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ORIGINAL ARTICLE

Influence of apical taper on the quality of thermoplasticized root fillings assessed by micro-computed tomography

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Abstract The objective of this study is to study the influence of final canal taper on the sealing ability of Real Seal 1 by using micro-computed tomography (micro-CT). Fifty-four single-rooted teeth were instrumented to apical size of 40 taper 4, 6, and 8. The teeth were divided into three groups. All teeth were filled with Real Seal 1 (RS1; SybronEndo, Orange, CA, USA). Roots were then scanned with mico-CT, and volume measurements of voids in the apical third and in sections at 1, 3, and 5 mm from the apex were calculated in the obturated roots using specialized CT software. Measurements were analyzed statistically by using ANOVA followed by Bonferroni multiple comparison correction. Data analysis showed that 0.08% and 0.06% apical tapered RS1 obturations provided better results than 0.04% tapered samples. The present study showed that none of the root canals filled teeth were gap free. Mean percentages of voids were significantly higher with Real Seal 1 taper 0.04% ($P=0.05$).There was no significant difference with 0.06 and 0.08 final taper. For Real Seal 1 technique 0.06 and 0.08 tapered preparations seem to be more optimal. At 1 mm, final taper 0.08 showed less voids and gaps than the two other final tapers. In our daily practice, enlarging the apical third (last 3 mm) of root canals to an 8% taper is necessary to achieve a better sealing ability and thus long-term success for our root canal obturations.

Keywords Real seal 1 · Taper · Micro-CT · Voids

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Introduction

One of the keys to successful root canal therapy is to adequately fill the prepared root canal space in order to prevent future bacterial contamination/recontamination of the canal space [1–3]. Conventional root fillings consist of a core material that closely conforms to the canal wall and sealer cement that seals the interface between the core and root canal wall. Several clinical methods can be used to accomplish this procedure [4, 5]. In recent years, a number of endodontic materials have been introduced attempting to provide a better seal of the root canal [5].

Real Seal 1 (RS1) is a carrier-based delivery system using Resilon as the filling material. RS1 coats the outside of the core and is thermoplasticized by a proprietary oven. According to the manufacturer, by using a resin-based filling material, a resin-based sealer, and a resin-based core, RS1 creates a homogenous fill that significantly enhances sealing and prevents leakage.

In the field of endodontic research, micro-CT technology is frequently used for the evaluation of root canal anatomy and for the assessment of root canal morphology after instrumentation. Reports of obturated root canals being investigated by micro-CT (Nielsen et al. 1995, Dowker et al. 1997) gave detailed evaluation of endodontic obturation [6]. Among these studies, only few compared micro-CT results with conventional histological sections calculating voids qualitatively and quantitatively [6].

In order to evaluate the sealing ability of RS1, the percentage of volume of voids and gaps in root canals prepared with three different taper sizes (4%, 6%, and 8%) was measured by using micro-CT at 1, 3, and 5 mm from the apex. The null hypothesis entails that there would be no voids between canals obturated with different tapers.

Materials and methods

Selection and preparation of teeth

Fifty-four single-canal freshly extracted teeth, with a curvature less than 10° determined by Schneider's technique [7, 8], were collected and kept in 10% buffered formalin. The teeth were marked then decoronated to achieve a length of 16 mm perpendicularly to the long axis using a cylindrical diamond bur. Once access to the pulp chamber had been gained, the patency of the apical foramen was checked using a stainless steel no. 10K-file (Dentsply Tulsa Dental, Tulsa, OK, USA). The working length was measured by inserting the instrument into the root canal until it was visible at the apex and subtracting 0.5 mm. After hand files introduction and establishment of a glide path, TF files no. 25 taper 4 prepared group 1, no. 25 taper 6 group 2, and no. 25 taper 8 group 3. In order to have all apical preparations to 40/100, the use of TF was followed by the use of GT (Dentsply Tulsa Dental) rotary files. In this way all groups were prepared to the same apical size of 40/100 but with different tapers of 4%, 6%, and 8% with respectively GT no. 40.04, no. 40.06, and no. 40.08. After preparation, the smear layer was removed with a 2-min rinse of a liquid EDTA solution such as SmearClear (SybronEndo, Orange, CA, USA).

