Fracture Load of Veneered and Monolithic Single-Unit Fixed Dental Prostheses Made from the High-Performance Thermoplastic Polyphenylene Sulfone

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Purpose: To investigate the fracture loads of differently veneered and monolithic single-unit fixed dental prostheses (FDPs) made of a novel potential framework material, polyphenylene sulfone (PPSU). Materials and Methods: The fracture loads of four PPSU frameworks with different veneers (manual polymer veneer with Ceramage Body A3B; prefabricated polymer veneer with Novo.lign; digital polymer veneer with Telio CAD; digital ceramic veneer with IPS Empress CAD) and a monolithic control group (PPSU, Gehr) were examined initially and after 1,200,000 masticatory (50 N, 1.3 Hz) and 6,000 thermal cycles (5°C/55°C). Fracture analysis was performed using light microscope imaging. Fracture types were classified, and relative frequencies were determined. Univariate analysis of variance, post hoc Scheffé, partial eta squared ($\eta_p^2$), Kruskal-Wallis test, and Weibull moduli using the maximum likelihood estimation method were calculated. The defined level of significance was adjusted by Bonferroni correction ($P < .005$). Results: Aging did not affect the fracture load values. Single-unit FDPs with a digital ceramic veneer showed lower values than monolithic and manual polymer veneer specimens. Single-unit FDPs with a prefabricated and digital polymer veneer were in the same value range as specimens with a manual polymer and digital ceramic veneer. No differences were observed between manual polymer veneer and monolithic single-unit FDPs. All veneered specimens showed a fracture of the veneer. For monolithic single-unit FDPs, plastic deformation was observed. Conclusion: Veneered and monolithic PPSU showed sufficient fracture load values to indicate successful clinical use in single-unit FDPs. The choice of veneering method and material may play a minor role.

In dentistry, frameworks for fixed dental prostheses (FDPs) have traditionally been made of metal alloys to provide the necessary stability for withstanding masticatory forces. While porcelain-fused-to-metal (PFM) FDPs show high survival rates of 97% after 3 years, the ever-increasing demand for highly esthetic prosthetic restorations has prompted research activity in the field of tooth-colored framework materials. High-strength ceramics have been investigated as a potential alternative and are, as of today, successfully employed for numerous indications. Despite their higher susceptibility to chipping, the survival rate of zirconia-supported FDPs (reported to be approximately 90% after 3 years in vivo) closely trails that of PFM FDPs. However, in comparison with the natural tooth, the high elastic modulus of zirconia may result in a more immediate transfer of masticatory forces. For implant restorations and periodontally damaged dentitions, the elastic behavior of high-performance thermoplastics could decrease detrimental loading conditions. In contrast to composite resins, thermoplastics are characterized by their lack of residual monomer content, which translates into a high biocompatibility. In dentistry, one prominent representative of this material class is polyetheretherketone (PEEK).
While PEEK has been successfully employed for a wide range of indications,5,6 the strong dependency of the material’s crystallinity and mechanical properties on the thermal processing conditions limits the fabrication of PEEK restorations by employing additive manufacturing.7 In this light, the thermoplastic polyphenylene sulfone (PPSU), which is characterized by a relatively low glass transition temperature and an amorphous structure that ensures constant properties of the 3D-printed structure,8 may possess a higher suitability for the seminal field of additive manufacturing. The first landmark investigation to examine the properties of PPSU in regard to dental applications reported that PPSU materials possessed satisfactory tensile bond strength values to a composite resin veneer (26.7 to 43.6 MPa) that were similar to those of the established PEEK.9 These results could be obtained by transferring pretreatment methods devised for PEEK to its novel competitor PPSU, with airborne particle abrasion increasing the surface properties of the naturally inert PPSU.9 PPSU furthermore shows promising mechanical properties, with values for three-point flexural strength (72.4 to 158.1 MPa) and two-body wear (–0.285 to –0.717 mm) being comparable to PEEK.10 In its monolithic form, PPSU appears yellowish translucent and is thus ideally suited as a framework material or monolithic restoration outside the visible area. To achieve a close imitation of the natural color transition from the tooth neck to the translucent incisal edge, high-end esthetic restorations do, however, call for the use of multilayer materials or a subsequent veneer.

