Root canal obturation by ultrasonic condensation of gutta-percha. Part II: an *in vitro* investigation of the quality of obturation

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Abstract

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Aim To compare the quality of root canal obturation using ultrasonic or cold condensation of gutta-percha and to determine the effect of power setting and activation time on the quality of obturation using the former technique.

Methodology An extracted human maxillary canine was used in an *in vitro* split tooth model to allow repeated obturation of the same root canal system using an ultrasonic device to thermocompact gutta-percha without sealer. After each obturation, the root filling was removed from the tooth to allow evaluation of its quality and for the tooth to be re-obturated. The influence of combinations ($n = 10$ per combination) of power setting (1, 3, 5) and activation times (4, 10, 15 s) was tested on the quality of root filling, assessed by measuring the voids within the body of the root filling as well as at the surface. Image analysis was used to quantify the voids within the body of the root filling. Cold lateral condensation of gutta-percha served as a control.

Results Both surface and cross-sectional analyses revealed that different power setting and activation time combinations produced significantly fewer voids than cold lateral condensation ($P < 0.05$) at the apical, mid-root and coronal levels.

Conclusions Taking surface and cross-sectional analysis together only power setting 5 and activation times of 10 and 15 s consistently produced ultrasonically thermocompacted root canal fillings with fewer voids than cold lateral condensation without sealer.

Keywords: obturation, root canal, ultrasonics, voids.

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Introduction

Obturation of the root canal system is intended to incarcerate any microorganisms, their toxins and necrotic tissue remaining after chemo-mechanical preparation. It should also prevent microleakage between the root canal and external environment, thus depriving microorganisms of nutrients and preventing their products from diffusing to the periradicular tissues. Therefore, root canal obturation should produce an homogenous three-dimensional filling of the complex root canal system.

Gutta-percha is the most widely used obturation material and cold lateral condensation of gutta-percha has been the most commonly taught technique at dental schools in the United Kingdom (Dummer 1991). The technique is at its most effective in regularly tapered canals but irregularities in taper and morphology may encourage voids or pooling of sealer (Brayton *et al.* 1973). Bacterial microleakage between individual gutta-percha cones and between root canal filling and the

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canal wall may contribute to failure (Kerekes & Tronstad 1979, Murrin *et al.* 1985, Sjögren *et al.* 1990).

Heat or solvents have been recommended as a means of improving the adaptation of gutta-percha without the need for excessive forces. Warm lateral condensation has been reported to produce a root filling with less dye leakage than cold lateral (Kersten 1988). The heat may be carried to the gutta-percha in the canal in a variety of ways including flame or electrically heated carriers. A less frequently used method is the softening of gutta-percha using frictional heat generated by introducing an ultrasonically activated file into the canal (Moreno 1977). A later study (Baumgardner & Krell 1990), using a different ultrasonic model and specially adapted plugger inserts found improved condensation and reduced dye leakage in comparison with cold lateral condensation. However, no study so far has investigated the presence and amount of voids at the surface and within the body of gutta-percha after using ultrasonic condensation.

The aims of this study were to assess the quality of ultrasonically condensed gutta-percha root fillings and to determine the effect of power setting and activation time.

Materials and methods

Preparation and mounting of extracted teeth

A reusable *in vitro* single tooth test model (human maxillary canine prepared with a stepback technique to an apical size 50) was prepared following the protocol described in a previous study (Bailey *et al.* 2004). The canal walls were seen to be smooth except for a fin in the coronal portion of the canal.

Procedures of obturation

A size 20 plugger (Enac; Osada Electric Co. Ltd, Tokyo, Japan) set at 20 mm from the hub attached through a no. ST 12 tip to an ultrasonic device (Enac model OE-3; Osada Electric Co. Ltd) was used. Power settings of 1, 3 and 5 and activation periods of 4, 10 and 15 s together gave nine experimental groups with 10 samples in each group (Table 1). Master and accessory gutta-percha cones (Davis, Schottlander and Davis, Letchworth Garden City, UK) were used throughout the study for both techniques. The test obturation technique involved the initial placement of a size 50 gutta-percha cone (batch no. 993492) to the working length with 'tug back' followed by cold lateral condensation of three accessory cones (batch no. 555392) using a matching finger spreader but no sealer. The ultrasonic device was then placed in the centre of the gutta-percha mass up to 1 mm from the working length and activated at the appropriate power setting and duration of activation under test. At the end of activation, the ultrasonic spreader was removed and an additional accessory cone placed followed by energization with the activated ultrasonic spreader again. This process was repeated approximately eight times until the canal was filled. During each subsequent energization, the ultrasonic spreader was placed to a slightly more coronal level.

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

Group 10 (cold lateral condensation control group) denoted with '0' power setting and duration of activation.

At the completion of each root filling the tooth model was dismantled and the root filling was carefully removed and temporarily stored in a container at room temperature for surface and cross-sectional analysis. The smooth surface of the gutta-percha canal walls allowed for easy removal of the gutta-percha root filling without distortion. The tooth model was then reassembled for the next experiment. Cold lateral condensation served as the control. The same master and accessory cones were used as before without sealer. After checking that the master cone fitted with 'tug-back' at the working length, a matching finger spreader to the intended accessory cone was placed to within 1 mm of the working length and an accessory cone placed. The spreader was then taken to increasingly shorter distances from the working length as the canal was filled with accessory cones.

Surface analysis

The root canal had a distinctive fin coronally that allowed a standardized orientation of the root canal fillings for photographing the mesial surface onto 35 mm slide film (Kodak 64 ASA; Eastman Kodak

Co., Rochester, NY, USA) under standard lighting conditions. The slides were subjected to image analysis using a Quantimet 520 image analysis system (Cambridge Instruments, Cambridge, UK) with a light source at a standardized angle of incidence to detect irregularities in the surface of the filling. The irregularities were seen as shades of grey within the gutta-percha root fillings. The grey scale representing an actual void was used to calibrate the analysis system to detect them. Apart from the coronal fin the canal walls were smooth and thus irregularities in the root filling including the grooves between individual gutta-percha cones were considered to be due to deficiencies in adaptation. Voids were recorded separately for the apical (within 3 mm from the apex), mid-root (between 3 and 10 mm from the apex) and coronal (beyond 10 mm from the apex) regions and expressed as the proportion of root filling present within a standardized analysis frame.

Cross-sectional analysis

The root fillings were also subjected to a cross-sectional analysis. In order to standardize the plane of section at the apical, mid-root and coronal levels of the root canal fillings they were placed into standardized holes pre-cut into brass blanks. Three brass blanks (H.S. Walsh Ltd, London, UK), 1.5 mm in depth, had 10 holes drilled through each one. The hole diameters in the first blank were 0.8 mm, in the second 1.0 mm and the third 1.25 mm. The root canal fillings were first placed in the 0.8 mm holes until light resistance was met. The amount of root filling passing through the blanks was measured so that it was the same for each specimen and therefore consistency in the level of section was ensured. It was established that the specimens were passing through the blanks by the same amount before sectioning the gutta-percha from both sides of the blank with a sharp razor blade (Agar Scientific, Stansted, UK). The remaining part of the gutta-percha was then placed in the 1.0 mm diameter holes and then in the 1.25 mm diameter holes. In this way the root canal fillings were sectioned at 3, 6 and 10 mm from the apex. The cross-sections were then subjected to image analysis using the Quantimet 520 image analysis system in combination with a Zeiss microscope (Carl Zeiss Oberkochen Ltd, Welwyn Garden City, UK) at ×73 magnification to measure the percentage voids within the measurement frame. The measurement frame consisted of a standard 'box' just 'touching' the rim of the circular hole in the brass blank. The specimens were viewed under transmitted light so that voids within the root canal filling and between the root canal filling and the hole would give a pre-calibrated grey scale in the image analysis system. The analysis system mapped the grey scale and this data could be used to express the void areas as a proportion of the measurement frame.

Statistical analysis

A Dunnett's one-tailed *t*-test (SAS Institute, Cary, NC, USA) was used to analyse both surface and cross-sectional data to establish the power setting and activation time combinations that produced significantly more void-free root canal fillings compared with cold lateral condensation.

Results

Surface analysis

The data for quality of the root canal fillings at the apical, mid-root and coronal levels are depicted in Table 2. At the apical and mid-root levels, only the combination of power setting 5 and activation time 15 s, produced significantly fewer voids than cold lateral condensation ($P < 0.05$). Coronally, combinations of power setting 3 and activation time 15 s and higher produced root fillings with significantly fewer voids than cold lateral condensation ($P < 0.05$).

Table 2 Mean (SD) of proportion of voids present on the surface of root filling

Power	Duration of activation	Apical level	Mid-root level	Coronal level
0	0	0.19 (0.04)	0.28 (0.05)	0.36 (0.09)
1	4	0.17 (0.05)	1.76 (0.06)	0.35 (0.10)
1	10	0.15 (0.05)	0.25 (0.05)	0.35 (0.06)
1	15	0.17 (0.05)	0.28 (0.04)	0.36 (0.07)
3	4	0.20 (0.06)	0.31 (0.06)	0.36 (0.03)
3	10	0.21 (0.06)	0.32 (0.04)	0.41 (0.05)
3	15	0.21 (0.06)	0.32 (0.06)	0.44[a] (0.05)
5	4	0.22 (0.05)	0.31 (0.02)	0.45[a] (0.06)
5	10	0.27 (0.04)	0.38 (0.05)	0.54[a] (0.07)
5	15	0.36[a] (0.08)	0.50[a] (0.10)	0.61[a] (0.10)

Cold lateral condensation = power '0' and duration of activation '0'.
[a]Mean values indicated significant ($P < 0.05$) difference from the mean proportion of the voids present in respective laterally condensed gutta-percha.

