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Thermal Behavior Variations among Commercial Gutta-percha Brands: An Optical Thermography Study

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Introduction: This study aimed to assess the thermal behavior of five different commercial gutta-percha brands using optical thermography. We focused on temperature differences and heat transfer characteristics at different apical distances. **Materials and Methods:** Gutta-percha cones from the following brands were tested: Autofit Greater Taper, Protaper Gold F2, TruNatomy Prime, ZARC Gutta-percha points # 25/0.06, and Reciproc Blue R25. A specific heating system was used to subject the cones to thermal imaging. Measurements were taken at 1-, 2-, 3-, and 4-mm apical distances for 5 mm and 10 mm cone lengths. Statistical analyses included Student's t-tests and Analysis of Variance with the significance level set at 0.05. **Results:** Upon intragroup comparison, we found subtle distinctions in thermal behavior when examining gutta-percha cone lengths (5 mm *versus* 10 mm). TruNatomy exhibited statistically significant variations ($P<0.05$) at 2- and 3-mm distances. Conversely, ZARC and Reciproc Blue R25 displayed notable differences ($P<0.05$) at 2-, 3-, and 4-mm distances. In contrast, Autofit Greater Taper and Protaper Gold F2 consistently diverged across all distances ($P<0.05$). In intergroup comparisons of 5 mm length, significant variances ($P<0.05$) emerged among brands at 1- and 2-mm distances. At 10 mm length, TruNatomy differed significantly ($P<0.05$) from other brands across all distances. The heat tip maintained an average maximum temperature of 154.54°C. **Conclusion:** Thermal behavior of gutta-percha brands varied significantly, with implications for endodontic treatments. While differences were observed in heat transfer and maximum temperatures, all brands remained within safe temperature ranges for clinical use. Understanding these variations can aid clinicians in selecting appropriate gutta-percha for specific clinical scenarios, ultimately optimizing root canal obturation quality.

Keywords: Endodontic Treatment; Gutta-percha; Heat Transfer; Optical Thermography; Thermal Behavior

Introduction

The first and most important aim of root canal filling is to create a hermetic seal within the canal system [1]. This seal is essential for preventing the entry and exit of microorganisms and thus reduces the risk of reinfection [1]. The filling or obturation of the root canal system is a crucial factor in the success of endodontic treatment and has a direct impact on the long-term prognosis of the treated tooth [2-4].

The complicated morphology of root canal requires a filling material and technique that can tightly seal the canal space to prevent microbial invasion [5]. The most commonly used materials in the obturation phase are gutta-percha as a core material and cement as a sealer [6]. Gutta-percha is an isomer of the polymer polyisoprene (trans-1,4-polyisoprene) [7, 8]. It comprises organic components (18-22% gutta-percha as matrix and 1-4% wax/resin as plasticizer) and inorganic components (1-18% metal sulfates for radiopacity and 59-76% zinc oxide as filler) [7].

These components vary according to the commercial brands of gutta-percha and may affect its physical properties, including its thermal behavior [9]. Gutta-percha is chosen as an obturation material due to its biocompatibility and thermoplastic properties, which allow it to adapt to the complex root canal system [10, 11].

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Among the various techniques available for canal filling, warm gutta-percha obturation is characterized by its adaptability to the canal's intricate anatomy and ensures a homogeneous seal, which is essential for preventing reinfection [12-14].

Warm gutta-percha techniques, such as the continuous wave of condensation and thermoplasticized injection, allow the flow of gutta-percha into irregularities, lateral canals, and isthmuses that are rarely reached with cold obturation methods [12, 13]. In addition, the thermal behavior of gutta-percha, particularly its softening and flow in response to heat, is an important determinant of its sealing capability and its adaptation to the canal walls [15, 16].

The different compositions of gutta-percha, including standard, fine, and ultrafine types, as well as those with additives intended to improve radiopacity or flexibility, may influence their thermal properties [16]. For instance, the melting temperature, thermal conductivity, and diffusivity are parameters that influence the behavior of gutta-percha during obturation [17, 18]. These properties determine the material's capability to adequately fill the root canal system, especially in complex anatomic variations [17, 19].

