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Original Article

The investigation of thermal behavior and temperature analysis of three types of contemporary gutta-percha points

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Root canal obturation;
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Abstract *Background/purpose:* The impact of thermal behavior on the clinical performance of gutta-percha points (GP) is unclear. This study aimed to investigate the thermal behavior of three different types of GP and their temperature changes (TC) in a simulated clinical environment.
Materials and methods: The GP tested were Conform Fit® Gutta-Percha Points (CF), Autofit™ Feathered Tip Gutta Percha (AF), and Gutta Percha Root Canal Points (GC). The phase transition temperatures of the samples were analyzed using differential scanning calorimetry (DSC). The TC at the tips of the GP was examined with the heat source positioned at specific distances from the tip. Additionally, the TC of the GP in the apical foramen of a simulated canal during the warm vertical compaction (WVC) technique was evaluated. Differences in the apical temperature of the GP during WVC were compared using two-way ANOVA, with statistical significance set at $P < 0.05$.
Results: The phase transition temperatures peaked at approximately 51 °C and 61 °C. The temperature analysis showed the maximum average temperatures of AF and CF decreased to 38 °C when the heat source was 3 mm from the tip. During WVC, the average maximum apical temperatures for AF, CF, and GC were 37.7 °C, 36.0 °C, and 35.5 °C, respectively. Both the elapsed time of WVC and the brand of GP significantly ($P < 0.05$) affected the apical temperature.
Conclusion: The apical temperature elevation of the GP during WVC was minimal. Neither AF nor CF reached the moldable temperatures when the heat source was 3 mm away.

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Introduction

"Vertical condensation of warm gutta-percha produces consistently dense, dimensionally stable, three-dimensional root canal fillings. Lateral canals are filled with extraordinary frequency, often with gutta-percha, sometimes with cement," stated Dr. Schilder in his classic article "Filling root canal in three dimensions."[1] Since this idea was introduced into endodontics, warm vertical condensation technique (WVC) has been worldwide used in root canal obturation for over half a century. WVC includes manipulation of a heat source to soften the dental gutta-percha points and a series of heating, vertical condensation, gutta-percha removal to progressively fill the root canal laterally and in depth.[1] However, the limited temperature elevation of gutta-percha in apical area is a big issue to overcome in clinical situation. According to the study by Schilder et al., the transformation temperatures of gutta-percha from the β-form to the α-form and from the α-form to the amorphous phase were around 42–49 °C and 53–59 °C, respectively.[2] In order to obtain sufficient plasticity for adapting the internal configuration of the root canal system during obturation, Goodman et al. suggested that an increase of 2–4 °C of the apical gutta-percha above the body temperature of 37 °C is ideal to provide the proper softening for compaction.[3] Nevertheless, the data from earlier researches showed that temperature elevation in apical area are quite minimal while down packing procedure was performed to the level 4–6 mm from apex.[3–6]

When it comes to the chemical composition of gutta-percha, they are mainly composed of 14.5–20.4 % gutta-percha and 66.5–84.3 % zinc oxide.[7] With the vigorous development of dental materials, different manufacturers produce their unique design and proprietary ingredients, which may affect the physical properties and thermal behavior of the materials.[7] Conform Fit™ Gutta-Percha (Dentsply Sirona, Charlotte, NC, USA), a product of Dentsply Sirona, was manufactured by Healthdent Technology International for offering more compatible shapes correspondent with multi-tapered file systems. The high-precision injection molding of gutta-percha master cones have consistently accurate dimensions and provide a lower melt temperature as a result of better performance of the gutta-percha in WVC. In the previous study, Liao et al. have investigated the relationship between the chemical composition and thermal behavior of six commercially available dental gutta-percha points, including Conform Fit® Gutta-Percha Points. They found that Conform Fit® Gutta-Percha Points had the lowest percentage of inorganic components and thermal conductivity.[8] Furthermore, they concluded that thermal conductivity had strong positive correlation with the percentage of inorganic components and zinc, whilst there was a negative correlation to the ratio of gutta-percha.[8]

Although Liao et al. have revealed the thermal conductivity and the phase transition temperature of dental gutta-percha points, there is still a missing link to connect the laboratory data with the actual temperature changes of the materials induced by an endodontic heat carrier. How the thermal behavior influenced the clinical performance of dental gutta-percha points and whether the phase transition temperature can be achieved during clinical procedure is still unclear. Therefore, the purpose of this study was to investigate the thermal behavior of three commercially available dental gutta-percha points by analyzing the relationship between their phase transition temperature and the actual temperature changes induced by an endodontic heat carrier in a simulated clinical environment.

