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ORIGINAL ARTICLE

Photomicrographic evaluation of the apical sealing capacity of three types of gutta-percha master cones: an in vitro study

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Abstract The purpose of this study was to compare the apical sealing capacity of three types of gutta-percha master cones of the same apical size and different tapers following root canal preparation with nickel–titanium ProTaper Universal rotary instruments and microstructural replication with System B and Obtura III. Thirty extracted human incisors having one single straight root canal (type I Weine) were instrumented with rotary ProTaper to an F3 (30/.09) and gauged to confirm a final apical size of #30. Teeth were divided into three groups ($n = 10$) to be obturated as follows: Group 1: master cone Meta 0.06 taper/AH Plus, Group 2: master cone fine-medium Autofit 0.08 taper/AH Plus, and Group 3: master cone ProTaper F3 0.09 taper/AH Plus. The chosen technique was the continuous wave of compaction (System B and Obtura III). Teeth were embedded in acrylic and incrementally reduced at 0.5 and 1.0 mm from the apical foramina in a grinding machine for metallographic samples. Sections were examined and digitally photographed under a metallographic optical microscope in normal and polarized light and the images were processed. The total cross-sectional area of the root canal, the gutta-percha/sealer/voids' areas were quantified for each sample and statistically compared using one-way ANOVA and Kruskal–Wallis tests. No statistically significant differences between groups were observed ($P > 0.05$); however, the mean percentage of the gutta-percha-filled area was slightly higher in Group 1 at both levels of observation. Despite different tapers, all the three types of cones provided a good sealing capacity in the last apical millimeter of the root canal, with good gutta-percha–sealer ratio and few or no voids.

Keywords Gutta-percha · Photomicrography · Root canal filling materials · Root canal obturation · Root canal preparation

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Introduction

Successful root canal treatment is critically dependent on the thorough cleaning and shaping of the root canal space (in order to control the pulp space infection [1, 2]), and on the tridimensional filling of the entire endodontic space with an inert, long time stable, root canal core material such as gutta-percha (in order to prevent reinfection [2, 3]). Obturation techniques as lateral condensation and warm vertical compaction of gutta-percha were widely used in the past 50 years, with good clinical results. Their predictability largely depends on the selecting and the fitting the proper gutta-percha master cone [4]. Compaction techniques using warm gutta-percha were perfected and promoted by Schilder since 1967, and were modified by

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Buchanan in 1996, in the so-called "continuous wave of compaction" technique. Both techniques require continuous tapered preparations, with a good apical control zone and properly fitted master gutta-percha cones [3–8]. These will prevent microleakage and the extrusion of the warm filling material during the compaction process [5, 8, 9].

Nickel–titanium (NiTi) rotary instruments have been developed during the past decades to create well-tapered preparations, to be obturated using any of the aforementioned techniques [10, 11]. Currently, gutta-percha cones are industrially produced to match the taper of the canal preparation created with the available NiTi rotary systems [12]. Special pluggers were designed with proper geometry to closely approximate the shape and the taper of the root canal preparation [13, 14]. Thus, the filling of the root canal became easier and more predictable, by using the proper techniques and tools.

In the past decades, various methods were used to evaluate the adaptation and the sealing capacity of different types of root fillings: leakage tests, dye penetration tests, cross-sectional studies of filled roots, bacterial penetration tests, electrochemical tests etc [7, 8, 12, 15–22]. Computed tomography (and lately cone beam CT) has also been widely used [23, 24]. Although exhaustive studies compare different methods of root canal filling, very few compare gutta-percha master cones with different tapers when used during the same root canal obturation method [25, 26].

The purpose of this in vitro study was to evaluate and to compare the apical sealing ability of three types of gutta-percha master cones, with same apical size (# 30) and different taper (0.06, 0.08 and 0.09), used in one obturation technique (the warm continuous wave of compaction with System B and Obtura III) by calculating the area filled with gutta-percha, sealer and voids, and by comparing it to the total cross-sectional area of the root canal.