During preparation and between each file, 1 mL of 5.25% sodium hypochlorite was used as irrigant. After drying all canals with paper points, RealSeal SE Self-Etch Sealer was applied in the canal. Teeth were then filled with RS1 thermoplastic technique with an obturator no. 40 4% for all groups.

Micro-CT acquisitions

All roots were stored at 37° with 100% humidity to allow the sealer to set completely until being imaged by micro-CT scan. A high-resolution computed tomography scanner, v|tome|x 240D (General Electric, Wunstorf, Germany) was used to scan the teeth. After adjusting the appropriate parameters for scanning, each tooth was positioned on the specimen stage and scanned with an isotropic resolution of 4 μm, rotational step of 0.60°, and rotational angle of 360°. With the measure/CT with datos/x 2.0 software, images obtained from the scan were reconstructed to show two-dimensional slices of the inner structure of the roots (Fig. 1) and velo/CT for the 3-D volumetric visualization (Fig. 2).

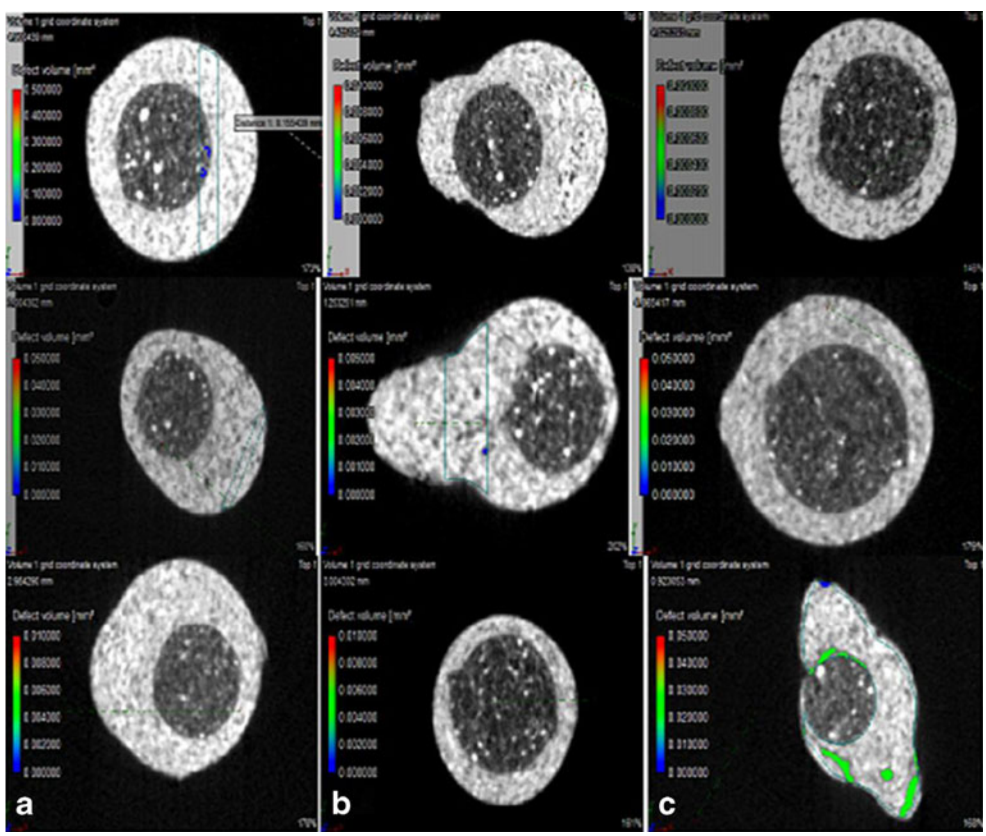

Fig. 1 Images reconstructed to show 2-D slices at different sections of the inner structure of the roots filled with Real Seal 1 respectively **a** taper4%, **b** taper 6%, and **c** taper 8%. Voids, when present, are shown in *colored spots* and calculated at 1, 3, and 5 mm from apex

