Cavity wall adaptation and voids in adhesive Class I resin composite restorations

Niek J. M. Opdam, Joost J. M. Roeters, Tilly C. R. B. Peters, Rob C. W. Burgersdijk, Miriam Teunis

TRIKON: Institute for Dental Clinical Research, University of Nijmegen, THE NETHERLANDS

ABSTRACT
Objectives. Handling characteristics and application modes of resin composites are important factors to achieve proper placement of the restorative materials. The present study was undertaken to assess the influence of the consistency of composite materials and the mode of application on voids and porosities in Class I adhesive restorations.

Methods. One hundred medium-sized Class I preparations with an adhesive design were restored with three composites of various consistencies using three different application modes. The restorations were sectioned, and each section of a restoration was inspected for the presence of voids. The total surface and the percentage of the cavity wall occupied by voids as well as the total number of voids in the sections were recorded. A Krusal-Wallis analysis of variance was carried out on the data. Differences between individual composite materials for each mode of application and between individual application modes for each composite material were analyzed using a Mann-Whitney U-test at p < 0.05.

Results. The injection technique with a Hawe Neos Centrix tip was the best mode of application. Both smearing and the condensation of composites appeared to produce unreliable results. Furthermore, there were more problems with voids and wall adaptation for the thicker-consistency composite than for the medium- and thin-consistency material.

Significance. The thick-consistency composite had more problems related to voids and wall adaptation than the medium- and thin-consistency composites.

INTRODUCTION

One of the factors that influences the clinical performance of a posterior composite restoration is the application procedure the dentist uses. Proper handling of dental adhesives and composites contributes to successful bonding of the restoration and should ideally lead to a restoration with perfect wall adaptation that is free of porosities and voids. According to Feilzer et al. (1993), the presence of porosity in a composite material introduced by the mixing procedure can help to reduce the stress caused by polymerization shrinkage. However, most studies consider the presence of voids and porosities as disadvantageous for the restoration. First, voids at the margins of the restoration may lead to gross microleakage and discoloration. Second, the initial stress concentration around voids will result in a lower resistance to fatigue and increased wear (O'Brien and Yee, 1980; Leinfelder and Roberson, 1983; McCabe and Ogden, 1987). Third, voids between successive increments of a composite will have a negative effect on the flexural strength of the material (Huysmans et al., 1996). Fourth, voids can appear as translucent areas on radiographs and may be misinterpreted as secondary caries. Porosities and voids in posterior composite restorations are reported in several clinical studies. In the study performed by Kreulen et al. (1992), voids were detected on radiographs in 56% of posterior composite restorations. Fuks et al. (1990) and Eidelman et al. (1989) reported radiolucent defects at the gingival margins of Class II resin composite restorations in primary molars. Nordbø et al. (1993) also reported the presence of voids which were visible on radiographs of posterior composite restorations. These voids were sometimes a reason for total replacement of the restoration.

There are various ways to apply a posterior composite in the cavity. The dentist can take a volume of composite from the syringe and apply it directly into the cavity with a hand instrument or the composite can be injected into the cavity from a preloaded tip. The injection technique will reduce the amount of porosity in the restoration for both chemical-curing and light-curing materials (Finger and Jorgensen, 1977; Medlock et al., 1985). Especially with light-curing composites, the presence of large voids can be eliminated by injecting the material (Medlock et al., 1985). Extensive manipulation of composites in the cavity will further increase the presence of porosity (Hansen and Asmussen, 1988; Ironside and Malinson, 1993). Chadwick et al. (1989) found differences with respect to porosities between composite restorations using a condensation technique or a smearing technique. Van Dijken
et al. (1986) found more porosities in composite materials which were condensed into the cavity compared with materials cured under pressure. However, some authors advise condensation of the composite to obtain good wall adaptation (Jordan and Suzuki, 1992). Regardless of the application technique, some manipulation cannot be avoided, as the resin should be placed incrementally to minimize the polymerization shrinkage.

