

Original research article

Infrared thermal analysis of root surface temperatures during the ultrasonically activated obturation technique

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ABSTRACT

OBJECTIVE: To evaluate the temperature changes on the external root surfaces of mandibular premolar teeth during ultrasonic condensation of gutta-percha in the root canal.

MATERIALS AND METHOD: Ten extracted mandibular premolar teeth were selected. The roots were cut to a uniform length of 14 mm. Root canal treatments were performed using the ProTaper system, and the master apical file was a ProTaper F3 instrument. After the root canal preparations, cone-beam computed tomography images were taken to detect the thinnest dentinal area on the root. Each root was embedded in acrylic plates. For temperature measurements, the specimens were placed in a stainless steel device that was specially designed for this study. Temperature changes during obturation (warm lateral condensation using ultrasonics as the experimental group and cold lateral condensation as control) were then recorded using a thermal camera. Unpaired t-test was performed using a statistical software ($\alpha=0.01$).

RESULTS: There were significant differences between the groups. The mean obturation times of the specimens were 232.8 s for the experimental group and 102.5 s for the control. The mean value of the temperature increase in the experimental group was 49.96 ± 11.12 °C; and no temperature increase was recorded for control group. The maximum temperature rises was 68.9 °C, and the minimum was 35.9 °C. The average cooling time of all samples were 17 s and did not exceed 1 min.

CONCLUSION: High temperatures that may cause hazardous effects on periodontium were observed; however, average cooling times of the samples were in normal ranges (less than 1 min). Further investigations are needed for testing different power settings.

KEYWORDS: Endodontics; gutta-percha; ultrasonics

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INTRODUCTION

Cold lateral condensation is a commonly preferred root canal filling technique in endodontic practice.^{1,2} In this technique, gutta-percha is used in conjunction with a root canal sealer in order to attain an entirely filled root canal. Although root canal filling may lack homogeneity,³ the cold lateral condensation technique has the advantage of controlled placement of gutta-percha into the root canal.⁴

Heat and solvents have been used for softening and improving the adaptation of gutta-percha both to root canal walls and the cones to each other without the need for excessive forces.^{5,6} A number of thermoplastic techniques have these advantages, such as continuous wave of condensation, thermo-mechanic compaction and injection of thermoplasticized gutta-percha.^{2,7,8} Furthermore, the use of ultrasonically-activated spreaders as an aid for lateral condensation of gutta-percha cones has been shown to be superior to the conventional lateral condensation technique *in vitro*.^{9,10} In endodontic practice, ultrasonic devices are used without water cooling for softening gutta-percha in root canal filling; this may result in heat generation. A greater than 10 °C increase sustained for 1 min may cause irreversible bone injury and lead to resorption and ankylosis.¹¹⁻¹³ To our knowledge, only one study has evaluated the temperature rise on the root surface caused by ultrasonic condensation.¹⁴

Thermocouples, although widely used for the evaluation of root surface temperature, have been shown to have some disadvantages, such as single point evaluation from the target surface and difficulty of separation from the surface.¹⁵ Infrared thermographic imaging

is currently widely utilized in dental examinations.¹⁶ Thermal imaging cameras detect radiation in the infrared range of the electromagnetic spectrum (~8.000–14.000 nm) and produce images of that radiation. Rises in temperature increase the amount of radiation emitted by an object, and thus, thermography allows the investigator to observe variations in temperature.¹⁷ Its principal advantage over thermocouple analysis is its ability to measure temperatures over a large surface area, and dedicated software packages allow the investigation and identification of points of temperature extremes.¹⁵

In literature, there is lack of knowledge about the subject of the present study. Thus, the purpose of this article was to assess temperature changes during the ultrasonically activated condensation technique and to measure the root canal filling times.

