

Marginal Fit of Implant-Supported All-Ceramic Zirconia Frameworks

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This study evaluated the effect of fabrication techniques and cyclic loading on the vertical marginal fit of implant-supported fixed partial denture (FPD) frameworks. Thirty implant-supported 3-unit FPD frameworks were fabricated on a model system, divided into 3 equal groups ($n = 10$). The first group (control) was constructed from base metal alloy; the other 2 test groups were constructed from all-ceramic zirconia using a computer-aided design/computer-aided manufacturing (CAD/CAM) Cerec 3 system and a copy milling (Zirkonzahn) system. A cyclic load of 200 N was applied to each framework for up to 50,000 cycles. Linear measurements were made in micrometers of the vertical gap between the framework and the implant-supported abutment at 16 predetermined points before and after cyclic loading. The frameworks were viewed using scanning electron microscopy to inspect any fractographic features. One-way analysis of variance was performed to compare the marginal discrepancy values of the control and the 2 test groups and for each group; a t test was applied to determine whether significant changes in the fit were observed after cyclic loading ($\alpha = 0.05$). The CAD/CAM group showed significantly higher marginal gap mean values (80.58 μm) than the Zirkonzahn and control groups (50.33 μm and 42.27 μm , respectively) with no significant difference. After cyclic loading, the CAD/CAM group recorded the highest marginal gap mean value (91.50 \pm 4.260 μm) followed by control group (72.00 \pm 2.795 μm); the Zirkonzahn group recorded the lowest marginal gap (65.37 \pm 6.138 μm). Cyclic loading significantly increased the marginal gap mean values in the control group only. A marginal chip was observed in one of the CAD/CAM ceramic frameworks. Within the limitations of this study, the fabrication technique influenced the marginal fit of the implant-supported 3-unit FPD frameworks. Cyclic loading failed to change the fit of all-ceramic zirconia frameworks, whereas significant changes were found in the metal frameworks.

Key Words: *implant-supported restoration, marginal fit, ceramic, zirconia, fabrication technique, cyclic loading, fractography*

INTRODUCTION

The continuous development of osseointegration and implantology makes it possible today to perform prosthetic restorations that provide for the reestablishment of function, esthetics, and phonetics in a foreseeable manner. Thus, the use of dental implants to replace absent teeth has

become routine in oral rehabilitation because it prevents the wearing of entire teeth and lateral loads on tooth abutments of removable partial with distal extension.¹ To ensure this predictability of treatment, the seating of the prosthesis with total passivity to implants or temporary abutments is very important. Therefore, a passive fit of the fixed partial denture (FPD) is desirable to prevent uncontrolled stresses not only in the adjacent bone but also in the reconstruction itself.² On the other hand, laboratory studies suggest that most complications with implant-supported prostheses can be directly connected to the lack of passive fit between the prosthetic framework and abutment,^{3–5} such as

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loosening or fracture of screws, as well as fracture of the frameworks or the veneering ceramic and even fractures of abutments or implants.^{1,6-9}

Different clinical methods are used to assess implant framework fit, including the use of alternate finger pressure,^{10,11} direct vision and tactile sensation,^{12,13} radiographs,^{12,14} disclosing media,^{12,13,15} and various instruments.^{16,17} Passive fit is a parameter commonly considered in the marginal fit. Some studies^{18,19} have considered vertical fit more relevant than passive fit as inappropriate torque can distort the marginal fit results. A framework is considered passive where there is simultaneous circular contact of all the prosthetic cylinders with their respective implant abutment.²⁰

To the level of superstructure accuracy, various studies dealing with the fabrication procedure have been conducted. Impression and master cast accuracy,²¹⁻²⁴ machining tolerance of the component as provided by the manufacturer,²⁵ and accuracy of the laboratory processes²⁶⁻²⁸ have been identified as major determinants. Previous studies^{29,30} found that inaccuracies resulting from impression making and master cast fabrication cause approximately 50% of stresses evoked by superstructure fixation.

The introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) has facilitated the use of superior dental ceramic, which has enhanced the fabrication of consistent and predictable restorations in terms of strength, marginal fit, and esthetics.^{31,32} Therefore, the aim of this study was to compare the vertical marginal fit of all-ceramic zirconia frameworks (CAD/CAM, Cerec 3 system, Sirona Dental System, Bensheim, Germany; copy milling, Zirkozahn, South Tyrol, Italy) with that of metal frameworks fabricated using the conventional lost wax technique before and after cyclic loadings.