Materials and methods

Samples preparation

Thirty extracted human lower incisors of similar length and diameter having one single straight root canal (Weine type I), fully formed apices and no prior endodontic treatment were included in the study. The teeth were radiographically verified as having each one straight, patent root canal. The teeth were cleansed of debris, soft tissue and periodontal tissue and stored in 0.2% thymol solution (Sigma Chemical Co., St. Louis, MO, USA) until used. All procedures were performed under the dental operating microscope OPMI Pico (Carl Zeiss AG, Oberkochen, Germany). To reduce inter-operator variables, all canals were prepared and filled by the same operator (A.B.). The access cavities were prepared using high speed diamonds and water spray. Apical patency was established by inserting a size 15 K-type file (Dentsply Maillefer, Ballaigues, Switzerland) to 1 mm beyond the apex. The working length was set 1 mm short. ProTaper Universal System Nickel–titanium rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) S1, S2 and F1–F3 were used in a crown down manner in combination with a torque controlled engine (X-Smart™ Endodontic Motor, Dentsply, UK) at 250 rpm according to the manufacturer's instructions, until the instrument F3 (30/.09) reached the working length. Apical patency was maintained with #15 K-files. The apical diameters were gauged with LightSpeed instruments (LightSpeed Technology Inc., San Antonio, TX, USA) to confirm that the final apical size was #30 for each sample, in order to be included in the study. The root canals were intermittently and copiously irrigated with 5 mL of 5.25% NaOCl at each instrument change; 5 mL of 17% EDTA was used during and after the instrumentation to remove the smear layer; 10 mL of 5.25% NaOCl was used at the end of the instrumentation for each root canal.

The canals were dried with fine-medium sterile paper points and obturated with gutta-percha and AH Plus sealer (Dentsply, DeTrey, Konstanz, Germany) using a single obturation technique, the continuous wave of condensation [6]. The teeth were randomly divided into three groups, according to the taper of the master gutta-percha cone, as follows: Group 1, ISO #30 master cone Meta 0.06 taper (Meta Dental Corp. Elmhurst, NY, USA) + AH Plus; Group 2, non-standardized master cone size FM (fine-medium) Autofit 0.08 taper (SybronEndo, Glendora, CA, USA) + AH Plus; and Group 3, F3 ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) master cone size 30, 0.09 taper + AH Plus. All cones were cut to fit at 0.5 mm short of the working length with a straight surgical blade No. 11 Bard-Parker [5, 6, 14, 19, 24, 26].

The sealer was placed into the canal on the tip of the master cone. A fine-medium 0.08 Buchanan plugger (SybronEndo Corporation, Orange, CA, USA) that could reach 4–5 mm short of the canal terminus (binding point) was selected for the down pack phase and marked using a rubber stop at the reference point [6]. The gutta-percha master cone was checked for each root canal, and coated with AH plus sealer and placed into the canal, in a slow pumping motion. The cone was severed at the canal opening with the tip of the plugger attached to the System B heat source (SybronEndo), in touch mode, with the temperature set at 200 ± 10°C and full power mode (mode 10). The heated plugger was driven through the gutta-percha cone in a single motion, to a point about 3 mm short of its apical binding point. The plugger was inactivated whilst apical pressure was maintained and then advanced apically to take up any gutta-percha shrinkage during cooling. The plugger was activated for 1 s again to separate it from the gutta-percha mass and to remove it. After the removal of the excess gutta-percha adhering to the canal walls, the middle and coronal thirds of the root canal were backfilled using thermoplasticized gutta-percha injected with the Obtura III gun (Obtura Spartan, Fenton, MO, USA), set at 200°C. Multiple waves of injection alternated with compaction using appropriate hand pluggers (sizes 9 and 10) were used to fill the root canal up to the orifice level.

The samples were radiographed in buccolingual and mesiodistal directions to confirm the quality of the root filling. All canals were sealed with Cavit (Premier Dental Products Co, Philadelphia, PA, USA) and the specimens were stored in 100% humidity and at 37°C for 1 week to allow complete setting of the sealer as in previous studies [27].

