Purpose: To test the push-out force and marginal leakage of different screw hole–sealing methods in monolithic zirconia implant crowns. Materials and Methods: Ninety monolithic zirconia (Prettau, Zirkonzahn) specimens were milled with two different screw access hole designs: conventional smooth hole or threaded screw hole (for group PMMA-SC), and divided into five groups (n = 18) according to filling method: unbonded composite (UBC); bonded composite (BC); airborne-particle abrasion of screw hole and unbonded composite (ABR-UBC); airborne-particle abrasion of screw hole and bonded composite (ABR-BC); and PMMA screw plugs (PMMA-SC). Twelve specimens per group were subjected to static push-out force with a universal testing machine. Before testing, 6 specimens per group were stored in dry conditions, and 6 were kept in water storage (+37°C) for 7 days. For the remaining specimens (n = 6), cotton pellets were placed under the screw access hole fillings, and the specimens were immersed in 0.5% basic fuchsin solution for 2 weeks. Dye in cotton pellets was dissolved in 2 mL of water, and absorbances of the solutions were measured with a spectrophotometer at 465 nm. Data are reported as mean and SD. Statistical analysis was made using a generalized linear model with logarithmic transformation. Results: PMMA-SC specimens showed the highest push-out forces (P < .0001) and lowest fuchsin penetration (P = .009). Airborne-particle abrasion increased the push-out force and decreased the microleakage in composite groups. The storage conditions affected the results of both unbonded groups. Conclusion: The design and sealing method of the screw access hole affect push-out force and microleakage. Int J Prosthodont 2022;35:194–200. doi: 10.11607/ijp.7445
teeth, a screw access hole can occupy more than 50% of the width of the occlusal surface.17 Restoring the anatomy of the occlusal surface with the right material is important. Cement-retained porcelain-fused-to-metal restorations14,15,18,19 or ceramic- and resin-based restorations16,20 with intact occlusal surfaces have higher fracture loads than screw-retained restorations. Additionally, incomplete filling of the screw access hole may result in microleakage and bacterial growth inside the implant parts. Previous studies show that the origin of microbial leakage is not only from the implant-abutment interface, but also from the screw access hole of the abutment.21–23

New monolithic ceramic materials meet the mechanical and esthetic demands of implant crown material well. Yttria-stabilized zirconia is well documented and has benefits such as low plaque retention, favorable soft tissue reaction, tooth-like color, and high strength values.24–28 These characteristics make monolithic zirconia a good alternative for a screw-retained implant crown material in both the anterior and posterior regions. However, the screw access hole is usually situated in occlusion and needs to withstand articulating forces.29

Composite resins are commonly used as screw access hole filling material, but they contain a risk of marginal leakage due to high polymerization shrinkage during light curing in the oral environment.30 The chemical inertness of yttria-stabilized zirconia is still a challenge for resin-based bonding.31,32 This applies to the bonding of screw access hole materials to zirconia implant crowns. Various surface treatments have been proposed to overcome these problems. These include airborne-particle abrasion with aluminum oxide (Al2O3) particles and adding 10-methacyrloyloxydecyl dihydrogen phosphate monomer to primer.32 There is evidence of a covalent bond among the oxygen, phosphorus, and zirconia.32,33 Technical simplification is offered by universal adhesives, which can be used as self-etch adhesives or etch-and-rinse adhesives.34

To the best of the authors’ knowledge, there is no information available about push-out force and marginal leakage in terms of the materials and methods used to seal screw access holes in screw-retained monolithic zirconia implant crowns. Therefore, the aim of this study was to assess push-out force and marginal leakage of different screw hole–sealing methods in screw-retained zirconia implant crowns. It was hypothesized that long-term water storage weakens the bonding strength of screw access hole filling materials.

**MATERIALS AND METHODS**

Altogether, 90 partially yttrium-stabilized zirconia (Prettau, Zirkonzahn) cylinder-shaped specimens (Ø 7 mm) were milled (M5, Zirkonzahn) and sintered in a non–vacuum sintering furnace (1,500°C, Zirkonofen 600/V2, Zirkonzahn) according to the manufacturer’s guidelines. Two different designs of screw access holes (diameter 2.5 mm) were milled: a conventional smooth hole (groups UBC, BC, ABR-UBC, ABR-BC) and a threaded screw hole (group PMMA-SC) using special thread milling burs. The study protocol is shown in Fig 1. Screw holes were filled using the following methods:
UBC: unbonded light-cured composite (Filtek Supreme XTE Universal Restorative, 3M Espe)
ABR-UBC: airborne-particle abrasion of the screw hole (Al₂O₃ 50 µm [Korox, Bego], 2.5-bar pressure, Renfert) and unbonded light-cured composite
ABR-BC: airborne-particle abrasion of the screw hole and bonded light-cured composite
PMMA-SC: PMMA resin screw plugs (Screw Blank A3, Zirkonzahn) milled for filling the threaded screw holes and screwed into the zirconia specimens (diameter 2.5 mm and height 3.5 mm; Fig 2). After screwing, the screw head was cut to the level of the specimen surface with a diamond bur and polished with an air-driven handpiece and composite polishing rubber tips.