Traditionally, frameworks for FDPs are veneered in an intricate manual layering process that relies heavily on the dental technician’s expertise. Against this backdrop, the manufacturing of veneers in a digital workflow may provide a higher reliability of results.11 Both polymer and ceramic materials are employed as veneers for fixed and removable dental prostheses.12–15 The combination of a ceramic veneer (data for IPS Empress CAD: hardness of 6.2 GPa, elastic modulus of 62.0 GPa)16 with a PPSU framework (data for Gehr Kunststoffwerk PPSU: hardness of 0.14 GPa, elastic modulus of 2.4 GPa)17 could allow for an optimal imitation of the soft dentin core (hardness of ~ 0.9 GPa, elastic modulus of ~ 19.9 GPa) and hard enamel shell (hardness of ~ 4.9 GPa, elastic modulus of ~ 80.4 GPa)18 of the natural tooth.

The purpose of this in vitro study was to determine if different veneering methods for thermoplastic PPSU, a novel potential material for dental restorations, showed an impact on the resistance to failure of single-unit FDPs during a fracture load test. The tested null hypotheses stated that neither the veneering method nor artificial aging would influence the fracture load of differently veneered and monolithic single-unit PPSU FDPs.

**MATERIALS AND METHODS**

The fracture loads of differently veneered and monolithic single-unit PPSU FDPs were examined initially and after 1,200,000 masticatory and 6,000 thermal cycles (Fig 1, Table 1).

**Specimen Preparation**

As prefabricated veneers can only be adjusted to an extent, a single-unit FDP of this group acted as the master crown.

Monolithic single-unit FDPs (control group [MO]; n = 24) and veneered frameworks (n = 96) were milled (Imes-icore 4030, Wieland Dental + Technik) from PPSU (Gehr Kunststoffwerk). The outer surface of each framework was airborne-particle abraded at 45 degrees from a distance of 10 mm using aluminum oxide (Al₂O₃)
particles with a grain size of 110 μm at 0.2 MPa (Basic quattro, Renfert) and subsequently cleaned with distilled water in an ultrasonic bath (Transistor Ultrasonic T-14, L&R). The frameworks were conditioned with Visio.link (Bredent, lot no. 171018) and polymerized for 90 seconds (bre.Lux Power Unit 2, Bredent). Thereafter, an opaque liner (Universal Opaque A30, lot no. 081942, Shofu) was applied and polymerized for 180 seconds (bre.Lux Power Unit 2).

For the manual polymer veneer (MPO), a translucent molding (Versyo putty, Kulzer) of the master crown was filled with composite resin (Ceramage Body A3B, Shofu). The alloy model with the attached PPSU framework was pressed into the form before curing of the composite resin veneer was performed for 180 seconds (bre.Lux Power Unit 2). The prefabricated polymer veneers (PPO; Novo.lign D3 G3, Bredent) were carefully adjusted to fit the shape of the framework using a molding of the master crown.

For the digital veneers, the master crown and PPSU framework were scanned (Ceramill Map 300, Amann Girrbach). To design the digital veneers, the two scans were subtracted from each other. Digital polymer veneers (PPO; Novo.lign D3 G3, Bredent) were carefully adjusted to fit the shape of the framework using a molding of the master crown.

For the digital veneers, the master crown and PPSU framework were scanned (Ceramill Map 300, Amann Girrbach). To design the digital veneers, the two scans were subtracted from each other. Digital polymer veneers (PPO; Novo.lign D3 G3, Bredent) were carefully adjusted to fit the shape of the framework using a molding of the master crown.

For the digital ceramic veneer (DCE) from IPS Empress CAD HT A2 I12 (Ivoclar Vivadent, Ceramill Motion 2, Amann Girrbach), Polymer veneers were airborne-particle abraded at 45 degrees from a distance of 10 mm using Al₂O₃ particles with a grain size of 110 μm at 0.2 MPa (Basic Quattro IS), ultrasonically cleaned (Transistor Ultrasonic T-14) in distilled water before conditioning was performed using Visio.link, which was polymerized for 90 seconds (bre.Lux Power Unit 2). DCE veneers were etched for 20 seconds (Total Etch, lot no. R29459, Ivoclar Vivadent) and subsequently cleaned in an ultrasonic bath (Transistor Ultrasonic T-14) with distilled water before conditioning was performed with Monobond Plus (lot no. Y33684, Ivoclar Vivadent), which was polymerized for 20 seconds (bre.Lux Power Unit 2). Prior to luting, Heliobond (lot no. Y00248, Ivoclar Vivadent) was applied. PPO, DPO, and DCE veneers were bonded to the PPSU framework by employing Crea.lign Incisal E2 (lot no. 123765, Bredent) and then polymerized for 180 seconds (bre.Lux Power Unit 2).