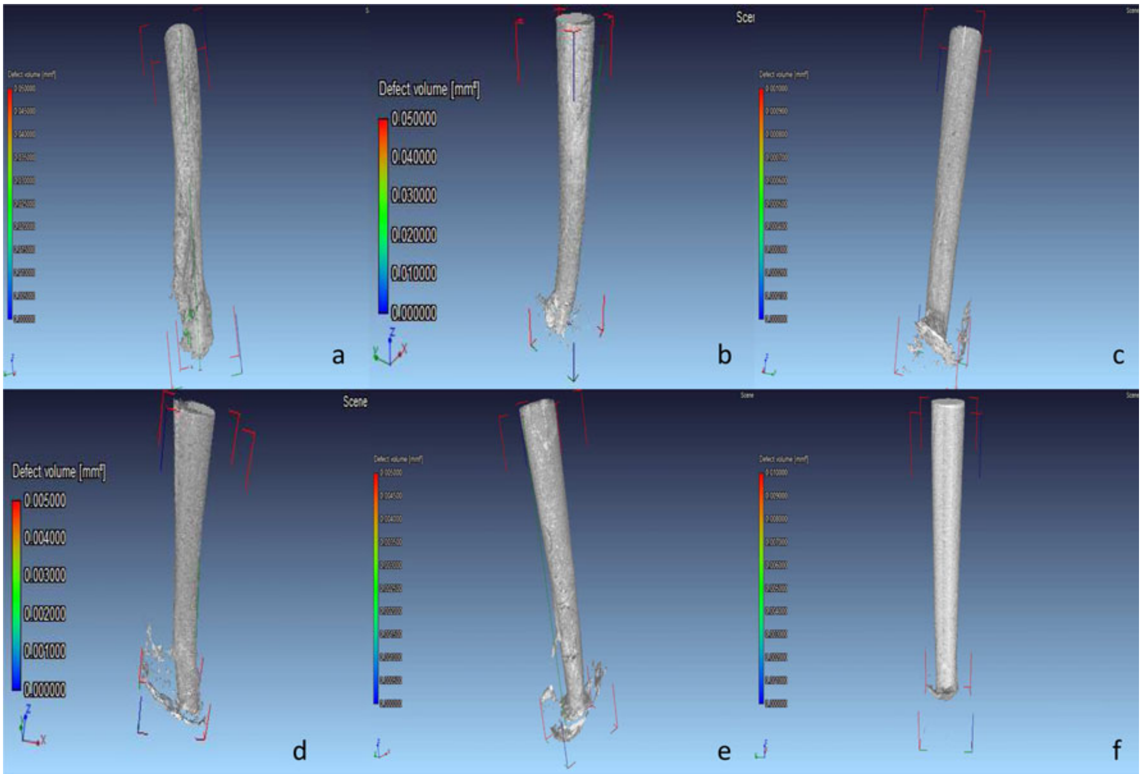

Fig. 2 Three-dimensional micro-CT scans of root canal systems of samples filled with Real Seal 1. **a**, **d** Three-dimensional reconstruction of root canal material with a final apical taper of 4%, **b**, **e** final apical taper of 6%, and **c**, **e** final apical taper of 8%

Statistical analysis

Repeated measure analysis of variance (ANOVA) with one between subject factor (Taper) and one within subject factor (distance from foramen) was conducted followed by Bonferroni multiple comparisons. The following outcome measures were assessed: (1) volume of voids within the apical third of the canals and (2) percentage of voids measured on sections at 1, 3, and 5 mm from the apex coronally. Relationship between taper and percentage voids was investigated using Pearson product moment correlation coefficient.

Results

Mean volumes of voids and percentage of voids at 1, 3, and 5 mm from the apex for different taper preparation are shown in Tables 1 and 2. At 1 mm, mean percentage of voids was significantly different among tapers (P=0.021). Mean percentage of voids was lower with taper 0.08, higher with taper 0.06, and intermediate with 0.04. No significant difference among tapers was found at 3 mm (P=0.253) and at 5 mm (P=0.234).

Among 0.04 tapered samples, mean percentage of voids was significantly higher in 1-mm sections (P=0.001), and no significant difference was found among sections at 3 and 5 mm (P=1.000) of the same group. No significant difference in voids percentage was found among sections (1, 3, and 5 mm) in 0.06 (P=0.93) and 0.08 (P=0.991) tapered samples (Table 1).