Optical thermography is an invaluable diagnostic tool that offers a unique advantage in endodontic research. It allows visualization of the temperature distribution in the material without any physical intervention that could alter the material's behavior [16]. With this technology, it is possible to observe the thermal response of different gutta-percha formulations when exposed to the heating processes commonly used in endodontic practice [20].

This technology can explore the nuanced differences in the thermal behavior of different gutta-percha types, providing insights into their practical applications [15]. These insights are critical for optimizing material selection based on specific clinical scenarios [18].

Building on this potential, the present study uses optical thermography to investigate the thermal behavior of five commercially available gutta-percha brands. Specifically, it evaluates temperature differences and heat transfer characteristics at various apical distances. The hypothesis driving this study is that compositional variations among gutta-percha brands result in significant differences in thermal behavior, which may influence their clinical performance during root canal obturation.

Materials and Methods

Sample preparation

Five different commercial brands of gutta-percha cones were selected for this study: Autofit Greater Taper 0.06 (Kerr), Protaper Gold Confort Fit F2 (Dentsply Sirona), TruNatomy Prime (Dentsply Sirona), Gutta-percha points # 25/0.06 (ZARC), and Reciproc Blue R25 Endo Easy Efficient (VDW). Twenty four gutta-percha cones of each brand were used. Each cone was attached to a brass ruler using double-sided adhesive tape for consistent positioning and measurement.

Thermal transmission

The gutta-percha tips were heated with the Fast-pack vertical compaction system and the small (Black) 40/0.025 tip (Eighteeth, Jiangsu, China). Several programs are available for selecting the temperature. The 250° C program was chosen since this temperature was considered suitable when conducting different tests to find the maximum temperature the gutta-percha cones could reach. The system applies heat for 5 sec before automatically deactivating, ensuring consistent heating across all samples. Optical thermography measurements were taken immediately after the heating cycle to capture the peak temperatures.

Thermal imaging and magnification camera

For thermal measurement, a thermal imaging camera (Hti HT-301, Dongguan, China) was used, with a resolution of 384×288, an image refresh rate of 25 Hz, and an error rate of +/-3° C. Since the camera has a field of view of 80 mm, a Zinc-Selenide lens with a focal length of 25.4 mm (Cloudray, Shenzhen, China) was used, resulting in a field of view of 12 mm to see the camera's area in more detail. The thermal imaging camera was connected to a Xiaomi Redmi Note 10S smartphone (Xiaomi, Beijing, China). In addition, a Zeiss Pico microscope (Carl Zeiss, Berlin, Germany) was used, with an adapter where a Sony Alpha 5100 (Sony, Tokyo, Japan) camera was attached to carry out the study and its documentation with greater precision.

Each gutta-percha cone was placed on a brass ruler and fixed with double-sided adhesive tape, leaving the tip of each gutta-percha on the line corresponding to 0. The thermographic camera was kept on supported with the regulation of micrometer height to focus the image on the phone. The desired heat measurement points were marked using a wireless mouse linked to the phone, and a video was recorded for each heat dynamics measurement.

The heat was applied with a small tip at an angle perpendicular to the gutta-percha cone, using the 250° C program, two heat waves were applied at each point. The heat was applied to the entire 10 mm length of gutta-percha and then to 5 mm; the temperature was recorded at 1-, 2-, 3-, and 4-mm apical to the tip (Supplemental Video). Since the thermal imaging camera has prominent characters, the temperature measurement numbers were too large for all four heat points to be simultaneously recorded in each video. Therefore, two recordings were needed to complete a data collection cycle; in each cycle, the points 1 mm and 3 mm were recorded in one video, and 2 mm and 4 mm in the following recording.

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It was estimated that at least 12 measurements for each point of heat application (10- and 5-mm) were necessary to obtain a significant data sample. Four distances (1-, 2-, 3-, and 4-mm) were measured, two lengths at a time, with 24 gutta-percha cones per system, resulting in 48 recordings per system with the thermographic camera. Five commercial brands of gutta-percha points were studied, resulting in 240 thermographic recordings.

