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ORIGINAL ARTICLE

Root Temperature Variation during Gutta-Percha Removal Using Stainless Steel and NiTi Instruments

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ABSTRACT
Objective: To assess the temperature variation of gutta-percha removal with stainless steel and two NiTi instruments using infrared thermography and thermocouples. **Material and Methods:** 45 single-rooted teeth were divided into three groups (n = 15) according to the following gutta-percha removal instruments: Largo Peeso (L), Protaper Retreatment (PR), and Reciproc (R). Thermal analysis was conducted using a FLIR T650sc infrared thermography camera and three thermocouples. For infrared thermography assessment, the infrared camera was programmed to acquire thermograms every 15 seconds before the gutta-percha removal started until temperature normalization. Root temperature was assessed in the thermograms using FLIR tools software v6.4 with the straight-line tool along the long axis of the tooth and in the cervical, middle, and apical thirds of each tooth. The temperature from the thermocouples was recorded and registered for each root third. Inferential statistical analysis Kruskal-Wallis and post hoc Tukey tests were used. **Results:** For the infrared thermography camera, the highest median temperature value was found 15 seconds after gutta-percha removal for the L technique (20.3°C), which presented the highest temperatures at all studied times. For thermocouples, the highest temperature was found in the middle third during gutta-percha removal with L (20.7°C). PR and R presented similar patterns of root temperature. **Conclusion:** Stainless-steel L temperature reaches values above 10°C; however, the exposure time was too short to cause injuries to the periodontium.

Keywords: Root Canal Preparation; Transition Temperature; Thermography; Endodontics.

Introduction

When gutta-percha removal is indicated due to unsuccessful endodontic treatment or for intracanal anchoring, the tooth structure is already weakened, caused by previous mechanical and biological tissue loss. Gutta-percha removal can be performed using stainless-steel, NiTi rotary, or oscillatory instruments, with or without solvents [1-3].

Temperature increases lead to changes in the microcirculation of the adjacent tissues, which can harm the adjacent connective tissue [4], leading to chronic periodontitis and tooth resorption. External root temperature increases can harm the periodontium when 10°C above the body temperature, though the damage is still reversible [5,6]. However, when the temperature increases over 16°C, the periodontium alterations may be irreversible and even injure the adjacent bone tissue [5-7].

Thermal measurements can be performed using thermocouples or infrared thermal cameras. A thermocouple is a temperature sensor made of two dissimilar metal wires, joined at one end, connected to a thermometer/data logger, which informs the temperatures of a surface where its wires are connected [8]. Previous studies used thermocouples to measure root temperature increases caused by gutta-percha removal techniques [1,2,7]; however, restricting heat measurement to a limited contact point or points of the sample may constitute a limitation of this method. Infrared thermography (IT) cameras can detect infrared radiation emitted by objects, creating real-time thermographic images (thermograms) [9]. IT captures and records the thermal distribution, allowing the measurement of temperatures and the observation of heat distribution patterns of the whole study subject [10-13].

During gutta-percha removal, dentin removal may be needed, which may increase the amount of heat irradiated to the root surface generated by stainless steel or NiTi instruments [12]. Previous studies report that using NiTi instruments is safer than stainless steel instruments, and there is no difference in the effectiveness between NiTi rotary and oscillatory (reciprocating) instruments [14-17]. However, few studies on temperature increase during gutta-percha removal used thermocouples as a method of temperature analysis [1,7].

Therefore, this study aims to analyze root temperature variation during gutta-percha removal using stainless steel and two NiTi (rotary and oscillatory) instruments, infrared thermography, and thermocouples.

Material and Methods

This *ex-vivo* experimental study, which follows the Helsinki Declaration, was approved by the University Ethics Committee (Protocol no. 3.442.932).

Sample Preparation

The sample consisted of 45 single-rooted premolars. Inclusion criteria determined that all teeth should have a maximum root curvature of ≤5°, similar dimensions, and a unique canal. The root height and dentine thickness were measured with a pachymeter and radiographed on phosphor plates (Digora Optime, Soredex, Tuusula, Finland) to verify its dimensions using the ImageJ software. After cleaning and disinfection protocols, all crowns were removed at the cementoenamel junction, and the sample was stored in a 0.9% saline solution.

Root canals were irrigated with 2 ml of 2.5% sodium hypochlorite (Ciclo Farma, Serrana, SP, Brazil). K-type hand files #10 (DentsplyMaillefer, Ballaigues, Switzerland) were introduced up to the apical foramen to determine the tooth's length (TL), which was considered the working length (WL). Then, the apical limit of instrumentation and obturation was defined as 0.0 mm (WL = TL).

