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Influence of Apical Patency on the Adaptation of the Master Filling Cone: A Cone-beam Computed Tomography Assessment

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Introduction: This study aimed to evaluate if the apical patency can influence the adaptation of the master cone of gutta-percha, quantifying the volume of voids and areas at the last 2 mm of the working length (WL). **Materials and Methods:** Sixty distobuccal canals of extracted upper molars were divided into 3 groups (*n*=20) based on the patency length (A: passed 1 mm beyond the apical foramen (AF), B: at the AF and C: 1 mm short of the AF) with the Easy ProDesign Logic 25/0.01 file. Each group was subdivided into 2 subgroups (*n*=10) based on the WL established to prepare the root canal (1: 1 mm short of the AF or 2: at the AF) with the Easy ProDesign Logic 25/0.05 file. After the scan, void volumes were calculated from the last 2 mm of the WL and void areas at 0 mm, 1 mm and 2 mm of the last of WL, as well as the relation between the tip and taper of the master cone with the amount of void volume and areas. To investigate statistically significant differences, we used the Kruskal-Wallis statistical test. **Results:** There were more voids in volume when patency was achieved 1 mm beyond the AF and the root canal preparation was conducted at 1mm short of the AF (A1 group). Furthermore, the same group showed more voids areas, mainly on the last millimeter of WL. **Conclusion:** Achieving apical patency at 1 mm beyond the AF followed by instrumentation 1 mm short of the AF created more voids between the master gutta-percha cone and the root canal wall, especially on the last millimeter of WL.

Keywords: Cone-beam Computed Tomography; Gutta-percha; Master Cone; Root Canal Obturation

Introduction

The patency technique, as mentioned by Buchanan [1] is the use of a small flexible K instrument that will move passively through the apical constriction without enlarging it. This procedure consists of using a narrow instrument, which reaches the foraminal length, going beyond the level of the apical constriction, without producing a shaping effect [2]. Despite the advance in automated instrumentation and the emergence of many root canal preparation systems, some instruments have been produced to perform glide path, but few have been approved for apical patency (AP) [2].

Some studies discuss if AP could influence the quality of obturation, and the majority agree that maintaining the apical constriction intact allows a better adaptation of the obturation [3, 4]; however, there are no recent studies about the influence of AP on obturation quality.

Recently, the Easy ProDesign Logic (EPL) system (BassiEndo, Belo Horizonte, Brazil) (Figure 1), with control memory thermal treatment, featured with an S-shaped cross-section, inactive tip and variable helical angles with two cutting edges was introduced. It is composed of a single file for instrumentation, having an equivalent end-point instrument for AP with a 0.01 taper and a quadruple-shaped cross-section [5]. Additionally, several patency and preparation techniques have been employed. A number of studies used the 0.01 taper instrument through the apical foramen (AF) [6, 7], and others used it only at the working length (WL) [8-10]. However, in these studies, there was no mention of the preparation's impact on root canal obturation or on adaptation of the main cone.

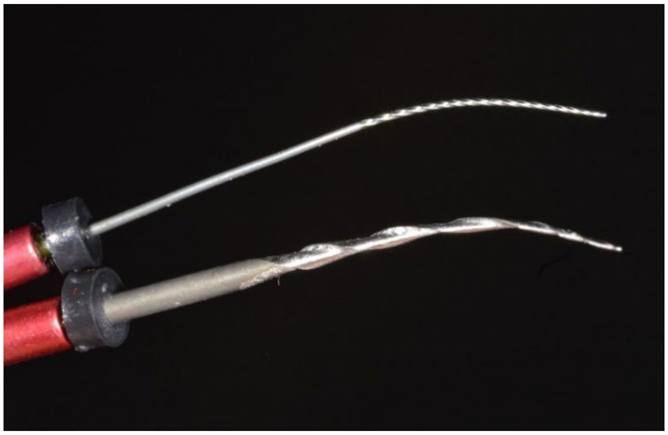

Figure 1. 25/0.01 and 25/0.05 files designed by the Easy Pro Design Logic (BassiEndo, Brazil)

Among the numerous techniques for filling root canals, all share the principle of using gutta-percha (GP) cones along with a cement to achieve a permanent seal. These depends on the adaptation of the master GP cone. The areas filled only with endodontic cement may be more vulnerable because of its physical properties.