For data analysis, the videos were observed frame by frame, recording the initial temperature at the measurement points, the maximum temperature of the heated tip, and the maximum temperature of the measurement points (1-, 2-, 3-, and 4-mm). The results were stated in Celsius and tabulated in an Excel spreadsheet for further comparison.

Statistical analysis

The Shapiro-Wilk test was performed to determine whether the data exhibited normality. Since the data showed a normal distribution, the T-test was used for the intragroup comparison of each brand for the pairs of 5 mm and 10 mm at 1-, 2-, 3-, and 4-mm apical distances. Analysis of Variance was used to compare 5 mm and 10 mm gutta-perchas across different brands at 1-, 2-, 3-, and 4-mm apical distances. An SPSS (Statistical Package for the Social Sciences 21.0; IBM Brasil, SP, Brazil) software with a significance level of 0.05 was used for all analyses.

Results

Heat transfer at 5 mm versus 10 mm sizes

The intragroup comparison of thermal transmission efficacy at different apical distances (1-, 2-, 3-, and 4-mm) from the heating source for each brand of gutta-percha in 5 mm and 10 mm lengths are reported in Tables 1 and 2. The findings are summarized as follows:

For TruNatomy Prime, significant temperature differences (P<0.05) were observed at 2- and 3-mm apical distances, with higher temperatures in the 10 mm length. Specifically, at 2 mm distance, the mean temperature was 48.20° C for 10 mm length *versus* 42.40° C for 5 mm, and at 3 mm distance, the mean temperature was 36.99° C for 10 mm length *versus* 35.60° C for 5 mm. However, no significant differences were observed at 1 mm and 4 mm distances (P>0.05).

Regarding ZARC 25/0.06, significant differences (P<0.05) were observed at 2 mm distance (62.48° C for 10 mm *versus* 51.50° C for 5 mm), 3 mm distance (43.62° C for 10 mm *versus* 38.81° C for 5 mm), and 4 mm distance (38.41° C for 10 mm *vs* 36.75° C for 5 mm), but not at 1 mm distance (P>0.05). Reciproc Blue R25 followed a similar trend, with significant differences (P<0.05) at 2-, 3-, and 4-mm distances, but no differences at 1 mm (P>0.05).

Autofit Greater Taper and Protaper Gold F2 consistently showed significant differences (P<0.05) across all distances, with higher temperatures in the 10 mm length compared with 5 mm.

Temperature comparison at 5 mm between the groups

Intergroup comparisons of thermal transmission at 5 mm length revealed significant variations (Table 1).

At 1 mm apical distance, Trunatomy exhibited significantly lower heat transmission (mean: 81.96° C) compared with ZARC (mean: 108.97° C) and ReciprocBlue (mean: 110.71° C, P<0.05). However, no significant differences (P>0.05) were found between Trunatomy and ProtaperGold (mean: 92.28° C).

At 2 mm distance, significant differences (P<0.05) were observed across most brands, except for comparisons between ZARC, ReciprocBlue, and Autofit, where no significant differences were detected (P>0.05).

Table 1. Thermal behavior values (° C) across the 5 mm length of various brands of gutta-percha at 1, 2, 3, and 4 mm apical to the heat tip, expressed as mean (median; range)

TruNatomy	ZARC	Reciproc Blue	AutoFit	Protaper Gold
81.9 (12.3; 54.3-100.0)	108.9 (13.5; 87.3-133.2)	110.7 (16.7; 90.9-141.9)	102.9 (13.4; 65.5-115.1)	92.2 (14.6; 57.0-108.1)
42.4 (2.1; 38.2-45.7)	51.5 (4.0; 46.1-61.3)	52.9 (3.5; 45.3-58.1)	51.1 (2.8; 46.2-55.9)	48.2 (3.8; 38.8-53.3)
35.6 (2.1; 30.6-37.6)	38.8 (4.5; 31.4-48.6)	40.7 (1.8; 36.6-42.4)	40.8 (3.1; 31.0-40.8)	38.6 (2.5; 31.1-40.8)
35.0 (2.0; 29.4-36.7)	36.7 (1.6; 32.2-38.4)	38.2 (0.8; 36.0-39.1)	38.7 (1.7; 34.6-40.5)	37.1 (2.2; 30.4-38.9)