DCE specimens were polished with a felt wheel employing the polishing paste Dia-Glace (Yeti Dental). All other single-unit FDPs were polished in two steps with a goat hair brush followed by a buffing wheel using Abraso-Starglanz polishing paste (Bredent).

The inner surface of each PPSU specimen was airborne-particle abraded with aluminum oxide particles with a grain size of 110 μm at 0.2 MPa (Basic Quattro IS), ultrasonically cleaned (Transistor Ultrasonic T-14) in distilled water, and bonded to standardized abutments with a 360-degree chamfer preparation of 1 mm cast from a Co-Cr alloy (Zenotec NP, Wieland Dental + Technik) with a dual-curing resin cement (DuoCem, Coltène/Whaledent) strictly following the manufacturer’s instructions. After bonding, specimens were stored for 7 days in distilled water at 37°C in an incubator (HERAcell 150).

**Table 1** Veneering Methods and Materials Used

<table>
<thead>
<tr>
<th>Veneering method</th>
<th>Veneer material</th>
<th>Manufacturer</th>
<th>Composition, weight %</th>
<th>Lot no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual polymer veneer</td>
<td>Ceramage Body A3B</td>
<td>Shofu</td>
<td>Urethane dimethacrylate, zirconium oxide silicate fillers</td>
<td>111701</td>
</tr>
<tr>
<td>Prefabricated polymer veneer</td>
<td>Novo.lign D3 G3</td>
<td>Bredent</td>
<td>NA</td>
<td>Z3304499</td>
</tr>
<tr>
<td>Digital polymer veneer</td>
<td>Telio CAD LT A2</td>
<td>Ivoclar Vivadent</td>
<td>Polymethyl methacrylate: 99.5</td>
<td>20027Y</td>
</tr>
<tr>
<td>Digital ceramic veneer</td>
<td>IPS Empress CAD HT A2 I12</td>
<td>Ivoclar Vivadent</td>
<td>SiO₂: 60.0 – 65.0</td>
<td>W33141</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Al₂O₃: 16.0 – 20.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>K₂O: 10.0 – 14.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Na₂O: 3.5 – 6.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Other oxides: 0.5 – 7.0</td>
<td></td>
</tr>
<tr>
<td>Monolithic PPSU (control group)</td>
<td>PPSU</td>
<td>Gehr</td>
<td>Polyphenylene sulfone</td>
<td>NA</td>
</tr>
</tbody>
</table>

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Fracture Load Measurement
Fracture load was determined with a universal testing machine (Zwick 1445, Zwick Roell) set to a crosshead speed of 1 mm/minute. The testing stamp with a diameter of 6 mm (chrome-nickel steel, Deutsche Edelstahlwerke) was positioned on the occlusal surface of each crown. A 0.1-mm tin foil (Dentaurum) was placed between the crown and stamp to avoid force peaks (Fig 2). The fracture load test was stopped as soon as the maximum fracture load decreased by 10%.

Light Microscope Imaging and Fracture Analysis
Light microscope images were taken using a digital microscope (KVHX-970F, Keyence). Fracture types were classified as (1) deformation or (2) fracture of the veneer.

Statistical Analyses
The sample size of n = 12 per subgroup was based on similar previous studies that reported significant differences between groups for a similar or even smaller sample size. Statistical evaluation of the results was performed with descriptive analysis followed by Kolmogorov-Smirnov test to test for a violation of the normal distribution. For global analysis, univariate analysis of variance (ANOVA), post hoc Scheffé, and partial eta squared (η²) were calculated. Kruskal-Wallis test was computed to analyze significant differences between groups. The defined level of significance was adjusted using Bonferroni correction (P < .05/10 = .005). Weibull moduli were calculated with the maximum likelihood estimation method at a 95% confidence level. Fracture types were classified, and relative frequencies were computed using a Ciba-Geigy table. Data were analyzed with SPSS version 26.0 (IBM).

RESULTS
The results of the descriptive analyses and Weibull moduli are presented in Table 2. As 1 out of 10 groups indicated a violation of the assumption of normality, nonparametric tests were performed.

While neither the aging level (P = .276; partial eta squared η² = 0.011) nor the interaction between the two parameters veneering method and aging level (P = .210; η² = 0.051) exerted an impact on the fracture load, the choice of veneering method showed a significant influence (P < .001; η² = 0.835). Except for DCE, where the Weibull modulus was lower after thermomechanical aging, Weibull moduli were not affected by the aging level.

