Accurate internal and marginal fit of implant-supported fixed partial dentures (I-FPDs) is essential for long-term clinical success, even though perfect accuracy with passive fit is only achievable in theory. An I-FPD with poor fit accuracy may provide a susceptible niche for bacterial invasion and peri-implant complications. Moreover, when there is desirable internal fit, the restoration can resist horizontal and vertical forces better, increasing the resistance and retention forms of the whole prosthesis. Several methods have been suggested to determine internal and marginal discrepancies of FPDs, including direct observation, observation after sectioning, three-dimensional scanning, replica technique, scanning electron microscope (SEM) analysis, and detection by an explorer. SEM analysis and replica technique are the most prevalent methods to assess marginal and internal fit.

It has been claimed that advances in computer-aided design/computer-aided manufacturing (CAD/CAM) have brought improvement in fabrication of FPDs with higher precision. CAD/CAM technology has made fabrication of cobalt-chromium (Co-Cr) I-FPD frameworks more feasible, as the Co-Cr alloys have high melting ranges and are difficult to handle during laboratory procedures. Moreover, by omitting the casting procedure of Co-Cr alloys, the Cr content of Cr-Co millable blocks can be increased to more than the conventional threshold of 30%, making the frameworks more resistant to tarnish and corrosion. A recent generation...
of millable Co-Cr blocks are wax-like and pre-sintered, known as soft Co-Cr metal alloy, which bring about the benefits of low wear of milling tools and the possibility of dry milling.\textsuperscript{10} Zirconia (Zr) blocks are another popular material for CAD/CAM fabrication of I-FPDs. Their esthetic properties and biomechanical characteristics make them comparable to conventional metal-ceramic FPDs.\textsuperscript{14} Several systematic reviews have evaluated 5-year survival rates for Zr prostheses. All of them have reported excellent survival rates of 90% to 100% for Zr-based I-FPDs.\textsuperscript{15–18}

Regarding the internal and marginal fit accuracy of CAD/CAM-fabricated prostheses, most of the available studies are on single implants/crowns.\textsuperscript{7–10,19} Even the studies that evaluate I-FPDs are primarily focused on materials such as titanium,\textsuperscript{5,9} evaluate the screw-retained I-FPDs,\textsuperscript{5,6} or have controversial results.\textsuperscript{4,8,19,20} Studies on the fit accuracy of three-unit CAD/CAM-fabricated cement-retained I-FPDs milled from two different pre-sintered materials (Co-Cr and Zr) are scarce. Therefore, the present study aims to fill this void by evaluating the effect of porcelain layering on internal and marginal discrepancies of these I-FPD materials using two different methods to measure fit accuracy. The null hypothesis is that neither framework material nor porcelain veneering process affects the internal and marginal accuracy negatively.

**MATERIALS AND METHODS**

The general methodology of the present study is in accordance with published studies by Park et al,\textsuperscript{10} Katsoulis et al,\textsuperscript{6} and Bayramoğlu et al.\textsuperscript{4} In summary, the two premolars and the first molar of an acrylic mandibular jaw model were removed to be replaced by a three-unit I-FPD. Two implant analogs (Straumann ITI) were positioned parallel to each other in the first premolar and the first molar sites with the aid of a surveyor. Self-cure acrylic resin (Heraeus Kulzer) was used according to the manufacturer’s instructions to stabilize the implant analogs in their appropriate positions. The corresponding abutments were tightened to the analogs with 25-Ncm torque force using a torque wrench according to the manufacturer’s instructions.

A sample size of eight retainers (four I-FPDs) for each group was calculated to ensure a 90% power. The four groups were prepared as follows:

- **Group SF:** I-FPD frameworks were prepared with soft millable Co-Cr alloy (n = 4).
- **Group ZrF:** I-FPD frameworks were prepared with pre-sintered Zr (n = 4).
- **Group SP:** SF frameworks were porcelain layered (n = 4).
- **Group ZrP:** ZrF frameworks were porcelain layered (n = 4).

