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RESEARCH AND EDUCATION

Influence of CAD/CAM on the fit accuracy of implant-supported zirconia and cobalt-chromium fixed dental prostheses

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ABSTRACT

Statement of problem. Relatively little information is available on the accuracy of the abutment-implant interface in computer-aided design and computer-aided manufacturing (CAD/CAM)-fabricated zirconia and cobalt-chromium frameworks.

Purpose. The purpose of this study was to compare the fit accuracy of CAD/CAM-fabricated zirconia and cobalt-chromium frameworks and conventionally fabricated cobalt-chromium frameworks.

Material and methods. Four groups of 3-unit, implant-supported, screw-retained frameworks were fabricated to fit an in vitro model with 3 implants. Eight frameworks were fabricated with the CAD/CAM system: 4 in zirconia and 4 in cobalt-chromium. Another 8 were cast in cobalt-chromium with conventional casting, including 4 with premachined abutments and 4 with castable abutments. The vertical misfit at the implant-framework interface was measured with scanning electron microscopy when only 1 screw was tightened and when all screws were tightened. Data were analyzed with the Kruskal-Wallis and Mann-Whitney tests (α=.05).

Results. The mean vertical misfit values when all screws were tightened was 5.9 ±3.6 μm for CAD/CAM-fabricated zirconia, 1.2 ±2.2 μm for CAD/CAM-fabricated cobalt-chromium frameworks, 11.8 ±9.8 μm for conventionally fabricated cobalt-chromium frameworks with premachined abutments, and 12.9 ±11.0 μm for the conventionally fabricated frameworks with castable abutments; the Mann-Whitney test found significant differences (P<.05) among all frameworks, except between the conventionally fabricated frameworks (P=.619). No significant differences were found among the groups for passive fit gap measurements (P>.05).

Conclusions. When all of the screws were tightened, the CAD/CAM frameworks exhibited better fit accuracy compared with the conventionally fabricated frameworks. High levels of passive fit were achieved for the evaluated techniques. (J Prosthet Dent 2015;113:22-28)

A passive fit of an implant-supported prosthetic framework is defined as a stress-free, simultaneous, circumferential contact at the implant-prosthesis interface before functional loading.[1,2] A passive fit is essential to maintain mechanical and biologic equilibrium and decrease loading on the abutment, screw, and supporting bone.[3-8]

The methods and materials used to fabricate implant-supported frameworks may lead to distortion and poor fit of the prosthesis.[9-14] A prosthetic framework can be fabricated by conventional 1-piece casting, casting and laser welding, casting and spark erosion, copy milling, computer numeric-controlled (CNC) milling, or computer-aided design and computer-aided manufacturing (CAD/CAM).[15-23] Materials used for casting include gold (Au) alloys, palladium-silver, commercially pure titanium (Ti), cobalt-chromium (Co-Cr), nickel-Cr, and nickel-Cr-Ti. CAD/CAM systems have enabled the fabrication of frameworks from solid blocks of Ti, Co-Cr, and zirconia.[22,24-29]

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Clinical Implications

CAD/CAM zirconia and cobalt-chromium may be an alternative for fabricating 3-unit, implant-supported, screw-retained frameworks in terms of definitive fit and passivity of fit.

In spite of the varied techniques and materials available for fabricating implant-supported frameworks, no combination currently provides standardized results, decreased processing time, low cost, and an accurate fit.[30-34] The use of CAD/CAM technology may decrease or avoid these problems.[6,35,36] Although CAD/CAM has been found to be a simpler and less time-consuming technique with improved accuracy, some studies have reported a higher incidence of misfit with CAD/CAM-fabricated frameworks compared with conventionally fabricated frameworks.[37,38]

The noble metal alloys are still the most suitable materials for fabricating frameworks that fit appropriately.[24] Nevertheless, the high costs of these materials inhibit their widespread use. Interest in Co-Cr alloys has increased because of their low price and different fabrication methods that can improve the fit of material.[37] However, few studies have focused on the fit of CAD/CAM-fabricated Co-Cr frameworks. The high demand for esthetics has led to the increased use of zirconia frameworks.[39] These, if well-made and accurate, can be an alternative to metallic alloys.[40-44]

