Temperature change within gutta-percha induced by the System-B Heat Source

M. Venturi[1], G. Pasquantonio[2], M. Falconi[3] & L. Breschi[4]

[1]Private Practice, Bologna, Italy, [2]Private Practice, Rome, Italy, [3]Department of S.A.U. & F.A.L., University of Bologna, Bologna, Italy and [4]Department of Science and Society, University of Cassino, Cassino (FR), Italy

Abstract

Venturi M, Pasquantonio G, Falconi M, Breschi L. Temperature change within gutta-percha induced by the System-B Heat Source. *International Endodontic Journal*, **35**, 740–746, 2002.

Aim This study evaluated the temperature change within gutta-percha during the vertical compaction technique performed with a System-B Heat Source.

Methodology Extracted human teeth were prepared and divided in two equal groups depending on the apex diameter (group 1: 0.20–0.25 mm and group 2: 0.30–0.35 mm). Teeth were root treated with a combination of step-back and coronal flaring instrumentation using Gates Glidden burs and hand stainless steel K- and H-files. Two thermocouples were connected to the outer surface of the root: the first one was placed 2 mm apically from cement–enamel junction (CEJ) (point C); and the second one 1.5 mm from the apex (point A). The instrumented canals were filled with size F gutta-percha cones. All teeth were then immersed in a thermostatic bath at a constant temperature of 37 °C and warm vertical compaction was performed using a System-B Heat Source. ΔT values were recorded by means of a digital thermometer connected to the thermocouples.

Results Increments of temperature (ΔT) recorded in point A revealed a mean value of 0.5 ± 0.5 °C for group 1 and 0.9 ± 1.1 °C for group 2; ΔT values recorded at point C gave a mean value of 4.1 ± 1.7 °C for group 1 and 3.9 ± 1.81 °C in group 2. No statistical difference was found between the groups, whilst a difference was present between the measurements at points A and C ($P < 0.01$).

Conclusions The use of the System-B Heat Source on root canals maintained at a constant body temperature by a thermostatic bath revealed that the increase of temperature of the gutta-percha at the apical third of the canal was negligible and that the compaction of the mass of the gutta-percha close to the apex was performed at body temperature. Minor changes in temperature of the outer surface of the root canals occurred, suggesting no danger for the periradicular tissues.

Keywords: gutta-percha, root canal, System-B Heat Source, temperature.

Received 30 July 2001; accepted 14 February 2002

Introduction

Complete filling of the root-canal system is a fundamental prerequisite for success in root-canal treatment (Schilder 1967). Several studies have revealed that an inadequate sealing of the apex is one of the most important causes of failure (Nguyen 1987, Ingle & Bakland 1994).

The combination of gutta-percha with sealer is the most common method of filling the root-canal system (Canalda-Sahli *et al.* 1992). Several techniques have been proposed to obtain the best adaptation of the gutta-percha to the canal walls. In particular, vertical condensation of warm gutta-percha is considered to be one of the most useful techniques to achieve complete filling (Dulac *et al.* 1999) and to ensure success of the treatment (Schilder 1967). This technique involves the use of a heat source to soften the gutta-percha cones so as to adapt them to the canal system (Schilder 1967). Different endodontic heating systems have been proposed to ensure correct heating of the gutta-percha cones after their

Correspondence: Dr Lorenzo Breschi DDS, Istituto di Anatomia Umana Normale, Università di Bologna, Via Irnerio 48, I-40126 Bologna, Italy (fax: +39 051 251735; e-mail: lbreschi@biocfarm.unibo.it).

placement within instrumented root canals. In particular, one of these systems combines the heating procedure with vertical condensation, in order to obtain the correct pressure of the warm and soft gutta-percha and to allow the homogenous distribution of the filling into the apical third of the endodontic system. This device is called System-B Heat Source (Analytic Technology, Redmond, WA, USA) and its clinical application is related to a modified vertical condensation technique called 'continuous wave of condensation' (Buchanan 1996, Analytic Technology Corp. 1997b). The correct use of this device simplifies the vertical condensation technique allowing an easier clinical approach. Evident limitations to this technique can be found when a minimal root-canal preparation is performed as it may be very difficult to reach the apical third of the root canal with the heat carrier and to transfer adequate heat to soften the apical gutta-percha. It must be emphasized that in a great number of roots the thickness of the dentine walls is minimal and thus, great efforts have to be taken to obtain minimal endodontic preparations to prevent fracture of the restored teeth.