Overall, canals with taper 8% showed the lowest percentage of voids whereas those prepared to taper 4% and 6% showed a higher percentage (Fig. 3). There was a significant correlation between the two variables (P=0.034) with high percentage of voids associated with lower taper (Table 2).

Table 1 Measures of voids at 1, 3, and 5 mm from apex and standard deviations of each group

Apical level (mm)	Taper	Number	Mean
1	0.04	9	22.5356±26.09023
	0.06	9	7.1443±7.65226
	0.08	9	0.7141±0.87699
3	0.04	9	1.2218±2.26147
	0.06	9	0.6702±1.28127
	0.08	9	0.0166±0.03285
5	0.04	9	0.4211±0.48879
	0.06	9	3.8181±8.69574
	0.08	9	0.0298±0.07606

Table 2 Mean volume measures of voids in the apical third and standard deviations of final taper

Taper	Number	Mean
0.04	9	7.4970±8.06176
0.06	9	2.8937±2.37145
0.08	9	2.0220±3.30109
Total	27	4.1376±5.57424

Discussion

A root filling should prevent the penetration of microorganisms and toxins from the oral cavity via the root canal into the periradicular tissues and block the portal of entrance to the periapex for organisms that, even after instrumentation and disinfection, have survived [3–7]. Voids in root fillings can, theoretically, compromise the outcome of root canal treatment. Voids along the canal walls are caused by the presence of a gap between the filling material and the dentinal walls and may jeopardize the outcome, because they are in contact with potentially infected canal walls; furthermore, they represent a gap that may promote the failure of the sealer and lead to leakage [9].

Clinically, voids in root fillings are difficult to detect [10]. Many methods (dye penetration, fluid transport, and cross-section analyses, etc.) have been used to investigate the sealing ability of root-filling techniques and materials [11, 12]. However, all had the limitation of measuring voids by analysis of sectioned roots and digital imaging software. This might not be accurate because some filling material might be lost in the process [12].

It is difficult to compare results with other studies as there is considerable variation in methodologies employed and a lack of standardized parameters evaluated [13]. Dye penetration method for evaluating root canal obturations is affected negatively by air entrapped in the gaps between the root-filling materials and the canal wall, resulting in failure to reveal the full extent of the void [14]. That explains our choice for using micro-CT scan in our study.

Micro-CT scanning has been used previously to evaluate the quality of root canal fillings. Micro-CT represents a noninvasive analytical method, which provides objective data because of the elimination of artifacts [9]. Jung et al. [6] have shown that the root canal filling may be differentiated from the canal wall in a micro-CT scan using digital root slices. Former studies of root canal obturation quality commonly used two-dimensional analysis of either root slices [6–15] or digital cross-sections generated from micro-CT scans [6]. These could serve as a semiquantitative representation of the root canal filling. A three-dimensional analysis of micro-CT images, similar to the one used in the present study, was applied by Hammad et al. [16] and Metzger et al. [17] for the analysis of voids and gaps present in root canal fillings. Bergmans et al. [10] validated the use of micro-CT in endodontics. Micro-CT was therefore compared with optical microscopy using custom-made software for quantitative registration-based validation. They demonstrated that micro-CT can be used for quantitative analysis of root dentine removal. The outcome of endodontic shaping procedures can be examined nondestructively in three dimensions (3D) and with a spatial resolution of at least 30 μm. For the validation they concluded that micro-CT will provide reliable and accurate cross-sectional views of the morphologic features associated with root canal shaping procedures if proper settings and software are used. On the other hand, they found that obturated canals should be analyzed with caution using this type of device because the presence of filling components and the limited resolution of micro-CT will complicate imaging and analysis procedures [10]. In recent years, the resolution of micro-CT has improved considerably from 81 μm and values between 34 and 68 to 25 and recently to 14 μm [16, 17].This study is considered to be among the firsts very few to use micro-CT to measure percentage of volume of voids and gaps in the root canal with a resolution <4 μm and with a relatively numerous samples (27/method, n=54).

