Polymerization Shrinkage and Push-out Bond Strength of Different Composite Resins for Sealing the Screw-access Hole on Implant-supported Crowns

João Paulo Mendes Tribst\textsuperscript{a} / Amanda Maria de Oliveira Dal Piva\textsuperscript{a} / Natália Inês Gonçalves\textsuperscript{b} / Alexandre Luiz Souto Borges\textsuperscript{c} / Marco Antonio Bottino\textsuperscript{c} / Cornelis Johannes Kleverlaan\textsuperscript{d}

\textbf{Purpose:} To evaluate the effect of composite resin polymerization shrinkage stress on the stress distribution in the implant-supported crown-access hole, and on the bond strength between the ceramic and composite resin.

\textbf{Materials and Methods:} A 3D model of a ceramic crown, in which the access hole was filled with composite resin (conventional or bulk-fill), was used to evaluate the stress distribution in the access hole using finite element analysis. The contacts were considered bonded and the polymerization shrinkage was simulated based on the coefficient of linear thermal expansion of each resin. The push-out test (1 mm/min, 100 kgf) was performed on perforated lithium disilicate samples filled with conventional or bulk-fill resins to validate the stress data of the bond strength. One-way ANOVA and Tukey’s test were used to analyze the bond strength data, with $\alpha$ set at 5%.

\textbf{Results:} Conventional resin showed the worst stress distribution and highest displacement values, von Mises stress, maximum principal strain, maximum principal stress, and maximum shear stress vs the bulk-fill resin. Statistically significantly greater bond strength was observed for bulk-fill ($13.40 \pm 5.59$ MPa) than the conventional resin ($8.70 \pm 3.02$ MPa).

\textbf{Conclusion:} Comparing both materials tested in the present study, the use of bulk-fill composite resin to seal the screw-access hole is suggested to reduce the stress concentration and increase bond strength to the ceramic crown.

\textbf{Keywords:} composite resins, finite element analysis, incremental technique, polymerization.


Submitted for publication: 31.05.20; accepted for publication: 18.06.20

Dental implants in the rehabilitation of patients with total or partial tooth loss have yielded high success rates, as shown by scientific and clinical evidence.\textsuperscript{21,31} The most important advantage of dental rehabilitation with implants is the restoration of quality of life and increased self-esteem of the treated patients, as their chewing ability and often their nutritional status are improved.\textsuperscript{50} In addition to being comfortable and not interfering with phonetics,\textsuperscript{15} implants protect adjacent teeth from long-term complications.\textsuperscript{16}

Implant-supported prostheses can be classified according to their fixation to the prosthetic components: 1) screw-retained prostheses, in which the restoration directly fixed to the implant or abutment using a screw; and 2) cemented prostheses.\textsuperscript{44} The main advantage of screw-retained crowns is their reversibility.\textsuperscript{20} They can be easily removed without damage if repairs or a new restoration are required.\textsuperscript{3,4,13,19,20,22,26,34,35,41,44,46,49} In addition, the screws may be removed for soft tissue evaluation or removal of dental biofilm.\textsuperscript{26} Other advantages are using the screw to seat the temporary restoration for the purpose of conditioning the mucosa\textsuperscript{7,18} and lower the incidence of biological complications,\textsuperscript{45} due to the absence of cement in the peri-implant region, which can interfere with wound healing and tissue integrity. Screw-retained prostheses exhibit significantly more predictable retention\textsuperscript{4} and adaptation between the restoration and the underlying implant compared to ce-
Table 1  Mechanical properties of the materials used in the computational analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic modulus (GPa)</th>
<th>Poisson ratio</th>
<th>Coefficient of thermal expansion (mm/°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>110</td>
<td>0.30</td>
<td>–</td>
<td>30</td>
</tr>
<tr>
<td>Lithium disilicate</td>
<td>82</td>
<td>0.23</td>
<td>–</td>
<td>30</td>
</tr>
<tr>
<td>Filtek Z350 XT</td>
<td>13.45</td>
<td>0.17</td>
<td>0.00033</td>
<td>9</td>
</tr>
<tr>
<td>Filtek Bulk Fill</td>
<td>13.46</td>
<td>0.18</td>
<td>0.00025</td>
<td>9</td>
</tr>
</tbody>
</table>