This study, therefore, was performed to compare the fit accuracy of 3-unit, screw-retained, fixed dental prostheses (FDPs) fabricated by CAD/CAM of zirconia, fabricated by CAD/CAM of Co-Cr, and conventionally fabricated of Co-Cr alloy, including those with premachined Co-Cr abutments and those with castable abutments when only 1 screw was tightened (passive fit) and when all screws were tightened (definitive fit). The null hypotheses were that the vertical misfit of a fabricated FDP would not be influenced by manufacturing technique or material when definitive fit was performed and that materials processed by CAD/CAM technology would provide a better fit.

MATERIAL AND METHODS

CAD/CAM and conventional casting techniques were evaluated in this study. Sixteen frameworks were fabricated with zirconia and Co-Cr alloy as follows (n=4): CAD/CAM-fabricated zirconia frameworks (ZirCAD group), CAD/CAM-fabricated Co-Cr frameworks (CoCrCAD group), conventionally fabricated Co-Cr alloy frameworks with premachined Co-Cr abutments with plastic sleeves and Co-Cr bases (CoCrUCci group), and conventionally fabricated Co-Cr frameworks with castable abutments (CoCrUCcl group) (Table 1). The conventional casting groups were used as controls.

Three external hexagon (EH) implants with regular platforms (4.1 mm diameter × 9 mm bone depth, Implant Titamax Cortical Ti; Neodent) were inserted in an aluminum matrix (ABNT/ASTM 6101; Alfa Alumínio) with a mesiodistal width of 34 mm, a buccal thickness of 13 mm, and a height of 19 mm (Fig. 1). The implants were positioned in the regions of the left mandibular second premolar (implant A), first molar (implant B), and second molar (implant C).

Three direct transfer copings (antirotational, ⌀4.1 mm, EH, open tray; Transfer implant; Neodent) were used for implant impression in the matrix. The transfer copings were splinted with metallic bars fixed with cyanoacrylate-based adhesive (Super Bonder; Henkel) and red autopolymerized acrylic resin (Dencrilay; Dencril) by using the brush technique. Splinting was used to stabilize the implant and avoid displacement within the impression. A medium body polyether impression material (Impregum F; 3M ESPE) was used to make impressions. The tray was previously prepared with polyether adhesive (Polyether Adhesive; 3M ESPE), and the material (1:1 ratio of base-catalyst paste) was manipulated on a glass plate to obtain a homogeneous mixture. Then, the material was transferred to the retentive areas with an impression syringe (Impression Syringe; Anthogyr) and loaded on the tray to make the definitive impression. After polymerization, the screws were loosened to separate the impression from the matrix. Implant analogs were attached and Type IV dental stone (Durone IV; Dentsply Intl) was mixed according to the manufacturer's instructions and poured to obtain a working cast.

Three abutments with Co-Cr bases (antirotational, ⌀4.1 mm, EH, UCLA Abutment; Neodent) were attached to the analogs for framework waxing. The framework and cast were sent to a milling center (NeoShape; Neodent). Initial scanning of the set was performed by using a digital, 3-dimensional (3D) laser scanner 3-axis motion (3Shape D-700; 3Shape A/S). The images obtained by scanning were managed and the design's infrastructure was developed with 3D software (3Shape Dental System 2012; 3Shape A/S). After obtaining the CAD file of a scanned wax pattern, CAM was conducted to mill the frameworks with a high-speed 5-axis simultaneous motion (3Shape Dental System 2012; 3Shape A/S), maintaining a mesiodistal width of 27 mm and a height of 8 mm. Then, the connectors were milled with a width of 2.5 mm and a height of 5 mm between the premolar and first molar and with a height of 4 mm between the first and second molars. Four frameworks were fabricated from presintered yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP) blocks (Zircônia Neoshape; Neodent), and 4 were fabricated from Co-Cr blocks (Co-Cr Neoshape; Neodent) (Fig. 2). All frameworks were

