After proper chemomechanical debridement of the root canal system, the subsequent 3-dimensional (3D) obturation of the canal space to full working length is another crucial treatment step that has an impact on treatment outcome (1, 2). According to a systematic review, root canal fillings with no voids are associated with an improved outcome of primary root canal treatment (3). Moreover, a long-term study assessing the outcome of primary root canal treatment in terms of periapical health reported that the apical extent and homogeneity of root canal fillings exerted a significant positive impact on treatment outcome in terms of periapical health (4).

Several techniques have been proposed to ensure void-free obturation of the debrided root canal space and to accomplish good adaptability of the root canal filling. These include the traditional cold lateral compaction of gutta-percha, the use of single-cone gutta-percha matching the taper and diameter of the canals prepared with engine-driven nickel-titanium (NiTi) instruments, and methods that are based on thermoplasticized gutta-percha (5, 6). The latter group includes the most common techniques the warm vertical compaction and core-carrier systems. Hillert et al. reported that the apical extent and homogeneity of root canal fillings exerted a significant positive impact on treatment outcome in terms of periapical health (4).

Recently, 2 new core-carrier systems were introduced: GuttaCore (GC) (Dentsply Maillefer, Ballaigues, Switzerland) and GuttaFusion (GF) (VDW, Munich, Germany). The core of these systems consists of cross-linked thermoset gutta-percha that does not melt at temperatures generated by the special oven (15). It is claimed that compared with traditional carrier-based systems, retreatment of root canal fillings performed with cross-linked gutta-percha cores is easier and requires less time. This was confirmed by Beasley et al. (14) because the time required removing GC root canal fillings by using rotary ProTaper instruments (Dentsply Maillefer) was significantly shorter than the time required to remove Thermafil Plus obturators. The push-out bond strength of GC was found to be significantly higher compared with Thermafil (Dentsply Maillefer) (15).

However, no attempts have been made to assess whether the type of instrument used for canal preparation had an influence on the quality of obturation when using GC and GF. Therefore, the purpose of this study was to compare different obturation techniques in terms of the percentage of gutta-percha filled areas (PGFA), sealer filled areas (PSFA), and voids (PVA) in straight root canals instrumented with different instruments. The null hypotheses tested were the following:

1. The type of root canal instrument used for canal preparation has no impact on the quality of obturation.
2. There is no difference between GC and GF versus single-cone obturation and cold lateral compaction regarding PGFA, PSFA, and PVA.
Materials and Methods

Selection of Teeth

One hundred sixty extracted human mandibular premolars with straight root canals (curvature <5°) were selected. All roots were observed with a stereomicroscope under ×20 magnification (Expert-2; Müller Optromic, Erfurt, Germany) to exclude cracks. Only single-rooted teeth with a single canal and a single apical foramen were included. This was verified by viewing their buccal and proximal radiographs. After coronal access, apical patency of the canal was checked. Working length (WL) was obtained by measuring the length of the initial instrument (size 10) at the apical foramen minus 1 mm. The canal width near the apex was approximately compatible with size 15. This was checked with silver points sizes 15 and 20 (VDW).

On the basis of the distance between the cementoenamel junction (CEJ) and the apex and the diameter of the root at the CEJ in both buccal and mesiodistal view, the teeth were allocated into 10 similar groups (n = 16 teeth per group). The homogeneity of the groups with respect to these 3 parameters was assessed by using analysis of variance (P = .996, P = .886, and P = .618, respectively).

Root Canal Preparation

All instruments were set into rotation with a 6:1 reduction handpiece (Sirona, Bensheim, Germany) powered by a torque-limited electric motor (VDW Silver Reciproc motor; VDW). For each rotary file the individual torque limit and rotational speed recommended by the manufacturer were used, whereas Reciproc and WaveOne were used in a reciprocating working motion. All engine-driven instruments were used in a slow in-and-out pecking motion.

After each instrument or after 3 pecks by using the reciprocating files, the canals were irrigated with 2 mL NaOCl by using NaviTip 31-gauge needles (Ultradent, South Jordan, UT). All preparations were completed by 1 operator. Apical patency was maintained by using EDTA (17%) to remove the smear layer and finally with 10 mL NaOCl and then dried with paper points.

In all groups, AH Plus (Dentsply DeTrey, Konstanz, Germany) was used as sealer, and before obturation small amounts were applied to the canal by using a K-file size 25 in a counterclockwise rotation. Before obturation by using GC and GF, the fitting of the obturators was checked with the corresponding verifiers. GC and GF obturators were heated in the GuntaFusion oven (VDW) on heat setting “1.” All treatment procedures were carried out by the same operator who was proficient in all the obturation techniques tested. The following groups were established.

**Group A.** Stainless steel K-Files (Dentsply Maillefer) sizes 15–40 were used according to the balanced-force technique. Cold lateral compaction was performed with an ISO-sized 40 gutta-percha master cone. A size 25 NiTi finger spreader was introduced for the first time to 2 mm short to WL. Sealer-coated 20.02 accessory cones (VDW) were used for lateral compaction. As many accessory cones as possible were placed into the canals until the same level (8 mm from the apex) was reached.

