Impact of high-speed sintering on accuracy and fit of 4 mol% yttria-stabilized
tetragonal zirconia polycrystals (4Y-TZPs)

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Submitted September 28, 2020; accepted January 19, 2021
Abstract

**Purpose:** To investigate the impact of high-speed sintering on the accuracy (trueness and reproducibility) and fit of 4Y-TZP full-coverage single-unit fixed dental prostheses (FDPs) and three-unit FDPs. **Materials and Methods:** Single-unit FDPs, conventional three-unit FDPs, and cantilever three-unit FDPs ($N = 108; n = 12$ per subgroup) were fabricated from: (1) high-speed sintered ($1,580^\circ C$, about 20 minutes) multi-layer 4Y-TZP (Zolid RS, Amann Girrbach; ZMLH group), as well as two conventionally sintered ($1,450^\circ C$, about 10 hours) materials: (2) multi-layer 4Y-TZP (Zolid Gen-X, Amann Girrbach; ZMLC group) and (3) monochrome 4Y-TZP (Ceramill Zolid HT+ PS, Amann Girrbach; ZMOC group). All specimens were scanned. Trueness, reproducibility, and fit were measured with 3D analysis software. For data analysis, Kolmogorov-Smirnov, Kruskal-Wallis, and Mann-Whitney $U$ tests were performed ($\alpha = .05$). **Results:** Three-unit FDPs made from ZMLH presented a deterioration of accuracy in comparison to ZMLC ($P \leq .001$ to .008). The influence of high-speed sintering on marginal and general fit was not clinically relevant ($P = .154$ to .877). **Conclusion:** High-speed sintering influenced the accuracy of 4Y-TZP full-coverage single-unit and three-unit FDPs. However, no clinically relevant impact on fit was observed. *Int J Prosthodont 2021. doi: 10.11607/ijp.7428*

Introduction

Besides the conventional sintering process, speed and high-speed sintering furnaces have become increasingly relevant in recent years for the fabrication of monolithic zirconia restorations. Changes have been made by using new techniques such as electrical induction and inductively coupled plasma. For speed sintering, the preheating rate can be increased ($100^\circ C$/minutes) and the sintering holding time can be reduced to about 30 to 60 minutes.
The new high-speed sintering processes are characterized by a high temperature increase (1580°C) and a greater heating rate (300 °C/minutes). These changes enable a sintering time of only 10 to 15 minutes for high-speed sintering. So, time-saving patient treatment with zirconia restorations of up to three-unit fixed dental prostheses (FDPs) in only one appointment becomes possible. The optical and mechanical properties of speed and high-speed sintered Y-TZP ceramics have already been investigated in several studies. At the same time, only a few studies have addressed the accuracy and fit of high-speed sintered zirconia.

In addition to improvements in the sintering processes, the materials’ compositions have been optimized. The development of cubic-tetragonal 4Y-TZP (yttrium content: approx. 4 mol%) allows great progress, as it exhibits good translucency with good mechanical properties such as a flexural strength of 900 MPa. Further improvements of the esthetics of 4Y-TZP ceramics can be achieved by using the multi-layer technique. According to the manufacturers, 16 VITA shades can be produced by mixing four base powders (white, grey, pink, yellow) in different ratios. These can be used to define color zones in a blank and thus create a color gradient in a restoration. As a drawback, however, it should be mentioned that color pigments can affect the mechanical and optical properties of zirconia through changes in the crystal lattice.

As partially sintered zirconia blanks are used for milling, the restorations must be virtually designed with enlarged dimensions to compensate for the final sintering shrinkage of approximately 15 – 30%. The shrinkage factor and the precision of the milling machine must be very precise to ensure the exact dimensions and thus a good fit of the restoration. Other important factors that play a role in the restoration’s accuracy, and thus fit, are the homogeneity of the blanks on the one hand, and the sintering parameters on the other.
In addition to factors such as strength, adequate luting process, restoration design and preparation, marginal fit is a decisive criterion for clinical success for all dental materials.\textsuperscript{17-19} The size of the marginal gap is a critical factor, as the luting material can be washed out by saliva faster\textsuperscript{20} and promotes the accumulation of plaque formations, leading more often to secondary caries and periodontal as well as endodontic inflammation.\textsuperscript{21,22} Several studies therefore recommend a maximum marginal gap size of 120 $\mu$m for FDPs.\textsuperscript{23,24} Overall, the fit of zirconia restorations with an average value of 60 $\mu$m can be regarded as clinically acceptable.\textsuperscript{25}

