Push-out Strength of 3 Warm Obturation Techniques: Warm Vertical Compaction, GuttaCore, GuttaFusion
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Abstract:
Background: The purpose of this study was to compare the bond strength of two techniques using the adhesion test. 

Materials and Methods: A total of 36 single-rooted permanent teeth were prepared. The teeth were randomly divided into 3 groups; each one was obturated using the warm vertical compaction (WVC) technique or with thermoplasticized technique (GuttaCore® [GC] and GuttaFusion® [GF]). The samples were sectioned transversally at 1, 2, 3, and 4 mm from the apex, and an increasing force was applied at each section at a constant speed of 1 mm/min in the apico-coronal direction until a fracture occurs. The maximum load applied to the filling material before the separation was recorded in Newtons. The bond strength is then calculated. Microscopic inspection of the canal walls at ×100 magnification, after extrusion of the filling material, was used to determine the failure mode. The data obtained was analyzed using Bonferroni pairwise comparisons. Fisher exact tests were conducted for the comparisons of failure mode among groups, with a significance level of 5%.

Results: No significant difference was found between the three groups concerning the bond strength in the apical third. Moreover, the mean bond strength was significantly different between the sections of each group.

Conclusion: The apical adaptation of GC and GF obturators was equivalent to those of WVC technique in the apical third regardless of canal level.

Key Words: Adhesion, GuttaCore, GuttaFusion, obturation, push-out strength

Introduction
Over the years, several filling techniques have been suggested to accomplish a hermetic seal of the root canal system. Schilder suggested that the ideal root canal obturating material should be well adapted to the canal walls and its irregularities.¹ In 1976, Grossman studied the physical properties of filling materials and found adhesion to be a very desirable property in root canal cements.² Caicedo and von Fraunhofer agreed with these findings and reiterated that endodontic cements must seal the root canal space and ideally should adhere to both the gutta-percha cone and the canal walls.³

Simplified techniques of thermoplasticizing gutta-percha have become progressively popular. Schilder introduced warm vertical compaction (WVC) concept of gutta-percha, in 1967, using an electrically heated Plugger to down-pack.¹ Another method stated as “obturator technique” was adapted by Johnson, in 1978, and consists of metal carrier with thermally plasticized gutta-percha.⁴ This system has been subjected to several enhancements: The metal support was substituted by a plastic one⁵ that was replaced recently by a gutta-percha core obturator GuttaCore® (GC) (Dentsply, Tulsa, OK) and GuttaFusion® (GF) (VDW, Germany). Gutta-percha core obturator and WVC techniques have been described by their proponents as being easy to manipulate and effective in filling the complexities of the root canal system compared to other methods available currently.⁶,⁷

During the obturation, some variables may impact the adhesion of gutta-percha on the canal walls such as the dentin surface treatment, cement surface tension, type of filling material and methods.⁸

The aim of this study was to evaluate the apical adaptation of these new obturation systems with WVC technique and compare the bond strength of GC and GF techniques to WVC technique using the adhesion test.

Materials and Methods
Sample selection and specimen preparation
About 36 single-rooted extracted teeth with a curvature less than 10°, as determined by Schneider’s method,⁹ were collected. Teeth with root resorptions, fracture, or immature apices were excluded from the study. Preliminary radiographs were taken in bucco-lingual and mesio-distal directions using a digital sensor (ERLM Digora® Optime – Soredex, Finland) to verify the absence of endodontic irregularities or multiple canals or root canal treatment.

Root surfaces were manually scaled, rinsed under running water then kept in Formol 10% for 1 week. The crowns were...
removed with a water-cooled diamond disc (KG Sorensen, Barueri, SP, Brazil) and length adjusted at 16 mm. A #10 K-flexofile (Dentsply Maillefer, Switzerland) was introduced, it reached the apical foramen, working length (WL) was determined and a radiograph taken.

**Root canal instrumentation**

After introduction of hand files and establishment of a glide path, WaveOne Primary® (25/08) (Dentsply Tulsa Dental Specialties, Tulsa, OK) instrument was used in a reciprocating movement with a light apical pressure. Afterward, a size #10 K-file was taken to the WL to check patency and irrigation followed with 1 ml of 5.25% NaOCl. The previous sequence was repeated until the instrument reached the WL. WaveOne Large® (40/08) (Dentsply Tulsa Dental Specialties, Tulsa, OK) was then used to the WL.

A final flush of 2 mL 17% EDTA (pH = 7.7) SmearClear (SybronEndo, Orange, CA, USA) was applied to eliminate the smear layer. Then, the canals were washed with 5 mL saline solution and dried with paper points (Dentsply Maillefer).

**Root canal filling**

After preparations, all root canals were randomly assigned to 3 experimental groups (n = 12) according to the filling techniques used. The first group received a root filling by WVC technique with gutta-percha and AH Plus® (Dentsply International), the second group GC and AH Plus®, and the third GF and AH Plus®.

**WVC**

A fine-medium sized gutta-percha cone (Dentsply Tulsa Dental) was selected as the master cone and trimmed to fit within 0.5 mm of the WL. The prefitted master cone coated with a thin layer of AH Plus® sealer was inserted into the canal and down-packed to 5 mm from the WL with a Touch n’ Heat source (SybronEndo, Orange, CA). Subsequently, 3–4 mm segments of gutta-percha were back-packed with the Obtura II Unit (SybronEndo, Orange, CA) until the canals were completely obturated.

**Obturator technique**

The canals were fitted with GC (Dentsply Tulsa Dental Specialties, Tulsa, OK) and GF (VDW Munich, Germany) obturators selected by passively inserting a verifier to WL-0.5 mm and the rubber markers on the obturators set accordingly. The prefitted obturator was heated in the oven (GC™ Oven [Dentsply Tulsa Dental Specialties, Tulsa, OK] and GF® Oven [VDW Munich, Germany]). A thin layer of the AH Plus® sealer was applied to the canal walls with the verifier. Once the heating cycle was completed, the obturator was removed from the oven and slowly inserted (6–7 s) into the canal to the WL. The handle of the carrier was stabilized with finger pressure and then separated at the orifice of the canal.

All roots were stored at 37°C with 100% humidity for about 72 h to allow the sealers to set completely.

Four horizontal slices of 1.00 mm thickness were cut from the apical portion of each root at 1, 2, 3, and 4 mm from the apex using a cutting system (EXAKT 300, EXAKT Technologies, Inc., Norderstedt, Germany). The specimens were examined to confirm a circular canal shape. Apical and coronal aspects of each slice were digitally photographed using an optical microscope (OLYMPUS CX41, OLYMPUS, Tokyo, Japan) at a magnification of ×100 with a mounted on the digital camera. After that, the circumferences of the filling material from the coronal and apical aspects of each slice were calculated using AutoCAD software program.

**Push-out test**

The filling material was then loaded with a 0.5 mm diameter cylindrical stainless steel plunger. Loading was performed on a universal testing machine (YLE GmbH Waldstraße 1/1a, 64732 Bad König, Germany) at a speed of 1 mm/min until bond failure. The load was applied in an apical-coronal direction to avoid any interference because of the root canal taper during push-out testing. The bond strength was determined using computer software program connected to the universal testing machine. The maximum load applied to the filling material before debonding occurred was recorded in Newtons N. Bond strength data were converted to MPa using the following formula:

\[
\text{Bond strength (MPa)} = \frac{\text{Debonding force (N)}}{\text{Interfacial area (mm}^2\text{)}}
\]

The interfacial area (mm²) was calculated by 0.5 (circumference of coronal aspect + circumference of apical aspect) * thickness.

The failure mode was assessed by two independent examiners with an optical microscope at ×100 magnifications:

1. Cohesive (>75% of canal surfaces with sealer or gutta-percha);
2. Adhesive (<25%);
3. Mixed failure (>25% to <75%) (Figure 1).

**Statistical analysis**

Statistical analyses were performed using software (SPSS for Windows, Version 18.0, Chicago, IL, USA). The level of significance was set at α = 0.05. The primary outcome variable of the study was the bond strength in MPa. The data obtained was analyzed using Bonferroni pairwise comparisons. The secondary outcome variable was the failure mode. Fisher exact tests were conducted for the comparisons among groups.

**Results**

The mean and standard deviation of the bond strength (MPa) in groups are presented in Table 1 and Graph 1. No significant difference was found between WVC, GC, and GF groups at 1 mm (P = 0.980), 2 mm (P = 0.560), 3 mm (P = 0.446), and 4 mm.
to the periapex of microorganisms that persisted in the root canal after cleaning and shaping.\textsuperscript{12}

The thermoplastic root filling methods, based on the principles of vertical compaction of warm gutta-percha conceived and described by Schilder,\textsuperscript{1} have been widely investigated over the years with good results regarding filling of the root canal system, homogeneity of the filling material, and apical seal.\textsuperscript{13}

Regardless of the inadequate bond strength of most sealers to dentin, the adhesion is necessary to maintain the integrity of the sealer-dentin interface during mechanical stress caused by tooth flexure, operative procedures, or preparation of a post.\textsuperscript{14}

This study evaluated the influence of two novel obturators on the adhesion of root filling materials to root canal walls. A push-out test is considered the best to measure the adhesiveness and effectiveness of an endodontic obturation technique or material, despite the fact that it cannot reproduce the exact clinical performance of the sealers and the obturation techniques.\textsuperscript{15}

### Table 1: Bond strength mean values and standard deviations (in MPa) necessary to dislodgement the filling material comparing the groups.

<table>
<thead>
<tr>
<th>Bond strength</th>
<th>Groups</th>
<th>Mean (MPa)</th>
<th>Standard deviation (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>WVC</td>
<td>4.61</td>
<td>2.312</td>
</tr>
<tr>
<td></td>
<td>GC</td>
<td>2.95</td>
<td>1.539</td>
</tr>
<tr>
<td></td>
<td>GF</td>
<td>3.42</td>
<td>2.498</td>
</tr>
<tr>
<td>2 mm</td>
<td>WVC</td>
<td>2.87</td>
<td>1.779</td>
</tr>
<tr>
<td></td>
<td>GC</td>
<td>1.73</td>
<td>0.980</td>
</tr>
<tr>
<td></td>
<td>GF</td>
<td>1.74</td>
<td>0.766</td>
</tr>
<tr>
<td>3 mm</td>
<td>WVC</td>
<td>1.31</td>
<td>1.143</td>
</tr>
<tr>
<td></td>
<td>GC</td>
<td>0.90</td>
<td>0.694</td>
</tr>
<tr>
<td></td>
<td>GF</td>
<td>1.11</td>
<td>0.669</td>
</tr>
<tr>
<td>4 mm</td>
<td>WVC</td>
<td>1.14</td>
<td>0.966</td>
</tr>
<tr>
<td></td>
<td>GC</td>
<td>0.66</td>
<td>0.557</td>
</tr>
<tr>
<td></td>
<td>GF</td>
<td>0.86</td>
<td>0.578</td>
</tr>
</tbody>
</table>

WVC: Warm vertical compaction, GC: GuttaCore\textsuperscript{®}, GF: GuttaFusion\textsuperscript{®}

### Table 2: Distribution of failure modes (%) after the push-out test for each type of root filling technique according to the section’s level.

<table>
<thead>
<tr>
<th>Section level</th>
<th>Failure mode</th>
<th>WVC (%)</th>
<th>GC (%)</th>
<th>GF (%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>Cohesive</td>
<td>11 (91.7)</td>
<td>8 (66.7)</td>
<td>8 (66.7)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>1 (8.3)</td>
<td>4 (33.3)</td>
<td>4 (33.3)</td>
<td>9</td>
</tr>
<tr>
<td>2 mm</td>
<td>Adhesive</td>
<td>2 (16.7)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cohesive</td>
<td>8 (66.7)</td>
<td>7 (58.3)</td>
<td>9 (75.0)</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>2 (16.7)</td>
<td>5 (41.7)</td>
<td>3 (25.0)</td>
<td>10</td>
</tr>
<tr>
<td>3 mm</td>
<td>Adhesive</td>
<td>1 (8.3)</td>
<td>0 (0.0)</td>
<td>1 (8.3)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cohesive</td>
<td>7 (58.3)</td>
<td>9 (75.0)</td>
<td>5 (41.7)</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>4 (33.3)</td>
<td>3 (25.0)</td>
<td>6 (50.0)</td>
<td>13</td>
</tr>
<tr>
<td>4 mm</td>
<td>Adhesive</td>
<td>1 (8.3)</td>
<td>0 (0.0)</td>
<td>1 (8.3)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cohesive</td>
<td>3 (25.0)</td>
<td>5 (41.7)</td>
<td>5 (41.7)</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
<td>8 (66.7)</td>
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WVC: Warm vertical compaction, GC: GuttaCore\textsuperscript{®}, GF: GuttaFusion\textsuperscript{®}

Discussion
The role of root canal filling is to avoid leakage of oral bacteria and their products from the oral cavity to the apical periodontium through the root canal and to prevent the exit of microorganisms that persisted in the root canal after cleaning and shaping.\textsuperscript{12}

The thermoplastic root filling methods, based on the principles of vertical compaction of warm gutta-percha conceived and described by Schilder,\textsuperscript{1} have been widely investigated over the years with good results regarding filling of the root canal system, homogeneity of the filling material, and apical seal.\textsuperscript{13}

Regardless of the inadequate bond strength of most sealers to dentin, the adhesion is necessary to maintain the integrity of the sealer-dentin interface during mechanical stress caused by tooth flexure, operative procedures, or preparation of a post.\textsuperscript{14}

This study evaluated the influence of two novel obturators on the adhesion of root filling materials to root canal walls. A push-out test is considered the best to measure the adhesiveness and effectiveness of an endodontic obturation technique or material, despite the fact that it cannot reproduce the exact clinical performance of the sealers and the obturation techniques.\textsuperscript{15}
After preparation, the smear layer was removed with a 1 min rinse of a liquid EDTA solution. In this study, the use of WaveOne Large® 40/8 till the WL has been supported by several previous studies because the increase in the final preparation taper improves irrigant replacement and wall shear stress. Moreover, enlarging the apical third (especially the last 3 mm) of root canals to an 8% taper is necessary to achieve a better sealing ability and thus long-term success for root canal obturations.\textsuperscript{16,17}

