External Root Temperature and Its Relationship With Dentin Thickness During Gutta-Percha Removal Procedures With Ultrasound. An *Ex Vivo* Study

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SIGNIFICANCE

This study demonstrated that the duration of gutta-percha removal with ultrasound should not exceed 20 seconds. The stainless steel modified by the diamond-like carbon surface layer present in the ultrasonic tips generates a lower temperature during gutta-percha removal.

ABSTRACT

Introduction: This study aims to evaluate the temperature rise on the external root surface during gutta-percha removal with 2 types of ultrasonic tips, and its relationship with the root dentin thickness. **Methods:** A total of 56 single-rooted teeth were prepared for gutta-percha removal procedures, conducted for 40 seconds using 2 types of ultrasonic tips at depths of 6 mm and 11 mm. The temperature generated was measured using a type K thermocouple at 3 measurement points. Nonparametric Wilcoxon test was used, and the correlation between thickness and temperature rise was evaluated with Spearman correlation test. **Results:** The temperature rise occurred in all groups, reaching maximum values of 21.0°C (mean = 14.6) with Clearsonic and 11.3°C (mean = 4.2) in the Clearsonic Black group, recorded at a 1-mm depth at 40 seconds ($P < .05$). At 20 seconds, the Clearsonic produced an increase ranging from 10.5°C and 12.9°C in 25% of teeth. No significant differences were observed between the 2 types of ultrasonic tips at an 11-mm depth, across all time intervals and measurement points. Spearman's coefficient showed significant correlations with Clearsonic use at 20 seconds. Significant correlations with Clearsonic Black were observed at 20 and 40 seconds at point T1. **Conclusions:** The Clearsonic Black generates a smaller temperature increase at a depth of 6 mm compared to the Clearsonic and within a time not exceeding 20 seconds ($P < .05$). There is a partial correlation between temperature increase and dentin thickness. *(J Endod 2025;51:340–347.)*

KEY WORDS

Nonsurgical retreatment; temperature rise; ultrasonic tip

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Gutta-percha removal techniques include the use of manual instruments, mechanized with NiTi instruments[1] and the use of ultrasonic tips[2]. Ultrasound generates sound energy that results in oscillations transmitted to the ultrasonic tips (USTs) producing noise heat[3]. Temperature rise (TR) caused by this device has been the subject of research[3-6].

USTs are manufactured in stainless steel[7], or incorporating a surface modification known as diamond-like carbon, as elucidated by Silva et al[8]. Clearsonic Black (CSB) UST (Helse Ultrasonic, Santa Rosa de Viterbo, Brazil) presents this superficial treatment, which improves hardness, chemical resistance, fracture resistance, and its tribological properties[8] and produces less friction forces than stainless steel[9,10] which could generate less heat.

The heat generated by the ultrasonic device promotes the softening of the gutta-percha, and its design featuring pendulum-like motions facilitates its removal[11]. The use of this technique without irrigation for 20 to 30 seconds has been suggested[11,12].

Temperature changes can be harmful to surrounding tissues, as the heat generated inside the canal is dissipated through the dentin, reaching the cementum, periodontal ligament and alveolar