MATERIALS AND METHODS

Residual Stress from Polymerization Shrinkage

A three-dimensional (3D) model of a ceramic crown cemented on a titanium base was modeled for the finite element analysis (FEA) of the stress distribution in the implant-supported crown access hole generated by different composite resins. The crown dimensions were approximately 10 mm in the mesio-distal direction, 8 mm in the bucco-lingual direction and 10 mm from the titanium base to the occlusal surface. The crown bore an access screw hole in the occlusal surface, characteristic of the screw-retained restorations. The 3DM file was subsequently replicated and imported to the analysis software (ANSYS 17.0, ANSYS; Houston, TX, USA) for numerical simulation. The 3D model was transformed into mesh, totaling 515,220 nodes and 242,310 hexahedral elements, with slow transition and high smoothing (after the convergence test of 10%). The composite/ceramic interfaces in all the models were considered bonded, simulating a perfect union. All materials were considered homogeneous, elastic, and isotropic. The mechanical properties of the materials used are summarized in Table 1.

Post-gel polymerization shrinkage was simulated by thermal analogy. This method can be applied to calculate the residual stress generated from bonded interfaces during polymerization shrinkage. The temperature was reduced by 1°C based on the coefficient of linear thermal expansion of each resin. A linear static structural analysis was performed to calculate the stress distribution in the cavity. The displacement, von Mises stress, maximum principal strain, maximum principal stress, and maximum shear stress were calculated to analyze the stressed areas. An in vitro test was performed to verify the validity of the bond strength.
stress data (Fig 1). In accordance with Dal Piva et al., the tensile stress data at the adhesive interface were exported and plotted for quantitative comparison with the bond strength data.

**Push-out Bond Strength Test**

Twenty perforated ceramic samples were used in this study (lithium disilicate, IPS e.max CAD, Ivoclar Vivadent; Schaan, Liechtenstein). The ceramic samples were cut with a diamond blade under water cooling (Isomet 1000, Buehler; Lake Bluff, IL, USA), resulting in 3-mm-thick flattened samples with the prosthetic screw-access hole in the center (3 mm diameter). The crystallization cycle of the material was performed following the manufacturer’s protocol in a specific oven (Programat P700, Ivoclar Vivadent). Next, the samples were divided into two groups according to the composite materials used: conventional (Filtek Z350 XT, 3M Oral Care; St Paul, MN, USA) or bulk-fill (Filtek Bulk Fill, 3M Oral Care) (N = 20, n = 10). Afterwards, the samples were cleaned with isopropyl alcohol in an ultrasonic bath (5 min), and the vertical walls of the central hole received a surface treatment with self-etching ceramic primer (Monobond Etch & Prime, Ivoclar Vivadent). The composite resin was used to seal the hole and light cured for 20 s using a light-curing unit set on high power (Bliphase, Ivoclar Vivadent), as recommended by the manufacturer. For the conventional composite resin, two increments of 1.5 mm were applied, whereas in the bulk-fill group, only one increment was placed. Figure 1 summarizes sample preparation and the push-out test.

For the bond strength test, the samples were positioned on a metal device with a central hole (Ø = 3.5 mm). Then a metal device (Ø = 3 mm) was used to apply an axial load on the composite restoration cylinder. The test was performed in a universal testing machine (Instron 6022; Norwood, MA, USA) with a load cell of 100 kgf at a speed of 1 mm/min. The bond strength (σ) in MPa was obtained by the formula 

\[ \sigma = \frac{F}{A} \]

where F is the load in Newtons at specimen failure, A is the lateral area (bonded) calculated using the formula

\[ A = \pi rh \]

where r is the composite resin cylinder radius and h is the cylinder height. Only adhesive failures were considered in the statistical analysis. One-way ANOVA and Tukey’s post-hoc test were used to analyze the bond strength data (Minitab 18, Pennsylvania State University; State College, PA, USA), with σ set at 5%.