Root canal preparation was done with a NiTi Reciproc file (VDW GmbH, Munich, Germany), R50 instrument (50.05) for wide canals, or R40 (40.06) for medium canals. Then irrigation was done with 2 ml of ethylenediaminetetraacetic acid (EDTA) 17% (Biodinâmica Química e Farmacêutica Ltda, Ibipora, PR, Brazil) for 3min under stirring, using k-15 hand file, followed by a second irrigation with 2 ml of 2.5% sodium hypochlorite and dried using paper cones.

Root canals were filled with gutta-percha using the thermomechanical compaction technique. A cone with identical size and conicity to the instrument used in the mechanical preparation (40.06 or 50.05) was adapted to the canal and then smeared on Ah Plus cement (Dentsply Maillefer, Ballaigues, Switzerland). A thermocompactor PacMac 45.04 of 21mm (SybronEndo Dental Specialties, Inc., Orange, CA, USA) mounted on the counter-angle with rotation to the right was inserted beside the cone, operating using back and forth movements to obtain the apical sealing.

The sample was divided into three groups (n=15), with a standardized number of wide and medium endodontic canals, to assess the following gutta-percha removal instruments: 1) Largo Peeso Reamer (Stainless-steel instrument), 2) Protaper Universal Retreatment (Rotary NiTi instrument) and 3) Reciproc (oscillatory/reciprocating NiTi instrument).

1) Largo Peeso Reamer: The instrument size was chosen according to the canal's diameter (length 28 mm and sizes #1 and #2). To avoid overheating the root, the gutta-percha fragments were gradually removed by repeatedly introducing and removing the reamer (intervals of 15 seconds between each three-movement sequence). The apical endodontic clearance limit was set at 3 millimeters from the end of the WL.

2) Protaper Universal Retreatment: ProTaper NiTi rotary instruments were used in a crown-down technique with an electric motor VDW Silver (VDW GmbH, Munique, Germany) at 2N torque and 250rpm. D1 (30.09 - 16mm) was used to remove gutta-percha from the cervical third, D2 (25.08 - 18mm) for the middle third, and D3 (20.07 - 22mm) until WL.

3) Reciproc: Reciproc NiTi reciprocating instruments were used in the crown-down technique, with an electric motor VDW Silver (VDW GmbH, Munique, Germany) in the reciproc function with intervals of 15 seconds between each three-movement sequence to avoid overheating. R25 (25.08), R40 (40.06), and R50 (50.05) files were chosen according to the radiographic diameter of the canal.

Gutta-percha removal was considered complete when it was impossible to observe gutta-percha on the last instrument used in each group. Digital periapical radiographs were acquired to confirm the complete Gutta-percha removal after temperature assessment. The external root temperature was assessed simultaneously using two different temperature assessment modalities: thermocouples and IT.

Thermocouples Root Temperature Assessment

Type k thermocouples with 0.1°C resolution and a temperature range of -50°C to 999.9°C were used to assess temperature values during gutta-percha removal. The thermocouples sensitive wire ends were fixed at the root external surface by creating three small spherical wears on the lingual surfaces of the roots using a n°1012 spherical diamond drill (KG Sorensen/Zenith Dental ApS, Agerskov, Denmark). The spherical wear positions were determined by dividing the roots in three-thirds equidistant from each other with an approximate depth of 1mm.

A thermometer was positioned outside the thermal box and filmed using a cellphone (iPhone XR, Apple Inc., Los Altos, CA, USA) to register the temperatures. The videos were analyzed, and the temperatures of the thermocouples were recorded (Figure 1).

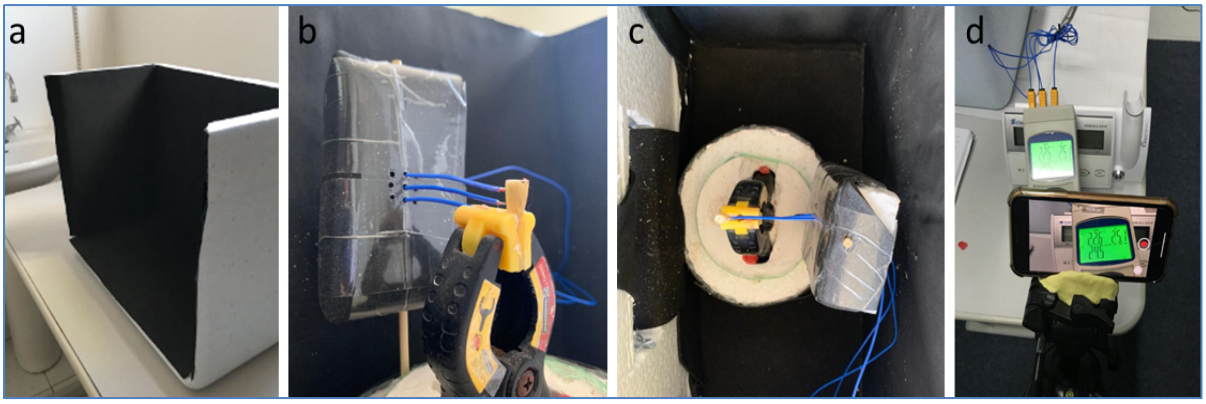

Figure 1. (a) Box of expanded polystyrene plates coated with aluminum foil covered by black Ethylene Vinyl Acetate (EVA); (b) The sample is fixed with plastic pliers and thermocouple plugs in frontal view; (c) The sample was fixed with plastic pliers and thermocouple plugs in the upper view; and (d) Temperature recording.

IT Root Temperature Assessment

A FLIR T650sc (FLIR Systems Inc., Wilsonville, OR, USA) handheld camera with an infrared sensor, 25mm lens, and spatial resolution of 640×480 pixels was used to capture the thermographic images. The room temperature and relative humidity were maintained constant at 20-21°C and 40 to 60%, respectively. The thermal camera was positioned 30cm from the samples according to the manufacturer's instructions. The exposure parameters were set at 98% emissivity and 44% relative humidity, and the camera was programmed to acquire thermograms every 15 seconds (s).

To eliminate the operator's thermal interference, a box of expanded polystyrene plates coated with aluminum foil and covered by black Ethylene Vinyl Acetate (EVA) was built to hold and isolate the sample. The box had a rectangular opening to capture the images. Plastic pliers were used to fix the sample in the orthoradial position and inserted in a Styrofoam cylinder (Figure 1).

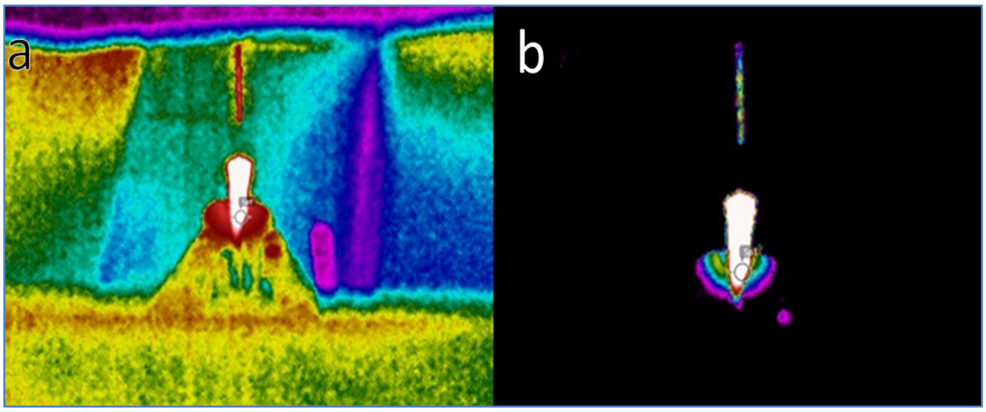

Figure 2. (a) Thermogram; (b) Thermogram with background removal using FLIR Tools v. 6.4 software.

Thermogram temperatures were assessed using the FLIR Tools v.6.4 (FLIR Systems, Oregon, USA) software. Initially, the temperature scale was reduced by eliminating background temperatures (Figure 2). Four lines were traced: One at the long axis of the tooth and three perpendicular to the long axis on the cervical, middle, and apical thirds of the tooth (Figure 3).