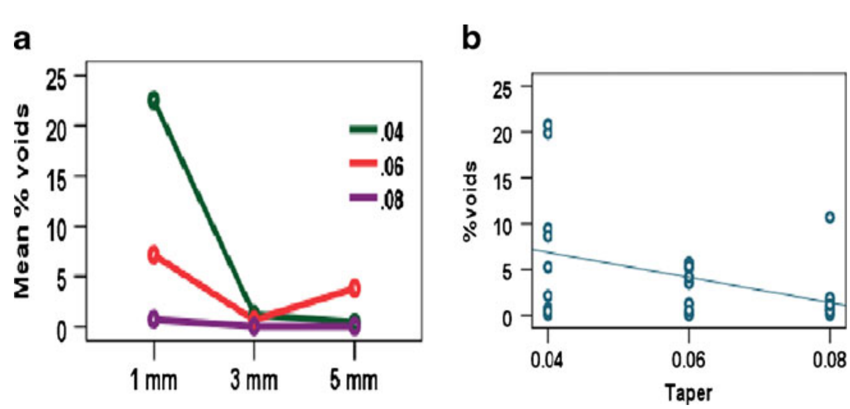

Fig. 3 Representative patterns of **a** void presence in the apical third with Real Seal 1 at 1, 3, and 5 mm for different taper and **b** in cross-sectional sections of the filled area using repeated measure analysis of variance (ANOVA) with **a** within subject factor (distance from foramen) and **b** between subject factor (Taper), and was conducted followed by Bonferroni multiple comparison correction

On the other hand, many obturation methods are used today, ranging from traditional lateral compaction to a variety of heat softened gutta-percha techniques. The goal of all these filling methods is to provide a good adaptation of the root canal filling material to the canal walls, by ensuring an adequate seal preventing contamination of the root canal system [16–18].

Recent advances in obturation materials introduced resins into the filling material, thus improving root canal adaptation of the filling to the canal walls [17]. The Real Seal 1 bonded obturation system was designed, according to the manufacturer, to eliminate the potential for poor fills. Like the original Real Seal obturation system, RS1 uses Resilon as root canal filling, coating the outside of the core and thermoplasticized by a proprietary oven. RS1 also introduces a new self-etching resin-based sealer which eliminates the priming step of the original system. According to the manufacturers, using Real Seal 1 creates a homogenous fill that significantly enhances sealing, preventing leakage [17].

This study was undertaken to assess the sealing ability of this obturation system in root canals prepared with different tapers. Overall none of the three groups were void free. The presence of voids can be attributed to the fact that resin-based sealers undergo a polymerization shrinkage which might lead to gap and void formation in the canal [19], and until now none of the existing materials and techniques were able to produce perfect fills.

When comparing group 3 (taper 0.08%) to group 2 (taper 0.06%) and group 1 (taper 0.04%), the percentage of voids was significantly higher in 0.04% group especially at 1 mm. No significant difference was found among sections (1, 3, and 5 mm) in 0.06 (P=0.93), and 0.08 (P=0.991) tapered samples. Our study supports other work evaluating the ideal final preparation taper that showed that an increase in root canal taper improves irrigant replacement and wall shear stress while reducing the risk for irrigant extrusion [20].

The RS1 technique consists of a one-step filling procedure in which thermoplasticized resin is inserted into the canal by means of a plastic carrier. Insertion may create voids because of imperfect resin adaptation to canal walls or stripping from the carrier especially in smaller tapered preparations. The RS1 technique can carry thermoplasticized gutta-percha towards the apical portion of the canal with the filling of irregularities being enhanced. A recent study investigated the in vitro sealing ability of RS1 and compared it with the Thermafil (Dentsply Maillefer, Ballaigues, Switzerland) and One-Step systems (CMS Dental, Copenhagen, Denmark) [21]. The results showed that the RS1 provided sealing ability significantly better than traditional carrier-based gutta-percha systems.

The present study revealed that RS1 was not able to provide a void-free root canal filling for most preparations and that root canal preparation with bigger taper exhibited less voids than smaller tapered preparation. In addition to the in vitro studies, clinical studies evaluating the different endodontic obturation systems and comparing them with Real Seal 1 would be beneficial.

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Conflict of interest The authors declare that they have no conflict of interest or any financial relationship with the organization that sponsored the research.

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