**Failure Mode Analysis**

To evaluate the fracture type, the ceramic slices were cleaned with isopropyl alcohol in an ultrasonic bath (5 min), gold sputter coated, and examined under in a scanning electron microscope (XL 20, Philips; Eindhoven, The Netherlands) before the test and in sagittal view after the push-out bond strength test.

**RESULTS**

**Finite Element Analysis**

The stress distribution for all models simulating different restorative techniques is presented in Figs 2 and 3, and the highest values (stress peaks) are summarized in Table 2. The composite resin influenced all stress parameters. The bulk-fill restoration resulted in a more homogeneous stress distribution at the ceramic/restoration interface, with
smaller peaks for all failure criteria. Regardless of the composite material, the stress maps show that shrinkage displacement is centripetal, resulting in a neutral zone at the center of composite cylinder for both materials. The shrinkage of restorative material results in stresses concentrated in the interface between composite and ceramic. These results suggest a possible gap, which could lead to future debonding at the interface.

**Pull-out Bond Strength Test**

The bond strength between the composite resin seal and the ceramic crown differed significantly according to the composite resin used (F = 5.43, p = 0.031). The specimens sealed with bulk-fill resin presented significantly higher bond strength (13.40 ± 5.59 MPa) than that of the conventional resin (8.70 ± 3.02 MPa). Adhesive failures were observed for both restorative materials, without fractures in the ceramic. The bond strength and the tensile stress for each group were plotted in Fig 3.

SEM analysis of the sample surfaces (Fig 4) showed that the group restored with conventional composite presented a less homogeneous interface, including marginal gaps, compared with the group restored with the bulk-fill resin. In the sagittal view, the ceramic surface of the bulk-fill group showed a rougher surface after the push-out test with more composite resin residue on its surface.
DISCUSSION

This study aimed to evaluate the effect of polymerization shrinkage stress of two composite resins used to seal the screw access hole on the stress distribution in the access hole and on the bond strength between the ceramic and resins. The results demonstrated that the bulk-fill resin reduced the stress magnitude at the interface between ceramic and composite resin, increasing the bond strength to the ceramic. This led to rejecting both null hypotheses.

With the use of a titanium base and perforated CAD/CAM blocks, it was possible to manufacture an implant-supported crown with a large bulk of ceramic material. In this way, the occlusal resin seal was placed entirely in ceramic and did not have contact with metal, as in the case of conventional metal ceramic restorations. Therefore, the bond strength of the sealing composite resin to the inner surface of the ceramic crown is an important factor.

Reversibility has been reported as the main advantage of implant-supported screw-retained crowns. However, esthetics, implant inclination, screw accessibility, crown retention, and hygiene should also be taken into consideration when manufacturing these prostheses. The loss of screw-access-hole sealing material is reported as a disadvantage which causes occlusal discomfort, food retention, and oral malodor. Composite debonding and marginal leakage can be facilitated due to the stresses in the interface between composite and substrate. The group with the highest residual stress showed reduced bond strength (Fig 3) and higher marginal gaps (Fig 4). Therefore, loss of the sealing restoration can be avoided using bulk-fill resin, since it reduces the stress in the adhesive area due to the lower centripetal shrinkage and consequent lower microstrain of the polymer material. Other studies demonstrated the biomechanical benefits of using bulk-fill composite to build tooth restorations; however, there is no data regarding the effect of its use for sealing an implant-supported ceramic restoration. A study compared the long-term durability of two conventional composites used for access-hole sealing. After 12 months, the 56 closed accesses presented no mechanical or esthetic problems. Another paper concluded that the material selection to seal the access hole is entirely dependent on the operator’s experience.