MATERIALS AND METHODS

A model system set up with two 4 × 11 mm and 5 × 11 mm implants (Friatiz, Dentsply, Mannheim, Germany) with an interimplant distance of 14 mm (average distance between upper second premolar and upper second molar)³³ from center to center served as a basis for the in vitro investigation. Two abutments of 3.8 mm and 4.5 mm (XIVE-Friadent, Dentsply) were fixed to the implant fixtures (Figure

1). They were tightened to 35 Ncm using the implant system's torque-controlling ratchet. The implant-abutment units were anchored in an epoxy resin block using autopolymerizing polyester resin (Polypoxy 700 polymer, Chemical Industries for Construction Co, Sadat City, Egypt) in a straight line configuration using a paralleling device (Bego fixator, Bego, Germany).

Superstructure fabrication

Three groups of 3-unit FPDs, each containing 10 samples, were manufactured: 1 control group and 2 test groups. The control group was constructed from nickel-chromium alloy (Protechno-N, Protechno, Vilamalla, Spain) (Figure 2) and the 2 test groups were constructed from yttria-tetragonal zirconia polycrystal using the CAD/CAM Cerec 3 technique and the copy-milling (Zirkozahn) technique (Figure 3).

CAD/CAM-Generated Frameworks

A Cerec 3 unit was used to manufacture the FPD specimens. An optical impression was made for the model system and the framework was designed. Ten FPD frames were milled from zirconia blocks (40/19 Vita yz).

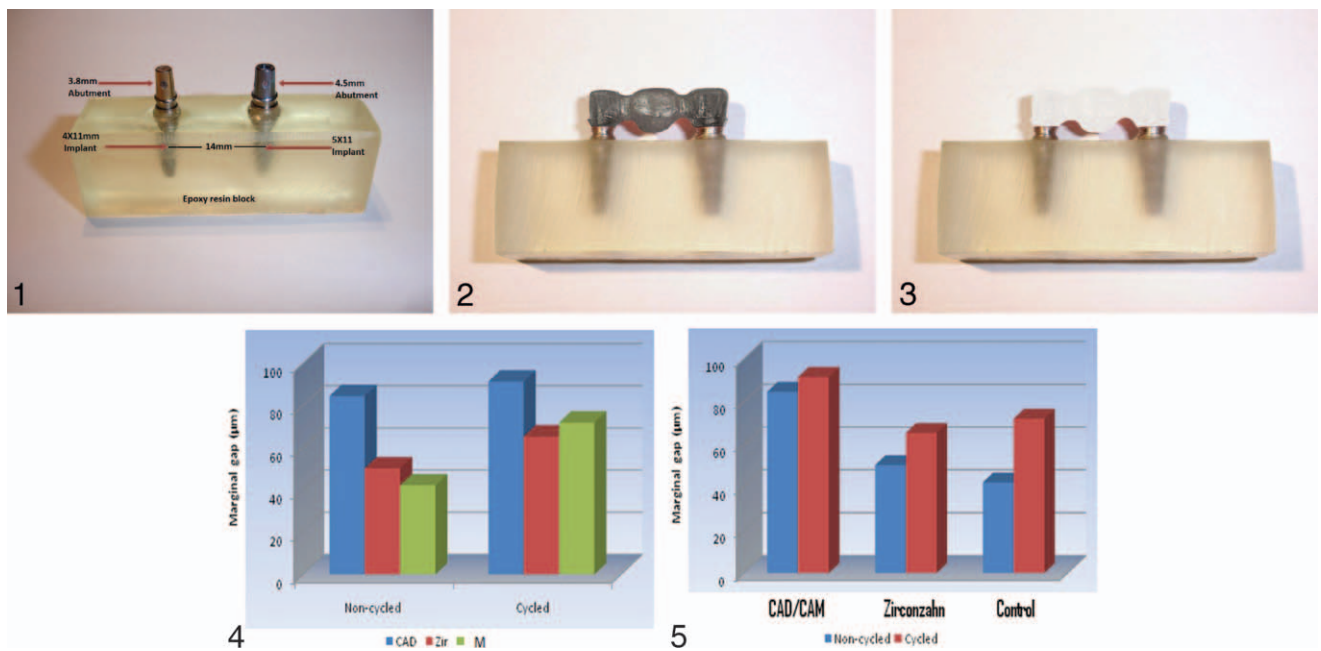
To standardize the thickness of the frameworks, a polyvinyl siloxane impression (President, Coltene AG, Altstätten, Switzerland) was taken for the CAD/CAM milled framework. A rubber mold was made to construct 20 standardized resin patterns.

Conventional Metal Frameworks

Following the manufacturers' protocol, 10 patterns were invested and cast using a conventional lost-wax technique. After casting, the frameworks were finished and polished using conventional lost-wax laboratory techniques.³⁴⁻⁴¹

Copy-Milling (Zirkozahn) Frameworks

To construct the copy-milling specimens, the Zirkozahn system was used for the manual-aid designing and the manual-aid milling of green ice zirconia translucent blocks. The resin pattern and zirconia blocks (9er/36 × 75 mm) were fixed into their relevant templates on the milling table. Milling was performed according to the manufacturer's recommendations. The milled zirconia frameworks were introduced in the Zirkonofen 600 sintering oven for sintering. A visual and tactile inspection of



FIGURES 1–5. **FIGURE 1.** Model system. **FIGURE 2.** Metal framework. **FIGURE 3.** All-ceramic zirconia framework. **FIGURE 4.** A column chart of marginal gap mean values for all groups before and after cyclic loading. **FIGURE 5.** Column chart of the marginal gap mean values for all groups as a function of cyclic loading.

all the frameworks was performed on the model to ensure an acceptable fit.^{29,30}

Cyclic loading

All samples were individually mounted in the lower fixed compartment of a computer-controlled materials testing machine (Model LRX-plus; Lloyd Instruments Ltd, Fareham, UK) with a load cell of 5 kN. Data were recorded using computer software (Nexygen-MT, ONDIO Application Builder Software Lloyd Instruments). The samples underwent pre-loading in a cyclic manner. Each sample underwent 50 000 cycles at loads between 20 N and a200 N. Force was applied with a custom-made load applicator (a steel rod with 3.6-mm round tip placed at the center of the occlusal surface of the pontic) attached to the upper movable compartment of the machine. Load profile in the form of a sine wave at a rate of 1 Hz was used as an equivalent to the average masticatory cycle of 0.8–1.0 seconds. A tinfoil sheet of 1 mm thickness was placed between the loading tip and the occlusal surface of the pontic to achieve homogenous stress distribution and minimization of the transmission of local force peaks.

Marginal gap evaluation

Linear measurements were made in micrometers of the vertical gap between the framework and the implant-supported abutment using USB digital microscope (Scope Capture Digital Microscope, Guangdong, China) at 50× magnification and photographed using image analysis software (Scope Capture version 1.1). The measurements were made at 16 (4 on each surface) predetermined reference points around the abutment before and after cyclic loading.

Scanning electron microscopy

The cycled zirconia frameworks were further analyzed using scanning electron microscopy (SEM; FEI Philips XL-30, Eindhoven, The Netherlands) to assess the structural failures. Images were viewed under different magnifications.

Statistical analysis

Data were collected and tabulated using Graphpad Prism-4 statistics software for Windows, version 4.0. One-way analysis of variance (ANOVA) was performed for all the groups before and after cyclic loading. A *t* test was also performed within each group before and after cyclic loading. A 2-factorial

TABLE 1

Comparison of the marginal gap results (mean \pm SD) of all groups before cyclic loading†

Group	Mean \pm SD	Rank	ANOVA Test	
CAD/CAM	84.58 \pm 3.767	A	F	P Value .0001*
Zirkonzahn	50.33 \pm 3.415	B	32.81	
Control	42.27 \pm 3.766	B		

*Different capital letters indicate statistical significance at $P < .05$.

†CAD/CAM indicates computer-aided design/computer-aided manufacturing.

ANOVA was used to examine effects of fabrication technique and cyclic loading and the interactions between these factors. Statistical analysis with P values $< .05$ was considered to be statistically significant in all tests.

RESULTS

One-way ANOVA revealed that before cyclic loading (Table 1; Figure 4), the CAD/CAM group showed significantly higher vertical marginal gap mean values (84.58 \pm 3.767 μm) than the Zirkonzahn and the control groups (50.33 \pm 3.415 μm and 42.27 \pm 3.766 μm , respectively), which showed no significant difference in between. After cyclic loading (Table 2; Figure 4), it was found that the CAD/CAM group recorded the highest statistically significant marginal gap mean value (91.50 \pm 4.260 μm) followed by the control group (72.00 \pm 2.795 μm); the Zirkonzahn group recorded the lowest marginal gap (65.37 \pm 6.138 μm). No significant difference was found between the control group and the Zirkonzahn group.