Table 1. Study groups

Group	Material Composition	Manufacturer
ZirCAD	Y-TZP: 95% ZrO_2, 5%Y_2O_3	NeoShape; Neodent
CoCrCAD	62% Co, 28% Cr, 9% W, 0.5% Si, 0.5% Mn	NeoShape; Neodent
CoCrUCci	65% Co, 27.5% Cr, 5.5% Mb, 2% C, Si, Fe, Mn	Nobil Star Ultra; Nobilium
CoCrUCcl	65% Co, 27.5% Cr, 5.5% Mb, 2% C, Si, Fe, Mn	Nobil Star Ultra; Nobilium

Y-TZP, yttria-stabilized tetragonal zirconia polycrystal; ZirCAD, CAD/CAM-fabricated zirconia frameworks; CoCrCAD, CAD/CAM-fabricated cobalt-chromium frameworks; CoCrUCci, conventionally fabricated cobalt-chromium frameworks with premachined abutments with cobalt-chromium bases; CoCrUCcl, conventionally fabricated cobalt-chromium frameworks with castable abutments.

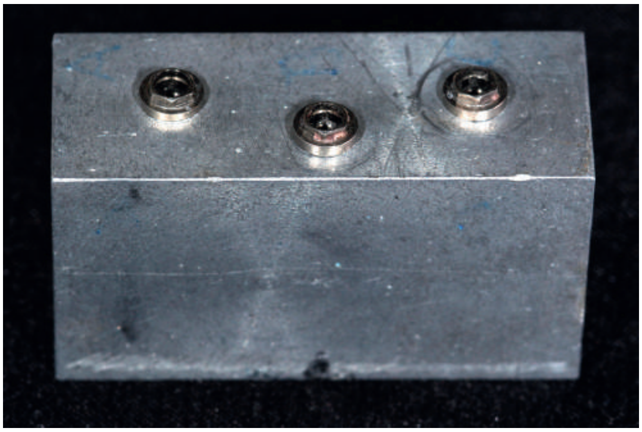

Figure 1. Aluminum matrix with implants.

simultaneously milled and left unfinished and unpolished.

A total of 8 three-unit FDPs were waxed, including 4 with castable abutments (antirotational, ⌀4.1 mm, EH, UCLA abutment; Neodent) and 4 with abutments with Co-Cr bases (antirotational, ⌀4.1 mm, EH, UCLA abutment; Neodent). An index obtained from the CAD/CAM frameworks was used to standardize the wax dimensions. The passive fit was assessed with the single-screw test. If misfit was observed, the connectors were separated with a number 12 scalpel (Surgical Blade 12 R0304; Swann Morton) and reconnected with melted wax to avoid distortion. The frameworks were invested for casting only when an accurate fit was achieved as per the single-screw test.

The waxed frameworks were invested in different metallic cylinders according to the abutment type. Dental casting investment material (Talladium Microfine; Talladium) was used for the Co-Cr alloy (Nobil Star Ultra; Nobilium). According to the manufacturer, this alloy has an elongation of 9%, a casting temperature of 1510°C, a burnout temperature of 1010°C, and a Vickers hardness of 430. The casting procedure was manually conducted, with the melting temperature adjusted according to the manufacturer's instructions. After casting, the

Figure 2. Zirconia and cobalt-chromium frameworks fabricated with computer-aided design and computer-aided manufacturing.

