SVOA Dentistry

e-ISSN 2753-9172

ScienceVolks Open Access

Original Research

Heat Transfer to the External Root Surface During Use of Wireless Heated Pluggers: An *In Vitro* Study

Joon Koh DMD[1], Albert F. McMullen DDS, FACD[2*]

[1]Postgraduate Endodontic Resident, Louisiana State University Health Sciences Center (LSUHSC), USA.

[2]Department Head and Postgraduate Director, Endodontics, Louisiana State University Health Sciences Center (LSUHSC), USA.

***Corresponding Author:** Albert F. McMullen DDS, FACD, Department Head and Postgraduate Director, Endodontics, Louisiana State University Health Sciences Center (LSUHSC), USA.

https://doi.org/10.58624/SVOADE.2026.07.021

Received: May 11, 2026

Published: June 03, 2026

Citation: Koh J, McMullen AF III. Heat Transfer to the External Root Surface During Use of Wireless Heated Pluggers: An *In Vitro* Study. *SVOA Dentistry* 2026, 7:3, 159-166. doi: 10.58624/SVOADE.2026.07.021

Abstract

Introduction: Heat generated during thermoplastic obturation may be transferred to surrounding periodontal tissues. The purpose of this study was to evaluate the thermal behavior of wireless heated plugger systems and to determine the time required to produce a 10 °C increase in external root surface temperature, as well as the influence of dentin thickness on heat transfer.

Methods: Five wireless heated plugger systems were evaluated for plugger tip temperature profiles during 25 seconds of continuous activation. Forty extracted human teeth were instrumented to ProTaper Ultimate F3 and obturated using a warm vertical compaction technique. External root surface temperature was measured 5 mm from the apex using a thermocouple, and the time required to reach a 10 °C increase was recorded for four systems. Each specimen was tested with all systems in randomized order. Dentin thickness was measured using cone-beam computed tomography. Data were analyzed using analysis of variance with Tukey post hoc testing and linear regression ($P < .05$).

Results: Plugger tip temperature profiles varied among systems, with Azdent and Gutta Smart demonstrating substantial temperature overshoot exceeding 500 °C, whereas B&L Alpha II and ZARC maintained more stable temperatures near the preset value. The time required to produce a 10 °C increase differed among systems ($P < .05$), with Gutta Smart demonstrating the shortest mean activation time (5.2 seconds) and Azdent the longest (11.4 seconds). A significant positive association was observed between dentin thickness and time to temperature increase for all systems ($R^2 = 0.34–0.53$, $P < .001$).

Conclusions: Wireless heated plugger systems exhibit distinct thermal behaviors; however, plugger tip temperature does not directly predict heat transfer to the external root surface. Dentin thickness is a primary determinant of heat transfer, and careful control of activation time is recommended, particularly in teeth with reduced dentin thickness.

Keywords: *Warm Vertical Condensation, Heated Pluggers, Endodontics*

Introduction

The primary goal of endodontic therapy is to eliminate microorganisms from the root canal system and to achieve a hermetic three-dimensional seal that prevents reinfection.[1] Gutta-percha used in combination with an endodontic sealer remains the most widely accepted material for obturation. Among available techniques, the continuous wave of condensation has gained widespread adoption due to its ability to thermoplasticize gutta-percha, thereby improving adaptation to canal irregularities and accessory anatomy.[2]

The continuous wave technique involves the application of heat through a heated plugger to soften and compact gutta-percha apically, followed by backfilling of the remaining canal space with thermoplasticized material. While this approach enhances obturation quality, the introduction of intracanal heat raises concerns regarding thermal transfer to surrounding periodontal tissues.

