Evaluation of Voids and Gaps in Oval-Shaped Canals Filled with Different Techniques using Micro-CT Imaging

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Aims

Root canal obturation aims to provide a complete filling of the canal creating a fluid-tight seal, which can prevent residual bacteria and their toxins from affecting the periapical tissues. Many obturation materials and techniques have been introduced over the years, each attempting to provide a better seal of the root canal.¹ The most common filling technique is the cold lateral compaction, which consists in the insertion of many cones packed tightly by the operator. Another technique uses an electrically heated plugger to apically condense a prefitted master cone seated into the canal. The coronal canal space is subsequently filled with the same thermoplasticized material from an injection device. On the other hand, the single-cone technique consists in insert a gutta-percha master cone coated with sealer into a root canal does not require compaction or sophisticated devices. The single-cone technique consists of matching a cone to the prepared canal. For this technique a type of canal preparation is advocated so that the size of the cone and the shape of the preparation are closely matched. When a gutta-percha cone fits the apical portion of the canal snugly, it is cemented in place with a root canal sealer.²

In vitro studies have demonstrated that most of the root canal filling techniques did not fill the entire root canal system.¹⁻⁹ The irregularities on dentin walls and the complex geometry of the root canal system, especially in oval and ribbon-shaped root canals, may be the main explanations for these results.¹⁰ These anatomical features of the root canal system may impede adequate cleaning of the narrow fissured areas increasing the risk of creating voids. It is assumed that unfilled areas may harbor unaffected residual bacterial biofilms and serve as a potential cause of persistent infection and poor treatment outcome.¹¹

Several methodologies were developed to evaluate the quality of root fillings, including dissolution of teeth in acid, leakage tests, simulated root canal models, serial sectioning technique, radiographic comparison, and SEM analysis of the interface between the filling material and the canal walls.⁸ These methodologies have been successfully used for many years. Notwithstanding, many of them create artifacts or involve irreversible structural damage of the specimens, allowing that only limited aspects of the filling quality can be investigated.⁵ The development of X-ray micro-computed tomography (µCT) has gained increasing significance in the study of dental tissues. µCT offers a noninvasive, reproducible technique for three-dimensional assessment of the root canal system and it can be applied both quantitatively and qualitatively to evaluate the root canal filling. This nondestructive, three-dimensional imaging tool overcomes the limitations of the aforementioned research models.¹⁰,¹²-¹⁴

To date, there is no consensus on the most suitable technique for obturation of root canals and relatively few articles assessed the quality of root canal filling by µCT. Thus, the aim of this ex vivo study was to measure the percentage of volume of voids and gaps in oval-shaped canals prepared with single-file and rotary systems and filled with either cold or warm filling techniques, by using µCT imaging.
Method

One hundred straight single-rooted human mandibular canine teeth with fully formed apices and a single root canal were randomly selected from a pool of extracted teeth, decoronated slightly above the cementoenamel junction and stored in labeled individual plastic vials containing 0.1% thymol solution. All teeth presenting isthmus, apical curvature or more than one root canal were excluded.

After being washed in running water for 24 h, each tooth was dried, mounted on a custom attachment, and scanned in a μCT scanner (SkyScan 1174v2; Bruker-microCT, Kontich, Belgium). The X-ray tube was operated at 50 kV and 80 mA (0.5 mm Al filter), and the scanning was performed by 360° rotation around the vertical axis, rotation step of 0.9 and an isotropic resolution of 19.6 μm. Subsequently, the cross-section image was reconstructed (NRecon v.1.6.3; Bruker-microCT) from the projection image and an automatic filter changer for beam-hardening compensation during reconstruction was used at a level of 25%. CTAn v.1.12 software (Bruker-microCT) was used for three-dimensional evaluation of the root canal system regarding volume, surface area, and structure model index (SMI).

Volume was calculated as the volume of binarized objects within the volume of interest (VOI). For the measurement of the surface area of the 3D multilayer dataset, two components to surface measured in 2D were used; first the perimeters of the binarized objects on each cross-sectional level, and second, the vertical surfaces exposed by pixel differences between adjacent cross-sections. Structure model index (SMI) involves a measurement of surface convexity in a 3D structure. SMI is derived as 6.(S'.V)/S2, where S is the object surface area before dilation and S' is the change in surface area caused by dilation. V is the initial, undilated object volume. An ideal plate, cylinder and sphere have SMI values of 0, 3 and 4, respectively. CTVol v.2.2.1 software (Bruker-microCT) was used for visualization and qualitative evaluation of the specimens.