Materials and methods

Three commercially available dental gutta-percha points were included in this study: Conform Fit™ Gutta-Percha Points for ProTaper Gold® (CF) (Dentsply Sirona), AutoFit™ Feathered Tip Gutta Percha (AF) (Kerr Corporation, Brea, CA, USA) and Gutta Percha Root Canal Points (GC) (GC Corporation, Tokyo, Japan). All samples were analyzed before the expiration dates established by the manufacturers.

Differential scanning calorimetry

Differential scanning calorimetry (DSC) (DSC 4000, PerkinElmer, Waltham, MA, USA) was used to analyze the phase transition temperatures of all samples. The weight of each sample was measured to be 2.5 mg by an electronic scale. The heating-cooling cycle procedure were as follows:

1. holding the temperature at 30.00 °C for 1.0 min
2. heating from 30.00 °C to 75.00 °C at a heating rate of 1.00 °C/min
3. holding the temperature at 75.00 °C for 1.0 min

Temperature analysis of gutta-percha at a given distance from the heat source over time

Fifteen gutta-percha points were used for the analysis in each group ($N = 15$). The sizes of all samples were selected as follows: medium size for Group AF, F5 size for Group CF, and large size for Group GC. All gutta-percha points were trimmed to a tip size ISO #80 by a gutta-percha cutter.

Each group was further divided into three subgroups as ($N = 5$): 1 mm, 2 mm, and 3 mm from the gutta-percha tip. The samples were then fixed with utility wax at one end on a plastic slot. An endodontic heat carrier (Fast-Pack Pro, Eighteeth, Changzhou City, China) set to 200 °C was applied as the heat source. The whole procedure was carried out in a constant temperature (37 °C) chamber. The gutta-percha was heated for 3 s at 1 mm, 2 mm, or 3 mm from the tip according to the different subgroups. A K/J type thermocouple (TES-1306, TES Electrical Electronic Corporation, Taipei, Taiwan) was employed to measure the temperature changes at the gutta-percha tip, and the variations in the gutta-percha temperature of relative time were recorded in video format for analysis.

Temperature analysis of the gutta-percha at apical area in a simulated canal during the procedure of warm vertical condensation technique

Three clear acrylic training blocks with a simulated canal were used for the analysis in each group ($N = 3$). The working length of all simulated canals was 20 mm, and the canals were prepared by ProTaper Gold® (Dentsply Sirona) to F5. Regarding the checking of the cone-fit, for the Group AF ($N = 3$): the medium-fine size was selected for cone-fit and the gutta-percha tip was trimmed to size ISO #50 by a gutta-percha cutter; for the Group CF ($N = 3$): the F5 size was selected for cone-fit and the gutta-percha tip size was ISO #50; and for the Group GC ($N = 3$): the large size was selected for cone-fit and the gutta-percha tip was trimmed to size ISO #50 by a gutta-percha cutter. Each gutta-percha point was checked for appropriate tug-back and applied a small and even amount of zinc oxide eugenol root canal sealer (Pulp Canal Sealer EWT, Kerr Corporation). An endodontic heat carrier set to 200 °C was applied as the heat source. The pluggers (Machtou Hand Pluggers, VDW, Munich, Germany) were properly selected before WVC according to Schilder's technique. The whole procedure was carried out in a constant temperature (37 °C) chamber. The compaction procedures were as follows:

1. The gutta-percha point was heated for a duration of 5 s, leading to the removal of the gutta-percha up to a distance of 5 mm short of the apex.
2. The exchange of instruments with the assistant took 3 s, followed by 10 s of compaction using the selected plugger, and another 3 s for the subsequent instrument exchange.
3. The gutta-percha was heated for a duration of 3 s, leading to the removal of the gutta-percha up to a distance of 3 mm short of the apex.
4. Repeat procedure 2.
5. The gutta-percha was heated for 3 s, 3 mm short of the apex, without removing any of the gutta-percha at this time.
6. The exchange of instruments with the assistant took 3 s, followed by 10 s of compaction using the selected plugger.