**Groups B–D.** Mtwo instruments were used to the full length of the canals. The instrumentation sequence was 10.04, 15.05, 20.06, 25.06, 30.05, 35.04, and 40.04. Canals were obturated by using a size 40 Mtwo-GuttaFusion obturator (group B), the lateral compaction with an ISO-size 40 gutta-percha master cone as described (group C), and a Mtwo size 40.04 matching single-cone gutta-percha (group D).

**Groups E–G.** A R40 Reciproc file was used to full WL in a reciprocating motion. Canals were obturated by using the size 40 Reciproc.
GuttaFusion obturator (group E), the lateral compaction with an ISO-size 40 gutta-percha master cone as described (group F), and a RI0 matching single-cone gutta-percha (group G).

Groups H–J. A large reciprocating WaveOne file with a size 40 was used in a reciprocating motion. Canals were obturated by using the size 40 WaveOne-GuttaCore obturator (group H), the lateral compaction with an ISO-size 40 gutta-percha master cone as described (group I), and a large WaveOne matching single-cone gutta-percha (group J).

After obturation a heated plugger was used to remove the coronal excess gutta-percha, with no further vertical compaction. The teeth were radiographed in buccal and proximal view to verify correct obturation. Teeth were stored for 14 days at 37°C and 100% humidity to allow the sealer to set completely.

Evaluation and Statistical Analysis

The teeth were embedded in resin blocks (Technovit; Heraeus-Kulzer, Wehrheim, Germany) and sectioned horizontally with a 0.1-mm low-speed saw (Leitz, Wetzlar, Germany) under permanent water-cooling at 2, 4, 6, and 8 mm from the apex. All slices were observed from a coronal to apical direction under a digital stereomicroscope (Expert DN) at \( \times 25 \) magnification, and pictures were taken. On these digital images of each segment, the total area of each canal segment and the areas of gutta-percha, sealer, and voids were measured in a metric system by using the ImageJ software (National Institutes of Health, public domain). The areas of gutta-percha, sealer, and voids were converted to percentages (PGFA, PSFA, and PVA) of the total area. The analysis of these sections was made by a second examiner who was blinded in respect to all experimental groups. For each section, measurements were repeated 3 times, and the means were calculated.

In a case where sectioning of the teeth revealed an oval canal (relation long: short diameter of the canal \( \geq 1.5 \) at the 4-mm level) or a canal with isthmuses, the tooth was discarded and replaced by a new one. This was the case for 13 teeth.

The average area values of each section for each filling component were compared for the groups. Because data were not normally distributed (Kolmogorov-Smirnov test), they were subjected to the nonparametric Kruskal-Wallis test and post hoc Dunn test. Regarding the number of void-free specimens, the nonparametric Friedman test was used. The level of significance was set at \( P < .05 \).

Results

At the 2-mm level, no significant differences in terms of PGFA and PSFA were obtained (\( P > .05 \)) (Table 1). At all other levels, canals filled with GC and GF produced significantly higher PGFA and significantly lower PSFA than all other groups (\( P < .05 \)). At the 8-mm level, single-cone obturation (groups D, G, and J) produced significantly lower PGFA and significantly higher PSFA than all other groups (\( P < .05 \)).

At the 2- to 6-mm levels, canals filled with GC and GF showed less voids than group A (\( P < .05 \)). At the 2-mm level, GC and GF produced also significantly less voids than group F, at the 4-mm level than groups I and J, and at the 6-mm level than groups G and I (\( P < .05 \)).

Regarding the number of void-free specimens, marked differences between the canals filled by GC and GF and all other groups were noted (Table 2). For the pooled data of all levels, groups B, E, and H showed significantly more void-free specimens than all other groups (\( P < .05 \)), whereas no significant differences were obtained between the other groups (\( P > .05 \)). At the 2-mm and 4-mm levels, all canals filled by GC and GF were free of voids. In total, 96.88%–100% of specimens filled by GC and GF were void-free (Table 2).

Discussion

Proper obturation of the enlarged and cleaned root canal aims at packing a maximum amount of gutta-percha into the canal and keeping the amount of sealer to a minimum because most sealers shrink on setting and dissolve over time (10, 11, 16), whereas gutta-percha is dimensionally stable (5). Therefore, the PGFA has been used to evaluate the quality of obturation in the present investigation, as was done before in other studies (6–8, 17–25).

In the present study lateral compaction after manual root canal preparation was used as control because this technique is still a common method (5, 12). In the experimental groups the canals were instrumented with 1 constant tapered NiTi system (Mtwo) and 2 variable tapered systems (Reciproc and WaveOne). Of the latter, the RI0 Reciproc and the large WaveOne instrument have a taper of 0.08 over the first 3 mm that reduces to 4% and 4.5%, respectively.