Processing and evaluation of the samples

Teeth were embedded in clear self-curing acrylic resin (Leica Historesin, Leica Instruments GmbH, Heidelberg, Germany), and were left to set according to the instructions of the producer. The resulting resin blocks were sectioned horizontally. The flat surfaces to be examined in optical microscopy were obtained by grinding and polishing of the samples in a rotary grinding machine for metallographic samples (WIRTZ Phoenix 4000, Wirtz-Buehler GmbH, Düsseldorf, Germany), under copious irrigation with running water to prevent the thermal modification of the gutta-percha within the section, at 0.5 and 1.0 mm from the apical foramen (levels 1 and 2). The protocol for incrementally reducing the examined samples was derived from the protocol described by Donath and Breuer [28] in 1982 for bone implant samples, in which the sections were obtained by slicing in a hard-tissue microtome.

Each specimen was observed under a metallographic optical microscope (Olympus BX51, Olympus Europe Holding GmbH, Hamburg, Germany) at 50× and 100× magnification, in normal and in polarized light (Figs. 1, 2). Digital micrographic images of the grinded samples were captured with an image acquisition system (Olympus Digital Color Camera UC30, Olympus Europa Holding GmbH, Hamburg, Germany). The images were analyzed and processed. The total cross-sectional area of the root canal, the area of gutta-percha, of sealer and of voids at two different levels was quantified for each group using the Olympus software analysis Auto (Olympus Europe Holding GmbH, Hamburg, Germany). The areas were recorded and compared between all three groups. The resulting values were expressed as percentages from the total cross-sectional area and were also compared between groups and levels.

This study was approved by the Commission on Bioethics, Victor Babes University of Medicine, Timisoara, Romania.

Statistical analysis

Data were expressed as mean values, standard deviations, medians, ranges, and percentages, as appropriate. One-way

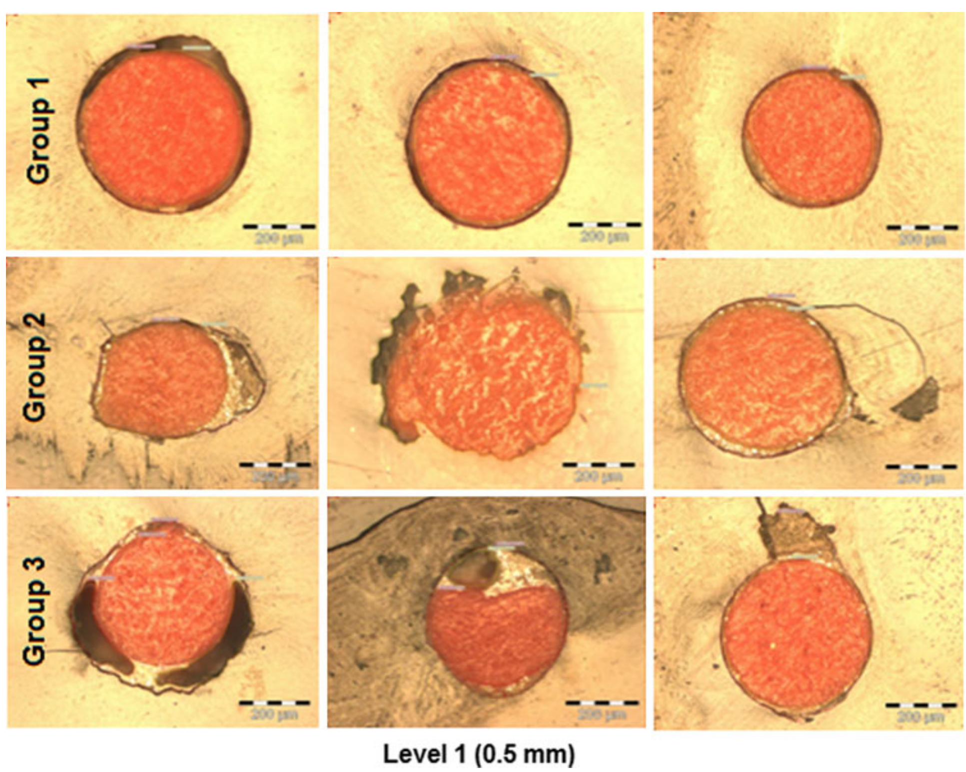

Fig. 1 Example of serial step sections from each sample group at 0.5 mm from apex (light microscopy)