Heat generated during thermoplastic obturation is transmitted through gutta-percha and dentin primarily by conduction. The magnitude of heat transfer is influenced by factors including plugger temperature, duration of activation, depth of penetration, and the remaining thickness of dentin. Dentin exhibits relatively low thermal diffusivity (1.83–2.6 $\times 10^{-7}$ m^2/s) and thermal conductivity (0.11–0.96 W/mK), allowing it to function as a natural insulating barrier.[3] However, variations in radicular dentin thickness—particularly the thinner dentinal walls observed in anterior teeth—may influence the extent of heat transmission to the external root surface.[4]

Previous investigations have demonstrated that thermoplastic obturation techniques can result in measurable increases in external root surface temperature. Reported temperature increases range from approximately 4–7 °C during conventional obturation procedures[5,6] to as high as 22.1 °C with injectable thermoplasticized techniques.[7] Use of devices such as the System B Heat Source has been shown to produce temperature increases approaching or exceeding 10 °C at sites 5 mm from the apex,[8] while computational models have predicted similar thermal elevations during short activation intervals.[9]

Thermal elevations of this magnitude may have biological consequences. Under physiologic conditions, periodontal tissues are maintained at approximately 37 °C. Temperature increases of approximately 10 °C have been associated with cellular stress and physiologic alterations in periodontal ligament cells.[10], while exposure to temperatures between 44 °C and 47 °C for one minute has been shown to cause irreversible bone injury.[11] Clinical reports have also documented cases of thermal damage to periodontal tissues, including gingival necrosis and periodontal breakdown associated with excessive intracanal heat application.[12-14]

Most existing studies evaluating heat transfer during obturation have focused on wired heating systems, such as System B and Touch 'n Heat.[8, 15-17] However, recent advancements in endodontic technology have led to the increasing use of wireless heated plugger systems, which offer improved ergonomics and clinical convenience. Despite their growing adoption, limited data is available regarding the thermal behavior of these devices and their potential effects on external root surface temperature. Furthermore, the influence of remaining dentin thickness on heat transfer during thermoplastic obturation has not been fully elucidated.

Therefore, the purpose of this study was to evaluate the thermal behavior of commonly used wireless heated plugger systems and to determine the time required for each system to produce a 10 °C increase in external root surface temperature. In addition, this study aimed to assess the relationship between dentin thickness and heat transfer during simulated obturation procedures. The null hypotheses were that (1) no differences would exist among systems in tip temperature behavior or time required to reach a 10 °C increase, and (2) dentin thickness would not be associated with time to reach this threshold.

Materials and Methods

Heated Plugger Tip Temperature Measurement

Five heated plugger systems were evaluated for plugger tip temperature behavior during continuous activation: Azdent (Azdent, Shenzhen, China), B&L Alpha II (B&L Biotech, Fairfax, VA, USA), Gutta Smart (Dentsply Sirona, Charlotte, NC, USA), Kerr Elements (Kerr Dental, Brea, CA, USA), and ZARC (Zarc4Endo, Madrid, Spain).

Temperature measurements were obtained using a digital temperature data logger (RDXL6SD; DwyerOmega, Michigan City, IN, USA) connected to a Type K 40-gauge thermocouple probe (DwyerOmega Engineering, Michigan City, IN, USA). The thermocouple was positioned directly at the tip of the heated plugger using thermal conductive paste (Arctic Silver 5; Arctic Silver, Visalia, CA, USA) to ensure stable contact and accurate temperature measurement.

Each heated plugger system was set to 200 °C. The plugger was activated continuously for 25 seconds, and temperature measurements were recorded at 1-second intervals throughout the activation period.

Tooth Selection and Preparation

Forty extracted human permanent teeth, including 10 mandibular incisors, 10 mandibular premolars, 10 maxillary central incisors, and 10 mandibular canines, were selected for this study. Teeth were included based on the absence of open apices, root fractures, or external or internal root resorption. Following extraction, teeth were stored in a 1.5% sodium hypochlorite solution for disinfection until use. All teeth were decoronated to facilitate standardization of access and instrumentation. Working length (WL) was determined by inserting a size #10 K-file (Lexicon K-files; Dentsply Sirona, Charlotte, NC, USA) into the canal until the tip was visible at the apical foramen and subtracting 1 mm from this measurement. Root canals were instrumented using ProTaper Ultimate rotary files (Dentsply Sirona, Charlotte, NC, USA) up to size F3. Canals were irrigated with water between each file during instrumentation because chemical disinfection was not necessary for this in vitro thermal model. Obturation was performed using matching ProTaper Ultimate gutta-percha cones (Dentsply Sirona, Charlotte, NC, USA) in conjunction with a bioceramic sealer (Komet BioSeal; Komet USA, Fort Mill, SC, USA) using a warm vertical compaction technique. The obturation material was not replaced between subsequent experimental trials.