Influence of the Veneering Method
Initially, PPO, DPO, and DCE showed fracture load results in the same value range (P > .999). Furthermore, no significant differences were observed between MPO and MO (P = .456). PPO, DPO, and DCE all presented lower fracture load values than both MPO and MO (P < .001 to .045). PPO showed the lowest Weibull modulus and was in the same value range as DPO and DCE. The highest Weibull modulus was observed for MPO. No differences were seen between MPO and MO, or among DPO, DCE, and MO.
After thermomechanical aging, DCE showed lower values than MPO and MO ($P < .001$). PPO and DPO were in the same value range as DCE ($P = .397$ to $.700$) and MPO ($P = .272$ to $.469$). Furthermore, no significant differences were observed between MPO and MO ($P = .344$). MO showed higher results than PPO, DPO, and DCE ($P < .001$). DCE presented the lowest Weibull modulus, followed by DPO, PPO, and MO, which all showed values in the same range. The highest values were seen for MPO. No differences were observed among PPO, MO, and MPO under identical loading than the aforementioned groups, while the monolithic single-unit FDPs showed a greater deformation. From a load of approximately 300 N, the curves demonstrated a nonlinear behavior. The relation between loading and plastic deformation thus seems to follow a function of higher order. In the linear segment of the load deformation curves, the observed modulus of elasticity seems to be independent of the veneering method and can thus be primarily attributed to the properties of PPSU.

### Fracture Analysis

All veneered single-unit FDPs showed a fracture of the veneer with cracks originating from the point of loading (Fig 3, Table 2). One DCE specimen fractured during chewing simulation (Fig 4). For this single-unit FDP, a fracture load of 0 N was assumed.

For monolithic PPSU, a plastic deformation was observed for all specimens (Fig 5). In these cases, the fracture load measurement was stopped as soon as the maximum fracture load decreased by 10%.

Figure 6 shows a typical load deformation curve for each group. The curves of the prefabricated and digital veneer single-unit PPSU FDPs exhibited a similar shape. MPO specimens displayed a slightly lower deformation under identical loading than the aforementioned groups, while the monolithic single-unit FDPs showed a greater deformation.

### DISCUSSION

The aim of this study was to examine the fracture load of differently veneered and monolithic single-unit PPSU FDPs before and after aging. The first hypothesis, that the veneering method would not present an influence on the fracture load of veneered and monolithic PPSU, had to be rejected. As the aging level did not exert an impact on the fracture load, the second null hypothesis was accepted.

Fracture load values of MPO single-unit FDPs were comparable to those of monolithic PPSU. This promising result for the manual veneering of PPSU FDPs, which is underlined by the observed high Weibull modulus, may

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**Table 2** Descriptive Statistics and Weibull Moduli for Fracture Load (N) and Fracture Type Distribution of the Differently Veneered Materials

<table>
<thead>
<tr>
<th>Veneering method</th>
<th>MPO</th>
<th>PPO</th>
<th>DPO</th>
<th>DCE</th>
<th>MO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parametric</td>
<td>Mean ± SD</td>
<td>1,947 ± 332.0</td>
<td>1,061 ± 591.9</td>
<td>1,078 ± 400.8</td>
<td>1,038 ± 297.7</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>(1,734; 2158)</td>
<td>(684; 1,438)</td>
<td>(822; 1,333)</td>
<td>(848; 1,228)</td>
</tr>
<tr>
<td>Nonparametric</td>
<td>Mean/median/maximum</td>
<td>1,568/1,920/2,541</td>
<td>432/857/2,037</td>
<td>558/982/1,923</td>
<td>582/1,067/1,493</td>
</tr>
<tr>
<td>Weibull modulus</td>
<td>Mean 95% CI</td>
<td>7.2 (3.8; 13.1)</td>
<td>2.1 (1.0; 3.9)</td>
<td>3.3 (1.7; 6.1)</td>
<td>3.7 (1.9; 6.7)</td>
</tr>
<tr>
<td>Deformation</td>
<td>N 95% CI</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
</tr>
<tr>
<td>Fracture</td>
<td>N 95% CI</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
</tr>
<tr>
<td><strong>Thermomechanical aging</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parametric</td>
<td>Mean ± SD</td>
<td>2,037 ± 371.4</td>
<td>1,385 ± 420.9</td>
<td>1,492 ± 533.5</td>
<td>847 ± 300.7</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>(1,799; 2,273)</td>
<td>(1,116; 1,653)</td>
<td>(1,152; 1,832)</td>
<td>(654; 1,039)</td>
</tr>
<tr>
<td>Nonparametric</td>
<td>Mean/median/maximum</td>
<td>1,388/2,074/2,618</td>
<td>620/1,355/1,981</td>
<td>597/1,666/2,284</td>
<td>0/914/1,214</td>
</tr>
<tr>
<td>Weibull modulus</td>
<td>Mean 95% CI</td>
<td>5.9 (3.1; 10.8)</td>
<td>3.3 (1.7; 6.1)</td>
<td>2.7 (1.3; 4.9)</td>
<td>0.2 (0.1; 0.4)</td>
</tr>
<tr>
<td>Deformation</td>
<td>N 95% CI</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
<td>0 (0; 27)</td>
</tr>
<tr>
<td>Fracture</td>
<td>N 95% CI</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
<td>100 (72; 100)</td>
</tr>
</tbody>
</table>