From the initial sampling (n=100), 72 teeth were matched to create 18 foursomes based on the three-dimensional morphology of the root canal assessed in the initial μCT evaluation. One tooth from each foursome was randomly assigned to one of the 4 experimental groups (n=18) for this study. After checking the normality assumption, the degree of homogeneity (baseline) of the four groups with respect to volume, surface area and SIM, was assessed using one-way analysis of variance (ANOVA) with a confidence interval of 95%. After the groups were established, a flip of a coin was used to define which group of teeth would be treated with each of the following root canal preparation techniques: Self-Adjusting File, WaveOne, Reciproc, or ProTaper Universal systems.

After preparation, canals were dried with paper points and submitted to a second μCT scan and reconstruction, applying the initial parameter settings. CTAn v.1.12 software (Bruker-microCT) was used for the evaluation of the volume of the root canal. Then, the roots in each group were subdivided into 2 subgroups (n=9), according to the root canal obturation technique: modified thermomechanical compaction (TMC) and cold gutta-percha (CGP) cone techniques.

Modified Thermomechanical Compaction Technique (TMC)

A size 40 taper .06 Resilon master point was trimmed with a scalpel in order to obtain a proper tug-back at the working length (WL). RealSeal self-etching primer was placed into the root canal system to the working length with paper points, allowed to soak for 30 s and excess primer removed with a dry paper point. The Resilon sealer was mixed by the auto-mix syringe and placed into the canal with lentulo spiral. Then, the master cone was also lightly coated with sealer and seated to working length in a slow plunging motion. After the master point was seared off at the orifice using a SystemB heat source, a size 55 taper .04 PacMac NiTi condenser was introduced 2–3 mm from the WL, without motion. Once introduced, low rotation was started (6,000–7,000 rpm), holding the instrument at this position with steady apical pressure for five seconds. Then, the rotating PacMac condenser was allowed to exit coronally from the canal, keeping the instrument in light contact with the
root canal wall. A fine plugger mounted on a System B heating unit set at 200º C was used to remove the excess of the Resilon material to a level within 3 to 4 mm of the WL. The filling material remaining in the canal was then compacted with a flat-ended plugger with steady pressure for a few seconds. Resilon sealer was coated again onto the root walls using sterile paper points and backfilling was achieved by the application of thermo-plasticized Resilon pellets in 4–5-increments, followed by uniform compaction with pluggers, until the whole canal was filled. Then, the coronal surfaces of the filled segments were light-cured for 40 s.

**Cold Gutta-Percha Cone Techniques (CGP)**

Root canals prepared with SAF system were obturated using lateral compaction technique with gutta-percha and AH Plus sealer. After filled the root canals with mixed AH Plus sealer, a master cone size 40 and 0.06 taper, coated with the sealer, was inserted to the predetermined WL. Nickel-titanium finger spreaders were used to conduct the lateral compaction using F accessory cones. When no additional cones could be inserted, the gutta-percha mass was cut at the canal orifice using a System B heat source and the freshly cut surface was vertically condensed using a flat-ended cold plugger. Root canals prepared with reciprocating and rotary systems were obturated using the single-cone technique. After filled the root canals with mixed AH Plus sealer, a size 40 tapered gutta-percha master cone corresponding to the final instrument of each system was chosen (Reciproc R40, WaveOne Large, ProTaper F4), coated with the sealer, and placed into the canal to the WL in a slow plunging motion. The excess gutta-percha was removed with a heat source and the remaining gutta-percha was vertically compacted using a flat-ended plugger. After the obturation procedure was completed, samples were stored in an incubator for 1 week (37°C, 100% relative humidity) and submitted to a postoperative µCT scan and reconstruction, applying the initial parameter settings.