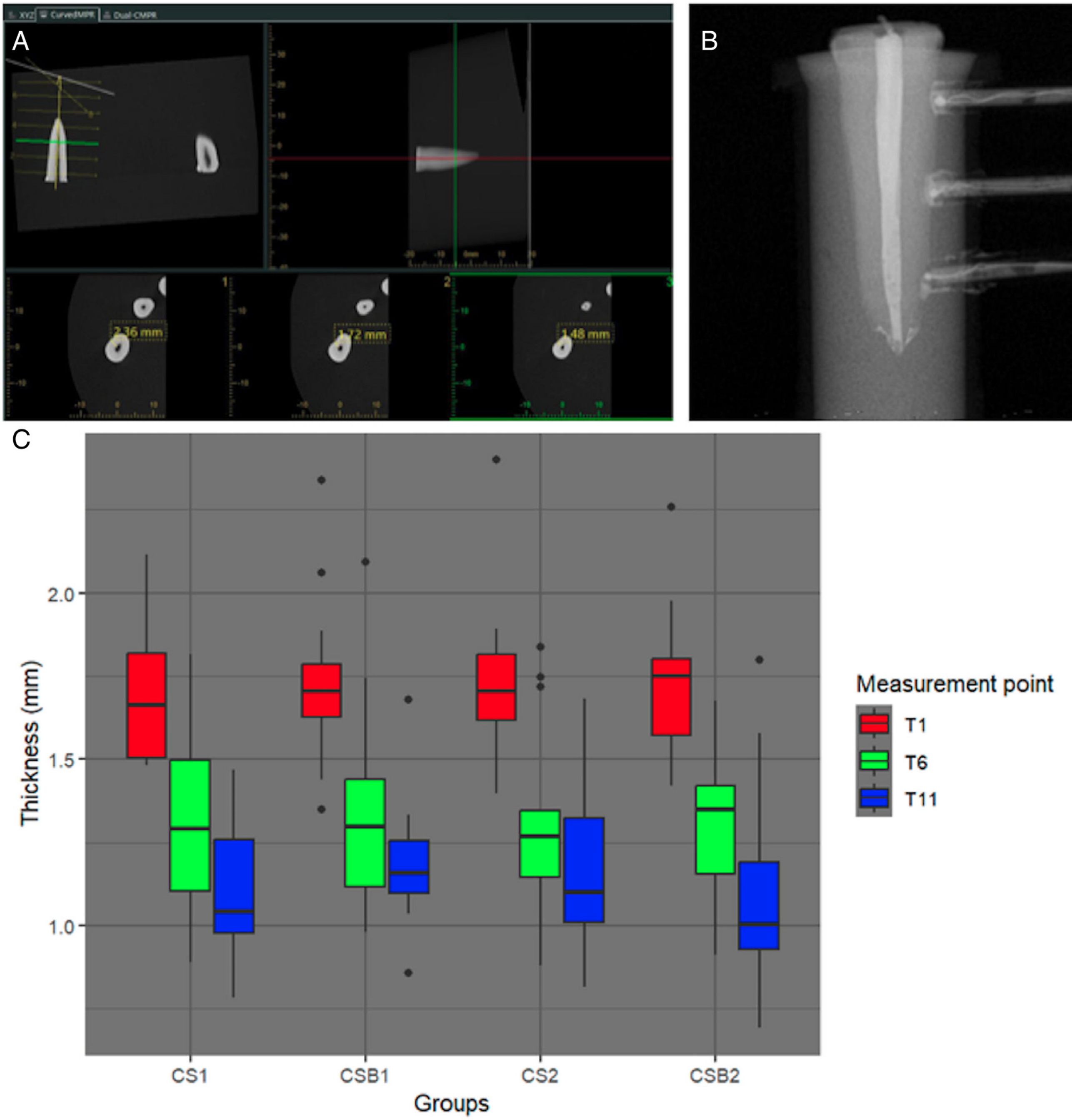

FIGURE 1 – (*A*) One Volume Viewer software (J Morita MFG Corp, Japan) used to measure dentin thickness at the 3 measurement points; (*B*) Radiographic verification of the thermocouples position at the measurement points; (*C*) Boxplots of the thickness values corresponding to each measurement point (T1, T6, and T11).

bone[13,14]. A TR exceeding 10°C can lead to bone resorption and tooth ankylosis[15]. However, this TR is influenced by dentin thickness, power of the ultrasound device, type of tip used, and the duration of clinical application[16,17].

The TR is important in clinical practice[18] as it affects the healing process of periapical tissues[19]. The literature highlights researchers' concerns regarding the heat produced by the use of ultrasound in dental supporting structures, such as during ultrasonic irrigation[18], removal of intraradicular posts[3,5,20], removal of separate instruments[4,21], root-end cavity preparation[22] and root resection surgery[6]. It is recommended to avoid prolonged use of ultrasonic devices to prevent tissues damage[16]. However, no studies have been found regarding the heat generation by USTs during gutta-percha removal on the external surface of root dentin.