The aim of this study was to evaluate *in vitro* thermal changes induced by the System-B Heat Source on the gutta-percha of the apical third of narrow root canals. The null hypothesis tested was that the use of this instrument, in accordance with the manufactures' instructions, would allow sufficient heat and soften the apical gutta-percha.

Materials and methods

Twenty-eight noncarious human teeth (27 maxillary incisors and one maxillar first molar, for a total of 30 canals) were selected for the study. The teeth had no restorations and apical foramena between 0.20 and 0.35 mm in diameter. Roots with resorption, fractures or open apices were discarded. Immediately after extraction the teeth were stored in 0.5% chloramine (Ogna, Milan, Italy) at 4 °C up to 1 month.

Specimens were prepared by the same operator under 3.5× magnification (Designs for Vision, Ronkonkoma, NY, USA). A conventional endodontic access to the pulp chamber was made using a tapered diamond bur (no. 845.314.012 Komet Brasseler, Lemgo, Germany) mounted on a contra-angle hand piece (Kavo Intramatic 25C, Kavo GmbH & Co, Biberach, Germany), and a Batt bur No. 4 (Dentsply Maillefer, Ballaigues, Switzerland) mounted on a low-speed hand piece (Kavo 20 LH Intra Lux 3 hand piece with a Kavo 68 LH Intra Lux head 1 : 1, Kavo GmbH & Co, Biberach, Germany). All preparations were performed under copious air/water spray.

Each canal was measured and the working length was calculated with a size 06 stainless steel K-file (F.K.G. Dentaire, La Chaux-de-Fonds, Switzerland) placed into the canal until it was just visible at the apical foramen. Root canals were divided in two equal groups on the basis of their apical diameter: in group 1, a size 20 or 25 K-file engaged the apex in D1; in group 2, a size 30 or 35 K-file engaged the apex in D1. The canals were instrumented at working length with a combination of step-back and coronal flaring instrumentation technique using K-files size 06–70 with a watch-winding and pull motion, and with linear filing. A size 20 or 25 K-file in group 1, and 30 or 35 in group 2 were controlled to engage in D1 at working length, and successively larger files were inserted at 1.0 mm steps short of each other until the midcanal area was instrumented to a size 70 file.

During the first phases of the instrumentation, Hedström files size 08–20 (Micro-Mega, Besançon, France) were also employed, and in the coronal and middle third of the canals flaring was obtained with Gates-Glidden burs size 1, 2 and 3 (Dentsply Maillefer). All root canals were prepared in order to obtain a continuous, tapered funnel, and without any apical stop. Apical patency was maintained by recapitulation with a size 10 K-file.

The canals were irrigated with 5% sodium hypochlorite between each file size, and were lubricated with RC-Prep (Hawe Neos Dental, Bioggio, Switzerland). After canal preparation, specimens were rinsed with water, then with 5% NaOCl, and finally dried with absorbent paper points.

Size F nonstandardized gutta-percha cones (Kerr Co., Romulus, MI, USA)) were placed in the canals 1 mm shorter than working length in anticipation of the apical movement of the gutta-percha during vertical condensation (Schilder 1967). No endodontic cement was used. Two small holes were then cut on the root surface of each tooth using a round size 10 bur mounted on a low speed hand piece: the first cavity (coronal, point C) was placed 2 mm apically from the cement-enamel junction (CEJ) and was 0.25 mm in depth; the second one (apical cavity, point A) was placed 1.5 mm from the apex and in direct contact with the gutta-percha in the canal. Two Cromel–Alumel type K (AG, Sunnyvale, California, USA) thermocouples equipped with a fine tip (diameter, 0.2) were secured at points A and C with a light-cured composite resin to fully seal the preparations (Z-250 Restorative System, 3M, Minneapolis, MN, USA).