Table 2. Thermal behavior values (° C) across the 10 mm length of different gutta-percha brands, measured at 1, 2, 3, and 4 mm apical to the heat tip, presented as mean (median; range)

Reciproc Blue	AutoFit	Protaper Gold
114.2 (15.6; 97.2-144.0)	111.9 (10.7; 81.6-122.9)	115.3 (12.9; 99.2-143.2)
61.1 (5.1; 50.0-67.9)	61.4 (4.0; 53.7-67.2)	60.1 (7.7; 49.4-75.0)
43.2 (1.6; 40.6-46.0)	45.0 (3.2; 35.1-47.5)	44.3 (2.0; 40.9-48.6)
39.0 (1.0; 36.3-40.2)	39.8 (1.6; 35.6-42.0)	38.5 (2.4; 31.9-41.5)

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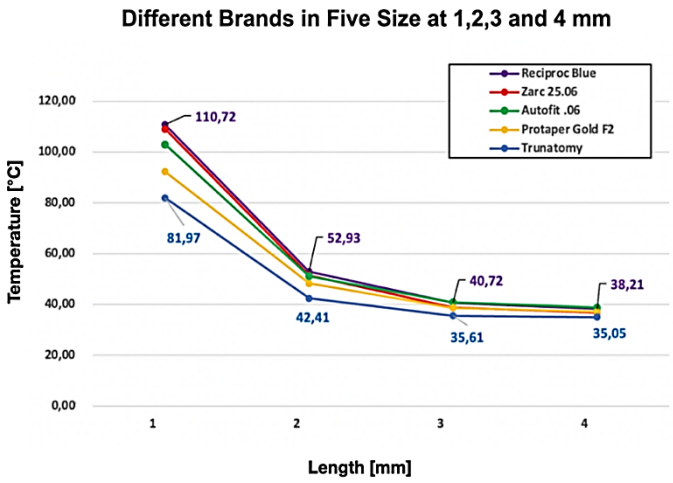

Figure 1. Comparative graphical representation of heat application measurement on five mm-sized gutta-perchas measured at 1, 2, 3, and 4 mm depths using Reciproc Blue # 25/0.08 (Purple), Zarc # 26/0.06 (Red), AutoFit 0.06 (Green), ProTaper Gold F2 (Yellow), and TruNatomy (Blue)

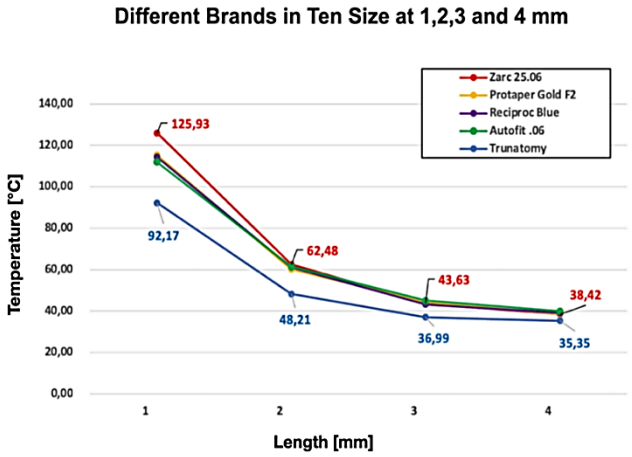

Figure 2. Comparative graphical depiction illustrating the heat application measurement on ten mm-sized gutta-perchas, assessed at depths of 1, 2, 3, and 4 mm. The evaluation was conducted using Reciproc Blue # 25/0.08 (Purple), Zarc # 26/0.06 (Red), AutoFit 0.06 (Green), ProTaper Gold F2 (Yellow), and TruNatomy (Blue)

At 3 mm apical distance, Trunatomy showed no significant differences (P>0.05) when compared with ZARC. Similarly, no significant differences (P>0.05) were found between ZARC, ReciprocBlue, Autofit, and ProtaperGold.