**µCT Evaluation of the Root Canal Filling**

Data Viewer v.1.4.4 (Bruker-microCT) and CTVol v.2.2.1 software (Bruker-microCT) were used for the qualitative evaluation of the root canal filling. CTAn v.1.12 was used for calculating the volume of filling material, defined as the volume sum of the gutta-percha/Resilon and the endodontic sealer. The mean percentage of voids and gaps was calculated using the formula 100-[(VF * 100)/VC], where VF is the volume of the filling material and VC is the volume of the root canal after preparation.

**Statistical Analysis**

Because normality assumptions could not be verified (Shapiro-Wilk test), the mean percentage of voids and gaps were compared by using Mann-Whitney U test within group and Kruskal-Wallis test between groups, with a significance level of 5%.
Results

Mean volumes (%) of gaps and voids are shown in Table 1.

Table 1. Percentage of voids and gaps (mean ± standard deviation) in canals shaped with rotary (ProTaper), reciprocating (Reciproc and WaveOne) and SAF systems and filled using modified thermomechanical compaction (TMC) and cold gutta-percha cone (CGP) techniques.

<table>
<thead>
<tr>
<th>All Root Canal</th>
<th>Thermomechanical Compaction Technique (TMC)</th>
<th>Cold Gutta-Percha Cone Techniques (CGP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProTaper Universal</td>
<td>3.41 ± 1.92</td>
<td>4.59 ± 2.42</td>
</tr>
<tr>
<td>WaveOne</td>
<td>2.78 ± 0.52</td>
<td>3.79 ± 2.42</td>
</tr>
<tr>
<td>Reciproc</td>
<td>3.12 ± 0.86</td>
<td>6.25 ± 3.81</td>
</tr>
<tr>
<td>Self-Adjusting File (SAF)</td>
<td>3.17 ± 1.21</td>
<td>5.49 ± 2.40</td>
</tr>
</tbody>
</table>

**Coronal Third**

| ProTaper Universal | 0.94 ± 0.56 | 2.87 ± 0.93 |
| WaveOne | 1.04 ± 0.74 | 2.55 ± 1.73 |
| Reciproc | 1.08 ± 0.77 | 4.56 ± 3.38 |
| Self-Adjusting File (SAF) | 1.19 ± 0.83 | 3.09 ± 1.28 |

**Middle Third**

| ProTaper Universal | 1.51 ± 1.92<sup>a</sup> | 0.93 ± 1.26 |
| WaveOne | 0.96 ± 0.66<sup>b</sup> | 0.85 ± 1.12 |
| Reciproc | 1.58 ± 0.77<sup>a</sup> | 1.08 ± 0.88 |
| Self-Adjusting File (SAF) | 0.57 ± 0.35<sup>b</sup> | 1.48 ± 1.62 |

**Apical Third**

| ProTaper Universal | 0.95 ± 0.14 | 0.68 ± 0.47 |
| WaveOne | 0.79 ± 0.77 | 0.40 ± 0.17 |
| Reciproc | 0.46 ± 0.14 | 0.61 ± 0.28 |
| Self-Adjusting File (SAF) | 1.41 ± 0.99 | 0.75 ± 0.51 |

Values with bold letters in the same line and different superscript letters in the same column represent statistical significant difference (p<0.05).

Overall, canals filled with TMC showed lower percentage of volume of voids and gaps than CGP only in the specimens of Reciproc and SAF groups (P<.05). Within group, no statistical difference in the percentage of volume of voids and gaps, in the comparison of the thirds, was observed (P>.05).

In the coronal third, root canals filled with TMC showed the lowest percentage of volume of voids and gaps (P<.05) and no difference between the obturation techniques was observed in the middle and apical third (P>.05).

In the middle third, canals prepared with ProTaper and Reciproc, and obturated with TMC, showed the highest percentage of volume of voids and gaps (P<.05). In the apical third, no statistically significant difference in the mean volume of gaps and voids was observed between and within groups (P>.05).
Figure 1: Representative three-dimensional reconstruction of the filling material (in pink) and bi-dimensional images (in gray) of 27 specimens filled by different techniques showing the presence of voids and gaps throughout the root canal system.
Conclusion
Within the limitations of this ex vivo study, it can be concluded that none of the tested filling techniques provided a gap-free or void-free root canal filling. The cold gutta-percha technique presented a significant percentage of voids only in the coronal third of the root canal.

References: