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Micro-CT evaluation of two different root canal filling techniques

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Abstract. – OBJECTIVE: The aim of this study was to compare the frequency and volume of voids in root canals obturated with two different filling techniques using micro-computed tomography (micro-CT).

MATERIALS AND METHODS: Forty single-rooted permanent teeth were selected and decoronated. The roots were instrumented with WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) to a large size until working length and irrigated with 5.25% sodium hypochlorite and 17% EDTA. Then, the samples were filled using a single-cone (n = 20) or the GuttaCore technique (n = 20). The presence and volume (mm^3) of voids (internal, external, and combined) was calculated in the coronal, medium, and apical thirds using micro-CT (SkyScan 1072; SkyScan, Kartuizersweg, Belgium). Statistical analyses were performed using the χ^2-test and Kruskal-Wallis tests (p<0.05).

RESULTS: The frequency and total volume of voids in the middle third and the external voids in the coronal third were statistically significant (p<0.05). Within the same group, both techniques (single-cone and Guttacore) showed statistically significant differences in external and internal voids (p<0.05).

CONCLUSIONS: The GuttaCore technique showed better results in the coronal and medium thirds than the single-cone technique. Our results showed that the single-cone and GuttaCore techniques were comparable in the apical third (p>0.05).

Key Words
Micro-CT, Gutta-percha, Canal obturations.

Introduction

The success of an endodontic treatment depends on the elimination of microorganisms from an infected root canal via canal debridement, followed by an effective disinfection to promote healing of the periapical tissue[1]. The root canal obturation is a tri-dimensional filling of the canal, historically achieved with gutta-percha and sealer to prevent a reinfection of the canal space[2,3]. The presence of voids inside an inadequate root canal obturation can contain bacteria. These could feed from the nutrients present in the periapical region or lateral canal, which can negatively influence the treatment outcome[4,5].

Several obturating techniques have been proposed to guarantee an efficient root canal filling while being, at the same time, easier to perform. The single cone, a cold gutta-percha technique, consists of a cone matching the size of the last engine-driven nickel-titanium instrument reaching the apex[6]. Several authors have been investigating the quality of this kind of root canal obturation in comparison with other techniques. The single-cone technique and cold lateral compaction showed comparable results in simulated canal curvatures of 30° and 58° in resin blocks or in mesio-buccal canals from extracted maxillary first molars[7]. More voids were found in root canals at 2, 4, and 6 mm from the apex of samples filled with a single cone compared to root canals filled with the System B and Thermafil

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techniques[8]. However, according to other authors, the single-cone apical sealing was more efficient *in vitro* than the System B/Obtura II and BeeFill apical sealing[9].

Recently, a thermoplasticised gutta-percha core-carrier system with a cross-linked thermoset gutta-percha carrier named GuttaCore (Dentsply Maillefer, Ballaigues, Switzerland) has been introduced.

A carrier-based system could create fewer voids than lateral condensation[10]. Additionally, the presence of a cross-linked gutta-percha core in the GuttaCore system favours and accelerates the retreatment of root canal filling[11]. Moreover, the push-out bond strength of the GuttaCore carrier was calculated to be much higher than in the traditional core-carrier system[12].

The aim of this study was to compare the volume and the distribution of voids in root filling on extracted teeth using the single-cone and GuttaCore techniques using micro-CT. The null hypothesis tested was that there would be no statistically significant difference in terms of voids between the two studied techniques.

Materials and Methods

Materials

Forty extracted single-rooted permanent teeth from adult patients (twelve lower incisors, twelve upper incisors, four canines and twelve lower premolars) were selected for this study after examination under a stereomicroscope at 12x magnification (Stemi SV6; Carl Zeiss, Oberkochen, Germany). The teeth harbouring roots with fractures, defects, resorptions or open apices were excluded. The selected teeth were initially placed in a 5.25% sodium hypochlorite solution, and the periodontal ligament was removed with a scaler. Then teeth were washed under tap water and stored in a 0.2% sodium chloride and thymol solution.

Bucco-lingual (BL) and mesio-distal (MD) radiographs were taken using a digital sensor (version 2.6; CDR-Schick Technologies Inc., Long Island City, NY, USA) for studying root canal anatomy. Teeth with abnormal endodontic anatomy and/or excessively wide canals were excluded.

The crown of each tooth was cut with a diamond bur obtaining a stable reference point for working length measurement and a simple access for the instruments. A stainless-steel size 10 K-file (Dentsply Tulsa Dental, Tulsa, OK, USA) was inserted under a stereomicroscope until it became visible at the apex and the working length was calculated subtracting 0.5 mm.