Experimental Design

Each specimen was tested with all four heated plugger systems, resulting in repeated measurements within the same tooth. A total of 160 measurements were obtained (40 teeth × 4 systems).

The four systems evaluated were:

- Azdent cordless obturation system
- B&L Alpha II
- Gutta Smart
- Kerr Elements

The order of plugger system testing was randomized for each specimen to minimize potential order effects. Pluggers were selected based on the smallest available size for each system to allow comparable canal penetration. Because plugger sizing systems differ among manufacturers, the smallest available plugger for each system was selected to allow standardized depth of insertion and consistent positioning within the canal. The specific pluggers used were:

- Kerr: Buchanan heat plugger, extra fine (.04 taper)
- Gutta Smart: size small (20 gauge)
- B&L: size 40/.04 plugger
- Azdent: smallest available size (manufacturer size not specified)

Each specimen was allowed to return to baseline temperature prior to subsequent measurements. No replacement of obturation material was performed to preserve canal morphology across trials.

Measurement of Root Surface Temperature

External root surface temperature changes were measured using a digital temperature data logger (RDXL6SD; DwyerOmega Engineering, Michigan City, IN, USA) connected to a Type K 40-gauge thermocouple probe (DwyerOmega Engineering, Michigan City, IN, USA).

The thermocouple was positioned on the proximal root surface (mesial or distal), corresponding to the thinnest dimension of the root, to capture clinically relevant areas of potential heat transmission. The measurement location was standardized at 5 mm from the apex using a periodontal probe. The thermocouple tip was placed in direct contact with the root surface and secured using thermal conductive paste (Arctic Silver 5; Arctic Silver, Visalia, CA, USA) to ensure consistent thermal contact. No additional stabilization devices were used in order to maintain direct tip-to-surface contact and avoid measurement distortion.

All measurements were performed at room temperature (23 °C). Prior to each trial, specimens were initially heated using the heated plugger system and then allowed to cool until the thermocouple reading reached a baseline temperature of 40 °C. This baseline was selected to approximate physiologic temperature conditions.

Each heated plugger system was set to 200 °C, except for the Azdent system, which does not allow temperature adjustment. The plugger was inserted to a depth of 5 mm from the apex, corresponding to the thermocouple measurement location. Continuous activation was performed until a 10 °C increase in external root surface temperature was reached. For devices with automatic shut-off features, activation was immediately resumed to maintain continuous heating.

Temperature data were recorded at 1-second intervals using the data logger, and the time required to reach a 10 °C temperature increase was recorded. Each specimen was tested once per plugger system, and all specimens were allowed to return to the baseline temperature of 40 °C prior to subsequent measurements. All measurements were performed by a single operator to ensure consistency.

Measurement of Dentin Thickness

Cone-beam computed tomography (CBCT) imaging was performed to measure dentin thickness at the level corresponding to the thermocouple recording site. All scans were acquired using a CS 9600 CBCT unit (Carestream Dental, Atlanta, GA, USA) with a voxel size of 300 µm. Specimens were positioned in a 24-well clear plate (square well, U-bottom, shared wall; 10 mL capacity) and stabilized using a custom 3D-printed mounting jig to ensure consistent orientation during image acquisition. Imaging was performed using a 10 × 5 cm field of view (FOV) at 120 kV and 8.0 mA.