The two thermocouples were then connected to a type K digital thermometer (range: −60–1200 °C; estimated error: ±0.1 °C below 200 °C and ± 1 °C over 200 °C). A

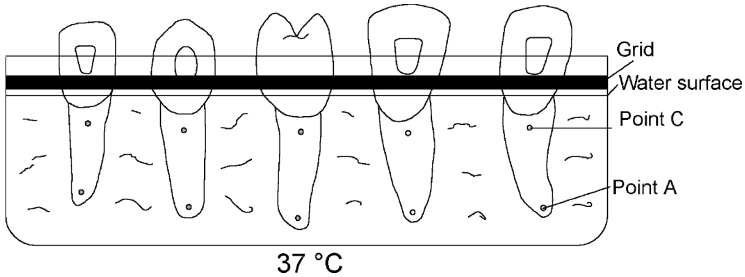

Figure 1 Image of the specimens preparation. The roots were connected to a metallic grid and immersed in a thermostatic bath (at constant temperature of 37 °C); the coronal part of the teeth remained above the liquid surface. The thermocouples were connected at points A and C.

small amount of composite resin was used to cover and insulate the apical foramen.

Teeth were then connected to a metallic grid with epoxy resin, in a vertical position so that each root could be immersed in deionized water, whilst the coronal part of the teeth remained above the liquid surface (Fig. 1). The metallic grid with the attached teeth were then immersed in a thermostatic bath of deionized water (at constant temperature of 37 °C). Specimens had the access of the root canal above the water level (Fig. 1).

Prior to down packing, the temperature of the tip of the System-B Heat Source used for the study was recorded by means of a thermocouple in order to compare the real temperature with the value indicated by the manufacturer. Temperatures were recorded in air on direct contact with the insert tip of the System-B Heat Source; measurements were performed at the tip of the instrument, and at 2, 4 and 20 mm from its tip. Four different System-B Heat Source devices with four different F tips were tested, but no statistical differences were found between the units.

Considering that no exact correlation was found between the temperature set on the display and the temperature recorded by the thermocouple on the tip, the System-B Heat Source was set to 250 °C, thus, at a higher temperature than the one suggested (200 °C on display during apical condensation, i.e. down-pack; Buchanan 1998).

Gutta-percha cones were then submitted to warm vertical compaction using the System-B Heat Source with a F plugger (Analytic Technology, Redmond, WA, USA, mod. 1005 Serial number #1532515) and following the System-B technique recommended by the manufacture (Analytic Technology Corp. (1997b). The heat carrier was left in the canal for 10 s (Buchanan 1996). The tip of the instrument was taken as deep as possible inside the canals: depending on the curves in some canals it approached at 1 mm from the apex, in others it stopped at 5 mm.

Temperature values were recorded at points C and A throughout the whole process of vertical compaction of the gutta-percha and the highest recorded value was taken as representative for each specimen.

Statistical analysis was performed in order to evaluate the distribution of the differences of temperatures recorded at points A and C of each of the two groups. A Kolmogorov–Smirne test was applied to evaluate the distribution of the data within the groups and means and standard deviations of each group were calculated. A two-way ANOVA was used to compare the two groups.

Results

Temperatures recorded in air and on direct contact with the insert tip of the System-B Heat Source are shown in Table 1. It must be emphasized that 2 mm from the end of the insert tip (thus, where the higher temperature is recorded), data obtained by means of a thermocouple revealed lower temperatures than the ones shown on the display. In particular, by setting the instrument at 250 °C the temperature reached by the instrument was 123 °C at the tip, and 160, 158 and 66 °C, respectively, at 2, 4 and 20 mm from the tip (Table 1).

The distance between the apex and the deepest point reached by the insert tip was also recorded (Tables 2 and 3); mean values obtained revealed a deeper penetration in group 2 (2.86 mm) than group 1 (3.26 mm) owing to the differences of the apex diameter (respectively, 0.30–0.35 and 0.20–0.25 mm).

Table 1 Temperature recorded in air with a thermocouple in direct contact with the tip of the System-B-Heat Source

Display	At the tip	At 2 mm	At 4 mm	At 20 mm
200	108	120	126	48
250	123	160	158	66
300	147	200	192	77
400	215	265	263	89
500	247	325	335	115
600	303	436	407	126

No correlation between the temperature set on the display and the recorded data was found.