In view of the above, the null hypotheses tested were that (1) there is no

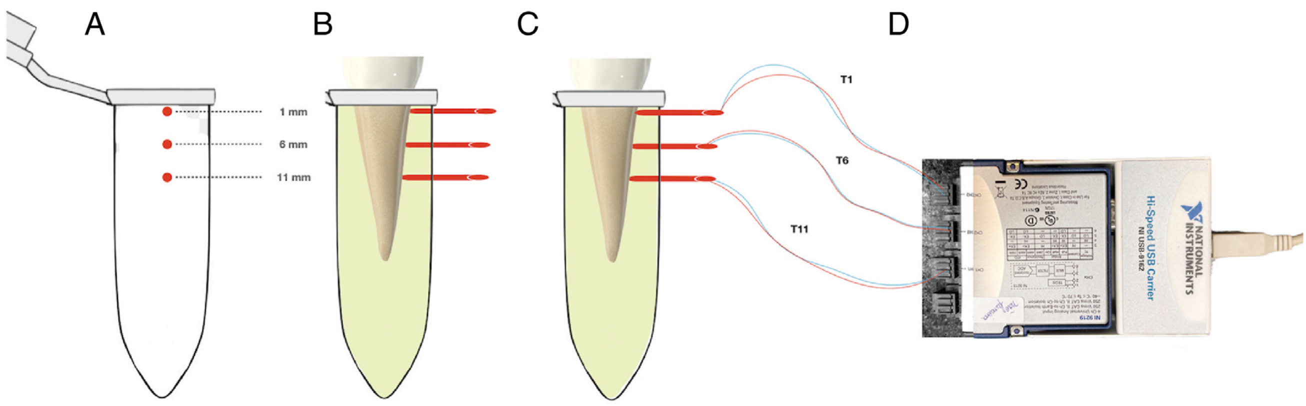

FIGURE 2 – A schematic representation of research methodology before using ultrasound: (*A*) Red dots indicate the place where the Eppendorf will be drilled; (*B*) Tooth specimen immersed in silicone contained within Eppendorf tube, and plastic pipes (in red) positioned; (*C* and *D*) Thermocouples inserted in the plastic pipes and connected to the Universal Analog Input Module NI 9219.

difference in the temperature variation in the external root dentin using two types of ultrasonic tips and (2) there is no relationship between variation in external temperature and dentin thickness.

MATERIALS AND METHODS

Samples Selection

After approval by an ethics committee (CAAE: 66480322.4.0000.0075), 56 human single teeth, extracted for reasons unrelated to this study with fully developed roots, without previous endodontic treatment, calcifications, cracks, and with curvatures of up to 5°[23] and with lengths between 20 and 22 mm, were selected using tomographic images obtained by cone beam computed tomography (Veraview X800, Morita Japan).

Endodontic Procedures

The teeth were prepared with an R50 reciprocating instrument (Reciproc, VDW, Germany). All 56 teeth were CT scanned again. DICOM images were used to measure dentin thickness using the One Volume Viewer (J Morita MFG Corp, Japan) in the axial plane at 1, 6 and 11 millimeters from the cementoenamel junction (CEJ), Figure 1*A*, corresponding to the locations where the thermocouples were placed (T1, T6 and T11). Dentin thickness was measured in triplicate at each point (T1, T6, T11), and the average was calculated for each tooth. These data were used to allocate the 56 teeth into four matched groups[24], ensuring that the difference between thickness was less than 15%, as shown in Figure 1*C*.

The teeth were filled with gutta-percha R50 (VDW, Germany) and AH Plus Jet cement (Dentsply, Ballaigues, Switzerland) and heated pluggers were used to cut the cone, followed by vertical condensation at 1 mm in the apical direction of the CEJ. All specimens were stored under relative humidity conditions at 37°C for at least 30 days and until the commencement experiment.

TABLE 1 - Mean, Median and Standard Deviation of Temperature Rise after 20, 30, and 40 Seconds From the Beginning of the Procedure, at the Measurement Points (T1, T6, and T 11). Wilcoxon Test *P* Values for Comparison Between the CS1 and CSB1 Groups