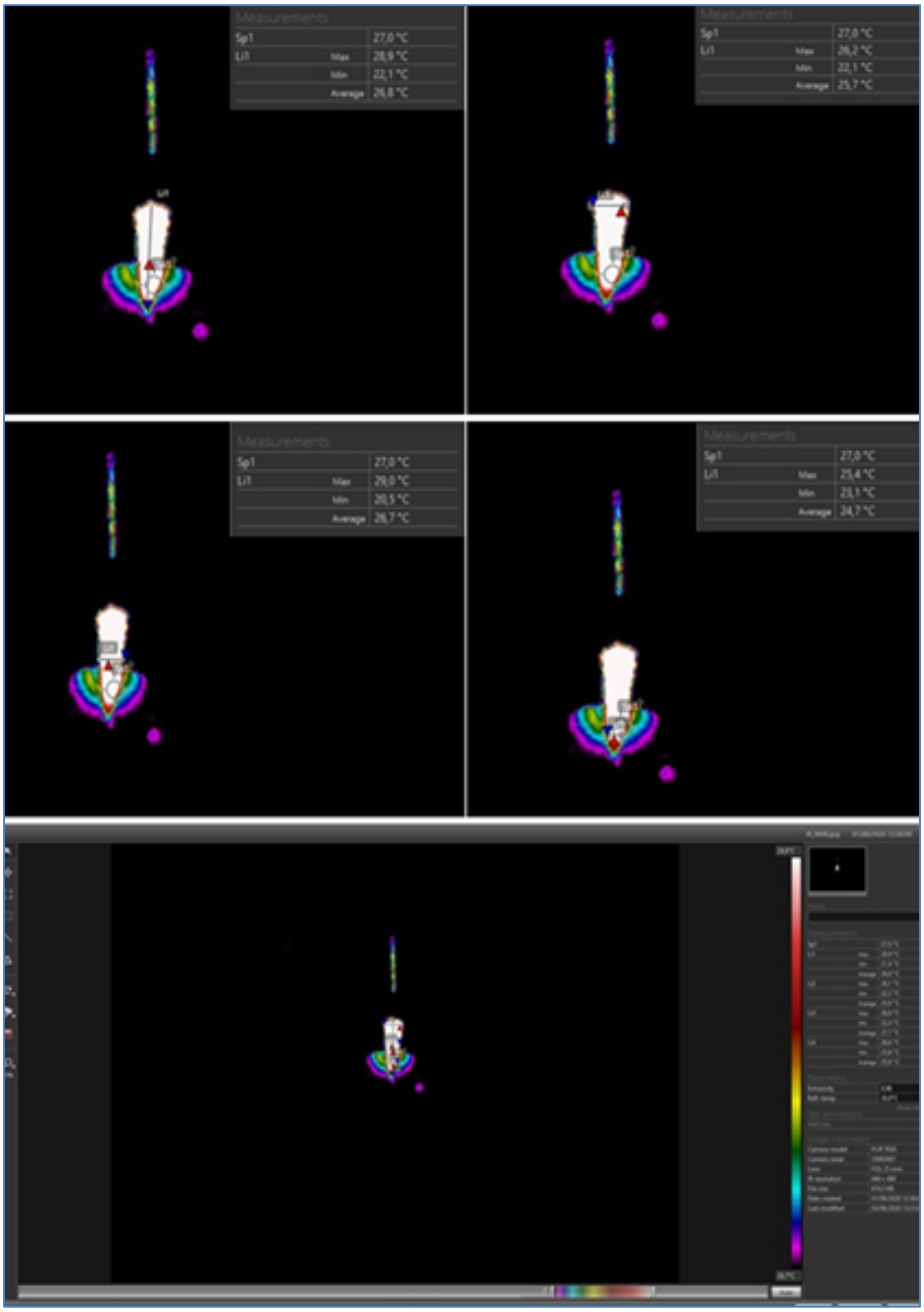

Figure 3. Temperature measurement in thermograms using FLIR Tools v. 6.4. Four lines were traced: One at the long axis of the tooth and the other three perpendicular to the long axis on the cervical, middle, and apical portions of the tooth.

Thermograms were acquired at an interval of 15 seconds, starting before the technique was initiated and continuing until the temperature was normalized.

Temperature Values

The measured temperature values were considered an increase from the initial temperature (the highest temperature in the established worktime minus the sample's initial temperature). After analyzing the root temperature during the gutta-percha removal technique, the temperatures were assessed 60 seconds after the technique was completed. Then, the time needed for temperature normalization was also registered.

Data Analyzes

Data were imported into the statistical package Sigma Plot version 12 (Systat Software, Inc., San Jose, CA, USA). Descriptive and inferential statistical analyses were done. The data was assessed using the Shapiro-Wilk, Kruskal-Wallis, and post hoc Tukey tests. The level of significance was set at 5% ($p<0.05$).

Results

For thermocouple analysis, the highest temperature increase values were found in the middle third of the teeth when Largo Peeso reamers were used (20.7°) ($p<0.05$) (Table 1).

Table 1. Comparison between the temperature increase (°C) generated by gutta-percha removal techniques for the different studied teeth thirds and working times using thermocouples.