The result of the application procedure will also depend on the handling characteristics of the composite. The consistency of composites which are indicated for application in posterior teeth varies greatly (Opdam et al., 1993). Jordan and Suzuki (1992) advise the use of a high-viscosity condensable composite. However, Chohayeb and Rupp (1989) observed that the thick consistency of the high-viscosity composite used in their study made it difficult to get good adaptation of the filling material. Sturdevant et al. (1993) reported about the clinical failure of an experimental condensable posterior composite due to insufficient matrix available for wetting of the cavity walls and the melting of subsequent layers. Until now, the prevalence of voids and porosities in the restoration was never related to the consistency of composites.

The aim of this study was to assess the influence of the consistency of composite materials and the mode of application on the incidence of voids and porosities in Class I adhesive restorations.

**MATERIALS AND METHODS**

Three composites were selected, as given in Table 1: a thick-consistency material (Herculite XRV) which is delivered in syringes or preloaded tips by the manufacturer, a medium-consistency material (Clearfil Ray Posterior) and a thin-consistency material (P50) both delivered in syringes.

As a control procedure, the tapered end of an unused syringe or preloaded tip from each composite was first cut off at approximately 0.5 cm from the start of the parallel part. The composite inside the syringe or tip was cured for 60 s with the polymerization unit. The cured composite samples were removed from the syringes or tip and embedded in acrylic resin. With a milling machine (R Jung AG, Heidelberg, Germany), slices of approximately 120 μm were removed from each sample of the composite to be inspected for porosity. Each section was photographed on color transparency film with a microscopic camera (Leitz, magnification 4x) for projection on the screen of a digital image analyzer (Hitach Digitizer, HDG 111B, Hitachi Seiko Ltd., Japan).

For this study, 50 extracted human third molars which had been stored in 1% chloramine between 1 and 3 mon were selected. A standardized adhesive Class I preparation was made in the mesial and distal fossa of each tooth (Fig. 1). A cavity of 3 mm depth perpendicular to the occlusal surface was ground with a round diamond bur (2.5 mm diameter) (001 025 Horico, Berlin, Germany) and placed in a high-speed water-cooled handpiece. An excavation procedure was simulated at the dentin-enamel junction using a 1.6 mm diameter round diamond bur (001 016 Horico, Berlin, Germany). Each cavity was water-sprayed, dried and etched for 15 s with 37% phosphoric acid (DMG, Hamburg, Germany). After etching, the cavities were water-sprayed for 20 s and carefully air-dried. A bonding agent (Clearfil Photo Bond, Kuraray, Osaka, Japan, Batch no. 162) was mixed and applied with a brush.
were finished with a fine grit diamond stone (830 C 016, Ivoclar Schaam, Liechtenstein, Batch No. 727112), they were embedded in acrylic resin (Pro Base, Bioggio, Switzerland) with the composite, the material was condensed into the cavity with an instrument (Ash 49). The action of condensation, in which the instrument was pressed into the cavity floor when filling the cavity, was applied ten times to each layer.

In Instruments Division, Weybridge, UK). The outer diameter at the end of the Unidose tip was measured as 2.8 mm. Herculite XRV was injected into the cavity with a composite delivery gun (Caulk-Dent, Trubyte Dental Laboratory, Konstanz, Germany). The cavities were filled in two layers, and each layer was cured indirectly through the tooth for 30 s, followed by an additional cure from the occlusal for another 30 s (Fig. 2). The resin composite materials were inserted into the cavity according to the following protocols:

Injection technique. After loading a Centrix tip (Hawe Neos, Bioggio, Switzerland) with the composite, the material was injected into the cavity with a composite delivery gun (Caulk-Dent, Trubyte Dental Laboratory, Konstanz, Germany). The tip was placed on the cavity floor when filling the cavity. After injection of each layer, the tip was wiped off along the cavity margin to cut off the composite, and the layer was carefully molded in the desired shape with a hand instrument (Ash 49, Dentsply, Ash Instruments Division, Weybridge, UK). The outer diameter at the end of the Hawe Neos Centrix tip was measured as 1.9 mm. Herculite XRV was injected into the cavity with a Hawe Neos tip in one group and with the commercially available Unidose tip in another group. The outer diameter at the end of the Unidose tip was measured as 2.8 mm.