At 4 mm apical distance, Trunatomy differed significantly (P<0.05) from ReciprocBlue, Autofit, and ProtaperGold, while no differences were observed between Trunatomy and ZARC (P>0.05) (Figure 1).

Temperature comparison at 10 mm between brands

At the 10 mm length, significant differences (P<0.05) in thermal transmission were observed at 1 mm apical distance between Trunatomy (92.16° C) and all other brands: ZARC (125.93° C), ReciprocBlue (114.25° C), Autofit (111.94° C), and ProtaperGold (115.38° C).

At 2 mm apical distance, Trunatomy (48.20° C) continued to show significant differences (P<0.05) compared with other brands, but no significant differences were noted among ZARC, ReciprocBlue, Autofit, and ProtaperGold (P>0.05).

At 3 mm and 4 mm apical distances, significant differences (P<0.05) were consistently observed between Trunatomy and other brands, while no differences were found among the remaining brands (P>0.05) (Figure 2).

Heat tip temperature

The heat tip's average maximum temperature was recorded at 154.54° C using a standard setting of 250° C in the Eighteeth Downpack program.

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Discussion

This study quantifies the thermal transmission of different gutta-percha cones, particularly with thermoplastic techniques from distinct brands.

The observed results, which indicate a higher average temperature at the 10 mm coronal point compared with the 5 mm apical point in all gutta-percha samples, are consistent with the established principles of heat transfer in endodontic therapy [21]. According to these principles, heat transfer efficiency generally decreases with increasing distance from the heat source. In this context, the heat source is assumed to be the heat tip used to soften and compact gutta-percha material [21]. This observation is of considerable clinical relevance as it underlines the importance of achieving optimal flow and adaptation of gutta-percha within the intricate root canal system. Ensuring a dense and homogeneous filling is crucial for minimizing the occurrence of voids and gaps that may jeopardize the success of endodontic treatment [17].

Studies highlight the role of understanding heat transfer mechanisms within the root canal in optimizing filling techniques and material properties [22]. Furthermore, our findings are consistent with previous studies that emphasize the need for precise heat application in endodontic procedures to preserve the integrity of the gutta-percha and mitigate the risk of thermal damage to the periapical tissues [23, 24].

Historically, studies have shown varied opinions on this matter; for instance, Schilder, Goodman and Aldrich (25) linked gutta-percha's thermal behavior to its composition, while Liao, Wang, Hsu, Huang, Gutmann and Hsieh (20) associated heat transmission with a higher inorganic proportion in the design. Conversely, in another study Maniglia-Ferreira, Gurgel-Filho, de Araújo Silva, de Paula, de Andrade Feitosa and de Sousa-Filho (15) found no correlation between chemical composition and thermal behavior, highlighting the ongoing debate in this regard.

However, the *in vitro* nature of this study represents a limitation. The simplified experimental setup, where gutta-percha cones were heated in isolation, does not fully replicate clinical conditions where factors such as dentinal walls, sealing cements, and canal curvature significantly influence heat transmission. These variables may alter the thermal behavior observed in a clinical setting [26]. Additionally, the fixed positioning of the heating tip perpendicular to the gutta-percha cone does not fully represent the clinical application, where the tip is typically used parallel to the gutta-percha during vertical compaction. These differences in orientation and environment could lead to discrepancies between in vitro findings and clinical outcomes, highlighting the need for future studies to simulate clinical conditions more closely.

The study also observed differences in thermal behavior based on the gutta-percha mass. Due to its larger mass and taper, a more significant heat transfer occurs in the coronal portion, resulting in higher temperatures and activation of more heat nuclei [18]. This phenomenon aligns with heat transfer principles, where the contact surface is crucial [18].