For bond strength testing, 60 specimens (n = 12 per group) were temporarily attached on titanium bases (Brånemark 4.1, Zirkonzahn) without cement, and the screw access holes were filled according to the five different filling methods. The titanium bases were then detached. Before the bond strength testing, half of the specimens in each filling material group were stored in dry conditions, and the other half were kept in water storage (+37°C, distilled water) for 7 days (n = 6 per subgroup).

The specimens were subjected to static push-out force with a universal testing machine (LR30KPlus, JLW Instruments; ISO Standard 604:2002). The load was applied to the screw access hole filling material with a steel piston (diameter 2.0 mm) with a crosshead speed of 1 mm/minute until failure. PC software (Nexygen, Lloyd Instruments) was used to record the results (Fig 3). Failure modes were visually detected with a light microscope (Wild Heerbrugg, Gais, Switzerland) with ×40 magnification.

The evaluation of microleakage with different filling methods was modified from Park et al.35 A total of 30 specimens (n = 6/group) were placed on a settle plate and covered midway with silicone (Elastosil Vario, Wacker Chemie) to allow fuchsin dye penetration only through the screw access hole. Cotton pellets were placed under the screw access hole fillings. The samples were covered with 0.5% basic fuchsin solution (Fuchsin Basic, Harleco) and kept at +37°C for 2 weeks (Fig 4). The screw access hole filling materials were removed, and penetration through the access hole alone and not through the silicone was visually verified. Two samples of group ABR-UBC were excluded from the study results due to fuchsin penetration through the silicone. The fuchsin dye of cotton pellets was dissolved in 2 mL of water,
and the absorbances of the solutions were measured with a spectrophotometer at 465 nm (Multiskan FC, Thermo Scientific).

The mean and SD push-out force were assessed for each filling method. The statistical analysis was made using a generalized linear model with a logarithmic transformation due to nonnormal data distribution. Wald chi-square test was used for pairwise testing. The non-logarithmic transformation for estimates was done after the modeling. Multiplicity was corrected with Bonferroni method. In the microleakage part of the study, statistical analysis was performed using Kruskal-Wallis test, and pairwise comparison with Mann-Whitney U test. The limit of statistical significance was set at .05. Analyses were conducted using IBM SPSS Statistics 25 and SAS statistical software 9.4.

RESULTS

Push-out forces varied from 25 N to 703 N depending on the filling method. The specimens with milled threads and prefabricated PMMA screws showed the highest push-out forces. Among the composite groups, the ABR-BC group showed the highest push-out forces. The results of the push-out test are presented in Table 1. There were no significant differences between dry and wet storage conditions in the bonded groups or in the PMMA-SC specimens. However, significant effects were noticed in both unbonded groups. Push-out forces decreased significantly in the UBC group after water storage \((P = .0056)\), but increased in the ABR-UBC group \((P < .0001)\).

Failure modes of the specimens were detected with a light microscope. The PMMA screws deformed in the push-out test, but the milled screw threads in the zirconia remained intact. In composite groups, all of the failures were adhesive, and there were no remains of bonding agent on the zirconia surfaces.

In the pairwise comparisons of absorbance values, groups UBC, BC, and ABR-UBC differed statistically significantly when compared to group PMMA-SC \((P = .009)\). The PMMA-SC specimens showed the lowest

### Table 1  
Mean ± SD Push-out Force Values (N) of the Specimens in Dry and Wet Storage Conditions

<table>
<thead>
<tr>
<th>Group</th>
<th>Dry</th>
<th>Wet</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBC</td>
<td>129 ± 69b</td>
<td>56 ± 13A</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>BC</td>
<td>177 ± 47c</td>
<td>233 ± 87A</td>
<td>NS</td>
</tr>
<tr>
<td>ABR-UBC</td>
<td>66 ± 31c</td>
<td>162 ± 38B</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>ABR-BC</td>
<td>517 ± 217b</td>
<td>358 ± 106A, C</td>
<td>NS</td>
</tr>
<tr>
<td>PMMA-SC</td>
<td>651 ± 30a</td>
<td>608 ± 47B</td>
<td>NS</td>
</tr>
</tbody>
</table>

UBC = unbonded light-cured composite; BC = bonded light-cured composite; ABR-UBC = airborne-particle abrasion of screw hole and unbonded light-cured composite; ABR-BC = airborne-particle abrasion of the screw hole and bonded light-cured composite; PMMA-SC = PMMA resin screw plugs. Statistical analysis was done after logarithmic transformation. \(P\) values indicate statistical differences within each group between dry and wet storage. Different lowercase superscript letters indicate significant differences \((P < .05)\) between dry-storage groups; different uppercase superscript letters indicate significant differences between wet-storage groups.
The filling material should also be removable in order to enable access to the screw head if peri-implantitis treatment is needed or if maintenance requiring technical complications occurs. Screw loosening is a common technical complication and occurs in 1% to 6.7% of screw-retained implant crowns after follow-up periods of up to 13 years.\(^1,3,39,40\) In the present study, recently introduced PMMA screw access hole filling plugs had the highest push-out force (651 N). This could be an efficient way of sealing the screw access hole, but in the case of screw loosening, the removal of PMMA screws without destroying the threaded screw hole needs to be delicate.