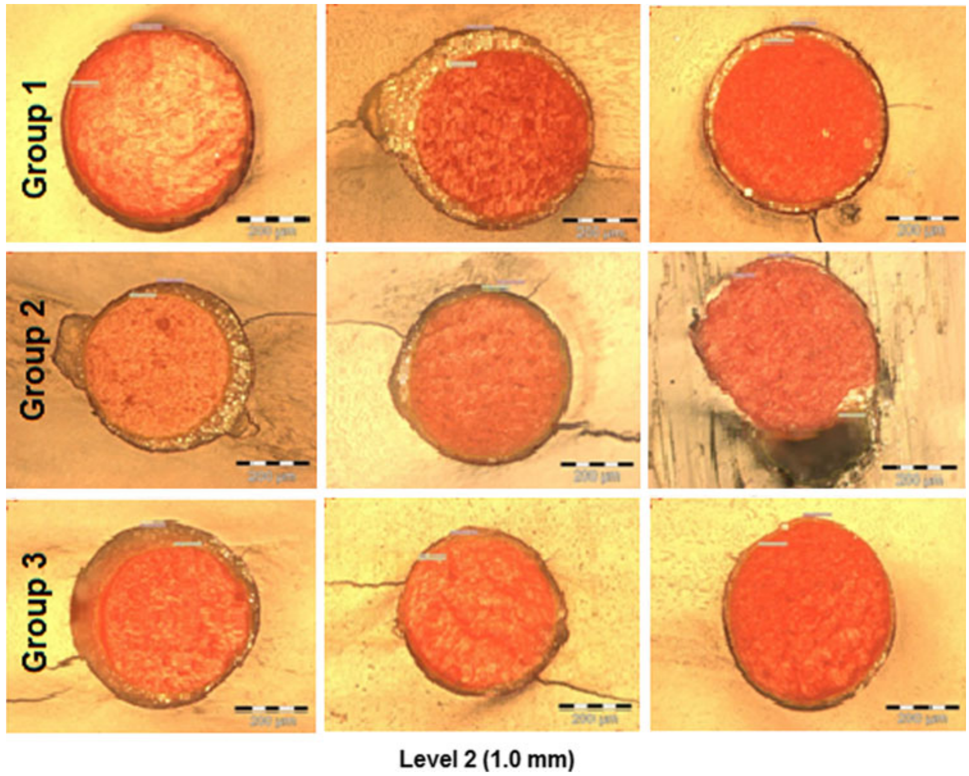

Fig. 2 Example of serial step sections from each sample group at 1.0 mm from apex (light microscopy)

Table 1 Mean values of total areas (μm^2) for all study groups at 0.5 and 1.0 mm from apex (Section levels 1 and 2)

Section level	Group	Observations	Mean	Standard deviation
1	1 (Meta.06)	10	239201.6	121271.8
1	2 (Autofit.08)	10	161344.9	52715.71
1	3 (ProTaperF3)	10	245857.9	124186.6
2	1 (Meta.06)	10	329666.5	161512.2
2	2 (Autofit.08)	10	333363	127062.7
2	3 (ProTaperF3)	10	309846.3	172714

analysis of variance (ANOVA) and the Kruskal–Wallis test were used to compare the differences between the groups. Stata 11C statistical software (StataCorp LP, Texas, USA, version 2009) was used for data analysis. A P value <0.05 was considered statistically significant.

Results

The mean values of the total cross-sectional areas of the root canals and the standard deviation for each group at levels 1 and 2 are shown in Table 1. No statistically significant differences were observed between groups, confirming the homogeneity of parameters of the selected samples.

For each section level, the percentages of the cross-sectional area of gutta-percha (gutta-percha-filled area, GFA), sealer (sealer area, SA), and voids (voids area, VA) calculated from the total cross-sectional area of the root canal are represented in Table 2.

Testing possible differences at each level showed no statistical significant results between the three groups ($P > 0.05$, Kruskal–Wallis test). However, after calculating the percentage values of gutta-percha/sealer/voids' areas from the total area, an increasing trend of mean VA was observed for the non-standardized fine-medium cones (Group 2) when compared with the other two groups.

Although no statistically significant differences were obtained between the groups, a slightly higher mean percentage of GFA was observed with the 0.06 GP master cones (Group 1) at both section levels, when compared to ProTaper F3 cones (Group 3) and non-standardized fine-medium cones (Group 2).

The area filled with gutta-percha increased from level 1 to level 2 of observation, while the area of sealer and voids decreased in all the three groups, respectively.

Table 2 Mean percentage (%) of gutta-percha/sealer/voids' areas in all three groups, at both section levels

Section level	Group 1 (Meta.06)			Group 2 (Autofit.08)			Group 3 (ProTaperF3)		
	GFA	SA	VA	GFA	SA	VA	GFA	SA	VA
1	77	22	1	59	30	11	64	26	10
2	75	25	0	64	36	0	71	27	2

For Group 1, the mean values of the gutta-percha filled area were constant at both levels, but no more voids were detected at 1.0 mm from the apex, in none of the samples. In 22 out of the 30 samples (73%), no voids were detected at level 1, and the same in 26 out of 30 (87%) at level 2.

The lowest percentage of SA was observed in Group 1 at both levels.

The comparative variations of the gutta-percha/sealer-filled area at each cut level are graphically represented in Figs. 3 and 4.

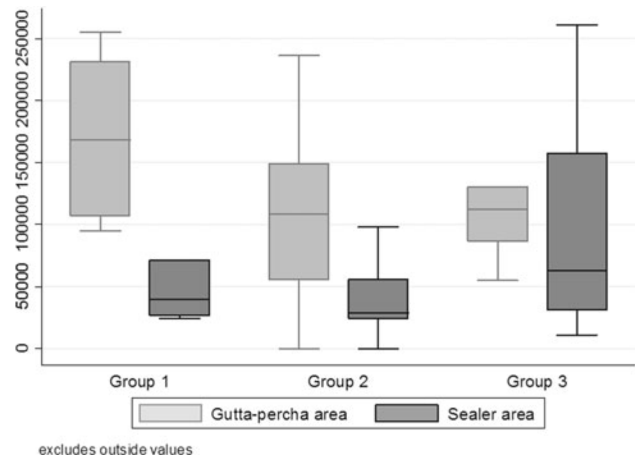

Fig. 3 *Box plots* representing gutta-percha and sealer-filled areas (μm^2) at level 1

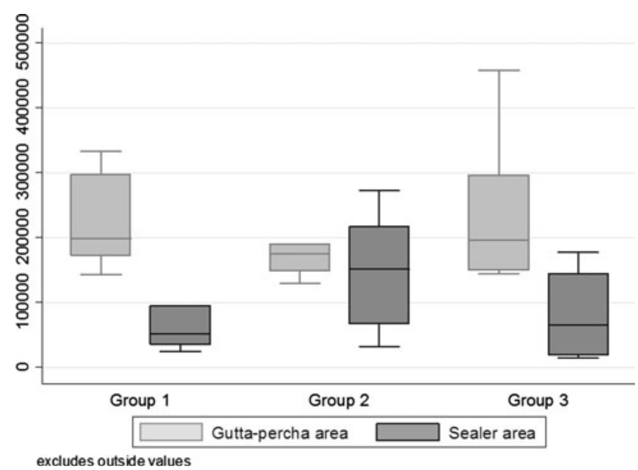

Fig. 4 *Box plots* representing gutta-percha and sealer-filled areas (μm^2) at level 2