MPO = manual polymer veneer; PPO = prefabricated polymer veneer; DPO = digital polymer veneer; DCE = digital ceramic veneer; MO = monolithic control. *Not normally distributed.
**Fig 3** Typical fracture patterns for the different veneer groups. (a) Manual polymer veneer. (b) Prefabricated polymer veneer.
Fig 3  Typical fracture patterns for the different veneer groups. (c) Digital polymer veneer. (d) Digital ceramic veneer.
be caused by the direct application of the composite veneer on the pretreated PPSU surface. Forgoing the additional use of a luting composite, the bond between the PPSU surface and the composite veneer might be higher. This could translate into an increased resistance against fracture. The manual veneering of prosthetic frameworks is an established technique that is frequently employed in the field of removable dental prostheses.\textsuperscript{14,15} Long-term data show high survival rates and a satisfactory esthetic outcome.\textsuperscript{14,15,23}

Initially, PPO, DPO, and DCE led to lower fracture load values than seen for single-unit FDPs with MPO and
the control group. While the observed values exceeded the occurring masticatory forces in all groups,\textsuperscript{24,25} this finding could indicate a manual veneering technique to yield superior results than observed for prefabricated and digital veneer FDPs. In the present investigation, manual veneering was performed by a first-rate dental technician with more than 30 years of experience (M.E.). Due to its complex sequence of steps, this operator-dependent process is, however, prone to error. In this context, a digital workflow may provide a higher reproducibility and homogeneity in the results. This theory was corroborated by a previous investigation that examined the fracture load of differently veneered three-unit PEEK FDPs in which digital veneer FDPs showed a higher load-bearing capacity than manual veneer FDPs or FDPs equipped with a prefabricated veneer.\textsuperscript{11}

After thermomechanical aging, the initially observed differences between the examined veneering techniques subsided, with MPO, PPO, and DPO showing results in the same value range. It can thus be concluded that all polymer veneers performed in a comparable fashion. When regarding the mechanical performance of a veneered FDP, the veneering technique may thus play a minor role. This is in line with a previous investigation that examined the shear bond strength between differently manufactured veneers and substrates, reporting digital veneers to yield similar results as observed for their conventional counterparts.\textsuperscript{26}

On the other hand, DCE showed inferior results when compared to MPO. One specimen with a DCE even fractured during chewing simulation. This event represents a catastrophic failure. In a clinical setting, this unrepairable fracture would entail the need for a new restoration. Aside from the financial expenditure, natural tooth structure would be irrevocably lost during the removal of the PPSU framework and the subsequent finishing. Possible causes of this premature failure include a pre-existing inhomogeneity of the ceramic block or an impairment of this single-unit FDP during milling, polishing, or bonding. As an increase in specimen stiffness has been reported to correlate with the contact force during dynamic loading, the impact of thermomechanical aging could furthermore be more pronounced for ceramic veneer specimens that present a higher elastic modulus.\textsuperscript{27} While this finding favors the combination of a manually applied polymer veneer over a digitally manufactured ceramic veneer, no significant differences were observed among the PPO, DPO, and DCE groups. It may thus be concluded that, similar to the veneering technique, the veneer material does not possess a large impact on the load-bearing capacity of veneered single-unit PPSU FDPs. Other factors may thus be pivotal when choosing between a ceramic or polymer veneer. Due to its low elastic modulus, a polymer veneer can display a buffering effect during function. For periodontally damaged dentitions or implant-supported structures that lack the inherent agility of the natural periodontium, this characteristic can be advantageous.\textsuperscript{6,28} In vitro studies have furthermore reported polymers to be less prone to the occurrence of chipping.\textsuperscript{29,30} In comparison with a ceramic, a polymer veneer may, however, be more vulnerable to discoloration and can require repeated polishing.\textsuperscript{31} Ceramics also provide a higher biocompatibility and reduced plaque accumulation.\textsuperscript{32,33}