The acquired datasets were analyzed using proprietary imaging software (Carestream Dental). Cross-sectional slices corresponding to 5 mm from the apex were identified for each specimen to match the location of thermocouple placement. Dentin thickness was defined as the minimum linear distance between the root canal space and the external root surface at this level. Measurements were obtained using the software's calibrated linear measurement tool. All measurements were performed by a single examiner under standardized viewing conditions.

Statistical Analysis

Statistical analysis was performed to evaluate differences in the time required to produce a 10 °C increase in external root surface temperature among the heated plugger systems. Because each specimen was tested with all 4 systems, measurements were treated as repeated observations within the same tooth. Differences among plugger systems were analyzed using analysis of variance (ANOVA) with Tukey post hoc adjustment for multiple comparisons. Subgroup analyses were performed to evaluate differences across tooth types. The association between dentin thickness and time required to reach the 10 °C threshold was assessed using linear regression analysis for each plugger system. Statistical significance was set at $P < .05$.

Results

Heated Plugger Tip Temperature Profiles

All heated plugger systems demonstrated a rapid increase in temperature during the initial seconds of activation (Figure 1). However, distinct differences in thermal behavior were observed among devices. The B&L Alpha II system reached approximately 210 °C within 3 seconds and maintained a relatively stable temperature range between 213 °C and 219 °C throughout the activation period. Similarly, the ZARC system demonstrated stable temperature behavior, reaching approximately 179 °C within 3 seconds and stabilizing between 190 °C and 204 °C. The Kerr Elements system exhibited a progressive increase in temperature over time, reaching approximately 217 °C within 3 seconds and continuing to rise to a maximum of approximately 304 °C. The Azdent and Gutta Smart systems exceeded the preset temperature of 200 °C, reaching peak temperatures of approximately 563 °C and 593 °C, respectively, within the initial seconds of activation, followed by variable temperature fluctuations.

Root Surface Temperature Changes

The time required to produce a 10 °C increase in external root surface temperature differed significantly among heated plugger systems ($P < .05$). Across all specimens, mean activation times were as follows: Azdent, 11.4 seconds; B&L Alpha II, 6.3 seconds; Gutta Smart, 5.2 seconds; and Kerr Elements, 6.9 seconds. The Gutta Smart system demonstrated the shortest activation time, whereas the Azdent system required the longest time. Post hoc analysis revealed significant pairwise differences among systems, with the Azdent system differing significantly from other devices across multiple comparisons.

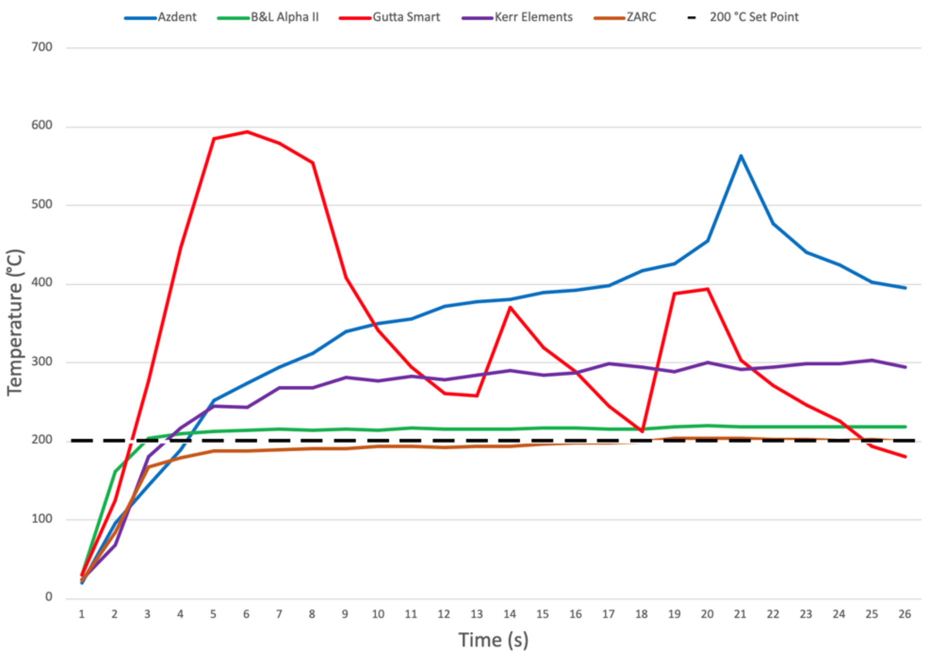

Figure 1. Time–temperature profiles of heated plugger systems recorded at the plugger tip during 25 seconds of continuous activation. Differences in temperature regulation and overshoot relative to the 200 °C set point are observed among devices.