To analyze the amount, volume, and void areas this study used cone-beam computed tomography (CBCT) for its efficient, non-invasive method of analysis that provides a 3D interpretation, offering easy access at reduced costs, good spatial resolution [11], reduced acquisition time, lower doses of radiation, and the capability to detect voids in endodontic fillings [12-17].

The presented study aimed to evaluate if the AP with the 25/0.01 instrument, followed by instrumentation with the 25/0.05 file, in different lengths, can influence the adaptation of the master GP cone at the last 2 mm from the WL by assessing the relationship between the cone number and the amount of void space, as well as volume and areas of voids at 0 mm, 1 mm and 2 mm of the WL located between the master cone of GP and the root canal walls.

Materials and Methods

The study was registered at the Ethics committee of the University of São Paulo (protocol n 2.865.395; CAAE: 95922718.0.0000.0075). Distobuccal canals of 60 human maxillary molars with an intact pulp chamber, no previous root canal treatment, fully developed root apices, single distal root canal and curvature ranging from 25º to 35º, according to Schneider's method [18], which was confirmed on baseline buccolingual and mesiodistal digital radiographic views, were used. Residual tissue and calculus were mechanically removed from the root surfaces. The roots were stored in saline until the start of the procedure.

All procedures described in this methodology were performed by a single operator. Coronal access was made with spherical diamond burs #1014 and Endo Z burs. Distal canals were negotiated by # 08 K-file with smooth movements and without applying force in an apical direction or cutting the canal walls until the emergence of its tip through the AF. Root canals in which the foramen passage was not achieved were excluded from the study. The teeth were divided into three groups (*n*=20) based on the determined WL using the AF as a reference point, to undergo apical patency (AP) or not with an automated instrument:

Group A: AP passed 1 mm beyond the AF;
Group B: AP at the AF;
Group C: AP 1 mm short of the AF, corresponding to not achieving patency.

To achieve patency, EPL 25/0.01 (BassiEndo, Brazil) was used with in-and-out movements according to the manufacturer's recommendations. The file was coupled to VDW Silver motor (VDW, Munich, Germany) with a speed of 350 rpm and 1 N/cm^2 torque. Each root canal was irrigated using a 30-gauge NaviTip needle (Ultradent Products, Inc., South Jordan, Utah, USA) with 5 mL of 1% sodium hypochlorite solution (Fórmula & Ação, São Paulo, Brazil) before and after this procedure.

Groups were subdivided into two subgroups (*n*=10) based on the WL to carry out the canal preparation:

Group A1: 1 mm short of the AF;
Group A2: at the AF;
Group B1: 1 mm short of the AF;
Group B2: at the AF;
Group C1: 1 mm short of the AF;
Group C2: 1 mm short of the AF.

Groups C1 and C2 had to be prepared at the same length since it would not simulate a realistic clinical scenario if they were prepared in different lengths.

The instrumentation was performed by introducing the EPL 25/0.05 file (BassiEndo, Brazil) into the canal apically to reach the WL according to the manufacturer's recommendations. The file was coupled to VDW Silver motor with the speed of 950 rpm and 4 N/cm^2 torque. Every time the instrument was withdrawn, the canal was irrigated with 5 mL of 1% sodium hypochlorite solution using a 30-gauge NaviTip needle. The instrument was cleaned after each introduction until the established length was achieved.

Final irrigation was performed with 5 mL of 1% sodium hypochlorite solution, 5 mL of 17% EDTA-T (Fórmula & Ação, São Paulo, Brazil) and an additional 5 mL of 1% sodium hypochlorite solution followed by drying with paper points, preparing the tooth for the tomographic scanning.