Pathfiles Nickel-Titanium rotary instruments were used for glide-path and WaveOne Large (Dentsply Maillefer, Ballaigues, Switzerland) was used for canal shaping. Irrigation with 2.5 mL of a 5.25% sodium hypochlorite solution (NaOCl) was performed constantly during canal instrumentation. All samples were rinsed with 5 mL of 17% EDTA (Pulpdent, Watertown, MA, USA) activated with Endoactivator (using tip size 40) for 120 s and finally rinsed abundantly with a 0.9% NaCl solution. Sterile WaveOne (Large size) paper points were used to dry root canals. Then, the samples were randomly divided into two groups (n = 20):

Group 1: Single-cone technique

AH-Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany) was spread with a paper point on root canal walls. A WaveOne gutta-percha master cone large size was coated with sealer and inserted into the canal. A radiograph was taken to assess the filling and the coronal part of master cone was cut using a heated plugger and compacted.

Group 2: GuttaCore obturation system

A verifier file (Dentsply Tulsa) corresponding to size 40 WaveOne GuttaCore obturator was assessed to reach 0.5 mm from the working length. The root canal wall was coated with AH Plus sealer with a sterile paper point. The size 40 WaveOne GuttaCore obturator was used. The obturator was placed into a Thermaprep Plus oven (Dentsply Tulsa Dental Specialities) and inserted until reaching the working length with constant pressure. The handle of the obturator was cut with diamond bur and the filling checked with a radiograph.

All the teeth were instrumented and filled by a single operator. The samples were stored at 37°C under a 100% of humidity atmosphere for 7 days to allow the sealer to set completely.

The analysis of each tooth consisted of approximately 2 hours of scanning and 2 hours of reconstruction procedures. A desktop X-ray microfocus CT scanner (SkyScan 1072; SkyScan, Kartuizersweg, Belgium) was used to scan the teeth using a voltage of 100 kV with a current of 98 μA to achieve a pixel size of 19.14 μm, corresponding to a 15X magnification. The data sets were acquired

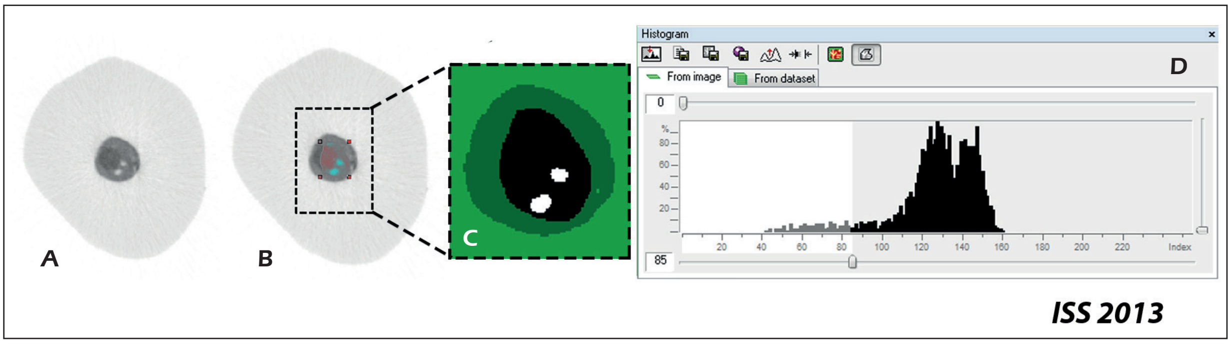

Figure 1. Example of internal void (**A**); selection of a region of interest that is, in this case, a void (**B**); image binarized (**C**) using a greyscale histogram (**D**).

using a 1 mm thick aluminium plate filter over a rotation range of 180° (with 0.45° rotation step) with a 5.9 s exposure time.

Digital data were further elaborated using a reconstruction software (NRecon V1.4.0; Sky-Scan) providing new axial cross sections of 19.1 µm x 19.1 µm pixel size. Successively, the data were processed using the CTan software (Sky-scan) (Figure 1). Micro-CT analysis was used to quantify the volume of the voids distributed inside the filling material (internal voids), along the canal walls (external voids), and into the materials communicating with the canal walls (combined voids)[13] (Figure 2). These data were obtained by considering 9 mm as the standard range (total voids) and for the three areas separately, namely the apical (0-3 mm), medium (3-6 mm), and coronal third (6-9 mm).

Statistical Analysis

The parametric distribution of continuous variables was tested using the Shapiro-Wilk test. Because variables showed a non-parametric distribution, inter-group and intra-group comparisons were performed using the Kruskal-Wallis test. Distribution differences in the discontinuous variables were assessed using the x^2-test. The significance level was set at $p<0.05$. Since there are no previous quantitative studies in literature, it was not possible to perform a power analysis but we doubled the samples of a similar study[14].