Time	Group US tip	Measurement point	Mean	Med	SD	Min	Per25	Per75	Max	*P* value
20 s	CS1	T1	8.1	8.3	2.8	3.7	5.8	10.5	12.9	**.0014**
	CSB1		1.6	1.4	1.5	-0.1	0.3	2.5	4.7	
	CS1	T6	1.0	0.9	1.0	-0.2	0.2	1.4	3.5	.0849
	CSB1		2.1	1.2	2.1	0.5	0.8	2.9	8.6	
	CS1	T11	0.1	0.1	0.1	-0.1	0.0	0.2	0.3	.0901
	CSB1		0.3	0.2	0.5	-0.1	0.1	0.4	1.9	
30 s	CS1	T1	11.7	11.4	3.5	6.5	9.0	14.0	18.6	**.0014**
	CSB1		2.9	2.0	2.8	-0.1	0.3	5.1	8.4	
	CS1	T6	2.0	2.1	1.6	-0.1	0.6	3.0	5.4	**.0229**
	CSB1		4.2	3.5	3.0	1.1	1.9	5.6	11.7	
	CS1	T11	0.3	0.2	0.3	-0.0	0.1	0.4	0.9	.1874
	CSB1		0.6	0.5	0.6	0.1	0.2	0.7	2.5	
40 s	CS1	T1	14.6	14.4	3.7	8.8	11.8	17.0	21.0	**.0011**
	CSB1		4.2	2.6	3.9	-0.1	0.7	7.1	11.3	
	CS1	T6	3.2	3.4	2.4	0.1	1.1	4.8	7.8	**.0259**
	CSB1		6.2	5.6	3.7	1.6	3.3	8.7	13.7	
	CS1	T11	0.6	0.5	0.5	0.1	0.3	0.7	2.0	.2585
	CSB1		1.0	0.9	0.8	0.1	0.4	1.2	3.1	

CS, Clearsonic; CSB, Clearsonic Black.
P values in bold indicate significant difference ($P < .05$)