Thirds	N	Gutta-Percha Removal Instruments						p-value*
		Largo		Protaper		Reciproc		
		Median	Q_{25}-Q_{75}	Median	Q_{25}-Q_{75}	Median	Q_{25}-Q_{75}	
During Work Time (°C)								
Cervical	15	$17.4^{a(A)}$	13.5-22.4	$3.7^{b(A)}$	2.3-5.4	$6.3^{c(A)}$	5.3-7.8	<0.001
Middle	15	$20.7^{a(A)}$	14.3-27.1	$3.8^{b(A)}$	2-4.6	$3.8^{b(A)}$	2.9-6.4	<0.001
Apical	15	$11.9^{a(B)}$	11.1-16.2	$2^{b(B)}$	0.7-2.9	$1.3^{b(B)}$	0.9-1.6	<0.001
p-value*		<0.001		0.005		<0.001		
15 Seconds After Gutta-Percha Removal (°C)								
Cervical	15	$12.1^{a(A)}$	8.2-15.7	$2.1^{b(A)}$	1.6-2.9	$3.8^{b(A)}$	2.8-4.9	<0.001
Middle	15	$11.9^{a(A)}$	108-14.5	$1.8^{b(A)}$	1.3-3.1	$2.8^{b(A)}$	2.4-3.7	<0.001
Apical	15	$6.1^{a(B)}$	5.3-10.2	$1.3^{b(B)}$	0.6-1.4	$1.3^{b(B)}$	0.9-1.6	<0.001
p-value*		<0.001		0.003		<0.001		
30 Seconds After Gutta-Percha Removal (°C)								
Cervical	15	$8.9^{a(A)}$	6.8-14.8	$1.9^{b(A)}$	1.3-2.4	$3.4^{c(A)}$	2.5-4.4	<0.001
Middle	15	$10.8^{a(A)}$	8.7-11.1	$1.4^{b(A.B)}$	1.1-2.6	$2.5^{b(A)}$	2.1-3.5	<0.001
Apical	15	$5.8^{a(B)}$	3.1-8.5	$1.1^{b(B)}$	0.5-1.2	$1.2^{b(B)}$	0.9-1.3	<0.001
p-value*		<0.001		0.002		<0.001		
45 Seconds After Gutta-Percha Removal (°C)								
Cervical	15	$7.7^{a(A)}$	5.8-11.3	$1.6^{b(A)}$	1.1-2.1	$3.1^{c(A)}$	2.3-3.7	<0.001
Middle	15	$8.3^{a(A)}$	7.4-9.3	$1.4^{b(A.B)}$	0.9-2.1	$2.4^{c(A)}$	1.9-3	<0.001
Apical	15	$5.6^{a(B)}$	2.6-6.5	$1^{b(B)}$	0.5-1.1	$1.1^{b(B)}$	0.7-1.2	<0.001
p-value*		<0.001		0.002		<0.001		
60 Seconds After Gutta-Percha Removal (°C)								
Cervical	15	$6.5^{a(A)}$	4.4-8.9	$1.4^{b(A)}$	0.9-1.9	$2.6^{c(A)}$	2.1-3.4	<0.001
Middle	15	$6.8^{a(B)}$	6.3-7.8	$0.9^{b(A.B)}$	0.8-1.9	$1.7^{b(B)}$	1.3-2.6	<0.001
Apical	15	$4.9^{a(A)}$	2.5-5.3	$0.8^{b(B)}$	0.4-1	$1.1^{b(C)}$	0.6-1.2	<0.001
p-value*		<0.001		0.005		<0.001		

*Kruskal-Wallis test; ^{a,b}Tukey's bidirectional analysis of variance - lowercase letters in horizontal and uppercase letters in vertical.

For IT analysis, the highest temperature increase throughout the long axis was 20.3°C ($p<0.001$) for the Largo Peeso reamer, at 15s after gutta-percha removal, being the highest value observed in the middle third region (26.5°C). Largo Peeso reamer showed the highest temperature values throughout the long axis for all studied times (p<0.001). Largo Pesso reamers and Reciproc presented similar temperature values at the apical third (Table 2).

Table 2. Comparison between the temperature increase (°C) generated by gutta-percha removal techniques for the different thirds of the tooth and working times using infrared thermography thermal analysis.

Thirds		Gutta-Percha Removal Instruments						p-value*
		Largo		Protaper		Reciproc		
	N	Median	Q_{25}-Q_{75}	Median	Q_{25}-Q_{75}	Median	Q_{25}-Q_{75}	
During Work Time (°C)								
Tooth long axis	15	18.9^{a}	10.5-20.9	2.9^{b}	2.2-3.6	4.8^{b}	4.2-6.7	<0.001
Cervical	15	$22.7^{a(A)}$	18.7-35.5	3.6^{b}	2-4.4	5.1^{b}	2.8-7	<0.001
Middle	15	$25.6^{a(A)}$	13.2-27.3	3.6^{b}	2.5-4.4	7.4^{b}	3.3-8.3	<0.001
Apical	15	$15.6^{a(B)}$	2.3-20.3	2.4^{b}	0.6-3.6	5.1^{a}	4.4-8.2	<0.001
p-value*		0.002		0.066		0.456		
15 Seconds After Gutta-Percha Removal (°C)								
Tooth long axis	15	20.3^{a}	13.5-27.7	2.4^{b}	2.1-3.5	5.3^{b}	3-6	<0.001
Cervical	15	23^{a}	19.4-24.3	2.7^{b}	1.7-3.8	3.7^{b}	3.3-5.8	<0.001
Middle	15	26.5^{a}	7-34.7	2.8^{b}	1.8-4.4	5.9^{c}	3.2-7.5	<0.001
Apical	15	17.3^{a}	1.5-33	2.3^{b}	0.8-3.1	5.1^{a}	2.9-6.6	<0.001
p-value*		0.163		0.122		0.322		
30 Seconds After Gutta-Percha Removal (°C)								
Tooth long axis	15	16.2^{a}	10.2-22.3	2.2^{b}	1.6-3.2	4.1^{b}	2.1-4.9	<0.001
Cervical	15	16.6^{a}	15.1-17.4	2.5^{b}	1.4-4.1	3.0^{b}	2.6-4.9	<0.001
Middle	15	20.1^{a}	6.6-27.4	2.7^{b}	1.4-4	4.8^{b}	2.5-5.9	<0.001
Apical	15	14.7^{a}	1.8-23.5	2^{b}	0.6-2.5	$3.9^{a,b}$	2.2-5.2	<0.001
p-value*		0.375		0.184		0.454		
45 Seconds After Gutta-Percha Removal (°C)								
Tooth long axis	15	13^{a}	9.2-15.9	1.8^{b}	0.9-2.6	2.6^{b}	1.8-3.9	<0.001
Cervical	15	14^{a}	11.1-14.8	2.3^{b}	1.2-3.2	3.7^{b}	2.4-4.3	<0.001
Middle	15	15.5^{a}	5.3-18.7	1.8^{b}	1.1-3.4	4.2^{b}	2.8-5b	<0.001
Apical	15	11.9^{a}	2.4-18.2	1.3^{b}	0.5-2.3	2.8^{b}	1.9-4.3	<0.001
p-value*		0.394		0.295		0.450		
60 Seconds After Gutta-Percha Removal (°C)								
Tooth long axis	15	9.2^{a}	6.9-13.7	1.3^{b}	0.7-3	2.7^{b}	2.2-3.4	<0.001
Cervical	15	11^{a}	8.9-13.1	2.3^{b}	1.3-3	2.6^{b}	2.4-3.5	<0.001
Middle	15	10.4^{a}	8.1-14.9	1.4^{b}	1-3.3	3^{b}	2.2-3.7	<0.001
Apical	15	8.3^{a}	2.5-14.3	1.2^{b}	0.4-3.3	$3.2^{a,b}$	2-3.9	<0.001
p-value*		0.179		0.596		0651		