Influence of Tooth Type

Mean dentin thickness at the thermocouple measurement site was 1.11 mm overall and varied by tooth type: mandibular incisors (0.78 mm), mandibular premolars (0.97 mm), mandibular canines (1.31 mm), and maxillary central incisors (1.39 mm). Activation times stratified by tooth type are presented in Table 1. Mandibular incisors demonstrated the shortest activation times across all systems, whereas mandibular canines and maxillary central incisors required longer activation times. These trends are illustrated in Figure 2, which demonstrates the relationship between tooth type and time required to reach a 10 °C increase in external root surface temperature. The Azdent system was excluded from this analysis due to its extreme temperature behavior, which exceeded the scale of the remaining systems and limited meaningful comparison. Among the remaining systems (B&L Alpha II, Gutta Smart, and Kerr Elements), no statistically significant differences were observed across tooth types ($P > .05$).

Tooth Type	Mean Dentin Thickness (mm)	Azdent (s)	B&L Alpha II (s)	Gutta Smart (s)	Kerr Elements (s)
Mandibular Premolars	0.97 ± 0.22	9.4 ± 4.2	6.0 ± 2.1	5.1 ± 2.5	6.5 ± 3.0
Mandibular Canines	1.31 ± 0.26	15.9 ± 7.7	7.8 ± 4.3	5.9 ± 1.7	8.3 ± 2.8
Maxillary Central Incisors	1.39 ± 0.25	12.2 ± 3.7	6.7 ± 1.6	5.8 ± 1.2	7.4 ± 2.3
Mandibular Incisors	0.78 ± 0.14	8.0 ± 2.5	4.7 ± 1.3	4.1 ± 0.7	5.2 ± 1.2

Table 1. Mean time (seconds) required to reach a 10 °C increase in external root surface temperature for each heated plugger system across different tooth types. Mean dentin thickness (mm) represents the average remaining dentin thickness at the measurement site for each tooth group.

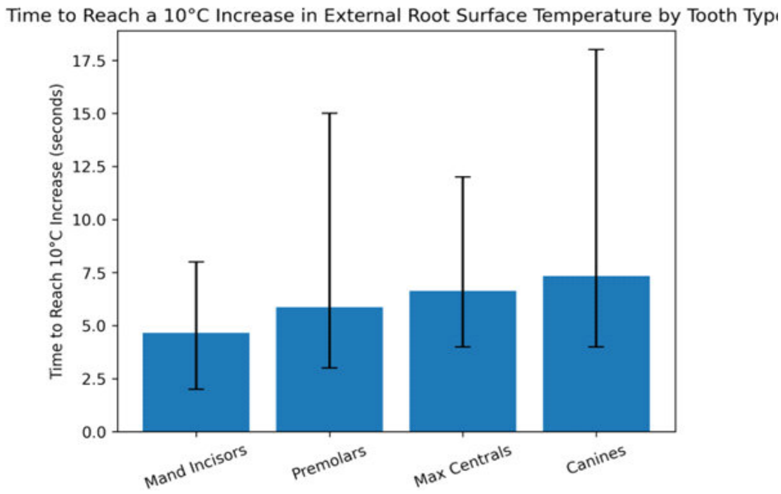

Figure 2. Mean time required to reach a 10 °C increase in external root surface temperature for mandibular incisors, premolars, maxillary central incisors, and canines. Data represent results from B&L Alpha II, Gutta Smart, and Kerr systems. The Azdent system was excluded from Figure 2 for visual scaling and comparability because its values were substantially higher and would have compressed visualization of the remaining systems Error bars represent the range of observed values.