While further studies are imperative to confirm the present findings, a manual polymer veneer for PPSU frameworks can be cautiously recommended to achieve similar fracture load results as observed for the monolithic control group.

As none of the tested specimens were susceptible to the employed artificial aging protocol that aimed to imitate a clinical situation after 5 years in vivo,\textsuperscript{34} the clinical performance of veneered single-unit PPSU FDPs could be auspicious. When exposed to an identical load (eg, 1,000 N), monolithic single-unit FDPs showed a larger deformation than their veneered counterparts (Fig 6).
While the repair of a chipped restoration with a composite resin is possible after appropriate pretreatment and conditioning, the reinstatement of missing contact points for a deformed FDP calls for a new fabrication of the restoration, entailing the numerous negative consequences described for the premature failure of a DCE specimen. If a deformed FDP is not replaced, the missing occlusal contact could result in the elongation of the restored tooth or an incorrect loading of the neighboring structures. In this context, future studies are necessary to evaluate the long-term performance of prosthetic restorations made from monolithic PPSU in vivo.

The observed findings must be evaluated in regard to the limitations of this in vitro study. The inclusion of a PEEK control group, as well as a high-strength ceramic or metal alloy control group, would increase the informative value for differences observed between groups and the explanatory power of PPSU’s performance as a veneered and monolithic single-unit FDP in future investigations. With previous investigations reporting a nonaxial force application at 30 or 45 degrees to yield lower fracture load values than observed for axial loading, the employed test set-up may embellish results and limit the clinical transferability of the observed findings. As the abutment material has also been reported to influence fracture load values, future studies are warranted to investigate whether the present results persist for eccentric loading and for resin abutments.

One further limitation of this investigation is that no power analysis was performed a priori to determine an adequate sample size. A post hoc power analysis that compared the initial fracture load values of the MPO and MO groups showed the resulting power of a two-sided two-sample t test to be equal to 100% for a sample size of 12 specimens per group, an observed effect of 2,175 N, and a pooled SD of 768.5. A second post hoc power analysis comparing the fracture load of the MPO and MO groups after artificial aging reported the resulting power of a two-sided, two-sample t test to be equal to 100% for a sample size of 12 specimens per group, an observed effect of 1,976 N, and a pooled SD of 909.9. The choice of these two groups was based on their practical relevancy, with MPO representing the most widespread veneering technique for thermoplastics within the investigated groups in dental laboratories as of today, and MO constituting the simplest and thus most frequently employed manufacturing procedure in the treatment of the posterior region with single-unit FDPs.

The first two investigations that examined the suitability of PPSU as a dental restorative material observed promising results regarding the tensile bond strength between PPSU and a composite resin veneer, as well as regarding surface and mechanical properties. Considered in conjunction with the present findings, a clinical trial with single-unit FDPs made from veneered PPSU is indicated. Future investigations should furthermore focus on the esthetic appearance of these restorations. At the beginning of the present investigation, PPSU was only available as a black material. Since then, a tooth-colored PPSU material has been developed. Whether this novel composition meets the esthetic requirements for use as a monolithic restoration in the posterior region needs to be determined in future investigations. As long as an esthetic veneer—and subsequently an adapted design of PPSU FDPs that considers the requisite space for the veneer material—remains imperative, the clinical indications of this material group for regions subject to high loading, especially in patients presenting with parafunctions, may be limited. It remains to be seen whether additively manufactured PPSU frameworks will one day represent the material of choice for multi-unit FDP frameworks.

Within the limitations of this study, the following conclusions can be drawn:

1. The high-performance thermoplastic PPSU demonstrated sufficient fracture load values to indicate a successful clinical application as a veneered or monolithic single-unit FDP restorative material.
2. The veneering technique and material may play a minor role in the load-bearing capacity of veneered PPSU frameworks.

ACKNOWLEDGMENTS

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