For analyzing the accuracy of a manufacturing process (milling and sintering), two factors can be determined. The trueness indicates how precisely a specimen matches to the originally designed situation while the reproducibility indicates the extent of the deviations between two specimens\textsuperscript{26} being checked with a digital 3D evaluation software.\textsuperscript{27} For investigations of fit, various methods can be used: for example, 2D evaluation methods including the replica technique and the cross-sectioning method, as well as three-dimensional (3D) evaluations with the triple-scan method.\textsuperscript{28-30} A 3D evaluation generates greater information density and comparability, since it does not require a manual sectioning plane and has been found to be satisfactory.\textsuperscript{29,31-33}

The aim of this study was to compare high-speed sintered 4Y-TZP FDPs (conventional three-unit FDPs, cantilever three-unit FDPs and full-coverage single-unit FDPs) with conventionally sintered 4Y-TZP FDPs according to trueness and reproducibility, as well as marginal and internal fit. The null hypothesis stated that there was no difference in accuracy (trueness, reproducibility) or marginal and internal fit of the different 4Y-TZP materials produced by their respective sintering processes.

**Material and Methods**
Abutment tooth preparations were performed on an anatomical mandibular model (Frasaco model AG-3, Frasaco GmbH) with rotating instruments (879.314.12, 8879.314.014, 8379.314.023, 879EF.314.014, Komet Dental, Gebr. Brasseler GmbH & Co. KG). For this purpose, a mandibular right first premolar and a mandibular right first molar were prepared for (a) a conventional three-unit FDP; a mandibular right first and a mandibular right second premolar for (b) a cantilever three-unit FDP; and a mandibular right first molar for (c) a full-coverage single-unit FDP with substance removal of 0.8 mm circular and 1.0 mm occlusal (controlled by a prep guide) combined with a preparation angle of 6° in the form of a pronounced chamfer.

A preliminary test was carried out to determine the accuracy of the scanner and the scanning spray layer thickness (Arti-Spray, white, BK 285, Bausch GmbH Co. KG). Five resin-reinforced plaster models (class 4) of the conventional three-unit FDP situation were made after impressions had been taken with a polyether material (Impregum, 3M). These were scanned (pre-scan) (Ceramill Map 400, Amann Girrbach) each three times, then the preparation dies were sprayed with scanning spray at a distance of 10 cm and the models were re-scanned (post-scan). The pre-scans no 2 and no 3 were superimposed to the pre-scan no 1, then the pre-scan no 1 and the post-scans were superimposed by using the local-best-fit strategy (GOM Inspect 2019; GOM GmbH). For this superimposition, only the model areas that were not treated with scanning spray were selected. The measurement results were derived by comparing the actual mesh functions (search range 0.5 mm) to the normal of the target function of the area that was treated with scanning spray.

The three preparation situations were digitized with a stripe light scanner (Ceramill Map 400, Amann Girrbach) by using scanning spray (Arti-Spray, 10 cm distance), exported as STL (standard triangulation language) and the mesh was closed basally for model fabrication (Meshmixer, Autodesk, Inc.) (Fig 1). For additive manufacturing of the models,
the final STL data were imported to a 3D software program (Netfabb Premium, Autodesk Inc.) in which the models were positioned on the printer’s platform. One hundred and eight epoxy resin (Tray Printing Material, Voco GmbH) models (SolFlex 350, Voco GmbH) were additively manufactured. Prior to printing, the material was mixed for 30 minutes (LC-3DMixer, NextDent). Subsequently, the printed models were cleaned for 5 minutes in an ultrasonically activated bath (Sonorex Super RK 102H, Bandelin) filled with 96% ethanol. After a 15 minutes drying phase (light-protected), they were post-exposed from two sides with 2,000 light flashes each with a post polymerization device (Otoflash G171, NK Optik) under an inert gas atmosphere (argon).

A conventional three-unit FDP, a cantilever three-unit FDP and a full-coverage single-unit FDP were separately constructed on the three STL files of the preparation scans (Ceramill Mind, Amann Girrbach) with a cement layer thickness of 0.03 mm. The connectors were placed in a reproducible position and left on the specimens throughout the manufacturing process (Fig 2). For each of the three clinical situations, a total of 36 specimens were fabricated from presintered zirconia blanks with a milling machine (Ceramill Motion 2, Amann Girrbach) (n = 12 per material as subgroups). The sintering process for Ceramill Zolid HT+ PS (ZMOC) and Zolid Gen-X (ZMLC) restorations was carried out conventionally with a sintering time of about 10 hours and a sintering temperature of 1450°C (Ceramill Therm 2, Amann Girrbach). Zolid RS (ZMLH) restorations were sintered in a high-speed furnace (Ceramill Therm RS, Amann Girrbach) with a temperature of 1580°C and a sintering time of about 20 minutes. All detailed material information and the study design used are summarized in Table 1 and Figure 3.

