Ultrasonic condensation of gutta-percha: the effect of power setting and activation time on temperature rise at the root surface – an *in vitro* study

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Abstract

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Aim To determine the effect of power setting and duration of activation on the temperature rise at the root surface during root canal obturation by ultrasonic condensation of gutta-percha.

Methodology A human maxillary canine was used in an *in vitro* split tooth model to allow repeated obturation of the root canal system using an ultrasonic device to thermocompact gutta-percha. Combinations of power settings (1, 3 and 5) and durations of activation (4, 10 and 15 s) were used to test their effect on temperature rise at the root surface using eight K-type thermocouples at the mid-root and apical levels. At the end of each obturation, the tooth was disassembled to remove the gutta-percha in preparation for the next obturation ($n = 10$ for each combination). Multiple linear regression models were used to investigate the effects of power setting, duration of activation and thermocouple location on the maximum temperature rise recorded.

Results Only one combination of power setting (5) and duration of activation (15 s) resulted in temperature rise in excess of 10 °C. The maximum temperature rise at the mid-root level was significantly ($P < 0.001$) greater than that recorded apically. It is also significantly affected by the combination of power setting and duration of activation.

Conclusions Temperature rises at the root surface during ultrasonic condensation of gutta-percha in excess of 10 °C were evident in only one combination of power (5) and time (15 s) settings at the mid-root level.

Keywords: obturation, root canal, temperature rise, ultrasonics.

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Introduction

The role of obturation in root canal treatment, although considered secondary to debridement and disinfection, still remains a critical stage for a successful outcome (Katebzadeh *et al.* 2000). The aim of obturation is to seal the peri-radicular tissues from the residual microorganisms left in the root canal system after chemo-mechanical debridement. The most commonly used and tested technique is cold lateral condensation, often used as a gold standard for comparison as its effectiveness has been established (Smith *et al.* 1993). More recent interest in various thermoplasticized gutta-percha techniques has led to their favourable comparison with this standard (Gulabivala *et al.* 1998).

Ultrasonically activated spreaders have been used to thermoplasticize gutta-percha in a warm lateral condensation technique and have been shown to be superior to conventional lateral condensation *in vitro* (Moreno 1977, Baumgardner & Krell 1990). The technique has also been evaluated clinically with favourable results (Zmener & Banegas 1999).

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When gutta-percha is heated within the root canal, the temperature must be adequate to allow its adaptation without incurring thermal injury to periradicular tissues. A 10 °C, rise sustained for 1 min is considered compatible with normal bone repair, but higher temperatures or longer application times may cause bone necrosis and its replacement with fatty tissue (Eriksson & Albrektsson 1983). Such temperature rises have been recorded at the root surface during obturation of root canals with a variety of thermoplasticized gutta-percha techniques (Hardie 1986, McCullagh *et al.* 2000). Hardie (1986) found temperature rise in excess of 10 °C when McSpadden compactors were used, and produced resorption and ankylosis in the periodontia of ferret canines (Saunders 1990b). It is possible that such localized damage may compromise long-term treatment outcome.

Intra-canal temperature rises between 1.66 and 3.74 °C apically and between 6.35 and 19.10 °C in the mid-root region have been recorded during ultrasonic condensation of gutta-percha (Joiner *et al.* 1989). There is, however, no data on temperature rises at the root surface nor the effect of power output and duration of activation.

The aims of this study were to measure the temperature rise at the root surface during ultrasonic condensation of gutta-percha to determine the combination of settings producing temperature rise above 10 °C and to determine the factors affecting the temperature rise at the root surface.