MATERIALS AND METHOD

Specimen preparation

Twenty human mandibular premolar teeth, extracted for periodontal reasons, with single canal and mature apices were selected for this study. The teeth were examined under an operating microscope at 4× magnification to ensure that there were no cracks or caries on the root surfaces. The roots were then cut to a uniform length of 14 mm using a slow-speed diamond saw on the horizontal plane (Isomet; Buehler, Lake Bluff, IL, USA). The root surfaces were debrided with an ultrasonic scaler (Cavitrion, Dentsply, York, PA, USA) and gently root-planed with hand curettes to remove adherent soft tissues. Working lengths were established radiographically at ~1 mm from the radiographic apex. Root canal preparation was performed with the ProTaper Ni-Ti rotary system up to a ProTaper F3 instrument as the master apical file, and according to the manufacturer's instructions (Dentsply Maillefer, Ballaigues, Switzerland). Five mL of 2.5% NaOCl was used for irrigation between each instrument, following by rinsing with 5 mL 17% EDTA for 1 min, then by copious irrigation with distilled water. Each canal was dried with paper points. Cone-beam computed tomography (CBCT) images were taken after root canal preparation to determine the remaining dentin thickness of each root in order to measure the thermal changes from the thinnest part of the root dentin during the ultrasonic filling.

Ultrasonically activated root canal filling and thermographic measurements

Each root was embedded into 3×5×0.2 cm acrylic plates, 1 mm below the cemento-enamel junction with an acrylic resin (Pattern Resin LS, GC America Inc., Alsip, IL, USA). For temperature measurements, the

specimens were fixed with the entire root surfaces exposed to air, and placed in a stainless steel device which was specially produced for this study. A camera was mounted 15 cm away on a stand perpendicular to the root surface, with the thinnest root surfaces in view of the camera (Figure 1). The experiment was carried out under controlled environmental conditions (ambient temperature: 26±0.9 °C; relative humidity: 44±5%). Specimens were randomly divided into 2 groups as experimental group and control group (n=10). In the experimental group, the warm lateral condensation technique was used for root canal filling by means of an ultrasonic motor (Minimaster, EMS, Nyon, Switzerland) and a size #70, 6% tapered ultrasonic lateral condensation tip (Instrument H, EMS). During the filling, 0.02 tapered gutta-percha (Dentsply-Maillefer, Petropolis, Rio de Janeiro, Brazil) and resin sealer (AH Plus; Dentsply DeTrey GmbH, Konstanz, Germany) were used to fill the canals. In each canal, a master gutta-percha cone that fit well to the working length was selected. The master cone was coated with root canal sealer and placed to the working length. The ultrasonic tip was introduced into the canal without force at 3 to 5 mm from the working length by hand until slight resistance was felt; the depth of spreader penetration was controlled by using rubber-stoppers. Ultrasonic unit was set to moderate power level 5. Then, the spreader tip was activated by the ultrasonic unit for 6 sec and light apical and lateral condensing pressure was applied. The activated spreader was then slightly rotated and removed. The specimen was left to cool down to ambient temperature. Then, an accessory gutta-percha cone was coated with cement and placed into the created space. The spreader was again inserted and the same procedure was repeated until the spreader could be advanced no more than coronal 3 mm into the canal space. Then, all teeth were observed with a radiograph to control the density of the filling. In all specimens, the ultrasonically activated spreader was placed into the canal by the thinnest root surface side during each gutta-percha condensation sequence. Recording function of the thermal camera (ThermaCam SC500, Flir, Danderyd, Sweden) was initiated 2 seconds before the activation of the ultrasonic tip and the recording was done until the root canal filling procedure was completed and the temperature of the root surface equalized with ambient temperature. This procedure was repeated for each accessory cone insertion into the root canal.

In the control group, cold lateral condensation technique was used for filling the root canals. During this, the identical filling materials were used. In each canal, a master gutta-percha cone that fit well to the working length was selected. The master cones were coated with the sealer and placed to the working length, and