There was no difference between the ceramic inlays and composites sealing the screw-access hole in terms of the wear from the antagonist tooth. Grooves and minor leakage were found in half of all composite seals after 2 years of follow-up. These may have occurred due to shrinkage of the

Table 2 Peaks of displacement ($\Delta_{\text{max}}$), von Mises stress ($\sigma$), maximum principal strain ($\varepsilon_{\text{max}}$), maximum principal (tensile) stress ($\sigma_{\text{max}}$) and maximum shear stress ($\tau_{\text{max}}$) according to the composite resin

<table>
<thead>
<tr>
<th>Composite resin</th>
<th>$\Delta_{\text{max}}$</th>
<th>$\sigma$</th>
<th>$\varepsilon_{\text{max}}$</th>
<th>$\sigma_{\text{max}}$</th>
<th>$\tau_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>0.010</td>
<td>45.9</td>
<td>0.010</td>
<td>13.7</td>
<td>25.5</td>
</tr>
<tr>
<td>Bulk-fill</td>
<td>0.008</td>
<td>28.9</td>
<td>0.009</td>
<td>11.2</td>
<td>16.3</td>
</tr>
</tbody>
</table>

Fig 3 Boxplot graph of tensile stress distribution (MPa) and bond strength means (MPa), according to the composite resin used to fill the screw-access hole.
Fig 4  Representative SEM micrographs of each specimen. a) Access hole restored with conventional composite resin [a: composite; b: ceramic]; b) access hole restored with bulk-fill composite resin [a: composite; b: ceramic]; c) conventional composite resin specimen; d) bulk-fill specimen after the push-out bond strength test (magnification 70X); e) conventional composite resin specimen; f) bulk-fill specimen after the push-out bond test (magnification 1000X).
conventional composite, as demonstrated in the results of the present study. The bulk-fill resin should be indicated for screw-retained prostheses to reduce stress in the interface, improve the bond strength to the crown, and reduce the number of problems such as small leaks. It is important that their wear resistance be examined in further studies.

A previous study affirmed that bulk-fill restorations showed mechanical performance and reliability similar to that of conventional resin composites in restoring natural teeth, but the bulk-fill resin composites presented lower stress concentration. The present study also found reduced tensile and shear stress concentrations for the bulk-fill group than the conventional composite resin.

The applied in vitro test is a reliable method in prostho-dontics to verify the adhesive bond strength between intraradicular posts to the root dentin. However, there is no previous study that has similarly evaluated different composite resins to seal implant restorations. The size of the screw access holes may also modify the biomechanical response of crowns on the implant when they exceed 3 mm in diameter, increasing the stress concentration at the screw-access hole margin under vertical loading. However, it is important to note that the authors did not consider polymerization shrinkage in their simulation, despite a significant influence of shrinkage on the bond strength as reported elsewhere.

This study was limited by not having performed oral environment simulations, such as pH variations, temperature changes, masticatory loading, and biofilm presence. These factors could modify the long-term survival outcome of occlusal sealing with composite resin. Marginal gap formation was not quantitatively compared between the groups, only qualitatively examined with SEM. Moreover, the numerical modeling used is ideal with perfect bonding, without voids in the composite resin or contaminants at the adhesive interface. Only two composite materials were compared; the results could be different for other materials. Another important limitation was that the authors did not measure the degree of conversion of the composite resin at the bottom of the restoration. Nevertheless, the present results may assist in developing new clinical and laboratory studies.

CONCLUSION

The use of bulk-fill composite resin to seal the screw-access hole is suggested to reduce stress concentration and increase the bond strength to the ceramic crown.

ACKNOWLEDGEMENT

The authors are thankful to the São Paulo Research Foundation for providing grants 17/09104-4 and 18/07404-3.

REFERENCES

The use of monolithic lithium disilicate for poster-

per plant-based oral rehabilitations: a systematic review on the clinical ou-


Clinical relevance: Screw-access sealing with a bulk-fill composite presents more favorable biomechanical behavior than restoring with a regular nanofilled composite.