After application of the scanning spray (Arti-Spray, white, BK 285, Bausch GmbH Co. KG; distance: 10 cm), the sintered restorations were scanned from all six sides (Ceramill Map 400, Amann Girrbach) (Restoration-Scan). In addition, both the individual models
(Model-Scan) and the models with attached restoration (Model+Restoration-Scan) were
digitized. The obtained data sets were subsequently used to determine the accuracy (trueness
and reproducibility) and fit (GOM Inspect 2019; GOM GmbH).

To evaluate trueness, the specimens were compared to the initial STL file of the
restorations, while reproducibility was checked by comparing the differences between the
restorations, respectively (Fig 4). For this purpose, the initial STL file was defined as the
target function and the post-scans were defined as the actual situation. The actual situation
was aligned to the target situation by using a local-best-fit matching process for the whole
restoration surface, in which the average distance of the mesh functions within a search field
(1 mm) was minimized. The irrelevant areas were deleted identically for each group. After
processing, each restoration (R-Scan) in each group was aligned to all restorations in the
same group with the local-best-fit method, in which the mean distance was minimized in a
defined search field (1 mm) (n = 12 per group). The results for trueness and reproducibility
were derived from comparison of the actual mesh functions (search range 0.5 mm) to the
normal of the target function (Fig 5).

For the evaluation of fit, the post-scans were aligned to the M-Scan by using the
triple-scan method (Fig 4). First, all models were aligned to one defined model, by using the
local-best-fit method with a search range of 1 mm and the whole surface of the models. This
alignment was performed to enable a uniform definition of the evaluation areas for all
restorations, namely the entire die (general fit), and the marginal area (marginal fit). The
marginal area includes all points that were a maximum of 1 mm from the edge. The MR-
Scans were then defined as the actual situation and were aligned to the target (M-Scan) by
using the same method as described above (local best fit) with a search range of 1 mm and by
using only the relevant parts of the surface. For aligning the R-Scans to the MR-Scan, the
procedure was identical. The R-Scans and M-Scans were used to determine the fit by
comparing the actual function (restoration) and the normal of the target function (M-Scan) with an appropriate search range. Here, the point on the other surface with the smallest distance was determined (Fig 6).

Normal distribution was tested by applying the Kolmogorov–Smirnov test. Kruskal–Wallis and Mann–Whitney U tests were performed to evaluate significant differences between the groups. A statistical software program (SPSS, IBM SPSS statistics for Windows, version 25, IBM Corp) was used and a significance level of $p < 0.05$ was set.

Results

The average deviation of the model scans was $0.13 \pm 0.08 \mu m$. The average thickness of the scan spray layer was $16.4 \pm 4.93 \mu m$. The measured values of trueness (22%), reproducibility (67%) and fit (25%) showed a deviation from the normal distribution. Therefore, a non-parametric evaluation was applied. Descriptive statistics by means and standard deviation for all parameters analyzed are listed in Table 2.

Trueness

The mean values for trueness presented no significant differences between the materials nor the restoration types ($P = .104 – .650$). The standard deviations for conventional three-unit FDPs were significantly higher for ZMLH compared to ZMLC ($P = .008$). For the cantilever three-unit FDPs, the values for ZMLH were significantly higher than for both other materials (ZMLC: $P = .002$; ZMOC: $P = .003$). For the single-unit FDPs, the standard deviations for all materials were within the same range ($P = .220 – .498$). The standard deviations for single-unit FDPs and conventional three-unit FDPs were within the same range ($P = .087 – .381$) for all materials. For ZMLH and ZMOC, the values for the cantilever three-unit FDPs were in the same range as for the single-unit FDPs ($P = .793$ for ZMLH and $P = .207$ for ZMOC). Within the material ZMLC, the standard deviation for the cantilever three-unit FDPs was the lowest ($P = .005$).
Reproducibility

For both three-unit FDPs, the mean values for ZMLC were significantly lower than those for ZMLH (conventional three-unit FDPs: $P < .001$; cantilever three-unit FDPs: $P = .002$).

