The sealing ability of a new silicone-based root canal filling material (GuttaFlow): an in vitro study using the percentage of gutta-percha-filled area

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INTRODUCTION
Complete obturation of the root canal system holds the key to successful root canal treatment. An ideal root canal filling should be a dense, well-adapted, three-dimensional filling of the entire root canal system with a homogeneous mass of core material.

There are the two basic obturation techniques: cold lateral condensation (LC) using gutta-percha (GP) cones versus vertical condensation using warm GP. Cold LC is the most commonly taught and practiced filling technique worldwide. It also serves as the gold standard against which new techniques are compared. It has the advantage of providing a tight apical seal by using a spreader for the condensation of many GP cones in the apical region. However, Brayton et al. reported that this method produces a nonhomogeneous filling containing voids between the accessory points and the canal walls, as well as many unfilled lateral canals and inadequate sealer dispersion. In addition, lateral condensation might increase the risk of root fractures due to the high forces transferred to the spreader.

In the 1960s, Schilder introduced the warm vertical condensation technique which incorporated the use of a heated spreader and plungers to obtain a root canal filling material of improved density. In 1994, Buchanan developed the continuous wave of condensation technique, which was a significant improvement of Schilder’s warm vertical condensation technique. Now, the continuous wave of condensation technique and LC technique are the most common methods used for obturation.

Thermoplasticized GP filling techniques offer numerous advantages: warm GP is more adaptable to small irregularities that exist in the walls of a prepared root canal system; consequently, warm GP results in a significantly denser, better adapted, and more homogeneous filling with fewer voids as compared to that obtained with cold lateral condensation technique. However, thermoplasticized GP techniques are not without drawbacks. They are difficult to perform in curved canals, have a higher incidence of GP or sealer extrusion into the periapical tissues, result in significant shrinkage during cooling, and cause a temperature rise on the external root surface — which may result in potential thermal damage to the periodontal ligament and alveolar bone.

In recent years, a new silicone-based root canal filling system GuttaFlow was introduced. It is a cold, flowable filling system for root canal obturation, with both sealer and GP homogeneously combined in one product. It flows easily into lateral canals and dentinal tubules, hence offering maximum sealing quality. On the assessment of the sealing ability of root fillings system such as GuttaFlow, several methods have been used — such as microbial leakage model, fluid filtration technique, and confocal laser scanning microscopy.

On investigating the sealing ability of different filling techniques, a method that examines the high-magnification micrographs of root canal cross-sections has been used. However, this method has not been used to evaluate the sealing ability of GuttaFlow. The aim of the present in vitro study, therefore, was to use this cross-section method — coupled with image analysis — to evaluate the sealing ability of GuttaFlow.

MATERIALS AND METHODS

Tooth specimens preparation
Having obtained approval from the ethics committee of the Stomatology Hospital of Nanjing Medical University for this research, extracted human single-rooted mandibular first premolars were collected from native Chinese patients. Immediately after extraction, any
attached calculus or soft tissues were removed and all teeth were stored in normal saline solution until experimental use. Teeth which received any previous endodontic treatment were not used, and neither teeth with any of the following conditions: presence of caries and/or violation of the pulp chamber by restorations. The roots were examined under a dental operating microscope (OPMI® pico, Carl Zeiss, Oberkochen, Germany) at 12.5×2.5 magnification. Only teeth with fully formed roots and mature root apexes were used, but roots with evidence of resorption or cracks were discarded.

Standard periapical images were taken from both the mesiodistal and buccolingual directions using a direct digital radiography (DDR) system (Sidexis, Siemens AG, Bensheim, Germany) by an experienced radiographic operator. Exposure parameters were set at 60 kV, 7 mA and 0.05 s. Distance between each tooth specimen and the X-ray tube was 70 mm, and the central X-ray beam was aligned perpendicular to the root canal. Root canal morphology was directly observed from the computer screen using the DDR measurement software at a magnification range of 2× to 4×. Teeth presenting more than one canal were excluded from the experiment. Canal curvatures were measured on the radiographs according to the method described by Schneider26. Canals with curvatures measuring more than 10 degrees were also excluded from the experiment.