Association Between Dentin Thickness and Temperature Rise

A statistically significant positive association was observed between dentin thickness and the time required to reach a 10 °C increase in external root surface temperature for all heated plugger systems. For the Azdent system, dentin thickness demonstrated a strong correlation with time to temperature increase ($R^2 = 0.53$, $P < .001$), with an estimated increase of 12.5 seconds per 1 mm increase in dentin thickness. Similarly, significant associations were observed for B&L Alpha II ($R^2 = 0.34$, $P < .001$), Gutta Smart ($R^2 = 0.45$, $P < .001$), and Kerr Elements ($R^2 = 0.44$, $P < .001$). Across all systems, increased dentin thickness was consistently associated with longer times required to reach the 10 °C threshold.

Discussion

The present study evaluated thermal behavior of plugger tips for 5 wireless heated plugger systems and heat transfer to the external root surface for 4 systems. Among the variables examined, dentin thickness was a significant determinant of the time required to produce a 10 °C increase in external root surface temperature.

Although all plugger systems generated elevated tip temperatures, these differences did not directly correspond to the rate of temperature increase at the external root surface. Higher plugger tip temperatures did not uniformly translate into faster external root surface heating. This finding suggests that heat transfer through dentin is not solely dependent on plugger temperature, but is strongly influenced by the insulating properties of dentin and root geometry.

A key finding of this study was the significant association between dentin thickness and time to temperature increase across all plugger systems. Teeth with thinner dentinal walls, particularly mandibular incisors, reached the 10 °C threshold more rapidly than teeth with greater dentin thickness, such as canines and maxillary central incisors. This is consistent with prior computational and experimental studies demonstrating the insulating effect of dentin thickness.[9]

Previous investigations have reported external root surface temperature increases ranging from approximately 4 °C to over 20 °C depending on obturation technique and experimental conditions, supporting the concept that intracanal heat can be transmitted to surrounding tissues.[5-9, 15-17] The present findings expand on this understanding by demonstrating that the rate of temperature increase is strongly influenced by dentin thickness and root morphology.

From a clinical perspective, these findings suggest that anatomic factors may play a more critical role in heat transfer than the specific plugger system used. In regions of reduced dentin thickness, such as proximal root surfaces or narrow anterior teeth, clinicians should exercise caution when applying sustained or repeated heat during obturation procedures.

Under the experimental conditions of this in vitro study, a 10 °C increase in external root surface temperature required several seconds of continuous activation across all systems. This suggests that brief, controlled activation during the downpacking phase may limit excessive temperature rise. Previous studies have suggested that temperature increases of approximately 10 °C above physiologic levels may be associated with biologic effects on periodontal tissues, including potential bone injury under sustained exposure conditions.[12]

Although uncommon, clinical reports have documented thermal injury associated with excessive heat application during endodontic procedures.[12-14] However, these findings should be interpreted cautiously, as the present study was conducted in vitro without simulation of periodontal ligament, alveolar bone, or blood flow, all of which may influence heat dissipation in vivo.

Several limitations should be considered when interpreting these results. This study was performed on extracted teeth in air without simulation of surrounding periodontal structures, which may affect heat conduction compared with clinical conditions. Temperature measurements were obtained at a single location on the proximal root surface and may not reflect temperature distribution across the entire root. In addition, differences in plugger size among systems, dictated by manufacturer-specific designs, may have influenced heat delivery. Temperature recordings were limited to 1-second intervals, which may not fully capture rapid transient changes. Finally, although repeated measurements were performed within each specimen, potential cumulative effects of thermal cycling or changes in obturation material cannot be completely excluded.

Within these limitations, the findings of this study demonstrate that while differences exist among wireless heated plugger systems, dentin thickness is a primary determinant of heat transfer to the external root surface. These results underscore the importance of considering root anatomy when applying thermal obturation techniques and suggest that careful control of activation time is particularly important in teeth with reduced dentin thickness.