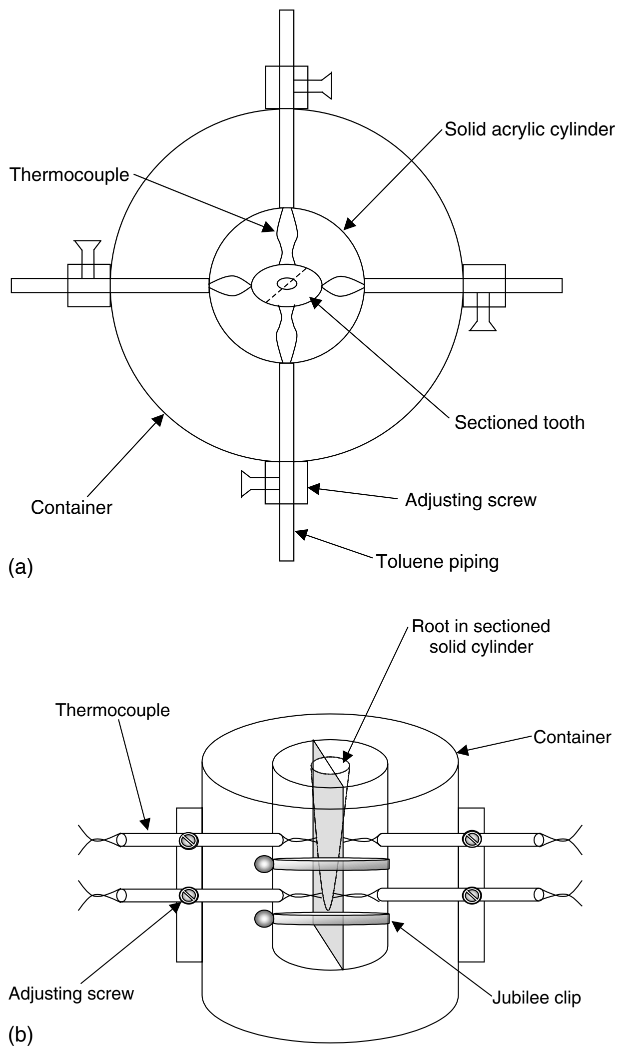

Figure 1 Schematic diagram of the temperature measurement apparatus viewed in longitudinal and transverse sections.

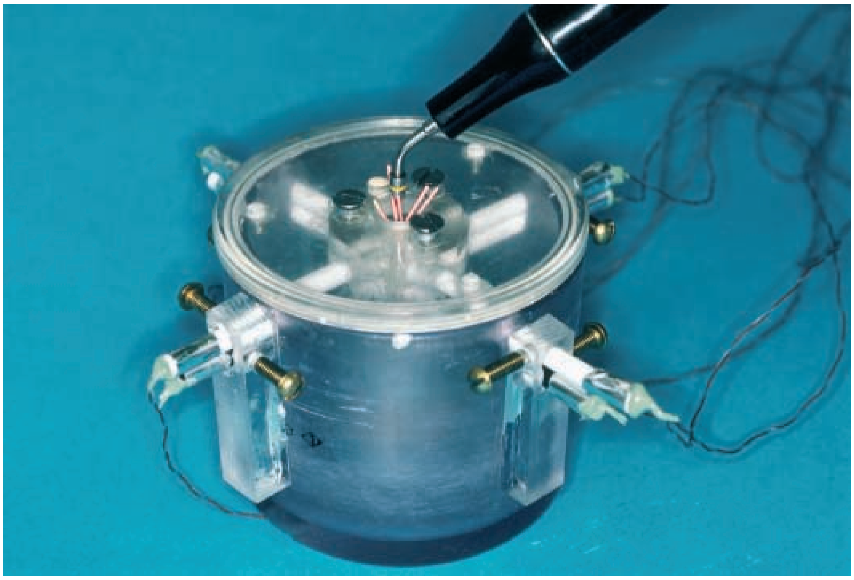

Figure 2 The tooth/acrylic cylinder assembly placed inside the plastic draft and temperature insulator.

Materials and method

Preparation and mounting of extracted tooth

An intact, permanent and mature human maxillary canine was selected to create a reusable *in vitro* test model. It was cleaned in 5% sodium hypochlorite to remove soft tissue debris. After rinsing and drying, it was mounted in a solid cylinder of orthodontic resin (Austenal Dental Products Ltd., Harrow, UK), with the longitudinal axis of the tooth perpendicular to the base of the cylinder. The root canal was prepared to apical size 50 and .05 taper with K-Flex files (Kerr UK Ltd., Peterborough, UK) using a step-back technique.

A thin diamond saw (Exact, Hamburg, Germany) was used to section the root and cylinder vertically into two halves. Channels were drilled into the side of the cylinder to allow type K-thermocouples (R.S. Components, Corby, Northants, UK) to be arranged circumferentially; four were placed equidistantly 3 mm from the apex in contact with the root surface (A_{1-4}) and a further four were similarly arranged 10 mm from the apex (M_{1-4}) (Fig. 1a). Heat sink compound (R.S. Components, Northants, UK) was used to ensure good contacts. The thermocouples were placed in 5-cm lengths of plastic tubing (Stanley Plastics, Midhurst, UK), so that the terminals protruded by 2–3 mm to facilitate placement of the thermocouples.

The two halves of the cylinder were reassembled and held together with clips. A stainless steel rod that passed through each half facilitated relocation. The whole assembly was placed in an acrylic pot with a lid (Fig. 2) to isolate the root from air currents and to provide a platform on which to mount the thermocouples. Screws tapped into the top of the cylinder from the lid ensured accurate relocation of the cylinder halves.

Procedures of obturation

An Enac size 20 ultrasonic spreader (set at 20 mm from the hub) attached through a no. ST12 tip to an Enac model OE-3 Ultra-Endo Instrument System (Osada

Table 1 Experimental groups

Group	Number of samples	Power setting	Duration of activation (S)
1	10	1	4
2	10	1	10
3	10	1	15
4	10	3	4
5	10	3	10
6	10	3	15
7	10	5	4
8	10	5	10
9	10	5	15
10	10	0	0

(i) Group 10 (cold lateral condensation control group) denoted with '0' power setting and duration of activation. (ii) For each experimental group, 10 experiment runs were carried out and data were recorded from 8 thermocouples for each experiment. This makes up a total of 800 data sets for the whole study.

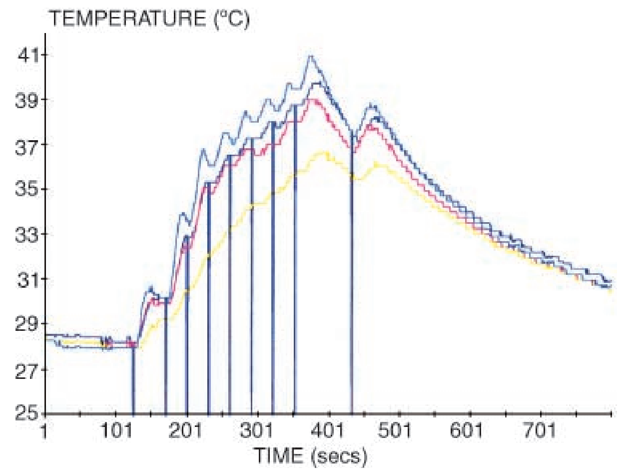

Figure 3 A typical tracing of temperature recorded versus time by thermocouples placed at the mid-root level. (Each of the thermocouples is represented by a single colour line, the blue vertical lines mark the beginning of each ultrasonic activation).

Electric Co Ltd., Tokyo, Japan) was used as the ultrasonic source. Power settings of 1, 3 and 5, and activation periods of 4, 10 and 15 s together gave 9 experimental groups with 10 experimental runs for each group ($n = 10$; Table 1). Cold lateral condensation served as the control.

Endic master and accessory gutta-percha cones (Davis, Schottlander and Davis, Letchworth, UK) were used throughout the experiment. The obturation technique involved the initial placement of a size 50 gutta-percha cone (batch no. 993492) to the working length followed by cold lateral condensation of three accessory cones (batch no. 555392) using a matching finger spreader but no sealer. The ultrasonic spreader was then placed into the centre of the gutta-percha mass up to 1 mm from the working length and was activated at the appropriate power setting and duration of activation under test. At the termination of activation, the ultrasonic spreader was removed and an additional accessory cone was placed followed by energization with the activated ultrasonic spreader again. This process was repeated eight times until the canal was filled. During each subsequent energization, the ultrasonic spreader was placed to a slightly more coronal level.

Thermocouple data collection

All data were collected at room temperature. The thermocouples were connected to a PC-73 system (Amplicon Liveline Ltd, Brighton, UK) analogue to a digital converter linked to an IBM 5150 personal computer (IBM UK, Basingstoke, UK) to allow direct capture of thermocouple data. The system was calibrated using boiling and frozen water, and was set to measure temperatures from all eight thermocouples at a frequency of once every second up to 800 s. A switch, a 1.5-V cell and a 64 kΩ resistor were connected in series and in reverse polarity to the first channel on the thermocouple board. At the start of each ultrasonic activation, an artificial dip in temperature on depression of the switch was recorded to act as a marker (Fig. 3). At the end of each run, the apparatus was disassembled, the gutta-percha removed and made ready for the next experiment.

Statistical analysis

For each thermocouple, only the maximum temperature rise recorded from each experiment was included for analyses. Multiple linear regression models were used to investigate the effects of the power setting, duration of activation and thermocouple location on maximum temperature rise recorded on root surface (dependent variable).

Results

Typical tracings recorded at the mid-root level during ultrasonic condensation of gutta-percha are shown in Fig. 3. The maximum temperatures recorded by individual thermocouples at mid-root and apical levels after various combinations of time and power settings are presented in Tables 2 and 3, respectively.

Table 2 Means, SDs and maximum temperature rises (°C) recorded by each thermocouple at mid-root level

Power setting	Duration of activation(s)	Couple	No. of samples	Mean	SD	Maximum
0 (cold lateral condensation)	0	M_1	10	0.39	0.58	1.53
		M_2	10	0.45	0.57	1.78
		M_3	10	0.36	0.44	1.44
		M_4	10	0.44	0.49	1.63
1	4	M_1	10	0.46	0.36	1.23
		M_2	10	0.84	0.37	1.48
		M_3	10	0.96	0.30	1.48
		M_4	10	0.76	0.26	1.23
	10	M_1	10	1.25	0.27	1.83
		M_2	10	1.72	0.47	2.81
		M_3	10	1.77	0.40	2.32
		M_4	10	1.35	0.25	1.82
	15	M_1	10	1.83	0.23	2.22
		M_2	10	2.46	0.45	3.05
		M_3	10	2.11	0.41	2.80
		M_4	10	2.11	0.39	2.80
3	4	M_1	10	0.83	0.22	1.34
		M_2	10	0.95	0.32	1.59
		M_3	10	1.11	0.30	1.58
		M_4	10	1.07	0.22	1.57
	10	M_1	10	2.14	0.58	3.31
		M_2	10	2.30	0.56	3.55
		M_3	10	2.80	0.58	3.93
		M_4	10	2.75	0.68	3.68
	15	M_1	10	2.61	0.58	3.68
		M_2	10	3.21	0.63	4.02
		M_3	10	3.36	0.59	4.51
		M_4	10	3.84	0.84	5.21
5	4	M_1	10	1.51	0.23	1.82
		M_2	10	2.46	0.55	3.68
		M_3	10	1.76	0.19	2.07
		M_4	10	1.93	0.25	2.45
	10	M_1	10	4.30	1.05	5.84
		M_2	10	6.35	0.89	7.70
		M_3	10	4.91	0.99	6.82
		M_4	10	6.57	1.15	8.18
	15	M_1	10	8.98	1.22	11.24
		M_2	10	10.26	1.10	12.32
		M_3	10	7.88	0.60	9.01
		M_4	10	10.74	1.22	12.61

At the mid-root level (Table 2), the mean maximum temperature rises after cold lateral condensation ranged from 0.36 to 0.45 °C, whereas the mean maximum temperature rises after ultrasonic condensation of gutta-percha ranged from 0.46 (power setting 1, duration of activation 4 s) to 10.74 °C (power setting 5, duration of activation 15 s).