Discussion

The continuous wave of obturation developed by Dr. L. Stephen Buchanan was a significant iteration in the obturation techniques' evolution [14]. It requires basically a single tapered plugger, used to capture the so-called "wave of condensation" at the orifice of the canal and to "ride it", without release, down to the apical extension, in a single continuous movement [6, 14]. The hydraulic forces will push the thermoplasticized gutta-percha and sealer into anatomical irregularities and lateral canals; best results in root canal filling can be achieved by maximizing the volume of core material (gutta-percha) and minimizing the amount of sealer [6, 14, 19, 27, 29]. Customized gutta-percha master cones, with the same size and taper as the preparation are fitted as the last step of the cleaning and shaping of the root canal [4–6, 26]. Only when the cone fits, the canal is thought to be ready for packing. The customization of the master GP cone is considered to be the only factor affecting the prevalence of voids in the apical third of the root canal [30]. In addition, the use of poorly fitting master GP cones is one of the causes of extrusion [3, 6, 9].

It is important that the taper of the master gutta-percha point fits the taper of the preparation; hence three types of cones, with the same apical size (ISO size 30) and different tapers, were used and compared in this study. Although the ProTaper NiTi rotary F3 instrument creates a 0.09 taper preparation in the apical third of the root canal (1–4 mm), cones with tapers of 0.06, 0.08, and specially designed cones for ProTaper with 0.09 apical taper (F3) were used in the present study, based on the fact that the heat conducted by the System B preheated plugger will thermoplasticize the master cone and, by hydraulic forces, will drive the gutta-percha into all root canal spaces, enhancing its microstructural replication [5, 6, 14].

A slightly higher percentage of GFA and the lowest percentage of SA and VA in our study were obtained with the Meta 0.06 taper cones, supposedly because the best hydraulic transmission was obtained with the FM-heated plugger.

Because the quality of the root canal filling in its apical third plays an important role in long time success of the endodontic therapy [8, 14, 15, 18, 20, 31], this study was designed to quantify the area of gutta-percha, sealer and voids only in the last apical millimeter of the root canal (at 0.5 and 1.0 mm from apex) and to provide a measure of quality.

Although in other studies no sealer was used and subsequently evaluated [19, 32], our study quantifies the detailed area of sealer and its percentage from the total cross-sectional area of the root canal. The role of the sealer is to improve the hydraulic of the gutta-percha and its adaptation to the root canal walls, and to fill the imperfections, accessory canals and multiple foramina [32].

According to the definition of obturation of the AAE [33], the ideal relative percentage of the amount of sealer when compared to the entire mass of obturation has to be about 10%. No ideal percentages of the sealer/gutta-percha ratio with respect to cross-sectional areas of the filling are given. In our study, the mean percentage of the sealer-filled areas on cross sections varied from 22 to 36%, however, a minimal mean value of 8.9% was recorded. That points out the importance of proposing an ideal relative percentage of the sealer covered area on horizontal sections, which are additionally easier to assess, rather than volumetric relative percentages. Thus, the above-mentioned results can be considered as favorable.

Another positive finding of the present study was that the voids area was much reduced or totally absent in many samples, at both levels of observation. Therefore, it seems that the continuous wave of condensation proved its efficacy in filling the root canals, with respect to the parameters evaluated, when used with well-adapted master cones of various tapers.

Conclusions

The continuous wave of compaction technique requires properly fitted gutta-percha master cones. All three different tapered GP cones used in our study provided a good sealing ability of the last apical mm of the root canal, with good ratio gutta-percha–sealer and few or no voids. Further studies focused on the impact of the shape characteristics of the gutta-percha master cones are necessary to compare the results of this technique with the lateral condensation, the vertical compaction, or with techniques that use carrier systems.

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