After instrumentation and drying of the canal, a 25/0.05 GP cone (Tanari (compatible with EPL); Tanariman, Manacapuru, Brazil) was inserted to the WL with clinical tweezers and assessed by means of the clinical criteria (visual, tactile, and radiographic)

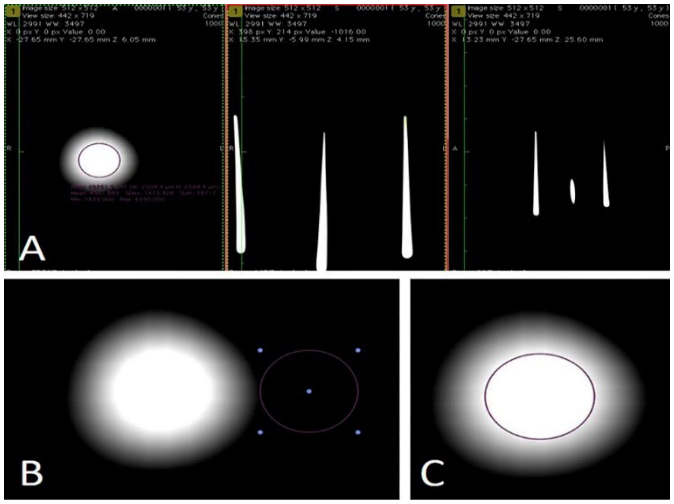

Figure 2. A) Print of the Horos program screen, showing the axial, sagittal and coronal sections of the GP cones used for a standardization, with the adjusted contrast, the axial cut of the cone 25/0.05 in the D0; *B)* Cone 25/0.05 with the axial cut in D0 showing an area designed for identification with the micrometer; *C)* Cone 25.05 with axial cut in the D0 with an area drawn exactly in the image

usually employed by dental practitioners giving an acceptance limit of 0.2 mm more or less of the length. In cases where the cone over-extended the WL, a test with a larger cone (30/0.05 or 35/0.05) was performed until it reached the required length, with a good tug back and confirmation from a digital radiography. In total, thirty-five 25/0.05 GP cones, of which the great majority was concentrated in groups C1 and C2 (sixteen) was used. Twenty 30/0.05 GP cones were used in total. Only five 35/0.05 GP cones were used and distributed on A2 and B1, and no 35/0.05 GP cone was used in groups C1 and C2.

A calibration of the GP cones compatible with EPL 25/0.05, 30/0.05 and 35/0.05 was made verifying a correct adaptation in the corresponding diameter in the endodontic millimeter ruler (Dentsply Maillefer, Ballaigues, Switzerland). The tip of the cervical segment of the cone was cut off with a scalpel blade. Coronal sealing was performed with light-cured composite resin (Charisma Classic A4; Heraeus Kulzer, São Paulo, Brazil) in order to prevent any displacement of the cone during the tomographic evaluations.

All specimens were scanned using CBCT with a PreXion 3D unit (PreXion Inc., Yoshida Dental, Tokyo, Japan) at two stages (before and after adaptation of the master GP cone). The teeth were mounted on a utility wax support placing 5 teeth at a time with the aim of putting the tooth in the same position for all the scans. The scan was performed with a voxel size of 0.1 mm, field of view of 5 cm; High-resolution/High-density; the tube voltage set at 90 kVp, 4 mA, and an exposure time of 37 sec. The images were reconstructed in a set of 3D data and then exported in DICOM format for later analysis of the results.