*Kruskal-Wallis test; ^{a,b}Tukey's bidirectional analysis of variance - lowercase letters in horizontal and uppercase letters in vertical.

When IT and thermocouples were compared, IT registered higher temperature values than thermocouples (p<0.05) (Table 3).

Largo Peeso reamer temperature increases surpassed 10°C at all studied thirds, persisting 60 seconds after gutta-percha removal (Table 4).

Temperature normalization was achieved for Largo Peeso reamers at approximately 5m54s after the gutta-percha removal was finished, differing statistically from the other studied instruments (p=0.002) (Table 5).

Table 3. Comparison between the studied thermal analysis methods (°C) temperature increase generated by the studied gutta-percha removal instruments for the teeth thirds.

Thirds	Gutta-Percha Removal Instruments								
	Largo			Protaper			Reciproc		
	Median ($Q_{25} - Q_{75}$)		p-value*	Median ($Q_{25} - Q_{75}$)		p-value*	Median ($Q_{25} - Q_{75}$)		p-value*
	Thermography	Thermocouples		Thermography	Thermocouples		Thermography	Thermocouples	
					Work Time (°C)				
Cervical	22.7 (18.7-35.5)	17.4 (13.5-22.4)	0.034	3.6 (2-4.4)	3.7 (2.3-5.4)	0.299	6.3 (5.3-7.8)	5.1 (2.8-7)	0.105
Middle	25.6 (13.2-27.3)	20.7 (14.3-27.1)	0.506	3.6 (2.5-4.4)	3.8 (2-4.6)	0.787	3.8 (2.9-6.4)	7.4 (3.3-8.3)	0.124
Apical	15.6 (2.3-20.3)	11.9 (11.1-16.2)	0.868	2.4 (0.6-3.6)	2 (0.7-2.9)	0.520	1.3 (0.9-1.6)	5.1 (4.4-8.2)	<0.001
					15 Seconds (°C)				
Cervical	20.7 (19.4-24.3)	12.1 (8.2-15.7)	0.002	2.1 (1.6-2.9)	2.7 (1.7-3.8)	0.171	3.7 (3.3-5.8)	3.8 (2.8-4.9)	0.361
Middle	11.9 (10.8-14.5)	26.5 (7-34.7)	0.031	2.8 (1.8-4.4)	1.8 (1.3-3.1)	0.032	2.8 (2.4-3.7)	5.9 (3.2-7.5)	0.006
Apical	17.3 (1.5-33)	6.1 (5.3-10.2)	0.243	1.3 (0.6-1.4)	2.3 (0.8-3.1)	0.078	5.1 (2.9-6.6)	1.3 (0.9-1.6)	<0.001
					30 Seconds (°C)				
Cervical	16.6 (15.1-17.4)	8.9 (6.8-14.8)	<0.001	1.9 (1.3-2.4)	2.5 (1.4-4.1)	0.124	3 (2.6-4.9)	3.4 (2.5-4.4)	0.371
Middle	20.1 (6.6-27.4)	10.8 (8.7-11.1)	0.038	2.7 (1.4-4)	1.4 (1.1-2.6)	0.029	2.5 (2.1-3.5)	4.8 (2.5-5.9)	0.034
Apical	14.7 (1.8-23.5)	5.8 (3.1-5.5)	0.096	1.1 (0.5-1.2)	2 (0.6-2.5)	0.031	3.9 (2.2-5.2)	1.2 (0.9-1.3)	<0.001
					45 Seconds (°C)				
Cervical	7.7 (5.8-11.3)	14 (11.1-14.8)	<0.001	2.3 (1.2-3.3)	1.6 (1.1-2.1)	0.124	3.1 (2.3-3.7)	3.7 (2.4-4.3)	0.299
Middle	15.5 (5.3-18.7)	8.3 (7.4-9.3)	0.038	1.4 (0.9-2.1)	1.8 (1.1-3.4)	0.077	4.2 (2.8-5)	2.4 (1.9-3)	0.010
Apical	5.6 (2.6-6.5)	11.9 (2.4-18.2)	0.046	1.3 (0.5-2.3)	1 (0.5-1.1)	0.176	1.1 (0.7-1.2)	2.8 (1.9-4.3)	<0.001
					60 Seconds (°C)				
Cervical	11 (8.9-13.1)	6.5 (4.4-8.9)	0.002	2.3 (1.3-3)	1.4 (0.9-1.9)	0.053	2.6 (2.1-3.4)	2.6 (2.4-3.5)	0.647
Middle	10.4 (8.1-14.9)	6.8 (6.3-7.8)	0.002	0.9 (0.8-1.9)	1.4 (1-3.3)	0.105	3 (2.2-3.7)	1.7 (1.3-2.6)	<0.001
Apical	4.9 (2.5-5.3)	8.3 (2.5-14.3)	0.157	1.2 (0.4-3.3)	0.8 (0.4-1)	0.114	1.1 (0.6-1.2)	3.2 (2-3.9)	<0.001