Crowns were removed using a low-speed diamond saw (IsoMet ILL, Buehler, Lake Bluff, IL, USA) under copious water-cooling. Length of the roots was standardized at 10 mm. A size 10 K-file (21 mm, Mani, Tochigi, Japan) was inserted into the root canal to establish the working length at 1.0 mm short of the apical foramen (AF). Root canals were instrumented by ProTaper NiTi rotary instruments (X-Smart™, Dentsply Maillefer, Japan) to size F2 using a crown-down technique. Glyde root canal lubricant (Dentsply Maillefer, Ballaigues, Chemin du Verger, Switzerland) was used during the cleaning and shaping of each root canal. Between files, all canals were irrigated with 5 mL of a freshly prepared solution of 5.25% sodium hypochlorite (NaOCl) and 5 mL of 17% EDTA. Apical patency was maintained with a size 10 file in all cases. To remove the smear layer after root canal preparation, all canals were ultrasonically irrigated (P5XS, Satelec, Cedex, France) with sterile water for 3 min. After the canals were dried using sterile paper points (#30; Dayading, Beijing, China), 80 tooth specimens were selected for this study.

**Root canal obturation**

Table 1 presents the materials used for root canal obturation in this study. The 80 tooth specimens selected above were randomly divided into 4 groups of 20 each as follows.

<table>
<thead>
<tr>
<th>Group</th>
<th>Materials</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>gutta-percha cones</td>
<td>Dentsply Maillefer</td>
</tr>
<tr>
<td></td>
<td>AH Plus sealer</td>
<td>Dentsply DeTrey GmbH, 78467 Konstanz, Germany</td>
</tr>
<tr>
<td>Group 2</td>
<td>E &amp; Q Plus</td>
<td>Meta Biomed Co., Ltd. Korea</td>
</tr>
<tr>
<td></td>
<td>gutta-percha cone</td>
<td>Dentsply Maillefer</td>
</tr>
<tr>
<td></td>
<td>AH Plus sealer</td>
<td>Dentsply DeTrey GmbH, 78467 Konstanz, Germany</td>
</tr>
<tr>
<td>Group 3</td>
<td>gutta-percha cone</td>
<td>Dentsply Maillefer</td>
</tr>
<tr>
<td></td>
<td>GuttaFlow</td>
<td>Coltène-Whaledent, Langenau, Germany</td>
</tr>
<tr>
<td>Group 4</td>
<td>gutta-percha cones</td>
<td>Dentsply Maillefer</td>
</tr>
<tr>
<td></td>
<td>GuttaFlow</td>
<td>Coltène-Whaledent, Langenau, Germany</td>
</tr>
</tbody>
</table>

Group 1: Cold lateral condensation technique
Root canals were filled using GP cones and AH Plus sealer (Dentsply DeTrey GmbH, 78467 Konstanz, Germany) using the cold LC technique. AH Plus sealer was prepared according to manufacturer’s instructions and applied to the root canal using a lentulo spiral. A master GP cone of 0.06 taper and multiple accessory GP cones of 0.02 taper (Dentsply Maillefer) were coated with AH Plus sealer and inserted into the canal until the entire length of the root canal was filled. Excess GP was removed using a heated plugger, and vertical condensation was performed at the orifice level.