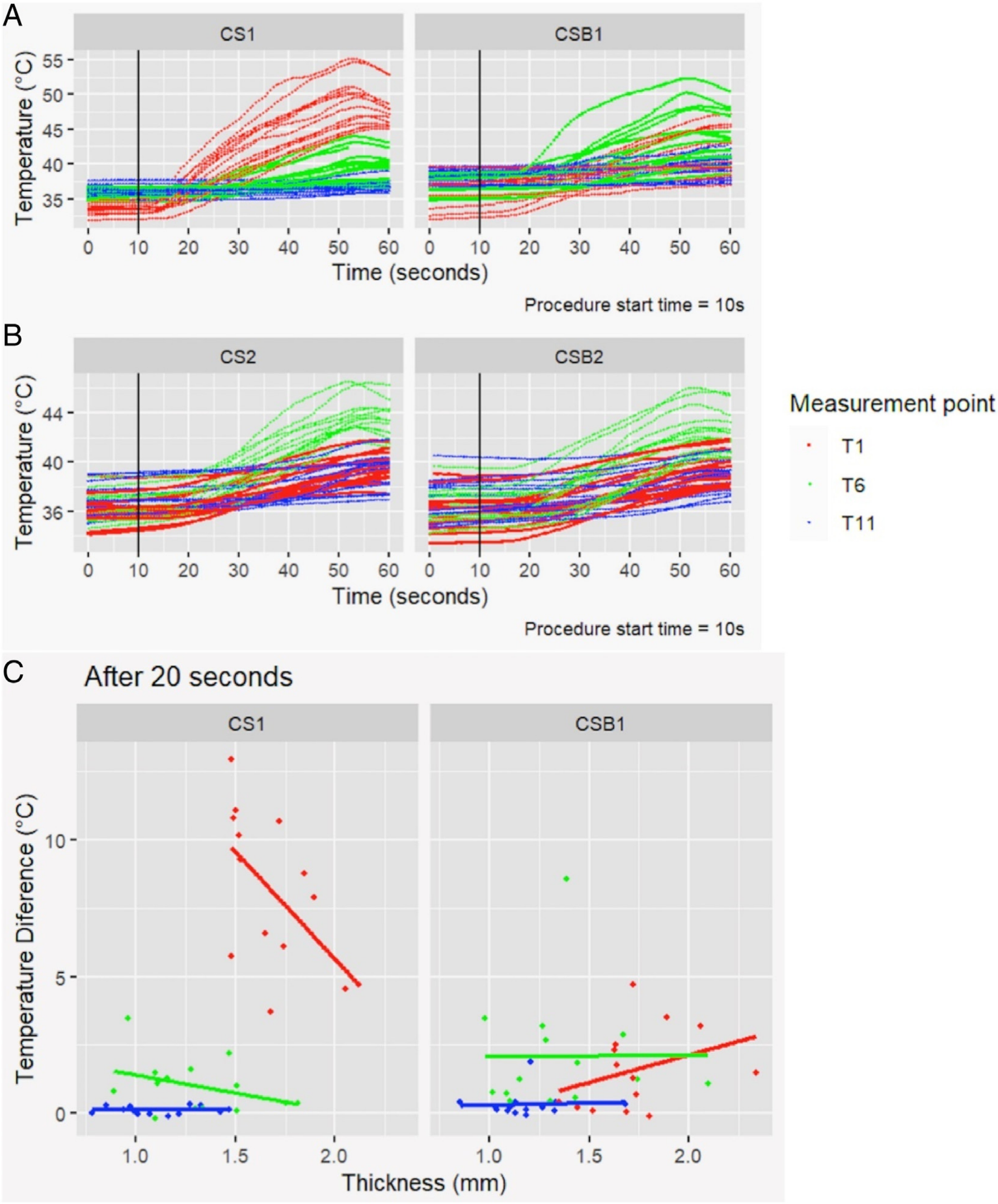

FIGURE 3 – Distribution of Temperature Increase in the Experimental Groups at Different Measurement Points: CS1, CSB1 (*A*); and CS2, CSB2 (*B*); Scatter Plot Between Temperature Variation and Dentin Thickness at 20 seconds, in CS1 e CSB1 Groups (*C*). CS, Clearsonic; CSB, Clearsonic Black.

Model Preparation

The teeth were embedded in elastomeric-based condensation inside Eppendorf tubes, with the CEJ aligning with the upper edge of the tube. Three holes were drilled at 1, 6 and 11 millimeters from the CEJ. Heat-conducting paste (Implastec, Votorantim, Brazil) was placed in each hole, followed by insertion of straight plastic pipes. Type K thermocouples, 130 micrometers thick (chromel-alumel NiCr-NiAl, Omega Eng, Inc, Stamford, USA) were inserted so that their ends aligned with the external root wall at the three measurement points (Fig. 1*B*), the other end was connected to the Universal Analog Input Module NI 9219 (National Instrument Corp, USA), Figure 2.

Groups and Removal of Filling Materials

Two USTs were employed: Clearsonic (CS) and CSB with a tip diameter corresponding to 0.50 mm[12]. The teeth were divided into 4 paired groups with similar dentin thickness ($n = 14$):

CS1 and CSB1 groups: removal of gutta-percha with CS and CSB, respectively, activated for 40 seconds to a depth of 6 mm below the CEJ; and CS2 and CSB2 groups: similar to the previous ones, except that the UST was deepened to 11 mm below the CEJ. The UST depths were limited to silicone stops.

The setup described previously was placed on a plastic support and immersed in a bath of heated water, with the temperature manually controlled at approximately 35.0°C. It was then subjected to gutta-percha removal using CS and CSB (Helse Ultrasonics, Santa Rosa de Viterbo, Brazil), batch number #67190123 and #67131222, respectively,

TABLE 2 - Mean, Median, and Standard Deviation of Temperature Rise after 20, 30, and 40 Seconds From the Beginning of the Procedure, at the Measurement Points (T1, T6 and T 11). Wilcoxon Test *P* Values for Comparison Between the CS2 and CSB2 Groups

Time	Group US tip	Measurement point	Mean	Med	SD	Min	Per25	Per75	Max	*P* value
20 s	CS2	T1	1.1	1.1	0.5	0.2	1.0	1.5	1.9	.706
	CSB2		1.2	1.2	0.4	0.4	1.0	1.4	1.8	
	CS2	T6	2.4	2.4	1.0	1.2	1.5	2.8	4.8	.346
	CSB2		2.0	1.9	0.9	0.8	1.4	2.4	3.6	
	CS2	T11	0.3	0.3	0.3	0.0	0.1	0.6	0.7	1.000
	CSB2		0.3	0.4	0.2	0.0	0.1	0.5	0.6	
30 s	CS2	T1	2.0	2.0	0.7	0.7	1.6	2.6	3.1	.754
	CSB2		2.2	2.2	0.6	0.9	2.0	2.6	3.1	
	CS2	T6	4.7	4.5	1.4	2.8	3.8	5.2	8.4	.233
	CSB2		4.0	3.8	1.2	2.2	3.3	4.5	6.8	
	CS2	T11	0.8	0.6	0.5	0.1	0.4	1.3	1.5	.851
	CSB2		0.8	0.8	0.5	0.0	0.4	1.0	1.6	
40 s	CS2	T1	2.8	2.8	1.0	1.1	2.2	3.6	4.5	1.000
	CSB2		3.0	3.0	0.7	1.5	2.6	3.6	4.1	
	CS2	T6	6.6	6.8	1.5	4.7	5.4	7.2	10.3	.259
	CSB2		5.8	5.6	1.4	4.0	5.0	6.2	9.0	
	CS2	T11	1.5	1.7	0.9	0.3	0.7	2.3	3.0	1.000
	CSB2		1.4	1.3	0.8	-0.019	1.1	1.9	2.7	

CS, Clearsonic; CSB, Clearsonic Black.
P values showed no significant difference ($P > .05$).

coupled to a Varios 560 Lux ultrasound device (NSK, Japan), with 30% power in mode E, and pendulum and brushing movements were performed, coming into contact with the dentin walls. All procedures were performed for 40 seconds by a single operator without any interruptions. The data recording was conducted using the LabVIEW 2010, version 10.0, software (National Instruments, USA).

Statistical Analysis

The Shapiro-Wilk and Kolmogorov-Smirnov normality tests were utilized to assess data distribution. TR were analyzed at 10-, 20-, 30-, and 40-second intervals and compared between the 2 types of USTs employed the Wilcoxon nonparametric test. The correlation between dentin thickness and temperature variation was evaluated using the Spearman correlation test. The significance level of the tests was 5%. The statistical analyses were performed with R, version 3.5.1 (R Core Team, 2018).

RESULTS

Table 1 shows that at different measurement points, the TR occurred in all groups (Fig. 3*A* and *B*). Using the CS UST at 40 seconds, TR mean of 14.6°C was obtained at T1, with a maximum value of 21.0°C. At the same point, the CSB UST reached a TR mean of 2.6°C with a maximum value of 11.3°C, ($P < .05$). In the CS2 group, a mean of 6.8°C was found at 40 seconds at T6, maximum value of 10.3°C, in this, the CSB2 resulted in a TR mean of 5.6°C ($P > .05$), Table 2.

In the CS1 and CSB1 groups, the CSB UST reached an average of 5.6°C and the CS UT reached an average of 7.8°C ($P < .05$) at 40 seconds. There were no differences in the TR at T11 between the two types of UST, and this point had the lowest temperature during the entire procedure (Table 1).

At 20 and 30 seconds, the difference in the TR with UST was significant ($P < .05$ for both) at the T1, with the largest TR produced with the CS. At 20 seconds, the CS UST produced a TR between 10.5 and 12.9°C in 25% of the teeth, Table 1.

The relationship between TR and wall thickness at each measurement point for each type of UST at 20 seconds is shown in Figure 3*C*. Table 3 shows the Spearman correlation coefficient that showed significance for CS1 at 20 seconds in T1 ($P < .05$), in the other groups no difference was observed ($P > .05$).

In groups CS2 and CSB2, there were no significant differences ($P > .05$) at any measurement point during the duration of experiment (40 seconds), Table 2.

Table 3 shows the Spearman correlation coefficient that showed significant correlations for CSB in time intervals between 20 and 40 seconds and at the T1 ($P < .05$), conversely, in the remaining groups, no differences were observed ($P > .05$).

TABLE 3 - Summary of the Results of the Spearman's Correlation Coefficient Indicating Only the Statistically Significant Values Between Temperature Rise and Dentin Thickness

Group US tip	Time sec	Measurement point	Spearman Rho	*P* value
CS1	20	T1	−0.5699	.0334
CSB2	20	T1	−0.679	.0095
	30		−0.560	.0401
	40		−0.543	.0479

CS, Clearsonic; CSB, Clearsonic Black.
P values did not indicate statistical significance.

DISCUSSION

Clinicians have rapidly accepted the utilization of ultrasound in diverse endodontic procedures[16], recommending that it be used without irrigation to improve visualization[20,25]. Suggesting an activation time between 20 and 30 seconds, with USTs positioned 1 mm below the working length, was proposed for gutta-percha removal[7,11,12,26].

The effect of ultrasonic gutta-percha removal on external root temperature has not been fully studied. This research measured the TR during gutta-percha removal for up to 40 seconds using 2 USTs at 3 sites (T1, T6, T11). CBCT images were used to determine average dentin thickness, which helped distribute the samples into 4 matched groups[24]. By accounting for dentin thickness, potential bias was minimized, allowing a more precise correlation between TR and dentin thickness. Thus, both null hypotheses were partially accepted.

Type K thermocouples have been utilized to measure TR in endodontic procedures, utilizing sample sizes ranging from 10 to 14 teeth[6,20,27-29]. In the present study, tomographic images were utilized to minimize anatomical variability by calculating the mean of dentin thickness, facilitating their correlation with TR.

To measure the temperature, a thermal bath[4,20] with controlled temperature was used. Thermal paste was applied to ensure thermal conductivity[6,22], and pendulum movements and/or brushing simulating clinical procedures were used for gutta-percha removal[7,11,12,25]. The time spent during gutta-percha removal was 40 seconds to observe the TR throughout this period.

The TR has been evaluated in endodontic procedures using a type K thermocouple coupled to a digital thermometer in *ex vivo* studies[3,6,11,22,27-29]. In the present study, a type K thermocouple with a thickness of 130 micrometers was used, connected to the Universal Analog Input Module NI 9219 (National Instrument Corp, USA) which provided a conversion time of 20 ms[30] demonstrating reliable temperature recordings throughout the experiment.

The use of thermocouples is considered to be the gold standard method for measuring TR, as it provides more precise measurements[31]. In the present investigation, the samples were immersed in heated water, which precludes the utilization of alternative methodologies employed by other researchers[3,32].

CSB USTs were used because the diamond-like carbon layer produces less friction forces than stainless steel[9,10], which can result in less heat generation during use.

In the present study, TR was found on the external root surface[3,4,21]. At point T1, a difference was observed between CS and CSB in all intervals tested, with the TR being lower for CSB ($P < .05$). It is important to note that when the UST was activated to a depth of 6 mm, point T1 recorded higher TR values. Similarly, when the UST was activated at 11-mm depth, the highest temperatures were at point T6. This could be explained by the fact that during pendulum and brushing movements, the UST does not always reach points T6 or T11, with the body of the UST remaining in contact with the most cervical region of the canal for the longest time[33]. Thus, it is imperative to consider the most coronal point in relation to the depth achieved by the UST; specifically, the T1 measurement point at a depth of 6 mm and the T6 measurement point at a depth of 11 mm.

A TR of 10°C can damage bone tissue[15], potentially affecting the healing process of supporting tissues[19]. This study found that 25% of the teeth in CS1 group experienced a TR exceeding 10°C at 20 seconds. Data analysis revealed that the four affected teeth had thicknesses ranging from 1.5 to 1.75 mm at the point T1, suggesting that this thickness may contribute to the TR observed[20]. Spearman's analysis indicated a significant correlation between TR and dentin thickness when using CS for 20 seconds at point T1 ($P = .0334$), indicating potential harm to supporting tissues in certain teeth. CSB was identified as a safer option regarding heat generation, with root thickness being the primary factor in heat transmission on its external surface[17,20].

In the CS2 and CSB2 groups, no significant variances were observed between the 2 USTs ($P > .05$). This could be attributed to the restricted movement of the UST at greater depths, resulting in reduced friction and changes in energetic vibration properties[17], consequently leading to lower temperatures (Table 2).

This *ex vivo* study does not intend to extrapolate the data presented here to clinical practice, as the presence of tissues surrounding the support structures may lead to rapid dissipation of thermal energy[16,22]. This may result in temperatures lower than those observed in *in vitro* studies[17]. It is important to highlight that during gutta-percha removal with UST, it is recommended to introduce irrigation after 20 or 30 seconds of UST usage[7,11,12,26]. This could help reduce the temperature levels. In this investigation, after 40 seconds of ultrasonic activation, the temperature continued to rise (Fig. 3*A* and *B*).

The literature lacks guidance on the operating time of the ultrasound device and the appropriate time to irrigate the tooth to dissipate heat and prevent cumulative damage[16]. The current study indicates that a 20-second duration of gutta-percha removal at 30% device's power may be safe for the supporting tissues. Additionally, it may be advantageous to evaluate dentin thickness through axial images obtained by CBCT before beginning endodontic treatment.

However, additional research is necessary to establish a clinical protocol that effectively protects periodontal tissues from damage during gutta-percha removal using USTs. This involves investigating the optimal timing for irrigation.

CONCLUSION

Within the limitations of this study, the CSB produces a smaller temperature increase when activated at a depth of 6mm compared to the CS and within a time not exceeding 20 seconds. There is a partial correlation between temperature increase and dentin thickness.

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