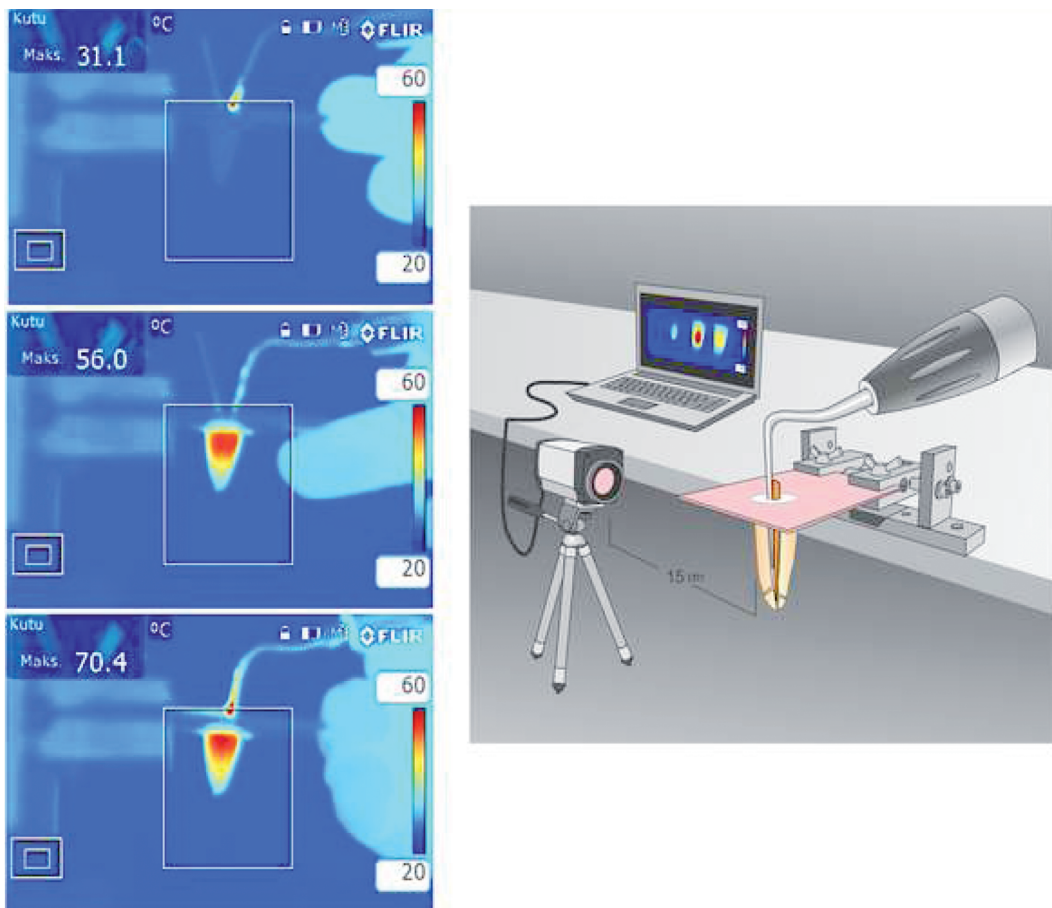


Figure 1. Specially produced stainless-steel device for this study and temperature measurements of a sample by a thermal camera is shown in the figure. Thermal camera images show different stages of filling of the root canal system. The temperature gradually increases during the procedure.

root canal was obturated by using accessory cones in conjunction with the root canal sealer after the lateral condensation with finger spreaders. Temperature changes, during the root canal filling procedure was recorded from the thinnest root surface between 2 sec before the operation until cooling to the actual controlled environmental temperature.

Statistical analysis

The data showed a normal distribution (Shapiro-Wilk test). Therefore, unpaired t-test was done to compare the groups with SPSS version 16.0 software (SPSS Inc, Chicago, IL, USA; $\alpha=0.01$).

RESULTS

Measurements obtained during the root canal filling procedures are displayed in Table 1. The mean value of maximum temperature increases on the roots at the thinnest root surface was 49.96 ± 11.12 °C in the experimental group. The maximum value was 68.9 °C, and the minimum value was 35.9 °C. The mean cooling time was 17 sec (range: 11-20 sec). In the control group, no temperature rise was recorded. There was an obvious difference between the groups.

The mean value of root canal filling durations of the control and the experimental groups were 102.5 sec and 232.8 sec, respectively. Comparisons according to the

Table 1. Descriptive statistics for obturation times and temperature changes

	Mean obturation time \pm SD (sec)	Mean temperature rise \pm SD (°C)	Max. (°C)	Min. (°C)
Control Group	102.5 \pm 18.86	0	0	0
Experimental Group	232.8 \pm 50.59	49.96 \pm 11.12	68.90	35.90

Max represents the maximum value among the maximum temperature rise values, and Min represents the minimum value among the maximum temperature rise values. SD: Standard deviation. There was a statistically significant difference between the mean obturation times of the groups and an obvious difference between the mean temperature rise values.

time spent during root canal filling showed that the control technique was significantly less time-consuming than the experimental technique ($p < 0.01$).