Table 2 Increments of temperature in (ΔT) recorded at point A (1.5 mm from the apex) and C (2 mm from the CEJ) of specimens of group 1 (apical diameter 0.20–0.25 mm)

		ΔT (°C)	
Specimen #	Distance tip-apex (mm)	Point C	Point A
1	2	4.1	0.5
2	3	3.7	0.1
3	3	3.5	0.0
4	5	3.2	0.5
5	5	4.1	0.3
6	4	7.0	0.1
7	4	5.4	0.4
8	4	8.5	1.4
9	3	2.7	0.1
10	1	4.1	0.9
11	2	1.6	0.1
12	1	2.3	0.5
13	3	4.5	0.2
14	4	2.9	2.1
15	5	3.9	0.4

The distance of the maximum depth reached by the tip of the heater from the apex is indicated for each specimen.

Table 3 Increments of temperature (ΔT) recorded at point A (1.5 mm from the apex) and C (2 mm from the CEJ) of specimens of group 2 (apical diameter 0.30–0.35 mm)

		ΔT (°C)	
Specimen #	Distance tip-apex (mm)	Point C	Point A
16	4	3.2	0.1
17	1	6.4	0.4
18	2	5.9	0.2
19	3	6.3	0.3
20	3	3.1	0.1
21	3	1.9	3.9
22	4	3.2	0.3
23	2	5.1	0.1
24	5	4.4	1.4
25	5	0.8	3.2
26	3	2.7	0.2
27	1	3.4	1.3
28	2	4.9	0.4
29	2	5.7	0.8
30	3	1.3	1.1

The distance of the maximum depth reached by the tip of the heater from the apex is indicated for each specimen.

Values of increments in temperature (ΔT) of the gutta-percha of the tested specimens revealed by the thermocouple at points A and C are shown in Tables 2 and 3 (respectively for specimens of groups 1 and 2). ΔT recorded in point A revealed a mean value of 0.5 ± 0.5 °C for group 1 and 0.9 ± 1.1 °C for group 2 (Table 4). It must be emphasized that point A was set 1.5 mm from the apex, and thus in the specimens in which the insert tip arrived at 1 mm from the foramen, the thermocouple was very close to the surface of the insert tip. ΔT values recorded at point C gave a mean value of 4.1 ± 1.7 °C for group 1 and 3.9 ± 1.81 °C in group 2 (Table 4).

Statistical analysis revealed that the data were normally distributed (Kolmogorov–Smirne Test). Lower and upper 95% were determined for each group (Table 4). The statistical analysis revealed that 95% of ΔT values at point A of group 1 were between 0.2 and 0.8 °C, whilst in group 2 were between 0.3 and 1.6 °C. Similarly, 95% of the data at point C of group 1 were distributed between 3.1 and 5.1 °C, and in group 2 were between 2.9 and 4.9 °C (Table 4).

The two-way ANOVA revealed a statistical difference between ΔT recorded at points A and C at both groups ($P < 0.05$), but no difference could be determined between the two groups as no relationship with the different apex diameter was found.

Discussion

Several parameters influence the heating of gutta-percha during vertical compaction, particularly because canal systems are complex and narrow. The main parameter to be considered is the low heat conductive capability of dentine (1.36×10^{-3} cal/cm^2 °C; Craig & Peyton 1961); other factors influencing the heating of

Table 4 Statistical analysis of the increments of temperature (ΔT) recorded at points A and C of the two groups considered in the study

	Group 1 (apex diameter 0.20–0.25 mm)		Group 2 (apex diameter 0.30–0.35 mm)	
	Point A	Point C	Point A	Point C
Mean	0.5	4.1	0.9	3.9
Std. deviation	0.57	1.77	1.16	1.81
Lower 95% CI	0.19	3.12	0.28	2.89
Upper 95% CI	0.82	5.08	1.56	4.89
P-value (two tailed)	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Coefficient of variation (%)	112.76	43.18	126.17	46.44

gutta-percha are the dentine thickness (Figdor *et al.* 1983), the dimension of the residual roots (Fors *et al.* 1985) and the periradicular blood circulation (Hardie 1986).