Additionally, a K/J type thermocouple was employed to measure the temperature changes of the gutta-percha at the simulated apical foramen, and the variations in the gutta-percha temperature of relative time were recorded in video format for analysis.

Statistical analysis

The temperature changes of each group at apical area during WVC were entered into a spreadsheet and analyzed statistically using Excel 2016 for Windows (Microsoft, Redmond, WA, USA). The two-way ANOVA was used to compare the differences among the apical temperature of all groups during WVC. The level of statistical significance was set as $P < 0.05$.

Results

Differential scanning calorimetry

The experimental thermograms obtained from all three products in the heating procedure are shown in Fig. 1. CF and GC exhibited two typical endothermic peaks, β-to α-form phase transition (β-α) and α-to amorphous-form phase transition (α-amorphous), while AF had the additional endothermic peak with lower temperature (44.69 °C) during the procedure. The temperature ranges of phase transition and peak temperature values of the tested products are presented in Table 1. There was a notable difference in the curvilinear patterns of the three thermograms. GC showed a gentle ascending slope with a small amplitude of the successive curve crest in the β-α range. AF and CF had a large amplitude of the obvious curve crest existed in the range of β-α, and CF showed the lowest peak temperature among three groups. All tested products had the temperature of α-amorphous higher than 54 °C during the heating procedure, among which CF exhibited the largest amplitude of the all crests.

Temperature analysis of the gutta-percha points at a given distance from the heat source over time

The average temperature changes of all three brand products at the setting distance from the intervention of the heat source are shown in Fig. 2. When the heat source was applied at 1 mm from the thermocouple, GC exhibited the highest maximum average temperature up to 68 °C among

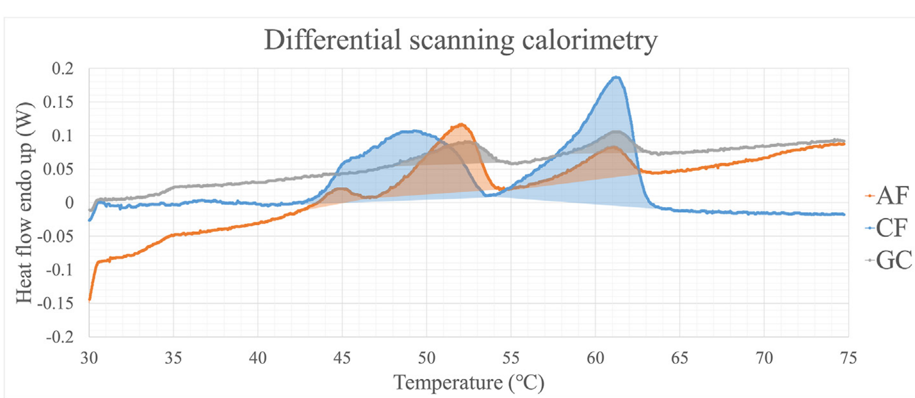

Figure 1 Thermograms of AF, CF and GC with the heating procedure. AF, AutoFit™ feathered tip gutta percha; CF, Conform Fit™ gutta-percha points for ProTaper Gold®; GC, Gutta percha root canal points. Heat flow endo up on the Y-axis indicates that endothermic events are represented in the positive direction; W, watt.

Table 1 Temperature ranges of phase transition and peak temperature values of AF, CF and GC analyzed by DSC.