**CAD/CAM Procedure**

The direct scanning method was used to provide a digital impression of the prepared model. Scan spray (Arti-Scan CAD/CAM Spray, Bausch) was used to produce a scannable surface. The three-unit I-FPD frameworks were designed with default recommended settings: 0.5-mm framework thickness, 30-µm cement space provided from 0.5 mm above the margin, and 1-mm cut-back space for applying porcelain. A uniform connector cross-sectional area with a surface area of 12.5 mm\textsuperscript{2} was designed, and the wall thickness of the abutment crowns was 0.6 mm. After the framework’s design was finalized, a wax model was milled (Ceramill Wax, Amann Girrbach) for final checking of the designed framework. The information data were saved in STL file format.

To prepare SF samples, pre-sintered soft alloy Co-Cr blocks (Ceramill Sintron 71 XS, Amann Girrbach) were milled according to the designed framework. After milling, the SF frameworks were placed in the sintering tray (Argovent sintering tray, Amann Girrbach) and fired at 1,280°C for 5 hours in a high-temperature sintering furnace (Ceramill Argotherm, Amann Girrbach). An inert argon gas was used in the chamber of the furnace to avoid any oxidation of the frameworks. For the ZrF samples, pre-sintered yttrium-stabilized tetragonal zirconia polycrystallate (Y-TZP) blocks (Ceramill Zirconia, Amann Girrbach) were milled based on the designed framework. The ZrF frameworks were sintered in the furnace for 6 hours at 1,450°C. All frameworks were carefully inspected to ensure there were no distortions or defects on the intaglio surfaces, which might interfere with their complete seating of the framework.
The silica replica technique was used for AMG and internal discrepancy measurements (Fig 2). The retainers were filled with light body silicone (Panasil soft, Kettenbach), then placed onto the abutments with a load force of 50 N. When the light body silicone was set, the frameworks were removed from the model while the thin silicone films remained on the retainers. The silicone films, which represent the abutment-retainer interface space, were stabilized by application of a contrasting heavy body silicone (Panasil Tray, Kettenbach). A razor blade was used to cut the silicones longitudinally in the buccolingual and mesiodistal directions. To measure the AMG and internal discrepancies (cervical [Cv.D], axial [Ax.D], and occlusal [Oc.D]), 16 defined points were measured in each abutment-retainer interface (four defined points per each side) according to the criteria published by Holmes et al.21 The measurements were done by a single operator (A.D.) who was already calibrated for a 100× magnification digital microscope (Moticam 480, Motic) in a pilot sample with repeated trials. For measuring the defined discrepancy points, the digital image of each sample provided by the digital microscope was transferred to the adjusted software.

To measure MG, the frameworks were sent to Razi Metallurgical Research Center to provide SEM images (Vega II Tescan, Tescan Orsay Holding) of the framework’s margins. The measurements were done on buccal (MG.B), lingual (MG.L), and proximal (MG.Px) surfaces (Fig 3). The SEM chamber was large enough to prepare a perpendicular analysis of framework margins. SEM images of MG of each abutment on the main model at defined sides (MG.B, MG.L, MG.Px except distal of premolar and mesial of molar abutments) were prepared with a magnification up to 150×. Three different points with similar distances from each other were measured by the adjusted software, and the means were recorded.

All measurements of marginal (AMG and MG) and internal discrepancies were done by a single operator (A.D.) at two sessions with a 1-week interval. Moreover, each defined point was measured three times, and the mean of the three measurements was recorded as the final measurement.

To prepare the samples of the SP and ZrP groups, a duplicate of the master acrylic model was prepared to protect the abutments during the veneering procedure. The cameo surface of the frameworks was sandblasted with 110-µm alumina particles for 10 seconds at 0.25-MPa pressure from 20-mm distance. The frameworks were then cleansed ultrasonically in 95% methyl alcohol for 20 minutes and dried with air pressure. Feldspathic ceramic (VITA VM13, VITA Zahnfabrik) was used for the veneering process. Veneering ceramic was first applied to one of the frameworks, and a two-piece silicone mold was prepared to standardize the other ceramic veneers. The porcelain layering, firing, and glazing protocol was in accordance with Katsoulis et al.6 The same porcelain layering procedure was used for Co-Cr and Zr frameworks. Finally, the internal and marginal discrepancies of these two groups were measured in the manner previously described.