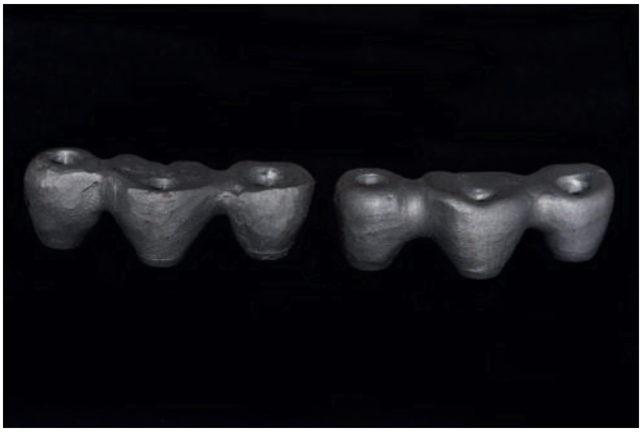

Figure 3. Conventionally fabricated cobalt-chromium frameworks.

frameworks were carefully airborne-particle abraded with aluminum oxide (100 μm; 0.55 MPa) (Aluminum Oxide; Polidental) to avoid damage to the fitting surfaces and were left unfinished and unpolished (Fig. 3).

The vertical gap between the framework platform and implant shoulder was evaluated for 2 conditions: definitive fit (vertical gap that is formed between the implants and the frameworks as a result of tightening all retaining screws) and passive fit (vertical gap that is formed on the nontightened implant as a result of manual tightening of the retaining screw on the other).[34] The tightening procedure was performed till the first fixation of the screw was felt.[8] When tightened the abutment screw implant corresponding to "A," the misfit was analyzed in the mesial and distal abutment interface-implant corresponding to implant "C" (loosened side). When tightened the abutment screw implant corresponding to "C," the misfit was analyzed in the mesial and distal abutment interface-implant corresponding to implant "A"

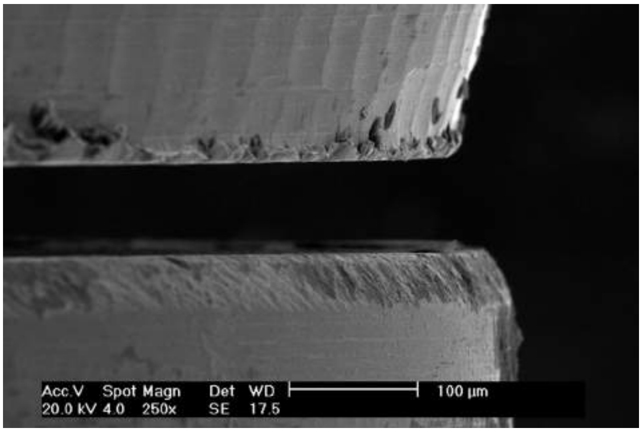

Figure 4. Scanning electron microscope image (×250 magnification) of analysis measurement.

(loosened side), totaling 16 images for each group (n=16). Scanning electron microscopy (SEM) at ×250 magnification (ESEM XL-30; Philips Research) was used for measurements. For definitive fit, the frameworks were tightened to 20 Ncm with an analog gauge (Torque Gauge; Neodent) following the B-A-C implant sequence.[2,5] One mesial and 1 distal image were obtained for each tooth; a total of 24 images were obtained per group (n=24). The same trained investigator made all vertical misfit measurements as follows: 2 lines were drawn parallel to the implant platform and abutment base, and the distance between the lines was measured (Fig. 4).

The definitive fit and passive fit values were compared among groups. The mean, SD, and minimum and maximum values in micrometers were calculated for each group. The Kolmogorov-Smirnov test was used to assess data normality. The Kruskal-Wallis test was used to detect quantitative differences among groups, and the Mann-Whitney test was used to compare statistical differences among groups (α=.05) The minimum critical value of vertical misfit for definitive fit was determined to be 10 µm for the purpose of data analysis.[1] Therefore, the specimens were divided into groups on the basis of values higher or lower than 10 µm. Then, the groups were categorized for risk verification of the manufactured frameworks.

RESULTS

In relation to the definitive fit, significant differences were found among the mean misfit values for all groups (P<.001). The lowest values were exhibited by the CoCrCAD group (Table 2). The Mann-Whitney test (Table 3) found significant differences among the mean vertical misfit values for all groups, except between the CoCrUCci and CoCrUCcl groups (P=.619). The calculated misfit values for the ZirCAD and CoCrCAD groups indicated a low potential for biomechanical damage (Table 4). When only 1 screw was tightened, high levels of passive fit were achieved for the evaluated techniques. However, no significant difference was found among the groups (Table 5).

