowed coronally into the area of least resistance, rather than apically and laterally, during apical positioning of the spreader. It is also possible that more shrinkage of the gutta-percha occurred than with the other techniques.

Kerr Pulp Canal Sealer EWT was used in this study because its dark grey, crystalline appearance contrasted well with gutta-percha when viewed under reflected light and it does not adhere to acrylic or dentine. Following all techniques, sealer was found between the canal wall and gutta-percha, and within the gutta-percha mass. More sealer was found following obturation by the System B techniques (Fig. 3) than following obturation by vertical condensation. This may have been due to less sealer being used during vertical condensation and/or the level at which gutta-percha was removed. Eguchi *et al.* (1985) found that the percentage of sealer increased as vertically condensed root fillings were sectioned progressively further occlusally. To minimize the amount of sealer within the gutta-percha mass, they recommended that gutta-percha be removed to a level less than 6 mm from the apex prior to final condensation. In the present study, gutta-percha was removed to within 4 mm of the canal terminus, and generally the percentage of sealer decreased as sectioning progressed occlusally, lending support to the recommendation by Eguchi *et al* (1985).

Following vertical condensation, the overall mean percentage of voids was less than 1% of the canal space (Fig. 2.), confirming a similar result by Eguchi *et al.* (1985). Voids occurred primarily between the canal wall and the root filling, although they were also present within the gutta-percha mass, generally at the levels associated with the segmental backfilling of the canal. Following the System B techniques, the percentage of area occupied by voids was low and these were routinely observed between the gutta-percha and the canal wall apical to the 3 mm level, whilst more coronally, voids were also found within the root filling mass. Comparison of the percentages of voids for each level between the three obturation techniques found no significant differences, except at the 3 mm level where a significantly higher percentage

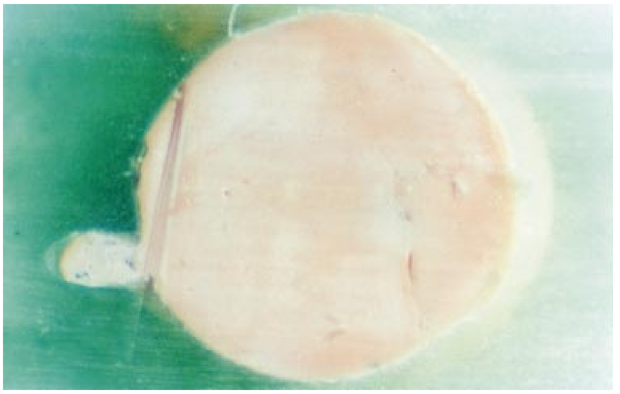

Figure 2 Section (5 mm) obturated by vertical condensation. Note that the root filling is primarily composed of gutta-percha and that gutta-percha extends into a lateral canal.

of voids was found following the System B techniques compared with warm vertical condensation ($P < 0.05$). At this level, the secondary gutta-percha cone (backfill cone) was seated during the System B techniques, and it is likely that a poor fit of the secondary cone, inadequate thermosoftening, and/or condensation pressure are reasons that voids occurred. Overall, the high percentage of gutta-percha, minimal amount of sealer and relative absence of voids suggest that the System B may produce an acceptable root filling, comparable to that produced by vertical condensation. However, the relative increase in the percentages of sealer and voids occupying the canal at the level of the secondary gutta-percha cone (Fig. 3) would suggest that the root filling may be prone to leakage in the critical apical third of the canal, particularly after sealer shrinkage and dissolution. This complication may also be enhanced by high insert-tip temperatures, which resulted in less gutta-percha filling than with lower insert-tip temperatures.

The heat transfer model permitted repeated obturations of the same root canal. This eliminated variables associated with using different teeth and allowed a direct comparison of the three techniques to be made. Temperature elevations were recorded from an established baseline room temperature. Since heat transfer in this model is a linear process (Fors *et al.* 1985, Saunders 1990a), the results obtained can be extrapolated to the clinical situation. However, *in vivo* temperature elevation may be lower due to the presence of sealer (Barkhardor *et al.* 1990), differences in dentine thickness (Fors *et al.* 1985), presence of fluid in the dentinal tubules (Weller & Koch 1995), and dispersion of heat by the periradicular vascular system (Fors *et al.* 1985, Saunders 1990a, Weller & Koch 1995).