Group 2: Continuous wave condensation technique
Root canals were filled using E&Q Plus (Meta Biomed Co., Ltd., Chung cheong buk-do, Korea) and AH Plus sealer according to the manufacturers’ instructions. A 0.06 taper master GP cone (Dentsply Maillefer) which fitted to within 1 mm of the working length with tugback was selected. Heating tip of the E&Q Pen handpiece was selected to fit 5 mm short of the working length without binding. AH Plus sealer was applied to the root canal and master gutta-percha cone was inserted into the canal.
Temperature of the pen tip was set at 250°C, and it was used to remove excess GP at the orifice level. It was also inserted into the canal to a depth 5 mm short of the working length and held thereat for 3 to 4 seconds. The tip was allowed to cool for 10 seconds and then removed after applying a single burst of heat for about 1 second. The canal was backfilled using the E&Q Gun set at 160°C until the canal was completely filled with gutta-percha. A vertical force was applied using a hand plugger (Dentsply Maillefer) to compact the root canal filling in the coronal portion of the canal.

Group 3: GuttaFlow with single master gutta-percha cone
GuttaFlow (Coltène-Whaledent, Langenau, Germany) was prepared according to the manufacturer’s instructions. The tip of the GuttaFlow dispenser was inserted into the root canal at 3 mm short of the working length, and a small amount of the filling material was dispensed into the canal until the flow of the material could be observed. A fresh mix was obtained on a glass slab by pressing the mixing pistol. A 0.06 taper master GP cone was coated with the freshly mixed GuttaFlow and slowly inserted into the canal until the working length was reached. The tip of the GuttaFlow dispenser was inserted lateral to the master cone, and the remaining canal was backfilled with GuttaFlow. Excess material was removed using an excavator.

Group 4: GuttaFlow with single master gutta-percha cone and accessory gutta-percha cones
Root canals were filled with GuttaFlow and a single master GP cone in the same way as in Group 3. Multiple 0.02 taper accessory GP cones (Dentsply Maillefer) were used without lateral condensation until the entire length of the root canal was filled.

Sectioning and image analysis
The number of teeth with sealer and/or gutta-percha extruded through the AF was recorded for each group. After filling, all teeth were stored in 100% humidity at 37°C for 7 days. Then, the teeth were horizontally sectioned at 2, 4, and 6 mm from the AF using a low-speed diamond saw (Isomet IIL, Buehler, Lake Bluff, IL, USA) under copious water-cooling.

All sections were observed under a stereomicroscope (Carl Zeiss, Germany) at 42× magnification. Captured images of sections (in TIFF format) were observed on a computer screen using Image-Pro Plus 5.0 software. Cross-sectional area of the canal and GP-filled area were measured. After 2 weeks, these measurements were taken again. Using the average value of two measurements, the percentage of PGFA was calculated for Groups 1 to 4 at each sectioning level. All empirical procedures were performed by an experienced endodontist.

Statistical analysis
All calculated PGFA data were analyzed using the non-parametric Friedman’s and Wilcoxon Signed Rank tests. Statistical significance was set at $P < 0.05$.

RESULTS
Sealer and/or gutta-percha extrusion
There were no teeth with extrusion in Group 1. In Group

Table 2 Area of canal and PGFA at 2 mm from AF

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Canal area (mm²)</th>
<th>PGFA±SD (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group1</td>
<td>20</td>
<td>0.38±0.13</td>
<td>84.91±13.19a</td>
</tr>
<tr>
<td>Group2</td>
<td>20</td>
<td>0.38±0.13</td>
<td>94.55±4.04b</td>
</tr>
<tr>
<td>Group3</td>
<td>20</td>
<td>0.37±0.17</td>
<td>99.64±1.38c</td>
</tr>
<tr>
<td>Group4</td>
<td>20</td>
<td>0.37±0.08</td>
<td>99.83±0.65c</td>
</tr>
</tbody>
</table>

The PGFA of Group 3 and Group 4 were higher than these of Group1 and Group 2 ($P<0.05$), but there were no significant differences between Group 3 and Group 4 ($P>0.05$).

*Groups with different letters are significantly different from each other.