The various influences related to the heating of gutta-percha can be classified into mechanical, physical, chemical and biological.

Mechanical factors are related to the fact that gutta-percha must be plasticized to become adapted to the canal, however, it should not be too soft in order to allow control of the material. Two aspects influence the degree of softening: the necessity to reach and fill narrow and small spaces that require a soft gutta-percha, and the clinical necessity of precise positioning of the cone at the apex in particular when the patency of the orifice is maintained. Moreover, with very soft gutta-percha, the pluggers would penetrate the material rather than compacting it; this could generate empty spaces inside the mass of the gutta-percha during the removal of the instruments (Jurcak *et al.* 1992).

Chemical–physical aspects are related to the fact that the gutta-percha heating process should remain within the range from 37 to 42–45 °C. Temperatures higher than 45 °C give volumetric changes during the cooling owing to phase changes in the structure of the material (Schilder *et al.* 1985). Heating gutta-percha over 100 °C gives irreversible modifications to the molecular structure (Marciano & Michailesco 1989).

Biological problems relate to possible damage to periradicular tissues when the gutta-percha is heated inside the root and when the residual dentine walls are thin (Lee *et al.* 1998).

Factors affecting heat distribution relate to the compaction technique (Silver *et al.* 1999) and the use of an endodontic cement, that acts as a heat insulator for the periodontal region. Indeed, it has been reported that an endodontic cement can decrease the temperatures by 1–2 °C on the root surface (Barkhordar *et al.* 1990). Considering this finding and to avoid unpredictable influences in the temperatures of the gutta-percha, the endodontic cement was purposely omitted during the specimen preparation particularly because differences in the thickness of the cement layer within the specimens could have affected the results.

Problems may be encountered during the application of warm vertical compaction techniques in small canals as it can be difficult to obtain real thermal effects on the apical portion of the root-canal filling materials. It has been demonstrated (Goodman *et al.* 1981) that an increase of 4 °C of the apical gutta-percha (over the body temperature of 37 °C) is the ideal level to obtain the correct softening for excellent compaction and good control of the material in accordance with the Schilder's technique (Schilder 1967). Moreover, it has been reported that using traditional heat-carriers (heated on flame) in wide canals (Marlin & Schilder 1973) the gutta-percha in the coronal third can reach an average temperature of approximately 50 °C, whilst getting closer to the apex the increase of temperature (ΔT) dramatically drops; at the apical third of the canal ΔT is only 2–4 °C, thus temperature rise over 42 °C are rare. Other similar data were recorded filling wide canals (Goodman *et al.* 1981, Marciano & Michailesco 1989) and confirmed that minimal increases in temperature of gutta-percha are obtainable when approaching the apex even if the carrier is heated with a flame at very high temperature. In thin root canals, these difficulties in heating gutta-percha at the correct temperature increase dramatically.

The use of an electric heat carrier such as Touch'n Heat (models 5001, 5002 and 5004) produces different thermal phenomena (Analytic Technology Corp. 1993). In fact, the heating source is the tip insert itself that can be continuously heated, moreover very thin and flexible tips are available allowing them to reach apical regions in curved and thin canals.

The System-B Heat Source (Analytic Technology Corp. 1997a), compared to the Touch'n Heat, presents more technological capabilities such as the display for the temperature control of the tip and the advantage of combining heating and compaction allowing the Buchanan's 'Continuous Wave' obturating technique (Buchanan 1996).

The suggested working temperature for the device using the smallest tip at a distance of 5–7 mm from the apex is 185 °C (Buchanan 1998). In the present study, different temperature settings were selected in order to evaluate the effective heating power of the device (Table 1) as previous studies have revealed that at the temperature reading on the unit's liquid crystal display was inaccurate and higher than achieved at the tip (Blum *et al.* 1997, Silver *et al.* 1999). These discrepancies have been confirmed in this study, thus a higher temperature (250 °C) than the suggested one (200 °C) was set for the down-pack. In fact by setting the tested System-B Heat Source at the temperature of 250 °C on the display, the highest temperature recorded was 160 °C, 2 mm from the tip (Table 1): this result was obtained by putting the thermocouple in direct contact with the instrument.