Results

General Remarks

The total average volume of internal, external and combined voids was 0.056 ± 0.132 mm^3 for the single-cone technique and 0.012 ± 0.033 mm^3 for GuttaCore technique. Concerning the total average volume in the apical, medium, and coronal parts of the canal, the lowest value was obtained using the GuttaCore technique in the medium third (0.0041 ± 0.0094 mm^3, $p>0.05$).

Comparison Among Different Techniques

The average of the volume and the frequency of internal, external and combined voids for the single-cone and GuttaCore techniques are reported in Table I. The single-cone technique showed the best average for the internal voids of the apical

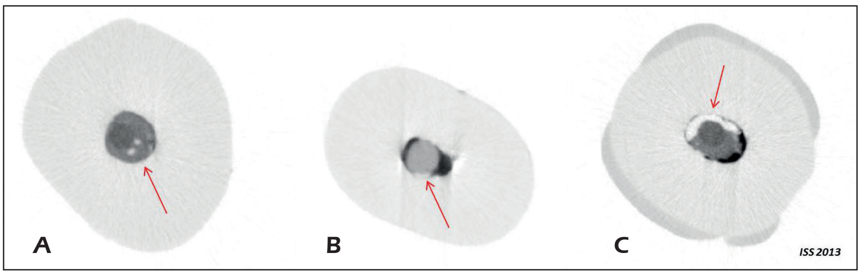

Figure 2. Classification of voids as internal (**A**), external (**B**), and combined (**C**).

Table I. Presence (Frequency), Mean (mm^3), Standard Deviation, Minimum and Maximum of internal, external and combined voids at apical, medium and coronal level of root canal in Single-Cone and Guttacore technique. More than one area of internal, external or combined could be detected for each slide-sample.

	SINGLE-CONE – n=20[1]					GUTTACORE - n=20[1]				
	Frequency	Mean	SD	Min	Max	Frequency	Mean	SD	Min	Max
Apical										
Internal voids	5	0.00008	0.00019	0	0.00079	4	0.00015	0.00060	0	0.00265
External voids	4	0.00162	0.00618	0	0.27777	5	0.00124	0.00476	0	0.20850
Combined voids	8	0.04912	0.15822	0	0.69906	8	0.00802	0.02829	0	0.12361
Total voids	17	0.05083	0.15785	0	0.69906	17	0.00939	0.02829	0	0.20850
Medium										
Internal voids	6	0.00044	0.00108	0	0.00108	3	0.00004	0.00012	0	0.00041
External voids	10	0.01215	0.00119	0	0.00428	6	0.00266	0.00881	0	0.03863
Combined voids	12	0.03913	0.12079	0	0.54006	10	0.00139	0.00290	0	0.01156
Total voids[2]	28	0.05173	0.11923	0	0.54006	19	0.00410	0.00947	0	0.03985
Coronal										
Internal voids	8	0.00014	0.00032	0	0.00111	9	0.00046	0.00087	0	0.00267
External voids[2]	12	0.01068	0.01987	0	0.07570	3	0.00056	0.00194	0	0.00828
Combined voids	12	0.05734	0.11900	0	0.47244	11	0.02338	0.04973	0	0.19508
Total voids	32	0.06817	0.12261	0	0.47244	23	0.02440	0.04943	0	0.19578

[1]Difference among Apical, Medium and Coronal levels for external void was statistically significant either when analyzed as dichotomous variable (χ^2-test<0.05) either when analyzed as a quantitative variable (Kruskal-Wallis test p<0.05).
[2]Difference between groups was statistically significant either when analyzed as dichotomous variable (χ^2-test<0.05) either when analyzed as a quantitative variable (Kruskal-Wallis test p<0.05).

third (p>0.05), whereas the GuttaCore technique was superior for the internal voids of the medium third of the canal (p>0.05). The single-cone technique showed the worst value for the combined voids in the coronal part of the canal (p>0.05). Statistically significant differences were found between filling techniques for the total voids in the middle part of the canal (p<0.05).

When the volumes of the voids were considered as dichotomous variables, the single-cone technique showed a high frequency of combined and external voids in the middle part of the canal (p>0.05) and in the coronal third (p<0.05), respectively. The GuttaCore technique showed a low frequency of external voids in the coronal third of the canal (p<0.05).