Table 3 Area of canal and PGFA at 4 mm from AF

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Canal area (mm²)</th>
<th>PGFA±SD (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group1</td>
<td>20</td>
<td>0.78±0.26</td>
<td>86.65±9.43a</td>
</tr>
<tr>
<td>Group2</td>
<td>20</td>
<td>0.77±0.31</td>
<td>95.6±3.1b</td>
</tr>
<tr>
<td>Group3</td>
<td>20</td>
<td>0.77±0.39</td>
<td>99.45±0.96c</td>
</tr>
<tr>
<td>Group4</td>
<td>20</td>
<td>0.79±0.27</td>
<td>99.94±0.23c</td>
</tr>
</tbody>
</table>

The PGFA of Group 3 and Group 4 were higher than these of Group1 and Group 2 ($P<0.05$), but there were no significant differences between Group 3 and Group 4 ($P>0.05$).

*Groups with different letters are significantly different from each other.
In practical application, the single-cone obturation technique emerged as a more convenient option than lateral condensation and continuous wave obturation techniques. The drawback was that the single-cone obturation technique resulted in a higher volume of sealer than the cone, and this ratio promoted void formation and reduced the sealing quality[35]. However, several recent developments favorable to the single-cone obturation technique led to the latter’s revival. The introduction of innovative nickel-titanium rotary instruments is accompanied with the use of greater taper gutta-percha master cones calibrated and designed to match the canals, hence keeping to a minimum the volume of sealer used in single-cone obturation technique[32-34]. Recent improvements of the sealer or root filling material also helped to increase the appeal of the single-cone obturation technique[36]. In addition, sealer development has even enabled long-term leakage performance to be compared between single-cone fillings under relatively standardized conditions[37].

According to manufacturer-provided information, GuttaFlow consists of a polydimethylsiloxane matrix highly filled with very finely ground gutta-percha. The finely ground gutta-percha powder and the silicone-based matrix are homogeneously distributed after mixing. GuttaFlow has extraordinary chemical and physical properties that offer maximum sealing quality. The material does not shrink, but expands slightly by 0.2%[27] and retains some elasticity even after it has cured. For this host of extraordinary advantages, GuttaFlow was used as the root filling material for single-cone obturation technique in this study. At 2, 4, and 6 mm from AF, the PGFA values of GuttaFlow groups (Groups 3 and 4) almost reached 100% and were significantly higher than that of cold lateral condensation group (Group 1) and continuous wave obturation group (Group 2), thereby indicating a superior sealing ability. These results agreed with those of other studies[16,38], and that the good sealing ability of GuttaFlow was highly attributed to the expanding capability of the material[19] or its fine flowability. Further, the high PGFA values of Groups 3 and 4 also indicated that the single-cone obturation technique was an effective root filling technique and that accessory GP cones were not necessary when root canals were filled with GuttaFlow.

Monticelli et al.[29] compared the sealing of root canals filled with two single-cone obturation systems (ActiV GP

Table 4 Area of canal and PGFA at 6 mm from AF

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Canal area (mm$^2$)</th>
<th>PGFA±SD (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group1</td>
<td>20</td>
<td>1.24±0.43</td>
<td>89.15±6.52a</td>
</tr>
<tr>
<td>Group2</td>
<td>20</td>
<td>1.25±0.53</td>
<td>98.08±1.84b</td>
</tr>
<tr>
<td>Group3</td>
<td>20</td>
<td>1.22±0.64</td>
<td>99.8±0.78b</td>
</tr>
<tr>
<td>Group4</td>
<td>20</td>
<td>1.25±0.48</td>
<td>100b</td>
</tr>
</tbody>
</table>

At the 6 mm level, there were no significant differences between Group 2, Group 3 and Group 4 ($p>0.05$), but the PGFA of these groups was all higher than that of Group 1 ($p<0.05$).

*Groups with different letters are significantly different from each other.

2, two teeth were found with extrusion: one being sealer and the other being GP cone. In Groups 3 and 4, four teeth in each group were found with GuttaFlow extrusion.
Fig. 1 Cross-sections of an irregular root canal in Group 3 under a stereomicroscope at 42× magnification:
(1) at 2 mm from AF; (2) at 4 mm from AF; (3) at 6 mm from AF. Complete fill of the root canal space by gutta-percha (GP) and GuttaFlow (GF).