DISCUSSION

The warm gutta-percha condensation technique provides homogeneous and well-adapted root canal fillings;^{18,19} however, the heated-gutta-percha may extrude through the apical foramen, and this extruded filling material may cause a foreign body reaction in the periapical tissues in the long-term.^{20,21} Therefore, the warm gutta-percha condensation technique can be modified to increase the safety of root canal filling. Hence, the warm gutta-percha technique performed with an ultrasonic device was preferred in the present study. Ultrasonic condensation of gutta-percha has some advantages over other warm lateral condensation techniques as being quickly mastered, and heat is only generated during ultrasonic activation and the plugger cools rapidly once the activation ceased.⁵ Furthermore, Bailey *et al.*⁵ and Deitch *et al.*⁴ reported that lateral condensation with ultrasonic tip resulted with a better filling quality over the cold lateral condensation technique.

In the control group, due to its established effectiveness and its use as a gold standard for comparisons, cold lateral condensation technique was used.¹ Also, it is the most commonly used and tested technique.¹⁴

In the literature, several studies concerning temperature rise at the root surface have been presented. Zhou *et al.*²² investigated the heat transfer to periodontal tissues during continuous-wave root canal filling in a finite element analysis model and reported that the highest temperatures on the periodontal ligament could reach as high as 46.9-48.9 °C. Venturi *et al.*²³ evaluated the temperature changes generated by the vertical condensation technique performed with a System-B Heat Source and found that minor temperature changes occurred on the outer surface of the root canal. In a study by Mc Cullagh *et al.*¹⁵ continuous wave of root canal filling resulted in an average temperature rise of 28.4 °C. In terms of measurement technique, thermocouples^{14,23-25} and, less often, finite elements analysis^{22,26} and thermal camera imaging^{15,27,28} were frequently used in previous studies. One disadvantage of thermocouples is the limitation to measure temperature only at the point on the surface with which it is in contact; only a limited number of arbitrarily selected points can be studied at one time, so the correct points of the temperature rises on root surface may not be selected accurately. Difficulty in detaching the metal wires from the surface is another limitation. Hence, in this study thermocouples were not used to measure the temperature changes.¹⁵ The time-consuming nature and high costs of dental modeling procedures in finite element analysis gener-

ally limit the use of this technique. Furthermore, using only a single tooth model for evaluation disregards the anatomical variations in the teeth, such as variations in the dentin thickness and the root canal length. This limitation impedes in generalization of the results, although helps to obtain accurate measurements.^{22,26} For the reasons mentioned above, the thermal camera imaging technique was preferred in this study. Although it requires controlled environmental conditions, the surfaces can be measured simultaneously, the cooling period can be assessed, and numerous measurements can be taken from the samples. Thermal camera has been used in the measurement of root surface temperatures in several studies.^{15,28,29} Temperature measurement from the thinnest area as marked with the aid of CBCT imaging allowed identification of the maximum heat transmission areas.

Filling of a single root canal using the ultrasonic device required an average time of 232.8 sec. The actual clinical conditions were properly mimicked in the study. The temperature was measured 2 sec before the procedure and continued until the temperature of the specimen returned to the ambient condition, which took an average of 17 sec. In this circumstances, the critical level of 10 °C temperature rise over 1 min as mentioned by Eriksson & Albrektsson¹¹ was not the case; and hence, the damage caused (if any) was minor and reversible. The average maximum temperature was 49.96 ± 11.12 °C; with a maximum value of 68.9 °C, and a minimum value of 35.9 °C. Bailey *et al.*¹⁴ investigated the temperature rise generated on the root surface using thermocouples during ultrasonically activated gutta-percha condensation. In this study, all specimens were obturated with ultrasonic activation at the master cone and accessory cone placement as in the studies by Bailey *et al.*^{5,14} However, Bailey *et al.*¹⁴ did not use a root canal sealer during the filling as opposed to this study, and this may have influenced the results. Their study used 1, 3 and 5 power settings of the 30-kHz ultrasonic device (Enac model OE-3, Osada Electric Co. Ltd, Tokyo, Japan) that ranged from 1 to 10, and they reported a 10.74 °C temperature increase at the power setting 5 of their device, which they attributed to a lack of the manufacturer's instructions for root canal filling. Also in the present study, there was no recommendation about root canal filling in the manufacturer's manual, and there was only one size of spreader in its catalogue, so it was decided to activate the spreader ultrasonically for approximately 5 to 10 sec, and the power level of the ultrasonic unit was adjusted to 5 (middle level) without water flow (24-32 kHz) as in the study by Bailey *et al.*¹⁴ The higher temperatures generated in this study in comparison to other studies may have derived either from methodological differences such as measuring from the thinnest root regions, operating with different power settings,