Conclusion

Within the limitations of this in vitro study, wireless heated plugger systems demonstrated significant differences in heat transfer to the external root surface. The Gutta Smart system produced the most rapid temperature increase, whereas the Azdent system required longer activation times despite higher plugger tip temperatures, indicating that tip temperature alone does not predict heat transfer through dentin.

Dentin thickness was a key determinant of heat transfer, with thinner dentinal walls associated with more rapid temperature increases. Clinically, heat application should be performed in short, controlled intervals—particularly in teeth with reduced dentin thickness—to minimize potential thermal effects on surrounding periodontal tissues.

Conflict of Interest

The authors deny any conflict of interest related to this study.

Acknowledgements

The authors acknowledge Louisiana State University School of Dentistry Graduate Student Research Fund for funding the research project. All authors have contributed significantly, and all authors are in agreement with the manuscript.

References

1. Schilder H. Filling root canals in three dimensions. Dent Clin North Am. 1967:723-44.
2. Buchanan LS. The continuous wave of condensation technique: a convergence of conceptual and procedural advances in obturation. Dent Today. 1994;13(10):80, 2, 4-5.
3. Lancaster P, Brettle D, Carmichael F, Clerehugh V. In-vitro Thermal Maps to Characterize Human Dental Enamel and Dentin. Front Physiol. 2017;8:461.
4. Arili-Ozturk E, Buyukgoze-Dindar M. Evaluation of Radicular Dentin Thickness in Maxillary and Mandibular Central Incisor, Canine, and Premolar Teeth. Cureus. 2024;16(3):e56974.
5. Hand RE, Huget EF, Tsakinis PJ. Effects of a warm gutta-percha technique on the lateral periodontium. Oral Surg Oral Med Oral Pathol. 1976;42(3):395-401.
6. Barkhordar RA, Goodis HE, Watanabe L, Koumdjian J. Evaluation of temperature rise on the outer surface of teeth during root canal obturation techniques. Quintessence Int. 1990;21(7):585-8.
7. Lipski M. In vitro infrared thermographic assessment of root surface temperatures generated by high-temperature thermoplasticized injectable gutta-percha obturation technique. J Endod. 2006;32(5):438-41.
8. Floren JW, Weller RN, Pashley DH, Kimbrough WF. Changes in root surface temperatures with in vitro use of the system B HeatSource. J Endod. 1999;25(9):593-5.
9. Zhou X, Chen Y, Wei X, Liu L, Zhang F, Shi Y, et al. Heat transfers to periodontal tissues and gutta-percha during thermoplasticized root canal obturation in a finite element analysis model. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;110(2):257-63.
10. Sauk JJ, Norris K, Foster R, Moehring J, Somerman MJ. Expression of heat stress proteins by human periodontal ligament cells. J Oral Pathol. 1988;17(9-10):496-9.
11. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent. 1983;50(1):101-7.
12. Gluskin AH, Ruddle CJ, Zinman EJ. Thermal injury through intraradicular heat transfer using ultrasonic devices: precautions and practical preventive strategies. J Am Dent Assoc. 2005;136(9):1286-93.
13. Walters JD, Rawal SY. Severe periodontal damage by an ultrasonic endodontic device: a case report. Dent Traumatol. 2007;23(2):123-7.
14. Barnes PL, Rossi-Fedele G. Excessive heat-associated gingival necrosis: a case report. Aust Dent J. 2017;62(3):382-5.
15. Lee FS, Van Cura JE, BeGole E. A comparison of root surface temperatures using different obturation heat sources. J Endod. 1998;24(9):617-20.
16. Romero AD, Green DB, Wucherpfennig AL. Heat transfer to the periodontal ligament during root obturation procedures using an in vitro model. J Endod. 2000;26(2):85-7.
17. Venturi M, Pasquantonio G, Falconi M, Breschi L. Temperature change within gutta-percha induced by the System-B Heat Source. Int Endod J. 2002;35(9):740-6.