Values for ZMOC were in the same range as for ZMLH for the conventional three-unit FDPs and in a range with ZMLC for the cantilever three-unit FDPs (ZMLH: $P = .427$; ZMLC: $P = .685$). Within the single-unit FDPs, no significant differences were found between the mean values for the three materials ($P = .292$). Regarding ZMLH, no significant differences could be determined between the mean values for all restoration types ($P = .082$). For ZMLC, single-unit FDPs showed the highest values, followed by cantilever and conventional three-unit FDPs ($P \leq .001 – .009$). Within ZMOC, the highest values were found for the conventional three-unit FDPs and single-unit FDPs ($P = .084$), whereas values for the cantilever three-unit FDPs were in the same range as for single-unit FDPs ($P = .109$). The standard deviation for ZMLC was lower than that for ZMLH for all three restoration types ($P \leq .001 – .003$). Within the conventional three-unit FDPs, the mean values for ZMOC ranged in between those for the two other materials ($P \leq .001 – .002$). For cantilever three-unit FDPs, the standard deviations for ZMOC showed no significant differences to those for ZMLC and ZMLH ($P = .074 – .230$). With regard to single-unit FDPs, values for ZMOC were in the same range as for ZMLC ($P = .358$). Comparing the restoration types, the standard deviation within ZMLH was highest for the conventional three-unit FDPs, followed by the single-unit FDPs ($P \leq .001$). The cantilever three-unit FDPs presented the lowest values ($P \leq .001$).

Within the material ZMLC, conventional three-unit FDPs also showed higher values than cantilever three-unit FDPs ($P = .001$). Values for single-unit FDPs were in the same range as for both conventional three-unit FDPs ($P = .053$) and cantilever three-unit FDPs ($P = .507$). For ZMOC, values for conventional three-unit FDPs were the highest and those for single-unit FDPs were the lowest ($P \leq .001 – .002$).
General fit

The mean value and standard deviation for general fit presented no significant differences between the materials ($P = .179 – .683$). Within the material ZMLH, only conventional three-unit FDPs presented a higher mean value ($81.6 \pm 56.6 \mu m$) than cantilever three-unit FDPs ($52.1 \pm 14.4 \mu m$) ($P = .011$). For ZMLC, the only significant difference was a higher mean value for the single-unit FDPs ($66.8 \pm 14.0 \mu m$) compared to the cantilever three-unit FDPs ($52.3 \pm 12.5 \mu m$; $P = .026$). For standard deviations, there were only significant differences for ZMLC. The cantilever three-unit FDPs had lower values than the single-unit FDPs ($P = .002$).

Marginal fit

ZMLH conventional three-unit FDPs showed a higher mean value ($52.3 \pm 69.0 \mu m$) than the single-unit FDPs ($24.8 \pm 13.7 \mu m$; $P = .049$). For single-unit FDPs, ZMOC had a higher mean value ($36.3 \pm 17.0 \mu m$) than ZMLH ($24.8 \pm 13.7 \mu m$; $P = .043$). Within the material ZMLH, the standard deviation was higher for conventional compared to cantilever three-unit FDPs ($P = .026$). For ZMOC, the standard deviation for conventional three-unit FDPs was higher than for single-unit FDPs ($P = .038$).

Discussion

In order to investigate the effect of high-speed sintering on accuracy and fit, the high-speed sintered material ZMLH was compared to the conventionally sintered materials ZMOC and ZMLC. Based on the presented results, the null hypothesis stating that the sintering protocol has no influence on the accuracy (trueness and reproducibility) and fit of the three restoration types was rejected.

Comparison with other studies remains difficult due to the variety of methods. In previous investigations, internal and marginal gaps were often determined to analyze the accuracy of restorations. In the past, 1D and 2D methods such as replica techniques and cross-sectioning
methods were commonly used.27 These methods can only provide information about points on a maximum of two section planes and are very error-prone due to the manual evaluation. More recent developments allow 3D analysis of the components. In this way, all measuring points of a restoration can be taken into account.30 To check the sinter shrinkage, it is also useful to check trueness and reproducibility. An advantage of these methods is that no inaccuracies occur due to the need for models. Furthermore, they provide information about the dimensional accuracy of the entire restoration.