Kolmogorov-Smirnov and Levene tests were used to assess the normality and homogeneity of the collected data. The data were analyzed with analysis of variance (ANOVA) and Scheffe tests using SPSS software version 22 at a significance level of .05.

**RESULTS**

Table 1 summarizes the means and standard deviations (SDs) of all measurements. On average, the rankings from the lowest gap to the highest gap for the main criteria were as follows: MG: SF < SP < ZrF < ZrP; AMG: SF < SP < ZrP < ZrF; internal discrepancies: SF < SP < ZrP < ZrF.

The Kolmogorov-Smirnov and Levene tests showed that the data were normally distributed and
homogenous. Therefore, one-way ANOVA and Scheffe tests were used to analyze the collected data.

Comparing the gaps for the molar and the premolar abutments, in general, the molar abutments had smaller MGs, while the premolars showed smaller internal discrepancies. As for AMG, no statistical difference was observed in the SF and the ZrF groups between the molars and the premolars; in the SP group, the premolars had smaller gaps, whereas in the ZrP group, the molars showed smaller gaps.

Regarding the effect of porcelain layering, the results showed that all measurements were higher in the SP group than the SF group (all P values < .001) except for the MG.Px (P > .05). Therefore, porcelain veneering increased both marginal and internal gaps in Co-Cr frameworks. However, the results for the Zr frameworks were quite different. MG in the molars and internal discrepancies (AcD and AxD in both molars and premolars, and CvD only in premolars) were all smaller in the ZrP
group compared with the ZrF group. Nevertheless, the AMG measurements were higher in the ZrP than the ZrF group, meaning that porcelain layering decreased the MG and internal discrepancies while increasing the AMG in the Zr frameworks.

For all measurements, there was a statistically significant difference between Co-Cr groups (SF and SP) compared with their Zr counterparts (ZrF and ZrP; all P values < .001), showing that smaller MG, AMG, and internal discrepancies were achieved with Co-Cr.

**DISCUSSION**

This in vitro study compared internal and marginal discrepancies of two different, contemporary materials used for CAD/CAM fabrication of I-FPDs before and after porcelain veneering. From the analyzed data, the null hypothesis was rejected, as both the material and veneering process influenced the internal and marginal discrepancies of CAD/CAM-fabricated I-FPDs.

Both internal adaptation and marginal adaptation are critical for the long-term success of FPDs. Two techniques of replica alongside SEM observation were used in the present study in an effort to provide more precise results. However, there is no consensus on a clinically acceptable amount of misfit for FPDs, with literature providing a range from 50 to 200 µm.

The highest and lowest marginal discrepancies were recorded as 136 µm and 14.09 µm for the ZrP and SF groups, respectively. The internal fit was also assessed, as it is important to be uniform to avoid compromising either the retention or resistance while still providing an appropriate luting space. The internal discrepancies (CvD, AxD, OcD) of the present study of all groups (41.31 to 141.60 µm) were in the reported range of previously published studies (39.61 to 165.22 µm) and 91.00 to 208.30 µm with similar presumed cement space of 30 µm.