Fig. 2 Cross-sections of an irregular root canal in Group 4 under a stereomicroscope at 42× magnification:
(1) at 2 mm from AF; (2) at 4 mm from AF; (3) at 6 mm from AF. Complete fill of the root canal space by GP, GF, and accessory gutta-percha (AGP).
and GuttaFlow) against a warm vertical compaction technique. They hypothesized that the inferior coronal seal of these single-cone obturation systems could be improved with the placement of accessory cones to reduce sealer thickness or with an immediate coronal adhesive restoration. In the present study, the root canals of Group 4 were filled with GuttaFlow and single master GP cone and accessory GP cones, but without lateral condensation. Interestingly, the PGFA of Group 4 reached 100% in the coronal portion of the root canals (Table 4), which was significantly higher than the PGFA values of cold lateral condensation group (Group 1) and continuous wave obturation group (Group 2). However, there were no statistically significant differences in PGFA between Groups 3 and 4 at every sectioning level (p>0.05), indicating that accessory GP cones were not necessary when obturating root canals with GuttaFlow.

Studies had been conducted to compare the sealing ability of GuttaFlow with other sealers, such as AH26 sealer (Dentsply Maillefer), AH Plus (Dentsply Maillefer), Epiphany (Pentron, Wallingford, CT, USA), and Sealapex (Sybron Endo, Orange, CA, USA)16-22. GuttaFlow was strictly regarded as a sealer in these studies16-22. In the current study, however, GuttaFlow was not used as a sealer but as a root filling material according to manufacturer’s instructions. Therefore, the area of GuttaFlow must be measured in Groups 3 and 4, which meant that the area of GuttaFlow was considered to be part of the area of GP during PGFA calculation. Incidentally, it was interesting to note that GuttaFlow could seal irregular root canals very well. Figures 1 and 2 showed that the specimens were irregular-shaped canals with long and narrow uninstrumented recesses. Nonetheless, GuttaFlow was able to produce superior obturation results: both the main space and long recess were completely filled with GuttaFlow without visible debris. Our result supported the viewpoint of De-Deus et al.18 in that the silicone-based sealer GuttaFlow exhibited the best sealing ability in oval-shaped canals than AH Plus and Pulp Canal Sealer EWT (Kerr, Sybron Maillefer), AH Plus in Canada, for her writing assistance on this English manuscript.

Four instances of GuttaFlow extrusion were recorded for Group 3 and Group 4 each. In the present study, only tooth specimens with fully formed roots and mature root apaxes were used. The procedure of root canal preparation was also carried out painstakingly to ensure that the apical foramina of the specimens were not destroyed. Root canal filling was carried out according to manufacturer’s instructions: a small amount of GuttaFlow was gently dispensed into the canal; the master cone was slowly inserted into the canal, and then slowly and gently pulled and twisted back and forth twice to ensure complete wetting of the cone and the canal wall. Nonetheless, some steps of the root canal filling operation —such as the dispensing of GuttaFlow or the insertion of master cone into the canal— might have been carried out rudely or hastily without sufficient due care and attention, resulting in GuttaFlow extrusion through the AF.

Apart from superior sealing ability, another laudable advantage of GuttaFlow is that there is sufficient nano-silver in the material to prevent further spread of bacteria —and nano-silver is highly biocompatible46-59. It is also widely mentioned in endodontic literature that the cytotoxicity of GuttaFlow is less than GP or other root canal sealers40-42, and that it has acceptable biocompatibility in terms of genotoxicity43. Therefore, whether the extruded GuttaFlow might pose a potential damage to the periapical tissue would require further studies to clarify and confirm.

CONCLUSION

GuttaFlow produced a superior obturation quality such that accessory gutta-percha cones became unnecessary when obturating root canals with GuttaFlow. Nonetheless, the extrusion of GuttaFlow warranted further attention on operational procedure and cytotoxicity issue.

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