Cross-sectional analysis

The data quantifying the presence of voids at apical, mid-root and coronal levels are depicted in Table 3. In this case the proportion of voids within the measurement frame was calculated by the image analysis system. The voids themselves were made up form a combination of surface irregularities and spaces between individual gutta-percha cones. Apically all power setting and activation time combinations with the exception of power setting 1, activation time 4 s produced significantly fewer voids than cold lateral condensation ($P < 0.05$). At the mid-root level there were generally fewer voids than found apically (Table 3). Combinations of power setting 3 and activation time 10 s, power setting 3 and activation time 15 s and all combinations of power setting 5 produced significantly fewer voids than cold lateral condensation ($P < 0.05$). At the coronal level all the power setting and activation time combinations except power setting 1 activation time 4 s produced significantly fewer voids than cold lateral condensation ($P < 0.05$). There were generally fewer voids coronally than found in the other two regions (Table 3).

Discussion

The single tooth model allowed direct comparison of the quality of root canal fillings whilst making it possible to relate these to temperature rise at the root surface. Surface and cross-sectional analyses were carried out in order to provide more information about the root canal filling as a whole. In the surface analysis the proportion of root canal filling appears small but this relates to the proportion of root canal filling within the computer-generated measurement frame as calculated by the image analysis system and not that within the original root canal.

Table 3 Mean (SD) of proportion of voids present in the cross-sectional surface

Power	Duration of activation	Apical level	Mid-root level	Coronal level
0	0	0.16 (0.06)	0.10 (0.02)	0.07 (0.02)
1	4	0.20 (0.06)	0.10 (0.04)	0.10 (0.04)
1	10	0.10[a] (0.04)	0.08 (0.03)	0.06[a] (0.02)
1	15	0.11[a] (0.05)	0.07 (0.02)	0.04[a] (0.02)
3	4	0.11[a] (0.05)	0.10 (0.04)	0.04[a] (0.02)
3	10	0.11[a] (0.04)	0.06[a] (0.04)	0.04[a] (0.01)
3	15	0.11[a] (0.04)	0.05[a] (0.02)	0.04[a] (0.02)
5	4	0.10[a] (0.04)	0.07[a] (0.04)	0.04[a] (0.02)
5	10	0.08[a] (0.02)	0.06[a] (0.02)	0.03[a] (0.02)
5	15	0.05[a] (0.03)	0.04[a] (0.02)	0.02[a] (0.01)

Cold lateral condensation = power '0' and duration of activation '0'.
[a]Mean values indicated significant ($P < 0.05$) difference from the mean proportion of the voids present in the respective laterally condensed gutta-percha.

Sectioning of gutta-percha may lead to artefactual changes. A pilot study had shown some smearing of the cut surface of the gutta-percha was evident but did not distort the cut surface of the root filling and therefore alter the results. Another possible inaccuracy may have arisen due to the fact that the gutta-percha root filling was taken from an oval-shaped canal and placed in a circular hole in the brass blank. This gave rise to 'false' voids between the root filling and the brass blank, However as these would be the same for all sample groups, they were not considered to be a source of error in the comparisons. The results do not represent the actual proportion of voids present within the root canal space but within the hole in the brass blank. As the root canal and measurement frame dimensions were constant, variations were a function of voids in the root filling.

Clinically the voids measured in this study would largely be filled with sealer. The voids measured were all small but varied considerably within each group. This meant that demonstration of a significant difference between many of the groups was not possible. When the overall results of the cross-sectional and surface analyses are taken together only power setting 5 and activation times of 10 and 15 s consistently produced root canal fillings, which were significantly better than cold lateral condensation ($P < 0.05$). In the study of temperature rises during ultrasonic condensation of gutta-percha it was found that power setting 5 and activation time 15 s produced an excessive rise at the root surface (Bailey *et al.* 2004). Thus it appears that, within the limitations of this study, power setting 5 activation 10 s is the optimum combination for root canal obturation when using the selected ultrasonic device.

From a practical viewpoint ultrasonic condensation of gutta-percha was quickly mastered and has several advantages over other warm lateral condensation techniques. It was observed that heat was only generated during ultrasonic activation and the plugger appeared to cool rapidly once activation ceased. As a result of this it was unusual for the gutta-percha to be pulled out of the canal when removing the plugger from the canal. A clinical outcome study showed that the use of ultrasonic condensation of gutta-percha to obturate root canal systems associated with preoperative radiolucent areas resulted in a 94% success rate based on criteria that accepted incomplete healing as successful (Zmener & Banegas 1999).

Further study should be carried out to ascertain the optimum protocol for obturation in different canal anatomies with regard to depth of ultrasonic plugger penetration and number of activations. Prospective clinical outcome studies should also be carried out.

Conclusions

Taking surface and cross-sectional analysis together only power setting 5 and activation times of 10 and 15 s consistently produced ultrasonically thermocompacted root canal fillings with fewer voids than cold lateral condensation when no sealer was used. It was found, in a previous study that power setting 5 and activation time 15 s produced excessive temperature rises at the root surface. Thus power setting 5 and activation time 10 s would appear to be optimal for root canal obturation using the test system.

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