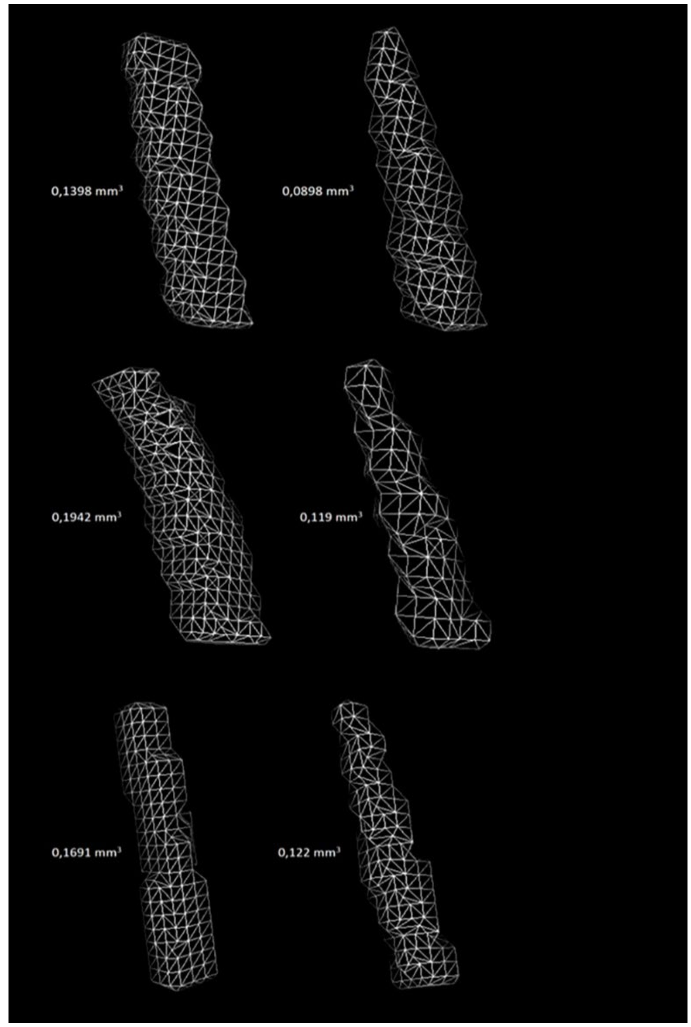

Figure 3. Comparison between canal volumes before and after placement of the gutta-percha cone for each group

Before the images' analysis, a contrast parameterization was performed to obtain a better data accuracy. Measurements were taken at 0 mm, 1 mm and 2 mm from the tip of the GP cones using a micrometer, and then CBCT scans of the same cones at the same levels were performed. Therefore, the ideal contrast parameters were set for GP visualization (WINDOW LEVEL: 2991, WINDOW WIDTH: 3497) (Figure 2).

After the reconstruction, the images were viewed and analyzed using an image processing software (Horos Project, Version 3.0) (Horosproject.org, Annapolis, MD, USA). The volume of the canal before and after the adaptation of the master GP cone that was not filled with the GP cone along the last 2 mm of the WL was analyzed. The void volume (Vol voids) between the GP cone and root canal wall was determined by subtracting the cone volume (V cone) from the volume of the canal preparation (V pre); Vol voids=V pre V cone (Figure 3).

Figure 4. Print of the Horos program screen with the axial cuts of the tooth 8 with the 2 mm areas of the instrumented canal with and without GP

The areas at 0 mm, 1 mm and 2 mm of WL before and after adaptation of the master GP cone that was not filled was analyzed as well. The image of the axial section of the tooth in these three measurements was chosen. The void areas between the GP cone (A cone) and root canal wall were determined by subtracting the cone area from the area of the canal preparation (A pre); Void areas=A pre_A cone (Figure 4).

Differences in the calculated measures were submitted to a Kruskal-Wallis test at a significance level of 5%.

Results

Table 1 shows the median±SD for the void volumes and areas at 0 mm, 1 mm and 2 mm between the GP cone and root canal wall for each GP cone number (25/0.05, 30/0.05, and 35/0.05) using the Kruskal-Wallis test. Results showed no significant statistical difference in volume and in the areas.

The median±SD for the volume and areas at 0 mm, 1 mm and 2 mm of all subgroups using the Kruskal-Wallis test is shown in Table 2. These results showed a statistically significant difference ($P<0.05$) between A1 and A2 group regarding the void volume. Results also showed a statistically significant difference ($P<0.05$) between A1 and B1 group, A1 and B2 group, and A1 and C1 group regarding the void area at 0 mm.