Several *in vitro* studies recorded different values of temperature of the gutta-percha during the warm vertical compaction technique (Blum *et al.* 1997, DuLac *et al.* 1999, Silver *et al.* 1999). The different results probably depend upon three factors: the dimension of canals, the periradicular temperature, and the use of a system of thermo-dispersion that can simulate the periradicular blood circulation by maintaining it at a constant temperature of 37 °C. Overall, in such narrow canals there is a small contact area between the tip of the instrument and the coronal part of the apical gutta-percha, reducing the transfer of heat.

The results of the present study revealed that the use of the System-B Heat Source in root canals immersed in a thermostatic bath of water at a constant temperature of 37 °C induces insignificant temperature increases on the apical gutta-percha (0.5 ± 0.5 °C for group 1 and 0.9 ± 1.1 °C for group 2) and in all specimens, this increase was lower than the 4 °C previously identified as optimal for the warm compaction. These findings were not related to insufficient penetration of the insertion tip inside canals as the mean distances from the apex were lower (3.26 mm in group 1 and 2.86 mm in group 2) than the suggested ones under normal clinical conditions (usually up to 5–7 mm from the apex). To obtain changes of 3–4 °C within the apical gutta-percha in narrow canals it would be necessary to use instruments at a higher temperature, which might negatively affect periradicular tissues, particularly at the CEJ where dangerous values can be recorded (Hand *et al.* 1976, Weller & Koch 1995). An increase of 10 °C in periradicular tissues is considered to be dangerous (Eriksson & Albrektsson 1983, Fors *et al.* 1985, Hardie 1986, Gutmann *et al.* 1987a, Gutmann *et al.* 1987b, Saunders 1990, Weller & Koch 1995), even if effective bone necrosis was found only after maintaining a constant temperature of 44–47 °C for at least 1 min (Eriksson & Albrektsson 1983). Previous studies revealed that traditional heat carriers and Touch'n Heat can create a 10 °C increase on the outer surface of the root (Blum *et al.* 1997, Silver *et al.* 1999), whilst the System-B Heat Source usually cannot reach this level (Lee *et al.* 1998, Romero *et al.* 1998). The results of this study also confirmed that the ΔT at point C was not higher than 10 °C in any of the specimens (mean value of 4 °C for group 1 and 3.8 °C for group 2), thus confirming the safety of the clinical use of the System-B Heat Source. Moreover, under normal clinical conditions the endodontic cement, by increasing thermal insulation of the endodontic canal system, reduces the possibility of creating damage to periradicular tissues using the System-B Heat Source.

Conclusions

This study demonstrated the thermal changes in gutta-percha that occur during the vertical compaction technique by means of a System-B Heat Source. The use of a thermostatic bath distinguished this study from previous reports.

The null hypothesis was rejected as the use of the System-B Heat Source (set at 250 °C) in thin canals revealed that the heating of the apical gutta-percha was inconsistent and that the compaction was performed usually at body temperature. Moreover, at the CEJ, the use of the heating device revealed that increases of outer surface temperature on the root was compatible with the periradicular tissues.

Acknowledgements

This work was partially support by 60 and 40% grants of 'Ministero Università e Ricerca Scientifica'.

References

Analytic Technology Corp. (1993) *Instruction Guidelines for Touch'n Heat, Models 5001, 5002 and 5004.* Redmond, WA, USA: Analytic Technology Corp.

Analytic Technology Corp. (1997a) *Instruction Guidelines for System-B Heat Source Model 1005.* Redmond, WA, USA: Analytic Technology Corp.

Analytic Technology Corp. (1997b) *The Buchanan 'Continuous Wave of Condensation' Technique.* Redmond, WA, USA: Analytic Technology Corp.

Barkhordar RA, Goodis HE, Watanabe L, Koumdijan J (1990) Evaluation of temperature rise on the outer surface of teeth during root-canal obturation techniques. *Quintessence International* **21**, 585–8.

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

Buchanan SL (1996) The continuous wave of obturation technique: 'centered' condensation of warm gutta-percha in 12 seconds. *Dentistry Today* **Jan**, 60–7.

Buchanan SL (1998) Continuous wave of obturation technique. *Endodontic Practice* **Dec**, 7–23.