DISCUSSION

This in vitro study compared the fit accuracy of 3-unit posterior FDP made of frameworks fabricated from zirconia and Co-Cr alloys with a CAD/CAM manufacturing system and from a Co-Cr alloy with conventional casting. The hypotheses that the vertical misfit of a fabricated FDP would not be influenced by manufacturing technique or material when definitive fit was performed and that a better passive fit would be found for materials processed by CAD/CAM technology were rejected.

After definitive fit measurements, the vertical misfit was less with the CAD/CAM-fabricated frameworks than with the conventionally fabricated frameworks. A comparison of Au and Ti FDP frameworks fabricated by the 2 methods found similar results.[6,11-13] These results were probably related to the accuracy and reproducibility of the CAD/CAM procedure, considering that it is faster and can avoid the errors that occur during investment, wax removal, casting, finishing, and polishing.[10,12,20,23] A previous study found that the manufacturing technique is also a variable that influences the presence of a microgap, probably because of the different surface roughness produced by each manufacturing method. The authors observed that milled surfaces have a better fit and a larger number of contacts with the implant mating surface than cast surfaces, which allows a better closure of the microgap between implant components.[9] The defects resulting from the casting procedure may explain the greater variability in vertical misfit in the CoCrUCci and CoCrUCcl groups. The proportion of misfit values >10 µm was higher with the CAD/CAM-fabricated frameworks than with the conventionally fabricated frameworks (Table 4).

An acceptable definitive fit does not necessarily mean that FDPs have a passive fit, because when all screws are tightened, fit is achieved; however, strains are induced in the prosthesis/implant connection to the surrounding bone and implants.[15,16,44] Although no statistically significant difference was observed between the groups when comparing passive fit condition, the CAD/CAM frameworks had a more uniform level fit, with lower SDs and minimum and maximum values with less variability. Similar results were observed for strain development of conventionally fabricated and CAD/CAM-fabricated FDPs.[18,39] This appears to be typical for well-controlled CAD/CAM processes, with a more uniform quality of frameworks than can be achieved by conventional fabrication.

Table 2. Mean vertical gap values (μm), SDs, minimum, and maximum in definitive fit condition for all groups

Group	Mean ±SD	Min-Max	*P*
ZirCAD[a]	5.9 ±3.6	0-13.89	<.001
CoCrCAD[b]	1.2 ±2.2	0-8.33	
CoCrUCci[c]	11.8 ±9.8	1.39-44.44	
CoCrUCcl[c]	12.9 ±11.0	2.78-55.56	

ZirCAD, CAD/CAM-fabricated zirconia frameworks; CoCrCAD, CAD/CAM-fabricated cobalt-chromium frameworks; CoCrUCci, conventionally fabricated cobalt-chromium frameworks with premachined abutments with cobalt-chromium bases; CoCrUCcl, conventionally fabricated cobalt-chromium frameworks with castable abutments.
[a,b,c]Statistically significant differences for $P<.05$ (Kruskal-Wallis test).

Table 3. Statistical comparisons of groups based on vertical misfit values (μm) in definitive fit condition

Comparison	*P*
ZirCAD versus CoCrCAD	<.001*
ZirCAD versus CoCrUCci	.011*
ZirCAD versus CoCrUCcl	.001*
CoCrCAD versus CoCrUCci	<.001*
CoCrCAD versus CoCrUCcl	<.001*
CoCrUCci versus CoCrUCcl	.619

ZirCAD, CAD/CAM-fabricated zirconia frameworks; CoCrCAD, CAD/CAM-fabricated cobalt-chromium frameworks; CoCrUCci, conventionally fabricated cobalt-chromium frameworks with premachined abutments with cobalt-chromium bases; CoCrUCcl, conventionally fabricated cobalt-chromium frameworks with castable abutments.
*Statistically significant difference; $P<.05$ (Mann-Whitney test).