As previously suggested, airborne-particle abrasion is a significant factor in achieving durable long-term bonding to zirconia ceramic.\(^41\) High push-out forces were also detected in the present study when airborne-particle abrasion was performed before applying the adhesive and filling materials. Therefore, airborne-particle abrasion of the screw access hole can be recommended before filling the access hole with composite.

A commonly used bonding protocol for zirconia involves also the use of 10-MDP monomer–containing primer.\(^32,42,43\) In case of using tribochemical silica in airborne-particle abrasion, the zirconia primer should additionally contain silane coupling agents.\(^43\) The adhesive used in this study was Scotchbond Universal, which contains both silane coupling agents and 10-MDP monomer and can be applied to zirconia. An increase in the bond strength of composite resin when Scotchbond Universal is applied to air-abraded zirconia has been shown previously and is in agreement with the present study.\(^44\)

A limitation of this study concerns the limited artificial aging protocol. Cyclic loading and long-term water storage have been considered as reliable tools to predict the clinical durability of materials, as the oral fluids can lead to slow crack growth in ceramics.\(^45,46\) In the present study, the specimens were exposed to load until failure, but in order to imitate an oral environment, cyclic loading could have given more reliable results concerning the behavior of the filling materials. Long-term water storage leads to volumetric expansion because of sorption and may alleviate the polymerization shrinkage stress in resin-based composites.\(^47,48\) In the present study, some of the specimens were aged in water for 7 days. However, the complete water saturation of the specimens would have taken several weeks.\(^49\) Only the unbonded composite (group UBC) showed clearly lower push-out force values after water storage. It may be that in this group, volumetric expansion did not occur, since water was able to penetrate right through the composite–zirconia interface. Airborne-particle abrasion, on the other hand, might have given sufficient mechanical interlocking, enabling
the expansion in the air-abraded and unbonded group (group ABR-UBC), which showed clearly higher push-out force values.

Regarding the fuchsin penetration, the results of the present study support the previous microleakage findings.\textsuperscript{35} Fuchsin penetration also supports the differences found in failure loads among the filling methods. The lowest absorbances were detected in the airborne particle–abraded and bonded specimens, as well as the PMMA screw plug specimens. However, it is important to bear in mind that the quality of bonding can vary in different areas of the access hole and between the specimens of the same group. Due to its cylindrical form, it might be that some areas of the screw access hole are not perfectly bonded, which allows for liquid penetration. This was also seen in the present study, as cotton pellets in the UBC, BC, and ABR-UBC groups showed significant differences in the amount of fuchsin penetration during 2 weeks of immersion. Only the ABR-BC and PMMA-SC groups showed a more stable result in this respect.

The low absorbances in the PMMA-SC group might be explained with lateral compressive forces when PMMA screws were tightened to zirconia specimens. The prefabricated PMMA resin screw plugs can be designed with a different tightness to match the threaded zirconia screw hole, and in the present study, the most tight version of the design was used. However, it should be noted that threads can only be made on zirconia and not extended inside of the Ti-bases.

Water sorption increases over 1 year of inspection time, with leveling off after 7 days of the storage period.\textsuperscript{50,51} The 2-week immersion time in the present study is relatively short and does not reflect the long-term clinical situation, which could be considered as a limitation of this study. However, this study set-up allowed the comparison between the different bonding and filling methods. Even after airborne-particle abrasion and bonding with an agent that contains a silane and 10-MDP monomer, the screw head must be secured and the abutment connection sealed with proper sealing material (ie, Teflon tape) below the composite filling.\textsuperscript{52}

Besides the limitations related to the lack of occlusal loading simulation and the short immersion time, the number of specimens could have been higher. High SDs in push-out force measurements did not allow for straightforward parametric statistical evaluation, and statistical analysis was conducted after logarithmic transformation. Therefore, some of the mean values presented in Table 1 that seem to differ from others did not reach statistical significance.

However, the present in vitro study provides clinically valuable information for sealing the screw access holes of monolithic zirconia implant crowns. In the future, these results could be validated in a clinical study with a larger study population investigating the durability of the screw access hole filling materials.

CONCLUSIONS

The design and sealing method of the screw access hole affect the push-out force and microleakage. Within the limitations of this study, it can be concluded that prefabricated PMMA screws reduce the marginal leakage through the screw access hole and enhance the push-out force compared to traditional composite sealing methods. The use of prefabricated PMMA screws can be recommended as a screw access hole filling method for monolithic zirconia implant crowns.

Airborne-particle abrasion of the zirconia screw channel together with the use of silane coupling agents and 10-MDP monomer–containing adhesive reduces marginal leakage in screw access hole composite fillings and can be considered as an alternative screw hole filling method.

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