For all methods used, the accuracy of the milling machine and the scanner and the thickness of the scanning spray layer are of great importance. These have a strong influence on the significance of the results. While the milling machine (Ceramill Motion 2, Amann Girrbach) has a repeatability of the axis positioning of 1 µm and the scanner (Ceramill Map 400, Amann Girrbach) has an accuracy of 6 µm according to the manufacturer, we assume an average scanning spray layer thickness of about 16 µm based on our own investigations. This value is consistent with scanning spray layer thicknesses found in the literature.34,35

In the 3D triple-scan method, the luting gap between two surfaces is measured, both scanned with scanning spray. The results for the cement gap can therefore be assumed to be too small. In addition, there is an inaccuracy caused by the model printing. The models are unavoidable because a rigid position of the abutment teeth cannot be guaranteed with Frasaco models. In addition, the clinical workflow is maintained in this way, as a restoration is also fitted on a model. The influence on our results should be kept as low as possible by producing several casts. Taking into account these inaccuracies, in other studies, the accuracy of this method as well as that of the methods for determining trueness and reproducibility was found to be satisfactory.30,34,35

The mean value and standard deviation were used as evaluation parameters. These describe, independently of the area, the deviations between the components (trueness and
reproducibility) and the size of the luting gap (fit). In the latter case, the values are also not influenced by a lack of fit and a resulting small evaluation area in the marginal area, as would be the case if the volume were used for evaluation. To interpret the results for trueness and reproducibility obtained in the study, the assumption is made that two volume-equivalent bodies with different shapes show no deviation in the mean distance of their outer surfaces when ideally superimposed. A deviation below the mean distance therefore means an increase or decrease in volume.

The comparison between monochrome material (ZMOC) and multi-layer material (ZMLC) showed only significantly better values for the standard deviation of trueness and for the mean and standard deviation of reproducibility for ZMLC three-unit FDPs. These values suggest that the size reproduction of the conventional three-unit FDPs made of ZMLC is better than for ZMOC. The difference between ZMLC and ZMOC is the multi-layer technology. Further information is not known from the manufacturer. High-speed sintering (ZMLH) compared to conventional sintering (ZMLC) had a negative influence on the size reproduction and dimensional stability of the three-unit FDP restorations. The standard deviation of trueness, as well as mean and standard deviation of reproducibility, presented higher values. For single-unit FDPs, only a deterioration in the standard deviation of reproducibility was observed, i.e. a deviation in the dimensional stability of the restorations from one another. Overall, this allows the thesis that conventional sintering still has an advantage over high-speed sintering in terms of size reproduction and dimensional stability. When the conventional three-unit FDPs were examined, it became clear that they showed greater distortion than cantilever three-unit FDPs for all zirconia materials – higher values for standard deviation of trueness and reproducibility. With ZMOC, the size reproduction of conventional three-unit FDPs deteriorated. In principle, this allows the assumption that a pontic has less influence on sinter distortion if it is located at the edge of the construction.
The fact that values for single-unit FDPs tended to lie between those for three-unit FDP constructions despite their lower complexity and volume suggests that a molar shape has a significantly more negative influence on the dimensional stability of a single-unit FDP than a premolar shape.

The differences found between the materials in regard to accuracy were not the same as those in regard to fit analysis. The reason could be the measuring tolerances of the methodology, with regard to small material deviations. For ZMLH, the marginal and general fit tended to be lower for conventional three-unit FDPs in contrast to the other restoration types analyzed. With the ZMLC material, the single-unit FDP restorations showed a lower general fit than the cantilever three-unit FDPs. Thus, the results of the fitting test confirm the observation regarding accuracy.

The deviation of the final dimensions could be influenced by the homogeneity of the material, and the milling and sintering parameters. Changing the sintering parameters (higher temperature, faster heating rate and shorter sintering process) can influence the shrinkage behavior. Due to faster heating, the final sintering temperature was reached faster in the outer part of the restoration, whereas the temperature change was delayed in the inner part. Therefore, the temperature gradient increased. This gradient depends largely on the inherent thermophysical properties of the material, such as thermal conductivity. These changes may lead to local differences in sinter shrinkage and thus to distortion and changes in the size of the restorations. The larger a restoration, the greater the influence appears to be. In order to guarantee the correct size reproduction (trueness) of a restoration, it is helpful to precisely preset the magnification factor.14-16