Endodontic sealers differ in physical properties which might determine the sealing ability of the root filling.\textsuperscript{18} The good dimensional stability of AH Plus® sealer has been demonstrated,\textsuperscript{19,20} and its application can be suggested. According to some studies, thickness of sealer decreases sealing ability of obturation materials regardless of the technique.\textsuperscript{21,22}

In this study, depending on the technique used to fill the root canal, no significant difference was found in the material displacement resistance and the bond strength at 1 mm (\(P = 0.080\)), 2 mm (\(P = 0.560\)), 3 mm (\(P = 0.446\)), and 4 mm (\(P = 0.171\)). These results can be caused by the presence of voids between dentinal walls and the filling material.\textsuperscript{23}

Among the experimental groups, the mean bond strength was significantly different between the sections. The highest values observed after push-out tests were obtained at 1 and 2 mm; the lowest ones at 3 and 4 mm. This outcome is in agreement with a study conducted by Gaston et al., who found that the adhesion is stronger at the apical third of a root canal.\textsuperscript{24}

In fact, the bond strength is inversely proportional to the interfacial area of the section, according to the formula mentioned previously, and the plunger as well as the speed applied at all the sections are the same, we can deduce that as much as the section is small the resistance will be higher.

In addition, a factor that could explain the difference in bond strength between the sections is the internal anatomy of each level of the root canal due to the variation in the number and diameter of tubules.\textsuperscript{25} However, according to Babb et al., variations in density of tubules along the root canal are insufficient to alter the adhesion of the sealing material.\textsuperscript{26} In 2007, Sly et al. affirmed that finding a possible difference of the adhesion for the same technique, depending on the location in the canal, does not provide significant results.\textsuperscript{27} Indeed, the position of the section has a slight effect on the adhesion regardless of the material and the technique used. These contradictions prevent to establish a clear correlation between the canal location and adhesion values.

In this study, inspection of the root slices using an optical microscope revealed that the failure mode was significantly different between the 4 sections for all groups.

The failure mode cohesive was more frequent at 1 mm and 2 mm in the three groups. The results of this study are in agreement with those Dias et al., who found that the most common type of failure mode was cohesive in teeth obturated by the lateral condensation of gutta-percha with AH Plus.\textsuperscript{27} This could be explained by a thin layer of sealer that might be more inclined to cause cohesive failures. It is possible that the gutta-percha has penetrated into the dentinal tubules, leaving a sealer layer formed of particles larger than the tubules diameter.\textsuperscript{28} This cohesive failure indicates that the interface performed in a stronger way than the core material.\textsuperscript{11}

The failure mode mixed was the most frequent at the 4 mm section. This outcome is in agreement with previous studies. Carneiro et al., in 2012, showed using a stereomicroscope, a predominance of cohesive failure at the coronal third and mixed failure at the middle and apical third, after adhesion test on teeth filled by the lateral condensation technique of gutta-percha with AH Plus.\textsuperscript{29} Moreover, the literature reports a predominance of mixed failure for teeth obturated with gutta-percha and AH Plus.\textsuperscript{30} This could be explained by a high particle ratio in the sealer layer that might result in a weak cohesive strength.\textsuperscript{28}

Adhesive failure was less frequent at all the sections of all the groups. This is in contradiction with the study of Shokouhinejad et al., in 2010, where the same methodology was used. The failure mode was mainly adhesive for the group rinsed with 5.25% NaOCl then by EDTA and obturated by lateral condensation of gutta-percha and AH 26.\textsuperscript{31} This means that the dentin surface was devoid of sealer, so the interface was weaker than the heart of the material.\textsuperscript{11} This finding is in disagreement with our study where we used different obturation techniques leading to a distinct sealer thickness influencing differently the failure mode.

One of the main limitations of push-out tests is the dissimilar cross-sectional shape of the canal at different levels of the same tooth. In this study, we used single-rooted teeth resulting in poor standardization according to De-Deus et al., who confirmed, in 2015, that the use of standardized geometrical test specimens is an attempt to overcome the individual anatomic differences of natural canal spaces, which generally make push-out test outcomes impossible to compare.\textsuperscript{32}

Conclusion

Under the conditions of this study, it could be concluded that obturator techniques showed similar bond strength results to the WVC technique in the apical third of root canals. The mean bond strength was significantly different between the sections of each group; the highest values were obtained at 1 mm in all the experimental groups. Since the
Influence of calcium hydroxide 
Dentin moisture conditions affect the 
Bonding of self-adhesive (self-etching) 
Quality of thermoplasticized and 
Influence of drying protocol 

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