Discussion

There are many controversies in the literature about achieving apical patency or not. Machado *et al.* [19] indicates that apical patency may not be strictly necessary, as there is no robust clinical or scientific evidence showing a direct correlation between apical patency and the success of endodontic treatments of necrotic teeth with apical periodontitis.

This study aimed to evaluate how AP can affect the adaptation of the master GP cone, leaving larger amounts of voids, which should be filled with endodontic cement.

We used thirty-five 25/0.05 GP cones, twenty 30/0.05 GP cones and five 35/0.05 GP cones. Moreover, most of the 25/0.05 GP cones were used in the groups with no apical patency (C1 and C2) and no 35/0.05 GP cones were used in the aforementioned groups. This demonstrates that not achieving AP and the instrumentation following the length established will allow a better adaptation of the GP cones compatible with the instrument used.

To achieve patency, we used automated instruments with a #25 tip diameter. As mentioned by other authors, regardless of the type of the instrument employed (stainless steel manual K-files or nickel-titanium automated instruments), the patency maneuver may result in different degrees of foramen deformation. This deformation possibly increases as the diameter of the instrument used increases [20].

Iqbal and Ku [21] mentioned that the superelastic property that allows nickel-titanium instruments to improve the preparation is also a disadvantage in preparing the apical third, especially in oval-shaped canals. The nickel-titanium files exert little pressure against the buccal and lingual walls, resulting in circular preparations surrounded by unprepared areas, causing a false adaptation of the GP cone and leaving void spaces. In addition, Pinto *et al.* [10] noted that in nickel-titanium instruments with control memory heat treatment, a greater malleability results in reduced hardness and the possibility of leaving untouched areas.

The images were captured using a Prexion 3D scanner, which improves the resolution, making the determination of minimum changes in dental structures, such as the root canal, more accurate [11]. Recently, with the evolution of a new software for visualization of CBCT images, it has demonstrated its efficiency for the analysis of the obturation quality [8, 13-17, 22], also volume measurement is possible with the Horos software.

In Table 1 we can observe the volumes and areas of the remaining voids for each GP cone number, where no significant differences (P<0.05) were found between the groups, but we noticed a slight difference in void volume when the 25/0.05 GP cone was used, which was smaller compared to the void volume for the 30/0.05 GP cone. We also observed a smaller void area at 0 mm and 2 mm from the WL when using the 25/0.05 cone compared to the other cones. This can be explained by the replacement of the 25/0.05 GP cone with a larger cone when it exceeded the required measurement; in some cases, even if the cone was visually at the pre-established limit, with tug back, and it had reached the length in the radiography, the cone may have undergone a distortion adapting below the desired limit. Jeon *et al.* [23] mentioned that when the master cone is fitted in the middle or coronal third, it may give a false impression of apical fitting. In addition, there are studies demonstrating the poor relation between radiography and CBCT, where some fillings may have reached the pre-established length on the radiographs, but with visualization in CBCT, they are under-extended or over-extended obturations [24]. The cone may also undergo slight distortions as it enters the root canal, suffering compression by the root walls in other areas, modifying the original shape of the cone.

The results presented in Table 2 compares all the subgroups. A significant difference (P<0.05) in volume between A1 and A2 group can be observed. Due to this, achieving AP in the A1 group 1 mm beyond the AF causes a wear on the root canal and the instrumentation will penetrate 1 mm less than the patency instrument, causing spaces to remain unassembled and creating more voids in the testing of the master GP cone compared to A2 group.

In the same table, at the 0 mm area we observed significant differences (P<0.05) between A1 and B1, and B2 and C1 groups. Based on the same justification, we conclude that in the groups B1, B2 and C1 the wear was minor, because the 25/0.05 instrument penetrated less in length.

The results of this study are complementary to the results of Dandakis *et al.* [4] which indicated a greater penetration of dye when achieving apical patency. The authors mentioned that not achieving the AP could avoid excessive wear and therefore extrusion of obturation material. In addition, Holland *et al.* [3] observed more cases of overfilling in the groups where the AP was achieved, assuming that the periodontal connective tissue in the cemental canal offers some resistance to sealer extrusion. Similarly, Albuquerque *et al.* [25] observed more filling material extrusion in the group with foraminal enlargement up to 1 mm beyond the foramen, with K-type files #15 up to #30.

Table 1. Void spaces by cone number [Median (Standard Deviation)]

	N of cone			*P-value*
	Cone #25.05	**Cone #30.05**	**Cone #35.05**	
Void volume (mm^3)	0.0713 (0.047)	0,0895 (0.089)	0.0491 (0.107)	0.674
Void area at 0 mm (mm^2)	0.0393 (0.038)	0.0594 (0.066)	0.0928 (0,042)	0.175
Void area at 1 mm (mm^2)	0.0391 (0.028)	0.0363 (0.041)	0.0462 (0.061)	0.811
Void area at 2 mm (mm^2)	0.0139 (0.035)	0.0274 (0.059)	0.0191 (0.121)	0.32

*Kruskal-Wallis; * P<0.05*

Table 2. Void spaces for all groups [Median (Standard Deviation)]

	Groups						*P-value*
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	
Void volume (mm^3)	0.1017 (0.100)^{A}	0.0455 (0.026)^{B}	0.0602 (0.078)^{AB}	0.0388 (0.045)^{AB}	0.0597 (0.058)^{AB}	0.0961 (0.057)^{AB}	0.03 *
Void area at 0 mm (mm^2)	0.1049 (0.062)^{A}	0.0465 (0.030) ^{ABCD}	0.0330 (0.030)^{B}	0.0122 (0.042)^{C}	0.0332 (0.059)^{D}	0.0771 (0.040)^{ABCD}	0.006*
Void area at 1 mm (mm^2)	0.0488 (0.044)	0.0238 (0.018)	0.0461 (0.044)	0.0374 (0.025)	0.0296 (0.027)	0.616 (0.038)	0.101
Void area at 2 mm (mm^2)	0.0313 (0.072)	0.0149 (0.012)	0.0199 (0.089)	0.0125 (0.031)	0.0175 (0.035)	0.0356 (0.051)	0.653

*Different letters indicate significant difference between the experimental groups; Kruskal-Wallis; * P<0.05*

Our study found more voids in the areas at 0 mm from the WL, which is in agreement with other studies. Haikel *et al.* [26] observed greater leakage in the last 3 mm of the apex, and as the canal progresses towards the apex, the filling tended to be more vulnerable.

Our results are in contrast to those of Hembrough *et al.* [27], who evaluated the filling quality, where the AP was achieved and the canal was obturated using cones with different tapers. They found that achieving AP made no difference on void spaces in the apical third. They also found very thin cement thicknesses in that area. This can be attributed to the #10 K instrument used for achieving AP, which may have caused less wear. The study was also performed by the sectioning method, which may have influenced the results.

Some factors such as the anatomy of the teeth (oval or irregular shapes of the foramen; regardless of the thorough selection process) [28, 29], might justify the presence of large voids in many cases. Ideally, all teeth should have very similar shapes. Wu and Wesselink [30], evaluated the quality of obturation of non-instrumented recesses in oval canals, concluding that non-instrumented spaces may not be completely filled with GP cones. The standardization of GP cones may also have influenced the results of the presented study, since we observed many non-standard cones, presenting minimal differences [23], even though they come standardized by manufactures.

The presented study also encountered limitations inherent to the execution of *in vitro* studies, and despite our effort to simulate conditions as close as possible to that of clinics, the results should be extrapolated to clinical practice with caution.

Conclusions

With the limitations of this *in vitro* study in consideration, it was concluded that the achievement of AP at 1 mm beyond the AF with the EPL 25/0.01 file, when followed by instrumentation at 1 mm short of the AF with the EPL 25/0.05 file, can cause larger amounts of voids between the master GP cone and the root canal walls, especially on the last millimeter of the WL.

Conflict of Interest: ‘None declared’.

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