At the apical level (Table 3), the mean maximum temperature rises after cold lateral condensation (control) ranged from 0.35 to 0.76 °C, whereas the mean maximum temperature rises after ultrasonic condensation of gutta-percha ranged from 0.14 (power setting 3, duration of activation 10 s) to 4.94 °C (power setting 5, duration of activation 10 s).

Maximum temperature rises higher than 10 °C were recorded at mid-root level after ultrasonic condensation of the gutta-percha only with the combination of power setting 5 and duration of activation 15 s (Table 2).

Statistical analysis

The least squares linear regression equations with maximum temperature rise as dependent variable are presented in models 1–3 (Table 4). Model 3 shows

Table 3 Means, SDs and maximum temperature rises (°C) recorded by each thermocouple at apical level

Power setting	Duration of activation(s)	Couple	No. of samples	Mean	SD	Maximum
0	0	A_1	10	0.37	0.43	1.15
(cold lateral condensation)		A_2	10	0.35	0.14	0.59
		A_3	10	0.63	0.21	0.99
		A_4	10	0.76	0.17	1.08
1	4	A_1	10	0.35	0.45	1.29
		A_2	10	0.35	0.16	0.59
		A_3	10	0.43	0.17	0.59
		A_4	10	0.57	0.15	0.74
	10	A_1	10	0.41	0.48	1.14
		A_2	10	0.39	0.28	1.04
		A_3	10	0.99	0.36	1.72
		A_4	10	0.87	0.38	1.47
	15	A_1	10	0.44	0.52	1.39
		A_2	10	0.51	0.22	0.99
		A_3	10	0.65	0.38	1.23
		A_4	10	1.02	0.39	1.77
3	4	A_1	10	0.17	0.30	0.74
		A_2	10	0.82	0.19	1.23
		A_3	10	1.41	0.44	2.40
		A_4	10	1.45	0.41	2.41
	10	A_1	10	0.14	0.26	0.74
		A_2	10	0.69	0.24	1.09
		A_3	10	1.53	0.34	1.93
		A_4	10	1.14	0.36	1.77
	15	A_1	10	0.36	0.26	0.98
		A_2	10	0.34	0.21	0.69
		A_3	10	2.31	0.62	3.63
		A_4	10	2.88	0.58	3.43
5	4	A_1	10	0.22	0.15	0.49
		A_2	10	0.19	0.25	0.69
		A_3	10	2.05	0.63	3.64
		A_4	10	3.79	0.94	5.29
	10	A_1	10	0.25	0.26	0.72
		A_2	10	0.54	0.26	0.94
		A_3	10	0.43	0.19	0.74
		A_4	10	4.96	0.97	5.83
	15	A_1	10	0.25	0.27	0.89
		A_2	10	0.43	0.25	0.89
		A_3	10	0.41	0.20	0.74
		A_4	10	4.45	0.92	5.52

that maximum temperature rises were significantly affected by the location of thermocouple, and the interaction of power setting and duration of activation. Maximum temperature rises recorded by thermocouples located at the mid-root levels were 1.841 °C (95% CI 1.623, 2.060; $P < 0.001$) higher than those recorded by thermocouples located in the apical level, after adjusting for the interaction of power setting and duration of activation. Furthermore, the maximum temperature rises increase on average by 0.062 °C (95% CI 0.057, 0.067; $P < 0.001$) per unit increase in combination of power setting and duration of activation, after adjusting for the location of thermocouple.