Smearing technique. With a hand instrument (Ash 6), the amount of composite required for each layer was taken from the syringe and directly placed into the cavity by wiping the material at the cavity wall. The composite layer was further contoured and carefully molded in the desired shape with an Ash 49.

Condensation technique. As in the smearing technique, the amount of composite required for each layer was taken from the syringe using a hand instrument (Ash 6) and placed directly into the cavity. Then each layer of composite was condensed into the cavity with an instrument (Ash 49). The action of condensation, in which the instrument was pressed into the composite, was applied ten times to each layer.

The various insertion techniques and composites resulted in 10 different combinations (Table 1). Finally, the restorations were finished with a fine grit diamond stone (830 C 016, Meisinger, Düsseldorf, Germany) and stored in tap water for 24 h. After embedding the samples in acrylic resin (Pro Base, Ivoclair Schaam, Liechtenstein, Batch No. 727112), they were sectioned with a diamond saw (Browneill, Rochester, NY, USA). The blade of the saw was 0.5 mm thick. Each restoration was sectioned twice in a bucco-lingual direction, and ideally, four sections were obtained from each restoration (Fig. 1). The sections were immersed in a dye solution (basic fuchsin) for 15 s to improve the visibility of voids, rinsed with water and air-dried. The sections were photographed on color transparency film with a microscope (Leitz, magnification 4x). The resulting transparencies were projected on the screen of a digital image analyzer (Hitachi, Hitachi Digitizer, HDG 111B, Hitachi Seiko Ltd., Japan). The circumference of each section, as well as the circumference of voids and porosities, was measured. Special attention was paid to the presence of voids at the cavity wall. The following calculations were applied to the data derived from each section: 1) The relative void surface area: Percentage of the total surface area of the restoration occupied by voids; 2) The relative wall void length: The percentage of the total length of the restoration wall occupied by voids; and 3) The total number of voids. A Kruskal-Wallis analysis of variance was carried out on the non-parametric data to assess the influence of materials and application methods on the results. Groups of the same material were compared among different application modes (Mann-Whitney U-test at p < 0.05) and groups among the same application mode were compared among different materials (Mann-Whitney U-test at p < 0.05). The p-values were corrected for multiple group testing.

RESULTS

Microscopic inspection of the composite taken from the syringes and preloaded tip showed that each brand of material was free of porosities. From the restorations made in this study, a total of 370 sections were available for inspection. The results for void surface area, wall void length, and number of voids (mean and standard deviation) are presented in Table 2. The results for the three application modes are shown in Fig. 3. The Kruskal-Wallis analysis of variance, carried out on the data for materials as well as for application methods indicated significant differences between groups for both aspects. The statistically significant differences between individual composite materials for each mode of application and between individual application modes for each composite material are presented in Table 2.

Considering the void surface area related to the mode of application, the injection method using the Hawe Centrix tip produced the best results for all composites, although the difference between Herculite injected and Herculite applied with a smearing technique was not statistically significant. The smearing technique resulted in the largest void surface area for the medium- and thin-consistency composites (P50 and Clearfil Ray Posterior). The use of the Unidose tip for injecting the medium-consistency material (Clearfil Ray Posterior), although the difference between P-50 and Clearfil Ray Posterior applied by smearing was not statistically significant. The thick-consistency composite (Herculite XRV) had the largest relative void surface area with the injection as well as the condensing technique.
TABLE 2: ANALYSIS OF VOIDS OCCURRING IN THE TESTED MATERIALS WITH THE THREE APPLICATION TECHNIQUES

<table>
<thead>
<tr>
<th>Material</th>
<th>n</th>
<th>Relative void surface* Mean ± SD (%)</th>
<th>Relative void length** Mean ± SD (%)</th>
<th>Number of voids Mean ± SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>37</td>
<td>0.15 ± 0.22 A*</td>
<td>0.88 ± 1.50 A</td>
<td>0.65 ± 0.68 A</td>
</tr>
<tr>
<td>PS</td>
<td>37</td>
<td>4.08 ± 4.51 B</td>
<td>5.72 ± 6.65 B</td>
<td>1.42 ± 0.87 B</td>
</tr>
<tr>
<td>PC</td>
<td>37</td>
<td>1.59 ± 1.64 B</td>
<td>1.22 ± 1.33 A</td>
<td>2.52 ± 1.04 C</td>
</tr>
<tr>
<td>CI</td>
<td>39</td>
<td>0.32 ± 0.42 A</td>
<td>0.64 ± 1.09 A</td>
<td>0.60 ± 0.64 A</td>
</tr>
<tr>
<td>CS</td>
<td>38</td>
<td>2.01 ± 2.47 B</td>
<td>5.02 ± 5.23 B</td>
<td>1.08 ± 0.65 B</td>
</tr>
<tr>
<td>CC</td>
<td>37</td>
<td>0.54 ± 0.53 A</td>
<td>2.99 ± 3.09 AB</td>
<td>1.50 ± 0.79 AB</td>
</tr>
<tr>
<td>HI</td>
<td>34</td>
<td>1.65 ± 0.96 A</td>
<td>5.66 ± 5.88 A</td>
<td>2.22 ± 0.81 A</td>
</tr>
<tr>
<td>HUI</td>
<td>40</td>
<td>3.55 ± 2.28 B</td>
<td>9.52 ± 5.48 BC</td>
<td>2.04 ± 0.59 A</td>
</tr>
<tr>
<td>HS</td>
<td>34</td>
<td>3.22 ± 2.69 AB</td>
<td>10.77 ± 5.16 C</td>
<td>3.88 ± 1.69 B</td>
</tr>
<tr>
<td>HC</td>
<td>37</td>
<td>4.03 ± 2.61 B</td>
<td>5.11 ± 3.54 AB</td>
<td>7.27 ± 1.81 C</td>
</tr>
</tbody>
</table>

The results of the groups marked with the same capitals show no statistical difference for the same material with different application modes (p < 0.05).

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<td>5.11 ± 3.54 AB</td>
<td>7.27 ± 1.81 C</td>
</tr>
</tbody>
</table>

The results of the groups marked with the same capitals show no statistical difference for the same application mode with different materials (p < 0.05).

* Percentage of the total surface area of the restoration occupied by voids.
** Percentages of the total length of the restorative wall occupied by voids.

For the wall void length, the injection technique had the best results when using thin-consistency and medium-consistency materials (P-50 and Clearfil Ray Posterior). Injecting the thick-consistency composite with the Unidose tip (Herculite XRV) resulted in more voids along the cavity wall compared to the same composite material injected with the Hawe Neos Centrix tip. The thick-consistency composite had the highest prevalence of voids along the cavity wall, whereas no statistical differences were found between the medium- and thin-consistency material.

In relation to the mode of application, the lowest number of voids was found for the injection technique and the highest number of voids for the condensation technique, although the difference between injected and condensed Clearfil Ray Posterior was not statistically significant. In relation to the composite material, the thick-consistency composite Herculite had the highest number of voids with each of the three techniques. The thin-consistency and medium-consistency of shrinkage but particularly due to the difficulty of condensation of the material to the gingival wall.

Though thick-consistency composites are often marketed as "condensable", better results were obtained in this study when thin- and medium-consistency composites were condensed. Von Beetz et al. (1993) observed porosities on the approximal surfaces of Class II restorations, and their data indicated a great difference in the prevalence of porosities between materials. In their study, P50 showed fewer porosities than Herculite XRV which is in accordance with the results of the present study. However, these authors made no comment on the relevance of consistency of the composites.

In the present study, the best mode of inserting a composite into the cavity was the injection technique using a Hawe Centrix tip. Injecting the thick-consistency composite, Herculite, with a preloaded Unidose tip resulted in a larger void surface area and an increased wall void length compared to the same material injected with the Hawe Centrix tip. As

DISCUSSION

From a clinical point of view, the void surface area and the wall void length can be considered more important than the total number of voids. Large voids may lead to a lower resistance to fatigue and decreased wear resistance and may be detected on radiographs, while voids along the margin may be responsible for marginal discoloration and gross microleakage. The composites selected for this study proved to be free of porosities when coming out of the package. However, Ironside and Makinson (1993) found microporosities in composites when inspected at high magnifications (60x and 240x). In the present study, a magnification of 4x was used for the inspection of the composites as well as for the restorations. Therefore, it can be assumed that microporosities, if present in the material, had no influence on the results of this study.

It can be concluded that both the consistency of the composite material and the application mode influence the presence of voids in the restoration. An explanation for the relatively poor results of the thick-consistency composite Herculite XRV might be its inability to achieve a good adaptation to the cavity wall. This could also be an explanation for the poor marginal adaptation of Herculite XRV Class II restorations on primary molars, as reported in an in vivo study by Eidelman et al. (1989). They stated that the dimensions of the defects found in their study were not predominantly the result of shrinkage but particularly due to the difficulty of condensation of the material to the gingival wall.

Materials showed no differences except for the condensation group where the medium-consistency material showed fewer voids.
the consistency between Herculite XRV injected with the Unidose or Hawe Centrix tip hardly varies (Opdam et al., 1993), the design of the Unidose tip is probably responsible for this phenomenon because the large diameter of the tip limits access to the cavity. In a study by Jørgensen and Hisamitsu (1983), the Hawe Neos Centrix tips were coated internally with a thin film of unfilled resin before loading the composite. This resulted in the reduction of porosity in the composite pressed out of the syringe. These findings were not found in this study, since the restorations made with uncoated Centrix tips were generally void-free. However, wetting the inside of the tip with unfilled resin also results in a thinner consistency of the composite (Opdam et al., 1993).

Smearing resulted in fewer but larger voids than condensation, especially for the thin-consistency and medium-consistency composites. Due to the smearing action, air is entrapped in the restorative material. The large standard deviation for the smearing technique indicates that the results with this technique are highly unpredictable for each composite used in this study. Condensation of the composite appeared to eliminate some of the air present in the material and resulted in improved wall adaptation compared with the smearing technique. However, the number of voids increased, which can be explained by the fact that the extensive manipulation during condensation will spread the air through the material. The results of the present study are not in accordance with the study by Chadwick et al. (1989). They found fewer smaller-sized porosities in restorations made with a smearing technique than with a condensation technique. This may be due to the differences in the application techniques as well as the cylindrical shape of the metal molds used in their study.

The differences between the thin-consistency and medium-consistency composites were negligible most of the time and smaller than between these materials and the high-consistency composite. However, the medium-consistency composite performed better than the thin-consistency composite when using the smearing and condensation techniques, although only for the condensation technique was the difference in void surface area statistically significant. Such techniques extensively use hand instruments, and other material characteristics related to the contact between the composite and instrument, such as stickiness, may be responsible for these findings. Another explanation may be the medium-consistency of Clearfil Ray Posterior, which makes this material more suitable for these techniques than the thin-consistency P50.

From this study, it can be concluded that a thick-consistency composite produces more voids and imperfect wall adaptation than composites of thin- and medium-consistency, whatever application mode is used. Evidently, there is a critical consistency for a composite to allow proper wetting of the cavity. Furthermore, the injection technique was found to be the best way to fill a cavity with resin composite under the condition that the design of the tip allows good access to the deepest part of the cavity. Manufacturers should carefully design the tip when they introduce their material in preloaded tips.

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Address correspondence and reprint requests to:

Niek J. M. Opdam
University of Nijmegen
Department of Cariology and Endodontology
P. O. Box 9101
NL 6500 HB Nijmegen
THE NETHERLANDS
Phone: +31-24-361-6410
Fax: +31-24-354-0265
E-mail: carendo@dent.kun.nl

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