*Mann-Whitney test; [a,b]Tukey's bidirectional analysis of variance.

Table 4. Comparison between the temperature increase generated at the studied worktimes for the studied gutta-percha removal techniques analyzed by thermography.

Thirds	Work Time	15 Seconds	30 Seconds	45 Seconds	60 Seconds	p-value*
			Tooth Log Axis			
Largo	18.9[a] (10.5-20.9)	20.3[a] (13.5-27.7)	16.2[a,b] (10.2-22.3)	13[b,c] (9.2-15.9)	9.2[c] (6.9-13.7)	<0.001
Protaper	2.9[a] (2.2-3.6)	2.4[a] (2.1-3.5)	2.2[a,b] (1.6-3.2)	1.8[b] (0.9-2.6)	1.3[b] (0.7-3)	<0.001
Reciproc	4.8[a] (4.2-6.7)	5.3[a] (3-6)	4.1[b] (2.1-4.9)	2.6[b] (1.8-3.9)	2.7[b] (2.2-3.4)	<0.001
			Cervical			
Largo	22.7[a] (18.7-35.5)	20.7[a] (19.4-24.3)	16.6[a,b] (15.1-17.4)	14[b,c] (11.1-14.8)	11[c] (8.9-13.1)	<0.001
Protaper	3.6[a] (2-4.4)	2.7[a,b] (1.7-3.8)	2.5[a,b,c] (1.4-4.1)	2.3[b,c] (1.2-3.3)	3.7[c] (2.4-4.3)	<0.001
Reciproc	5.1[a] (2.8-7)	3.7[a] (3.3-5.8)	3[a,b] (2.6-4.9)	3.7[b,c] (2.4-4.3)	2.6[c] (2.4-3.5)	<0.001
			Middle			
Largo	25.6[a] (13.2-27.3)	26.5[a] (7-34.7)	20.1[a,b] (6.6-27.4)	14[b] (11.1-14.8)	10.4[b] (8.1-14.9)	<0.001
Protaper	3.6[a] (2.5-4.4)	2.8[a] (1.8-4.4)	2.7[a,b] (1.4-4)	1.8[b] (1.1-3.4)	1.4[b] (1-3.3)	<0.001
Reciproc	7.4[a] (3.3-8.3)	3.7[a,b] (3.3-5.8)	4.8[a,b] (2.5-5.9)	4.2[b,c] (2.8-5)	3[c] (2.2-3.7)	<0.001
			Apical			
Largo	15.6[a,b] (2.3-20.3)	17.3[a] (1.5-33)	14.7[a] (1.8-23.5)	11.9[a,b] (2.4-18.2)	8.3[b] (2.5-14.3)	0.002
Protaper	2.4[a] (0.6-3.6)	2.3[a] (0.8-3.1)	2[a,b] (0.6-2.5)	1.3[a,b] (0.5-2.3)	1.2[b] (0.4-3.3)	0.002
Reciproc	5.1[a] (4.4-8.2)	5.1[a,b] (2.9-6.6)	3.9[a,b] (2.2-5.2)	2.8[b,c] (1.9-4.3)	3.2[c] (2-3.9)	<0.001

*Friedman test; [a,b]Tukey's bidirectional analysis of variance - lowercase letters in horizontal and uppercase letters in vertical.