Discussion

A single tooth was selected as a test model to eliminate variation in dentine properties and thickness between teeth. The acrylic used to construct the solid surrounding cylinder had a thermal conductivity of 0.21 W mK^{-1} (Anderson & McCabe 1985), which is comparable to that of normally perfused human sternal bone (0.27 and 0.47 W mK^{-1}; Duck 1990). There is

Table 4 Multiple linear regression models predicting the 'maximum temperature rise' on root surface (dependent variable) by various independent variables: 'location of thermocouple', 'power setting', 'duration of activation' and ''interaction of power setting and duration of activation

	Coefficients *B*	95% CI	*P*-value
Model 1			
Location of couple	1.841	1.623, 2.060	**<0.001**
Power setting	−0.016	−0.126, 0.094	0.778
Duration of activation	−0.025	−0.059, 0.009	0.149
Power setting × Duration of activation	0.067	0.055, 0.078	**<0.001**
Model 2			
Location of couple	1.841	1.623, 2.060	**<0.001**
Duration of activation	−0.022	−0.051, 0.007	0.131
Power setting × Duration of activation	0.066	0.059, 0.072	**<0.001**
Model 3			
Location of couple	1.841	1.623, 2.060	**<0.001**
Power setting × Duration of activation	0.062	0.057, 0.067	**<0.001**

Bold *P*-value indicates significance at 5% level.

no published literature on the thermal conductivity of human teeth. It may be that the temperature rises recorded in this study were higher than those likely to occur *in vivo* because the equilibrating effect of a blood supply was lacking. The apparatus containing the tooth/acrylic cylinder assembly was designed to prevent air currents from causing variability in the readings. Variation of the ambient temperature has been shown to have no significant effect on recorded temperature rises (Figdor *et al.* 1983, Saunders 1990a), and in this study, ambient temperature rises did vary between 22 and 24 °C.

A number of obturation protocols have been described for ultrasonic condensation of gutta-percha: ultrasonic softening of the master cone only followed by cold lateral condensation (Moreno 1977), one or two ultrasonic activations after completion of cold lateral condensation (Amditis *et al.* 1992), ultrasonic activation after placement of each second accessory cone (Deitch *et al.* 2002) or ultrasonic activation after placement of each accessory cone (Baumgardner & Krell 1990). In this study, ultrasonic activation after each additional accessory cone was used as this was likely to produce the greatest temperature rises.

During obturation, a single batch of gutta-percha was used to minimize variations in the properties of the gutta-percha (Tagger & Gold 1988). Sealer was not used for obturation in this study in order to reduce the number of variables influencing the result. It is possible that the absence of a sealer would affect the temperature rise, but this has been disputed (Figdor *et al.* 1983, Hardie 1986).

Power settings of 1, 3 and 5 were selected from a range of 1–10 because those greater than 5 caused charring on root surface and resulted in spreader fracture. However, no information was available from the manufacturer for converting the power setting into energy output from the ultrasonic machine.

The maximum temperature rises were significantly higher in the mid-root than in the apical region; this is a common finding with thermoplasticized gutta-percha techniques (Saunders 1989). The reason for this difference is most likely because of the spreader spending more time in the mid-root region. The maximum temperature rise also has a positive linear relationship with the combination of power setting and duration of activation, with a gradient of 0.062. The recorded temperature rises at the mid-root level revealed that only one combination of power setting with duration of activation produced temperature rises exceeding 10 °C (threshold for continued periradicular health); this was power setting 5 and activation time 15 s. It may be inferred that root canal obturation using ultrasonic (Enac) activation of gutta-percha technique is unlikely to cause damage to the periodontal tissue, if the power and time settings are lower than this combination. This also assumes that the majority of machines are configured to have a standard power output calibration.

Further studies are required to determine an optimum combination of the settings which could produce adequate softening effects on the gutta-percha well below the safety threshold of temperature rise on the root surface. The quality of obturation was also measured, but is not reported in detail here. The outcomes revealed that the majority of obturations produced homogenous root fillings that were adapted to the canal walls: the relationship of quality of obturation and the variable studied will be reported separately. In addition, the effect of preparation size, residual dentine thickness and the frequency and number of activations on temperature rise at the root surface should be investigated further.

Conclusions

1 Temperature rises in excess of 10 °C (threshold for continued periradicular health) were evident only in one group – the combination of power setting 5 with an activation time of 15 s.

2 Temperature rises were significantly ($P < 0.001$) affected by the coronal/apical location of the thermocouple (higher at mid-root level), and interaction of power setting and duration of activation.

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