Table 4. Proportion of vertical misfit values above and below 10 μm in definitive fit condition

Group	0-10 μm (%)	>10 μm (%)
ZirCAD	83.3	16.7
CoCrCAD	100	0
CoCrUCci	50	50
CoCrUCccl	54.2	45.8

ZirCAD, CAD/CAM-fabricated zirconia frameworks; CoCrCAD, CAD/CAM-fabricated cobalt-chromium frameworks; CoCrUCci, conventionally fabricated cobalt-chromium frameworks with premachined abutments with cobalt-chromium bases; CoCrUCcl, conventionally fabricated cobalt-chromium frameworks with castable abutments.

Table 5. Mean vertical misfit values (μm), SDs, minimum, and maximum in passive fit condition for all groups

Group	Mean ±SD	Min-Max
ZirCAD	107.2 ±36	31.9-163.8
CoCrCAD	107.5 ±26	65.2-143.0
CoCrUCci	124.7 ±74	25.0-263.8
CoCrUCcl	108.8 ±85	25.0-317.8

ZirCAD, CAD/CAM-fabricated zirconia frameworks; CoCrCAD, CAD/CAM-fabricated cobalt-chromium frameworks; CoCrUCci, conventionally fabricated cobalt-chromium frameworks with premachined abutments with cobalt-chromium bases; CoCrUCcl, conventionally fabricated cobalt-chromium frameworks with castable abutments.
No statistically significant differences; $P=.819$ (Kruskal-Wallis test).

The procedure used to scan and transfer the implant positions may influence the fit accuracy of CAD/CAM-fabricated prostheses.[19,37] Scanning can be direct (intraoral capture) or indirect (laboratory scanning of the cast obtained with a conventional impression technique).[17] In this study, indirect scanning was performed because this method reportedly provides more precise data compared with the direct approach.[21] A recent study using direct scanning reported higher vertical misfit values for CAD/CAM-fabricated frameworks than for conventionally fabricated frameworks.[38] These findings were in contrast to those of the present study. Although these findings suggest that indirect scanning may ensure the vertical fit of CAD/CAM-fabricated frameworks, additional studies comparing different scanning methods are required.

With the current fabrication materials and methods for implant frameworks, a certain degree of inaccuracy is unavoidable. Several in vitro studies have found that it is not uncommon to introduce vertical discrepancies similar to those introduced in the present study.[15,25,26] Many authors have tried to define passive fit or the clinically acceptable fit of implant frameworks. Brånemark[4] considered the framework to be passively fitting if the gap between the framework and the abutment is 10 μm or less. Others have suggested that misfit should be smaller than 150 μm for the framework to be acceptable.[3] Lack of strain developments after placement is also another definition of passive fit.[33] However, a genuine definition of passive fit from a biomechanical perspective is lacking. Based on this, many authors have argued against the significance of passive fit and concluded that well-controlled techniques are needed to provide long-term successful implant treatment.[1] Therefore, considering the inaccuracies that can occur in the clinical protocol, the vertical misfit applied in this study is a reasonable representation of what can occur clinically.

The ZirCAD and CoCrCAD frameworks were associated with lower vertical misfit values. Factors related to precision milling machines, such as machine calibration between milling and the condition of the milling cutters, can affect the fit in the CAD/CAM technique. In this study, the same machine with high-speed 5-axis simultaneous motion under conditions of controlled pressure and temperature was used to mill the blocks of zirconia and Co-Cr. For the milling of each new block, specific milling cutters were used, and after each block was milled, the machine was recalibrated. These steps should be routinely performed according to the manufacturer's recommendations. However, when processes are not well-controlled, differences in the precision of the fit achieved may occur.[37] Because the same conditions were used for the different materials, these factors did not influence the outcome of the present study.