The variation in temperature at the 5 mm length between different groups, particularly the TruNatomy group's lower temperatures and the Reciproc Blue R25 group's higher temperatures, suggests the influence of the gutta-percha formulation and perhaps the manufacturing process on its thermal behavior. The significant differences observed, especially at the 1- and 2-mm points, suggest that some compositions may be more susceptible to heat than others, influencing the choice of gutta-percha for specific clinical scenarios. The temperature at the 3- and 4-mm measurements did not exceed 40° C in any groups which ensures safety during the procedure.

Comparing the transition temperatures of gutta-percha forms from various studies, it is possible to observe differing findings. Schilder, Goodman and Aldrich (25)] reported a beta-to-alpha transition between 42° C and 49° C, whereas Maniglia-Ferreira, Gurgel-Filho, de Araújo Silva, de Paula, de Andrade Feitosa and de Sousa-Filho (15) found it to occur between 48.6° C and 55.7° C. Liao, Wang, Hsu, Huang, Gutmann and Hsieh (20) reported the occurrence of this transition to be between 39.85° C and 50.63° C. These disparities is indicative of the influence of gutta-percha's composition on its thermal behavior.

The comparison at the 10 mm length further emphasizes the differences in thermal behavior among brands. Trunatomy's lower temperatures across all measured points suggest a possibly more conservative heat transfer characteristic, making it safer for use near sensitive areas. In contrast, the ZARC 25/0.06 group's higher temperatures highlights the importance of understanding each product's thermal profile to tailor the heating strategy according to clinical needs and avoid excessive heating, which could compromise the integrity of the gutta-percha or harm periapical tissues. In all instances, the temperature increase within the 4 mm distance did not surpass 40° C, indicating that all brands are safe for thermoplastic sealing applications.

While no unexpected results were observed, the slight variations in temperature dissipation between brands highlight the influence of manufacturing processes and material compositions. Addressing these differences in future studies could offer additional insights into optimizing gutta-percha performance.

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A notable outcome of this study is that none of the selected gutta-percha brands transmitted sufficient heat beyond 3 mm, with most heat dissipating within the first two millimeters. This finding is noteworthy for clinical practice, where reaching distances of less than 4 mm in curved or calcified canals can be challenging [27]. Our findings suggest that the average maximum temperature reached at 4 mm is insufficient for altering gutta-percha's crystallization state into the desired alpha-form [28].

The results of this study imply that achieving the alpha-form of gutta-percha cones would require the heat source to be within 2-3 mm of the working length. The study by Chen, Shen and Hsieh (29)] supports this statement, showing that heating and compacting gutta-percha twice at 3 mm from the apex can effectively mold it. However, a single heating unit results in insufficient temperatures for proper molding.

Furthermore, maintaining a constant temperature between 44-47° C for at least 1 min is crucial for mitigating periodontal damage and bone necrosis. This aligns with the findings of Kytridou et *al.* [30] and underscores the importance of temperature control in endodontic procedures. Liao *et al.* [20] also highlighted that the ratio of organic to inorganic components in gutta-percha influences its physical properties, including thermal conductivity.

The recorded heat tip's average maximum temperature of 154.54° C, against a standard setting of 250° C, emphasizes the importance of understanding the heat transfer characteristics of endodontic equipment. The disparity between the set temperature and the maximum temperature recorded at the tip is indicative of a thermal loss during operation; clinicians must keep this under consideration when adjusting settings for optimal gutta-percha softening and manipulation.

Conclusion

The maximum temperature is higher at 10 mm than at 5 mm from the heat application point. While there are significant variations in temperature dissipation among the different gutta-percha brands, all measurements at the 4 mm distance are a temperature within the safe range for heating, demonstrating that the evaluated brands can be used for thermoplastic sealing without safety concerns.

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Conflict of interest
José Aranguren and Alejandro R. Pérez are opinion leaders of the ZARC Company. The other authors deny any conflicts of interest related to this study.

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Authors' contributions
Conceptualization: MU; Methodology: MU/JA; Formal Analysis and Investigation: JA/ARP/AR; Writing-Original draft preparation: NN/ARM/JA; Writing-review and editing: MU/JA/ARP/ARM/NN; Supervision: ARP. All authors read and approved the final manuscript.

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