using infrared-imaging rather than thermocouples and ultrasonic devices or from especially preferring premolar teeth over canine teeth which have larger roots. According to the results of the present study, ultrasonically activated filling of root canals may be considered as a harmful technique because of the rising temperature on the root surface that exceeded the hazardous limits (10 °C). However, it has been reported that, a frequently used application in clinics, such as post-space preparation with drills could cause high temperature rise at root surfaces.^{28,30}

There is no consensus regarding the power settings of ultrasonically activated filling methods, and the manufacturers have largely neglected this subject, leading to insufficient information in user manuals and a limited selection of spreader tips. To prevent the possible hazardous effects of temperature increases on the periodontium during root canal filling, the ultrasonically activated tip should be used carefully. Although high temperatures were detected in this study, the average cooling time of all samples were 17 sec and did not exceed the limits (1 min). Further studies are needed to elucidate the exact power settings that are both useful and harmless during ultrasonically activated warm gutta-percha techniques.

Within the limits of this *in vitro* study; ultrasonic device may be used at lower power settings during the procedure, and caution should be exercised when performing the root canal filling. Further investigations are needed for different power setting levels.

Conflict of interest disclosure: The authors declare no conflict of interest related to this study.

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Ultrasonik olarak aktive edilen obturasyon tekniği esnasındaki kök yüzeyi sıcaklıklarının kızıllötesi termal analizi

ÖZET

AMAÇ: Güta-perkanın ultrasonik kondensasyonu tekniğinin mandibular premolar dişlerin dış kök yüzeyi üzerinde meydana getirdiği sıcaklık değişimlerinin değerlendirilmesidir.

GEREÇ VE YÖNTEM: On adet çekilmiş mandibular premolar diş seçildi. Kökler, boyları 14 mm olacak şekilde kesildi.

Kök kanal tedavileri ProTaper sistem ile gerçekleştirildi ve ana apikal eğe F3 enstrümanı olarak belirlendi. Kök kanal preparasyonlarından sonra, kök üzerinde en ince dentin noktasının belirlenmesi amacıyla konik ışınli bilgisayarlı tomografi görüntüleri alındı. Tüm kökler akrilik plakalara gömüldü. Sıcaklık ölçümleri için örnekler, bu çalışmaya özel olarak tasarlanmış olan paslanmaz çelik bir mekanizmaya yerleştirildi. Dolum sırasında meydana gelen sıcaklık değişimleri (deney grubu olarak ultrasonik ile sıcak lateral kondensasyon tekniği ve kontrol olarak soğuk lateral kondensasyon) bir termal kamera yardımıyla kaydedildi. İstatistiksel karşılaştırma bir bilgisayar yazılımı kullanılarak bağımlı olmayan t-testi ile yapıldı ($\alpha=0.01$).

BULGULAR: Gruplar arasında anlamlı farklılık vardı ($p<0.01$). Örneklerin ortalama obturasyon süreleri deney grubu için 232.8 sn ve kontrol grubu için 102.5 sn idi. Deney grubundaki maksimum sıcaklık artışı ortalaması 49.96 ± 11.12 °C olarak gözlemlendi; kontrol grubunda herhangi bir sıcaklık artışı kaydedilmedi. Maksimum sıcaklık artışları arasındaki en büyük değer 68.9 °C, en küçük değer 35.9 °C idi. Örneklerin ortalama soğuma zamanları 17 sn idi ve 1 dakikayı aşmadı.

SONUÇ: Bu çalışmada, periodonsiyum üzerinde zararlı etkilere yol açabilecek yüksek sıcaklıklar gözlemlenmiştir; ancak, örneklerin ortalama soğuma süreleri normal sınırlar içerisindeydi (1 dakikadan az). Farklı güç derecelerinde gerçekleştirilecek daha ileri çalışmalara ihtiyaç bulunmaktadır.

ANAHTAR KELİMELER: Endodonti; guttaperka; ultrasonik