Presintered Y-TZP blocks were milled with minimal pressure and heat production, reducing potential chipping on the margins during milling and transformation for monolithic phase during milling due to heat generation. The frameworks milled 20% to 25% larger were sintered to obtain the definitive framework.[24] During the sintering process, zirconia shrinks to result in the definitive framework design with the appropriate resistance and physical properties. However, micrometric dimensional alterations may occur in different directions because shrinkage due to sintering is uncontrollable.[32,42] The extent of the shrinkage poses an extra challenge for the software that has to accurately mill an enlarged framework that will shrink precisely to the required dimension after sintering. In addition, the success of this numerical compensation depends on the composition and homogeneity of the presintered zirconia blanks.[40] This sintering process may explain the difference of the vertical misfit values for the CAD/CAM-fabricated zirconia frameworks and for the CAD/CAM-fabricated Co-Cr frameworks. Therefore, shrinkage due to the sintering process should be better controlled. Clinically, the micrometric differences observed in this study did not represent a problem for the use of zirconia. Given its biocompatibility, decreased bacterial adhesion, favorable chemical properties, high flexural strength, and better esthetics compared with Co-Cr alloy,[41,43] it can be substituted as an alternative material for 3-unit, implant-supported frameworks.

The vertical fit of CoCrCAD frameworks was better than that of Co-Cr frameworks fabricated by CNC milling[22] and conventional casting.[5,27] This result indicates promising applications of Co-Cr alloys with the CAD/CAM system, considering that these materials are more homogeneous and the properties are less affected during the CAD/CAM procedure than during conventional casting.[24] These advances and the rapid development of CAD/CAM processes will continue, making this computerized technique more cost-effective and flexible, with better accuracy and precision. Initially, it is costly, which is a potential limitation.

Although it is difficult to judge whether the parameters chosen are clinically relevant or reflect important information for predicting clinical problems, it should be the goal of each clinician to strive for maximum passivity of fit. The small differences observed in this study must be judged with caution and are probably more theoretically than clinically relevant.[30] Nevertheless, techniques that provide high precision and minimize variability should be mandatory.

With the evolution of implant dentistry, the search for esthetic or low-cost solutions in situations of partial edentulism has intensified, often without proper evaluation of the situation or the role of available materials. When prostheses are connected directly to the implants, without abutments, higher preload forces can be expected, because the tightening force recommended for such prostheses is much higher. As a consequence, a higher stress is achieved in the periimplant tissues for comparable gap distances when tightening the frameworks on the implant level. In addition, new materials that are less flexible than the earlier commonly used gold alloys, such as cobalt-chromium and zirconia, might introduce even higher stress levels.[30] Thus, the focus fit is essential to minimize the strain generated by these materials with a high modulus of elasticity.

Physical and virtual laboratory methods are commonly used for mismatch analysis.[1,30] The virtual method has the advantage that the framework and scanned cast can be virtually superimposed to observe the lowest possible setting. However, the scanning procedure may produce inaccurate values and inconsistent results, leading to false interpretations.[12,30] In the present study, SEM was chosen to evaluate misfit. Evaluation of the abutment/implant interface with SEM is a valid procedure and allows for direct measurement on photomicrographs by using the provided scale.[32,33] In addition, it provides amplification and greater sharpness, which allows for a more accurate measurement of misalignment.

Statistically significant results were obtained from this study. A possible limitation of the results, however, is related to the number of specimens included and number of measurement points in each abutment. Inclusion of more measurement points would involve practical difficulties because of the format of the infrastructure. The sample size and number of measurement points was similar to those of other studies of accuracy fit and microgap,[5,9,16,25,29] and the compelling correlation between manufacturing technique and microgap is an applicable result of this study. Clinical trials would be meaningful to assess bone loss, periimplant health, and the fracture of veneers with zirconia frameworks.

CONCLUSIONS

Within the limitations of this in vitro study, it can be concluded that CAD/CAM-fabricated frameworks exhibit better vertical misfit values compared with conventionally fabricated frameworks. Furthermore, CAD/CAM-fabricated Co-Cr frameworks may exhibit decreased vertical misfit compared with CAD/CAM-fabricated zirconia frameworks. High levels of passive fit were achieved for the evaluated techniques. The passivity of the frameworks was not influenced by the manufacturing technique or the material used. CAD/CAM can be used to achieve higher fit accuracy in implant-supported FDPs.

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