			β to α phase		α to amorphous phase	
Gutta percha brand	Range (°C)	Peak value (°C)	Range (°C)	Peak value (°C)	Range (°C)	Peak value (°C)
AF	42.84–46.14	44.69	47.04–54.06	51.96	55.02–62.76	61.06
CF	–	–	42.57–53.44	49.26	54.01–63.51	61.24
GC	–	–	48.41–54.14	52.26	58.72–62.79	61.01

AF, AutoFit™ Feathered Tip Gutta Percha; CF, Conform Fit™ Gutta-Percha Points for ProTaper Gold®; GC, Gutta Percha Root Canal Points; DSC, differential scanning calorimetry.

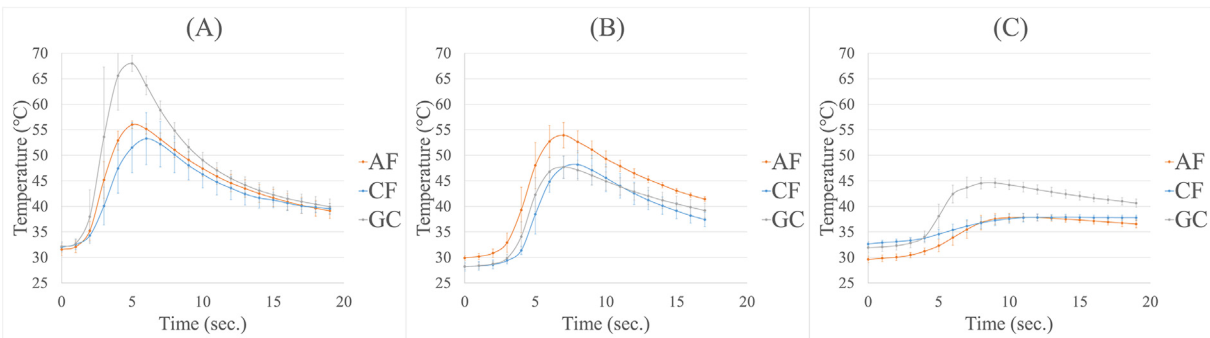

Figure 2 Average temperature of AF, CF and GC at the setting distance from the heat source over time. (A) distance set at 1 mm (B) distance set at 2 mm (C) distance set at 3 mm. AF, AutoFit™ feathered tip gutta percha; CF, Conform Fit™ gutta-percha points for ProTaper Gold®; GC, Gutta percha root canal points. The vertical bars represent the standard deviation of the mean at each second.

the tested products, and the others had the maximum around 55 °C (Fig. 2-A). When the distance between heat source and thermocouple was added to 2 mm, two maximum average temperature values were recorded in the experiment: one was around 54 °C detected from AF; the other was about 48 °C obtained from CF and GC. Nevertheless, all products showed a similar pattern of temperature change (Fig. 2-B). By contrast, when the distance between heat source and thermocouple was set at 3 mm, the maximum average temperature values of AF and CF were obviously decreased to 38 °C (Fig. 2-C). It is worth noting that the temperature of heated AF and CF gradually increased to the maximum, then reached a plateau at 38 °C for about 10 s.

Temperature analysis of the gutta-percha at the apical area in a simulated canal during the procedure of warm vertical condensation technique

The average temperature values of all three products detected from the apices of plastic blocks during WVC were shown in Fig. 3. By the 25th second, the increased