Recently, more attention has been given to the use of pre-sintered soft alloys for CAD/CAM fabrication due to various advantages, including rapid preparation times, the possibility of dry millings, low density, and longer life span of milling tools. In a recent study, Park et al compared the fit of metal copings fabricated via a conventional casting technique with those fabricated from CAD/CAM fully sintered and pre-sintered Co-Cr alloy. They claimed that the final fit of the pre-sintered group was better than the fully sintered group, which might be due to the 11% contraction of the framework during the sintering process. Despite different study designs, their reported discrepancy results for the pre-sintered group (56.34 ± 31.32) were similar to the present SF group. By contrast, in a study by Vojdani et al measuring the marginal and internal discrepancies of Co-Cr frameworks fabricated by CAD/CAM with both full and pre-sintered alloys, the results showed that hard Co-Cr copings had significantly improved marginal and internal adaptation. Their final report of marginal discrepancies for the pre-sintered group (195 ± 2 µm) is obviously higher than the present results obtained from the SF group. Different study design, different cement space (40 µm), and fewer measurement points may explain the different results of the studies.
One novelty of the present study was comparing two different non-completely sintered materials for fabrication of CAD/CAM frameworks. De França et al. compared the marginal fit of CAD/CAM-fabricated Zr (pre-sintered) and Co-Cr (solid) frameworks prepared for three-unit screw-retained I-FPDs. Their final results showed that the Co-Cr CAD group had the lowest marginal misfit. Although they used screw-retained frameworks and evaluated the marginal fit at two stages of passive seating and definitive situation, their final SEM analysis was in accordance with the present study. A recent systematic review on marginal adaptation of CAD/CAM-prepared FPDs represented interesting results. From 55 included studies, they concluded that Co-Cr and titanium-milled I-FPDs had better marginal adaptation than that of milled Zr frameworks. Also, they suggested that the final marginal adaptation could be influenced by the restorative material. The results of the present study were generally in accordance with the mentioned studies, as the SF group had better marginal adaptation than the ZrF and ZrP groups at a statistically significant level.

Another novelty of the present study was evaluating the effect of porcelain layering on the final fit accuracy of Zr and Co-Cr frameworks. The results suggested that the porcelain veneering reduced the internal and marginal accuracy of Co-Cr frameworks. In similar studies, Kocaağaoğlu et al. investigated the effect of porcelain veneering on internal and marginal fit of CAD/CAM-fabricated frameworks from pre-sintered Co-Cr. They stated that ceramic veneering increased both internal and marginal discrepancies of frameworks but with no statistically significant difference. The results of the present study supported the idea that ceramic firing may alter the metallurgic structure of Co-Cr alloy and cause changes in the marginal and internal adaptations of frameworks. The effect of porcelain veneering on the fit accuracy of Zr frameworks was quite different from Co-Cr frameworks in the present study because some measurement points showed a significant decrease in both internal and marginal discrepancies after porcelain veneering. The data are controversial among available articles. Vigolo and Fonzi measured the marginal fit of four-unit Zr FPDs fabricated by CAD/CAM before and after porcelain veneering. They concluded that the porcelain veneering did not influence the marginal accuracy of samples significantly. In another study, Bayramoğlu et al. designed a study on Zr I-FPDs with the same purpose as the present study and reported similar results by noting a significant decrease of MG after porcelain layering. In contrast, two other studies stated that porcelain layering had a negative effect on marginal fit of four-unit Zr FPDs. A systematic review on ceramic crowns confirmed the presence of contradicting reported results of Zr FPDs. The suggested explanations included different material used, contamination of the internal surface of framework, and multilayered crowns with different coefficients of thermal expansion, which can cause deformation of frameworks.

There are some limitations in the present study, including: no observation on solid Co-Cr frameworks, no three-dimensional analysis of internal discrepancies, and investigating only cement-retained I-FPDs. Future researchers are encouraged to design more comprehensive studies covering the limitations of the present study. Furthermore, conducting a systematic review or meta-analysis on this topic, especially on Zr FPDs, seems to be appropriate.

CONCLUSIONS

Considering the limitations of this in vitro study, the following conclusions can be drawn:

Three-unit CAD/CAM-fabricated cement-retained I-FPDs (with both Zr and Co-Cr soft alloy) are in the range of clinically acceptable internal and marginal fit accuracy. The internal and marginal discrepancies from the lowest to the highest values are as follows: SF < SP < ZrP < ZrF.

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