On the basis of the present results, the multi-layer material has no disadvantages compared to the monochrome ZMOC material since comparable values for fit could be measured with the conventional sintering process. The high-speed sintering process seems to
show disadvantages in terms of size reproduction and dimensional stability for large restorations. However, these hardly affected the fit of the restorations themselves. A comparison with the accuracy of other Y-TZP materials is not possible due to the variety of evaluation methods. Comparison with the fit of other materials is difficult. For zirconia materials, a mean value of $83 \pm 24 \ \mu m$ and a standard deviation of $59 \pm 25 \ \mu m$ can be taken as a reference for the marginal gap, and a mean value of $101 \pm 30 \ \mu m$ and a standard deviation of $53 \pm 30 \ \mu m$ for the general gap.\textsuperscript{25} For the high-speed sintering of 3Y-TZP (IPS e.max ZirCAD), a marginal gap of $41.06 \pm 14.03 \ \mu m$ was analyzed.\textsuperscript{9} For another high-speed sintered 3Y-TZP (inCoris TZI, Dentsply Sirona), a marginal fit of $61.5 - 68.2 \ \mu m$ was observed.\textsuperscript{8} The present values were in a similar range. Clinically, a maximum marginal gap of 120 $\mu m$ is considered a prerequisite for successful therapy.\textsuperscript{23,24} This could be achieved in any case by fitting the restorations.

A limitation of this study was the lack of power analysis to determine sample size, it is not clear if the sample size was adequate. Further studies with equal testing arrangements, parameters, and evaluation techniques should be conducted to allow the comparison of research results.

**Conclusions**

Within the limitations of the present investigation, the following conclusions can be drawn:

1. High-speed sintering had no relevant impact on the fit of single-unit FDPs and three-unit FDPs.
2. High-speed sintering (ZMLH) led to a deterioration in size reproduction and dimensional stability compared to conventional sintering (ZMLC).
3. Conventional three-unit FDPs showed a worse accuracy and fit than cantilever three-unit and single-unit FDPs.

**Acknowledgments**
The authors would like to thank Amann Girrbach for supporting this study with materials.

References


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Fig 6 Visualization of fit in the 3D analysis software GOM.
Table 1 Detailed material information and study design

<table>
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<tr>
<th>Material</th>
<th>Abbreviation</th>
<th>Zirconia type</th>
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<th>Sintering procedure</th>
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<td>Zolid Gen-X</td>
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## Table 2 Descriptive statistics: trueness, reproducibility and fit

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<td>29/36.5/61 A,a,b</td>
<td>−24/16.5/44 A,a</td>
</tr>
<tr>
<td>Reproducibility</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Conventional 3-unit FDP</td>
<td>0/17.0/57 A,a</td>
<td>21/46.0/124 A,a</td>
<td>0/5.0/33 B,c</td>
</tr>
<tr>
<td>Cantilever 3-unit FDP</td>
<td>1/16.0/49 A,a</td>
<td>3/31.0/41 A,c</td>
<td>1/10.0/34 B,b</td>
</tr>
<tr>
<td>Single-unit FDP</td>
<td>0/12.0/44 A,a</td>
<td>19/35.0/59 A,b</td>
<td>0/15.0/64 A,a</td>
</tr>
<tr>
<td>General fit</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Conventional 3-unit FDP</td>
<td>45/64.0/258 A,a</td>
<td>44/66.5/250 A,a</td>
<td>43/58.0/88 A,a,b</td>
</tr>
<tr>
<td>Cantilever 3-unit FDP</td>
<td>31/55.0/77 A,b</td>
<td>29/60.0/121 A,a</td>
<td>33/52.0/73 A,b</td>
</tr>
<tr>
<td>Single-unit FDP</td>
<td>36/60.5/86 A,b,a</td>
<td>35/59.5/106 A,a,b</td>
<td>48/64.5/94 A,a</td>
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<td>Marginal fit</td>
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<tr>
<td>Conventional 3-unit FDP</td>
<td>14/30.5/268 A,a</td>
<td>33/45.0/135 A,a</td>
<td>15/27.0/60 A,a</td>
</tr>
<tr>
<td>Cantilever 3-unit FDP</td>
<td>−1/28.5/56 A,a,b</td>
<td>31/39.0/56 A,b</td>
<td>13/30.0/54 A,a</td>
</tr>
<tr>
<td>Single-unit FDP</td>
<td>5/23.5/50 B,b</td>
<td>33/43.0/56 A,a,b</td>
<td>4/26.0/45 A,B,a</td>
</tr>
</tbody>
</table>
Superscript lowercase letters (a,b,c) indicate differences between the restoration types within a material.
Superscript capital letters (A,B,C) indicate differences between the materials within a restoration type.
This peer-reviewed, accepted manuscript will undergo final editing and production prior to publication in IJP.