It is generally accepted that a 10°C elevation in temperature on the root surface can irreversibly damage the periodontium (Hardie 1986, Gutmann *et al.* 1987, Saunders 1990b, Weller & Koch 1995). The

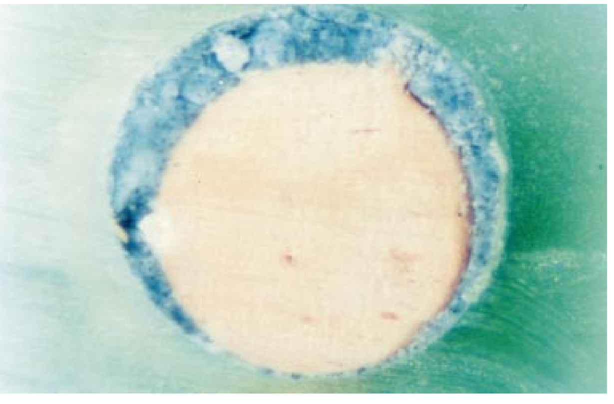

Figure 3 Section (3 mm) obturated by System B 250/300°C. Note that at this level, sealer makes up a high percentage of the root filling.

present study showed that vertical condensation using the Touch 'n Heat elevated root surface temperatures by more than 10°C at both recording sites. Similarly, Blum *et al.* (1997) found root surface temperature elevation of greater than 10°C at 8 mm from the apex during vertical condensation using a Touch 'n Heat; however, temperature elevation at 4 mm from the apex did not exceed the critical level. This difference may be due to the lower temperature setting of the Touch 'n Heat in the study of Blum *et al.* as compared with the present study, which produced a tip temperature 60–150°C greater than that reported by Blum *et al.* (1997). The present findings also contrast with other studies, which reported that root surface temperature elevations during vertical condensation did not exceed 10°C (Hand *et al.* 1976, Goodman *et al.* 1981, Barkhordar *et al.* 1990). However, those studies used a flame-heated spreader, which can reach temperatures of 293–380°C (Hand *et al.* 1976, Marciano & Michailesco 1987), but may only produce a temperature of 141°C at the surface of the gutta-percha (Marciano & Michailesco 1987). Furthermore, flame-heated spreaders cool rapidly, whilst the Touch 'n Heat sustains high temperatures and poses a greater risk of elevating the root surface temperature by more than 10°C. Another variable may be different volumes of gutta-percha between studies, as greater volumes would sustain intracanal temperatures and result in higher root surface temperatures (Weller & Koch 1995).

The destructive effect of a temperature elevation of more than 10°C on bone is significantly influenced by time (Eriksson & Albrektsson 1983). During vertical condensation, root surface temperatures remained elevated by more than 10°C for 3.27 ± 2.36 min at the E-9 thermocouple and 2.30 ± 1.40 min at the E-4 thermocouple. This was due, in part, to the temperature of the gutta-percha produced by the Touch 'n Heat tip, the volume of gutta-percha at the recording sites and the length of time it took to obturate the canal (8.3 ± 1.8 min). A similar time was reported by Wong *et al.* (1981). In contrast to vertical condensation, the System B techniques did not elevate the root surface temperature by more than 10°C, and obturation using the System B techniques was significantly faster.

The results of this study demonstrate that the System B technique produced a root filling composed primarily of gutta-percha, which was similar to one produced by warm vertical condensation. However, the high percentages of sealer and voids at the level of the secondary cone subsequent to System B obturation may compromise the seal of the root filling in the critical apical third of the canal. The use of a Touch 'n Heat device as a heat source during vertical condensation resulted in elevation of the root surface temperature by more than 10°C. Obturations using the System B technique did not raise the root surface temperature by more than this critical amount, and obturation time was significantly less than with vertical condensation.

Acknowledgement

We thank Mr S. Israel, Department of Surveying, University of Otago, for help with digital scanning techniques.

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