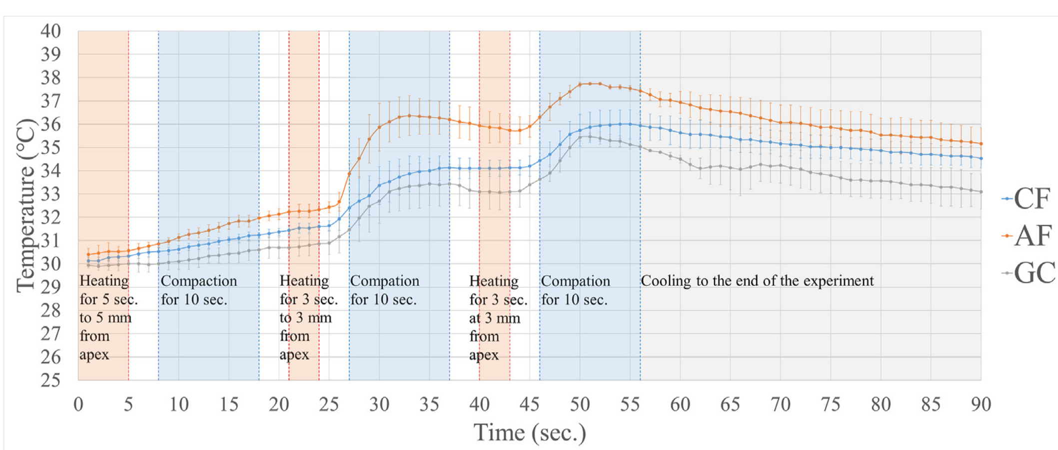

Figure 3 Average apical temperature of AF, CF and GC during the down-packing procedure. The 3-s interval between heating and compaction means time for instrument exchange. AF, AutoFit™ feathered tip gutta percha; CF, Conform Fit™ gutta-percha points for ProTaper Gold®; GC, gutta percha root canal points. The vertical bars represent the standard deviation of the mean at each second.

temperature values of AF, CF and GC were 2 °C, 1.5 °C and 1 °C, respectively. All tested products had two obvious temperature rises in which the starting points were as follows: one was at the 27th second and the other was at the 46th second. The average maximums of AF, CF and GC were 37.7 °C, 36.0 °C and 35.5 °C, respectively. The results of statistical analysis were as follows. Firstly, with all three gutta-percha points under investigation, either two of three had significant different apical temperature. Secondly, not only the elapsed time of the experiment but also the brand of the gutta-percha point significantly ($P < 0.05$) affected the apical temperature of the heated material.

Discussion

WVC has long been a popular method for achieving root canal obturation. This widely adopted technique is favored for its ability to achieve a three-dimensional seal within the root canal system, ensuring long-term success and minimizing the risk of reinfection. Nevertheless, this technique still has limitations in terms of thermal penetration depth. Several studies had demonstrated the limited temperature elevation of gutta-percha in the apical area. Goodman et al. had monitored the intraradicular temperature changes in natural teeth during the packing procedure by thermocouples, and they found significant thermal penetration effects rarely showed more than 4–6 mm from the point of the heat source.[3] Venturi et al. had also used thermocouples to evaluate the temperature change within gutta-percha during WVC in a thermostatic bath at a constant temperature of 37 °C; their work revealed that the rise in gutta-percha temperature at the apical third of the canal was negligible and that the compaction of the gutta-percha at 1.5 mm from the apex was performed only at body temperature.[4] With the development of dental materials, more and more precise dental gutta-percha was produced. The improved flow and melting characteristics of Conform Fit™ Gutta-Percha Points were emphasized by the manufacturer, and they claimed that the heat can transfer through the gutta-percha cone up to 4 mm beyond the heat source. In the present study, therefore, we investigated the thermal behavior of CF, AF and GC: their phase transition temperature and the temperature changes during the procedure of WVC were demonstrated and compared.

DSC can measure the changes in heat flow of materials under specific temperature conditions. The samples are subjected to programmed temperature changes using a heating-cooling furnace. By observing the variations in heat flow with temperature or time, it is possible to detect the thermal behavior of the materials such as reaction heat, melting point, glass transition temperature, crystallization temperature, specific heat, material stability, and more. In this study, we were trying to connect the relationship between the glass transition temperature (β-to α-form phase transition) of the products and the actual temperature changes induced in clinical situations, and glass transition temperature can be identified in a single heating run in DSC analysis. Therefore, in this case, the single heating process without the cooling one was performed. Fig. 1 and Table 1 showed two typical major endothermic peaks of all three gutta-percha points: the first region between 42 °C and 54 °C corresponded to the β-α; the second region between 54 °C and 64 °C matched the α-amorphous. Another third endothermic with lower temperature peak can be noted in the thermogram of AF. Based on the study by Ferrante et al., the existence of the third peak might be the reaction of another high temperature sensitive substance of the dental gutta-percha during the heating process.[9] Compared to the α-amorphous of dental gutta-percha, where melting occurs, the β-α is closer to the clinical manipulation during WVC. Within the β-α, AF and CF had more prominent amplitudes of the wave crest than GC. Furthermore, AF and CF had larger area under the curve in Fig. 1, which represented the greater phase transition enthalpy. It is worth noting that the enthalpy is proportional to the specific heat capacity at constant pressure under the same temperature change. In other words, it can be inferred that AF and CF had higher specific heat capacity and lower thermal diffusivity, which are consistent with those of the study by the work of Liao.[8] Hence, AF and CF might possess the better ability for thermal energy storage under the same heat energy input, which means that these brand products might be suitable for WVC due to proper operating time before cooling. According to Liao et al., CF had the lowest percentage of inorganic fraction and the highest percentage of organic fraction compared to the composition of AF and GC.[8] It is possible that the relatively low initial β-α temperature of CF is associated with its characteristic composition, and this feature makes CF easier to soften during WVC than other products in clinical situation. Further studies are needed to investigate the relationship between the composition and the phase transition temperature of dental gutta-percha cones.