Comparison Within the Same Filling Technique

The single-cone technique showed statistically fewer external voids (χ^2-test between different levels: p<0.05) in the apical third than in the medium and coronal portions of the samples. However, no statistically significant difference was found between the coronal, medium and apical thirds in the presence of internal and combined voids (p>0.05).

The GuttaCore technique produced statistically significant differences between the coronal, medium, and apical thirds in the presence of internal voids (p<0.05). However, no statistically difference was observed in the external and combined voids at all three different levels.

For the single-cone technique, statistically significant differences were found in the average volumes of external voids between the apical, medium, and coronal thirds (Kruskal-Wallis test, p<0.05).

Discussion

The aim of an endodontic treatment is the instrumentation and disinfection of a root canal followed by an adequate root canal filling[15]. A complete three-dimensional root canal obturation avoids the ingress of bacteria and improves the outcome of root canal treatment[16]. Today Cone Beam Computer Tomography (CBCT) can provide *in vivo* an accurate evaluation of the quality of the root canal filling[17].

In this study, the volume and the presence of voids were investigated in samples filled with two different obturation techniques using micro-CT analysis.

The efficiency of micro-CT in endodontics to evaluate *in vitro* root canal filling has been investigated in previous studies[3,18,19]. The use of this non-destructive technique led to a rapid visualization of voids and 3D reconstruction of root canal filling (Figure 3) and avoided causing irreversible damages to the specimens, similar to those usually caused by other procedures, such as the cross-section[7] of the root surface that can cause the smearing of the filling[6]. Moreover, a 2D method cannot be as precise as a 3D evaluation[3]. Conversely, according to other authors, micro-CT axial sections showed a minor resolution compared with electronic scanning microscope in discerning the interfacial gaps from the interfacial and intracanal voids[14].

At the coronal level, the single-cone technique showed a high frequency of total voids and a statistically significant difference with the GuttaCore in terms of external void ($p<0.05$) frequency and volume. These results are in accordance with other studies showing a greater coronal leakage with the single-cone technique due to the greater amount of sealer used in comparison with termoplasticised gutta-percha and lateral compaction[6,20]. The single-cone technique poses a major risk of void formation from an imperfect adaptation of a single master cone to the middle and coronal third of an irregular-shaped canal[21].

Again, in the middle third, the GuttaCore exhibited the lowest frequency and volume of total voids ($p<0.05$). This result is in agreement with previous studies. Indeed, Li et al[14] found that the GuttaCore technique produced excellent results in comparison with a cold gutta-percha technique at 5 mm from the anatomical apex. Even though our study is similar, in this case the cold gutta-percha technique tested was a cold lateral compaction. Schäfer et al[22], using a destructive method of investigation, reported a statistically significant difference in the percentage of voids between the GuttaCore and single-cone techniques at 4 mm. However, in contrast with our study, Schäfer's samples, filled with GuttaCore, were voids free. The capacity to flow into the lateral canal of the thermoplasticised gutta-percha using the core-carrier techniques and the ability to better replicate root canal anatomy may explain this result[10]. The null hypothesis of this study was rejected.

Figure 3. 3D model of a sample filled with the Guttacore technique showing the gutta-percha *(red)*, cement *(green)*, and voids *(white)*.

At the apical level, no significant differences in terms of frequency and volumes were found ($p>0.05$). This result has been confirmed by other studies[8,23] recognising that the single-cone technique allows for filling the last 2 mm as well as the warm gutta-percha technique. However, the limitation of this study is that the volume and the frequency of voids were evaluated without considering the volume of the root canal filling and sealer.

Within the same filling technique, the GuttaCore technique produced a statistically significant difference in terms of internal void, while the single-cone technique in terms of external voids in the apical, medium and coronal third ($p<0.05$). However, the internal voids inside the filling material could be considered less relevant than the external and combined voids because these are closed and unfavourable environments for bacterial growth[13].

Our results confirmed that single-cone is a simple technique, suitable for a narrow and circular canal or for a canal prepared with a tapered circular preparation[7]. This technique cannot be employed in larger diameter root canals and oval-shaped canals to avoid the formation of voids, mostly in the apical and middle third. Indeed, the presence of voids in these parts of canal tooth results in a significantly worse outcome than for a filled tooth with voids in the coronal third or without voids[24].

Conclusions

Even if no samples were free of voids in this study, the GuttaCore technique showed a more homogenous filling of the canal and can be used with all canals to obtain a very good obturation.

The GuttaCore technique *in vitro* is better and more adaptable than the single-cone technique. The GuttaCore is also an easy technique, representing a valuable alternative to warm vertical compaction, which is considered by some clinicians as a more sensitive and difficult technique[14].

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Conflict of Interests

The Authors declare that they have no conflict of interests.

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