Canalda-Sahli C, Brau-Aguade E, Sentis-Vilalta J, Aguade-Bruix S (1992) The apical seal of root canl sealing cements using a radionuclide detection technique. *International Endodontic Journal* **25**, 250–6.

Craig RG, Peyton FA (1961) Thermal conductivity of teeth structures, dentin cements, and amalgam. *Journal of Dental Research* **40**, 411–8.

Dulac KA, Nielsen CJ, Tomazic TJ, Ferrillo PJ, Hatton JF (1999) Comparison of the obturation of lateral canals by six techniques. *Journal of Endodontics* **25**, 376–80.

Eriksson AR, Albrektsson T (1983) Temperature threshold levels for heat induced bone tissue injury: a vital-microscopy study in the rabbit. *Journal of Prosthetic Dentistry* **50**, 101–7.

Figdor D, Beech DR, Waterson JG (1983) Heat generation in the McSpadden compaction technique (Abstract). *Journal of Dental Research* **62**, 405.

Fors U, Jonasson E, Bergquist A, Berg JO (1985) Measurements of the root surface temperature during thermo-mechanical root canal filling in vitro. *International Endodontic Journal* **18**, 199–202.

Goodman A, Schilder H, Aldrich W (1981) The thermo-mechanical properties of gutta-percha. Part IV. A thermal profile of the warm gutta-percha packing procedure. *Oral Surgery* **51**, 544–51.

Gutmann JL, Creel DC, Bowles WH (1987a) Evaluation of heat transfer during root canal obturation with thermoplasticized gutta-percha. Part I. *In vitro* heat levels during extrusion. *Journal of Endodontics* **8**, 378–83.

Gutmann JL, Creel DC, Bowles WH (1987b) Evaluation of heat transfer during root canal obturation with thermoplasticized gutta-percha. Part II. *In vivo* response to heat levels generated. *Journal of Endodontics* **13**, 441–8.

Hand RE, Huget EF, Tsaknis PJ (1976) Effects of a warm gutta-percha technique on the lateral periodontium. *Oral Surgery* **42**, 395–401.

Hardie EM (1986) Heat transmission to the outer surface of the tooth during the thermomechanical compaction technique of root canal obturation. *International Endodontic Journal* **19**, 73–7.

Ingle JI, Bakland LK (1994) *Endodontics*, 4th edn. Baltimore, USA: William & Wilkins, pp. 1–46.

Jurcak JJ, Weller N, Kulid JC, Donley DL (1992) *In vitro* intracanal temperature produced during warm lateral condensation of gutta-percha. *Journal of Endodontics* **18**, 1–3.

Lee FS, Van Cura JE, Begole E (1998) A comparison of root surface temperatures using different obturation heat sources. *Journal of Endodontics* **24**, 617–20.

Marciano J, Michailesco P (1989) Dental gutta-percha: chemical composition, X-ray identification, enthalpic studies, and clinical implications. *Journal of Endodontics* **15**, 149–53.

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

Nguyen NT (1987) Obturation of the root canal system. In: Cohen, S Burns, RC, ed. *Pathways of the Pulp*, 4th edn. St. Louis, USA: Mosby, pp. 183–94.

Romero AD, Wucherpfennig AL, Green DB (1998) Heat transfer during root obturation procedures (Abstract). *Journal of Endodontics* **24**, 300.

Saunders EM (1990) *In vivo* findings associated with heat generation during thermomechanical compaction of gutta-percha. Part II. Histological response to temperature elevation on the external surface of the root. *International Endodontic Journal* **23**, 268–74.

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

Schilder H, Goodman A, Aldrich W (1985) The thermomechanical properties of gutta-percha. Part V. Volume changes in bulk gutta-percha as a function of temperature and its relationship to molecular phase transformation. *Oral Surgery* **59**, 285–96.

Silver GK, Love RM, Purton DG (1999) Comparison of two vertical condensation obturation techniques: Touch'n Heat modified and System-B. *International Endodontic Journal* **32**, 287–95.

Weller RN, Koch KA (1995) *In vitro* radicular temperature produced by injectable-thermoplasticized gutta-percha. *International Endodontic Journal* **28**, 86–90.