In Fig. 2, the maximum average temperature of heated gutta-percha point decreased with increasing given distance away from the heat source regardless of the brands. The decreasing value of maximum average temperature of GC was 20 °C as the given distance increased from 1 mm to 2 mm. By contrast, the decreasing values for AF and CF under the same experimental condition were 2 °C and 5 °C respectively. It can be inferred that there was much heat dissipated to the surroundings for GC compared to that of AF and CF. While adding the distance to 3 mm, none of the three gutta-percha points reached a maximum average temperature higher than the glass transition temperature. In other words, the tip of the gutta-percha cannot attain a moldable temperature when heated by a distance of 3 mm from the heat source application. This finding is consistent with the result of Goodman et al. that significant thermal effects were infrequently more than 2–3 mm beyond the point of deepest penetration of the heat source.[3]

Fig. 3 revealed that employing WVC in simulated canals at a constant temperature of 37 °C led to negligible temperature increases in the apical gutta-percha. In all specimens, the temperature at apical area remained below 42 °C, which was previously identified as optimal for WVC.[4] This outcome aligns with the findings of Venturi et al., in 2002.[4] While Chen et al. found that heating and compacting gutta-percha twice at 3 mm from the apex can completely mold the gutta-percha, the disparity in results likely stemmed from differences in experimental designs. Chen et al. longitudinally sectioned the teeth and employed infrared thermography to observe temperature changes, which differs from the methodology used in our study.[6] It is noteworthy that non-contact temperature measurements using infrared thermometers may present potential accuracy issues.[10] When it comes to the heat transfer ability of CF, our findings are inconsistent with the product description by the manufacturer; the data from Figs. 2 and 3 has demonstrated that CF didn't exhibit the superior heat transfer ability when the materials were tested in a well-controlled environment and heated over a reasonably operating time. The discrepancy may result from the different experimental methods. In order to simulate the clinical environment, we have used human extracted teeth as the models in our pilot study, and it showed similar results to the present study. But the morphology variation of extracted teeth hindered the standardization of the models and therefore acrylic training blocks were applied in this research. Despite our efforts to simulate the environment of oral cavity, the lack of periodontium in the study design may affect the results. Upon the limitation of this work, neither AF or CF can attain a moldable temperature at the apical area of a simulated canal during the procedure of WVC. However, the unique shape of CF that precisely match corresponding rotary file systems may decrease the thickness of sealer and facilitate the goal of three-dimensional root canal obturation, which is a major advantage of this product.

Within the limits of this study, we concluded that AF and CF might possess the better ability for thermal energy storage under the same heat energy input. In other words, they might be suitable for WVC because of their proper operating time before cooling. However, neither AF or CF can attain a moldable temperature when heated at a given distance of 3 mm or more. On top of that, the temperature elevation of all tested groups at the apical area of a simulated canal during the procedure of WVC was very limited and didn't reach a moldable temperature. Also, CF may not be able to transfer heat up to 4 mm beyond the heat source as the manufacturer described in a simulated clinical environment with well-controlled operating time.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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