According to the results obtained, the type of instrument used for canal preparation had no influence on the quality of obturation when using GC and GF obturators; therefore, the first null hypothesis was accepted. Thus, both core-carrier systems were able to equally obturate both constant and varied tapered preparations (Fig. 1). This observation is of clinical relevance because for single-cone obturation it has been shown that higher PGFA resulted in constant tapered canals compared with variable tapered canals (6).

At the 2-mm level, no significant differences in terms of PGFA and PSFA were obtained (\( P > .05 \)) (Table 1). This corroborates the findings of previous studies that obtained no significant differences between

<p>| Table 2. Number and Percentage of Void-free Specimens |
| --- | --- | --- | --- | --- | --- |</p>
<table>
<thead>
<tr>
<th>Group</th>
<th>2 mm</th>
<th>4 mm</th>
<th>6 mm</th>
<th>8 mm</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, Man/LC</td>
<td>10</td>
<td>62.50</td>
<td>9</td>
<td>56.25</td>
<td>8</td>
</tr>
<tr>
<td>B, Mtwo/GF</td>
<td>16</td>
<td>100</td>
<td>16</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>C, Mtwo/LC</td>
<td>11</td>
<td>68.75</td>
<td>13</td>
<td>81.25</td>
<td>10</td>
</tr>
<tr>
<td>D, Mtwo/SC</td>
<td>12</td>
<td>75</td>
<td>13</td>
<td>81.25</td>
<td>11</td>
</tr>
<tr>
<td>E, Rec/GF</td>
<td>16</td>
<td>100</td>
<td>16</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>F, Rec/LC</td>
<td>9</td>
<td>56.25</td>
<td>11</td>
<td>68.75</td>
<td>12</td>
</tr>
<tr>
<td>G, Rec/SC</td>
<td>11</td>
<td>68.75</td>
<td>10</td>
<td>62.50</td>
<td>8</td>
</tr>
<tr>
<td>H, WO/GC</td>
<td>16</td>
<td>100</td>
<td>16</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>I, WO/LC</td>
<td>11</td>
<td>68.75</td>
<td>9</td>
<td>56.25</td>
<td>10</td>
</tr>
<tr>
<td>J, WO/SC</td>
<td>11</td>
<td>68.75</td>
<td>12</td>
<td>75</td>
<td>13</td>
</tr>
</tbody>
</table>

A, manual instrumentation + lateral compaction (LC); B, Mtwo + GF; C, Mtwo + LC; D, Mtwo + single-cone (SC); E, Reciproc + GF; F, Reciproc + LC; G, Reciproc + SC; H, WaveOne (WO) + GC; I, WaveOne + LC; J, WaveOne + SC.

For values with the same superscript letters were not statistically different at \( P > .05 \).

Values with the same superscript letters were not statistically different at \( P > .05 \).
laterally compacted and single-cone gutta-percha at any level (6, 18, 22, 23) and reported that single-cone obturation was able to fill the apical portion of canals effectively (19, 24–27).

The second null hypothesis was rejected because at 4- to 8-mm levels, canals filled with GC and GF produced the significantly highest PGFA and the lowest PSFA of all groups \((P < .05)\). Concurrently, at the 2- to 6-mm levels, obturation with these core-carrier systems was associated with fewer voids than the lateral compaction in canals enlarged with hand instruments (group A, \(P < .05\)). At all assessed levels, the number of void-free specimens was considerably higher when canals were filled with GC and GF compared with all other techniques (Table 2). This observation corroborates the finding of a previous study that evaluated the quality of obturation in canals obturated by GC by using micro–computed tomography and scanning electron microscopy (13). The percentage of voids was significantly higher in canals obturated by cold lateral compaction compared with the GC technique (13).

At the 8-mm level, single-cone obturation (groups D, G, and J) produced significantly lower PGFA and significantly higher PSFA than all other groups \((P < .05)\). This finding is agreement with several previous reports (6, 25, 28).

The methodology used in this study has some immanent weaknesses (13, 18), although light microscopy of root sections has been frequently used in previous studies (17, 18, 20, 24, 29, 30). Utmost care (extensive water-cooling) must be taken to avoid smearing of the filling on the section surface when cutting the teeth because smearing might influence the detection of small void areas. Moreover, evaluation of sliced sections only allows 2-dimensional assessments of void areas, and the resolution of the light microscope might not be sufficient to detect very small voids and interfacial gaps between the root canal filling and the canal walls (13). Nevertheless, regarding the detection of voids, the results of the present study are in good agreement with those obtained by using micro–computed tomography and scanning electron microscopy analysis of canals filled by GC (13). In this study 100% of canals were void-free at the 4-mm, 8-mm, and 12-mm levels (13), which corroborates the present findings.

Within the limitations of this study it was concluded that independent of the instrument used for canal preparation (constant versus variable taper), GuttaCore and GuttaFusion produced very homogenous obturations with high PGFA and a low incidence of voids at all levels.

Acknowledgments

The authors deny any conflicts of interest related to this study.

References