Table 5. Comparison between temperature decrease time for the studied gutta-percha removal instruments.

Thirds	N	Time until Temperature Normalization (Minutes)		p-value*
		Median	Q25-Q75	
Largo	15	354[a] (5'54")	286-481 (4'45"-8'06")	0.002
Protaper	15	210[a,b] (3'30")	180-285 (3'-4'45")	
Reciproc	15	180[b] (3')	180-225 (3'-3'45")	

': Minute (s); ": Second (s); *Kruskal-Wallis test.

Discussion

Using thermocouples limits the temperature assessment to a limited sample point [1,7]. IT was added to the methodology to increase the surface thermically analyzed in this study. However, IT presents higher temperature values than thermocouples when comparing temperature assessment methods, with no statistical difference.

IT is an imaging method capable of producing accurate temperature data due to its high resolution, allowing precise temperature measurements when heat reflections are avoided and the ambient temperature is kept constant [10-13]. It is important to acknowledge the advantages and limitations of this method when establishing the methodology to create an environment for acquiring thermal images with minimal external interference [13,18-20]. The IT camera used in this study is a new-generation high-resolution IT camera with a spatial resolution of 640×480 pixels.

According to García-Cuerva et al. [7], heat generation during gutta-percha removal can be affected by the type of instrument used, the condition of the instrument's cutting edges, rotation type, and speed, the cutting pressure applied, the duration of contact with the tooth structure. The external root temperature increase caused by low-speed rotary stainless-steel instruments may damage the periodontium [7].

This study assessed stainless steel and NiTi instruments with different kinematics to verify if the metal alloy and kinematics may interfere with temperature variation during gutta-percha removal. The highest temperatures were observed when using the Largo Peeso rotating stainless steel instrument in all studied tooth thirds and working times, probably because this instrument is used with a contra-angle with low-speed rotation micromotor (5.000 a 20.000rpm). In contrast, NiTi instruments are used with 250-300rpm rotation speed micromotors. Stainless steel rotary instruments with low rotation speed can generate significant external temperature increases and harm the periodontium [7].

Furthermore, a higher value was observed in the middle third region (26.5°C) using the Largo Peeso. This was probably because gutta-percha is more easily removed in the cervical third and does not work as much in the apical third compared to the middle third.

A systematic review states that the application of the different gutta-percha removal protocols can be effective, and NiTi retreatment files have no advantages over conventional techniques [17]. However, in this study, NiTi oscillatory and rotatory instruments generated a minimum temperature increase during gutta-percha removal, which can be considered an advantage.

In thermocouple thermal analysis, the apical third showed lower temperatures than the cervical and middle thirds, probably due to gutta-percha's low thermal conduction. Gutta-percha starts plasticizing 2mm from where heat is applied [21-23].

Largo Peeso reamers presented a temperature increase above 10°C in all tooth thirds and above 16°C at 30s worktime. An increase of 10°C can lead to changes in the adjacent connective tissue, chronic periodontitis, and tooth resorption, which can be reverted until the temperature increase surpasses 16°C (3,4). According to Zhang et al. [24], temperature increases above 10°C for 5 minutes can lead to bone resorption. Largo Peeso reamers temperature normalization time after gutta-percha removal was 5m54s, and after the 60s, the warmest region of interest presented 11°C surface temperature; therefore, the damage caused by this technique to the periodontium is considered reversible.

Larger preparation sizes and hybrid techniques are associated with less remaining filling material [17]. Dentin has a lower thermal conductivity; however, additional dentin removal is usually needed to anchor intracanal posts, which can lead to an increase in gutta-percha thermal irradiation through the root. In this study, premolars were assessed; however, teeth with thinner dentin thickness, like lower incisors, may present a higher temperature increase in the external surface of the root, which may lead to irreversible periodontium injuries, and molars with furcation areas have great heating potential, which can also affect the periodontium [21,25]. Another limitation of this study was that dentin thickness was not measured using Micro CT images. Studies assessing different teeth, dentin thicknesses, canal shapes, and gutta-percha removal techniques are needed to verify potential periodontium harm.

Conclusion

Protaper Universal Retreatment and Reciproc NiTi instruments present lower temperature increase values and should be chosen for gutta-percha removal. Stainless-steel Largo Peeso temperature reaches values above 10°C; however, Insufficient time to cause injuries to the periodontium.". Infrared thermography and thermocouples can be used to assess root temperature variation.

Authors' Contributions

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All authors declare that they contributed to a critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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