The t test analysis (Table 3; Figure 5) revealed no significant difference in the vertical marginal gap mean values regarding the CAD/CAM and Zirkonzahn groups before (84.58 \pm 3.767 μm and 50.33 \pm 3.415 μm , respectively) and after (91.50 \pm 4.260 μm and 65.37 \pm 6.138 μm , respectively) cyclic loading. In the control group, however, the vertical marginal

gap mean values was significantly higher after cyclic loading (72.00 \pm 2.795 μm) than before (42.27 \pm 3.766) ($P = .0001$).

Two-way ANOVA revealed a significant influence of the fabrication technique ($P = .0001$), cyclic loading ($P = .0001$), and the interaction between these factors was statistically significant ($P = .0306$) on the vertical marginal gap (Table 4; Figure 2).

Visual and stereomicroscopic observation of the cycle loaded samples showed a minor chip at the gingival margin of one of the CAD/CAM samples (Figure 6). No obvious changes were detected in the samples of the other groups.

SEM analysis

Inspection under SEM using different magnifications showed fractographic features in the chipped CAD/CAM specimen such as arrest line, hackle, and wake hackle (Figures 7 and 8a, b, and c). An arrest line is a well-defined line produced when the crack comes to a halt before resuming its propagation, often in a slightly different direction. Arrest lines are also indicators of the direction of propagation as the beginning of a crack event is always located on the concave side of the first arrest line. A hackle is a line on the fracture surface that runs in the local direction of cracking. Hackle lines are commonly formed when the crack moves rapidly. A wake hackle is a trail (wake) emanating from a pore (or other irregularity) that is created by the crack front

TABLE 2

Comparison of the marginal gap results (mean \pm SD) of all groups after cyclic loading†

Group	Mean \pm SD	Rank	ANOVA Test	
CAD/CAM	91.50 \pm 4.260	A	F	P Value .0029*
Zirkonzahn	65.37 \pm 6.138	B	9.100	
Control	72.00 \pm 2.795	B		

*Different capital letters indicate statistical significance at $P < .05$.

†CAD/CAM indicates computer-aided design/computer-aided manufacturing.

TABLE 3

The *t* test comparison of marginal gap results (mean \pm SD) between noncycled and load cycled categories within the control and the 2 test groupst

Group	Noncycled/Load Cycled	Mean \pm SD	Mean Difference	t Test	
				t Value	P Value
CAD/CAM	Noncycled	84.58 \pm 3.767	6.917	1.2	.2761 ^{NS}
	Load cycled	91.50 \pm 4.260			
Zirkonzahn	Noncycled	50.33 \pm 3.415	15.03	2.2	.05 ^{NS}
	Load cycled	65.37 \pm 6.138			
Control	Noncycled	42.27 \pm 3.766	29.73	6.5	.0001*
	Load cycled	72.00 \pm 2.795			

*Significance is set at $P < .05$.

†NS indicates nonsignificant.

advancing along the sides of the pore before continuing on slightly different planes. Thus, wake hackles are indicators of the direction of crack propagation.^{42,43} On the other hand, no fractographic features were detected in the other specimens (Figure 9a and b).

DISCUSSION

The reconstruction of partially edentulous jaws by implant-supported FPDs has been shown to be a successful therapy.^{44,45} Osseointegrated implants show little mobility; hence, in contrast to the situation on abutment teeth, where a certain degree of misfit of a superstructure may be compensated by the resilience of the periodontium, misfit of FPDs seated on implant may cause a certain stress that is directly transmitted to the surrounding bone.⁴⁶

Before performing in vivo studies or applying materials for clinical use, in vitro tests should be undertaken to prove the materials' applicability and performance. In vitro tests can be performed in a short period of time and have the advantages of reproducibility and the possibility of standardizing a test parameter.⁴⁷ Attempts to fabricate perfectly

fitting superstructure are affected by a number of factors, such as fabricating techniques,^{21–32} increasing the number of implants and different angulations of the implant axes.⁴⁸

The optical impression concept is emerging rapidly on the high-technology horizon. An optical impression system for dental restorations is a device used to record the topographic characteristics of teeth, dental impressions, or stone models by analog or digital methods for use in the CAD/CAM of dental restorative prosthetic devices. Some researchers have observed some dimensional inaccuracy compared to the master die, however; possible reasons may be that the dimensions of the infrared camera head limited the image capture, the optical quality of the optical material sprayed on the die was not optimal, or the resolution of the surface digitization device was not high enough.⁴⁹ This was consistent with the results of the present study, which found that the vertical marginal gap is significantly higher for the CAD/CAM group than the Zirkonzahn and control groups.

This may also be attributed to the types of manufacturing techniques. There may be less distortion of the ceramic framework in Zirkonzahn compared to CAD/CAM, as Zirkonzahn involves a

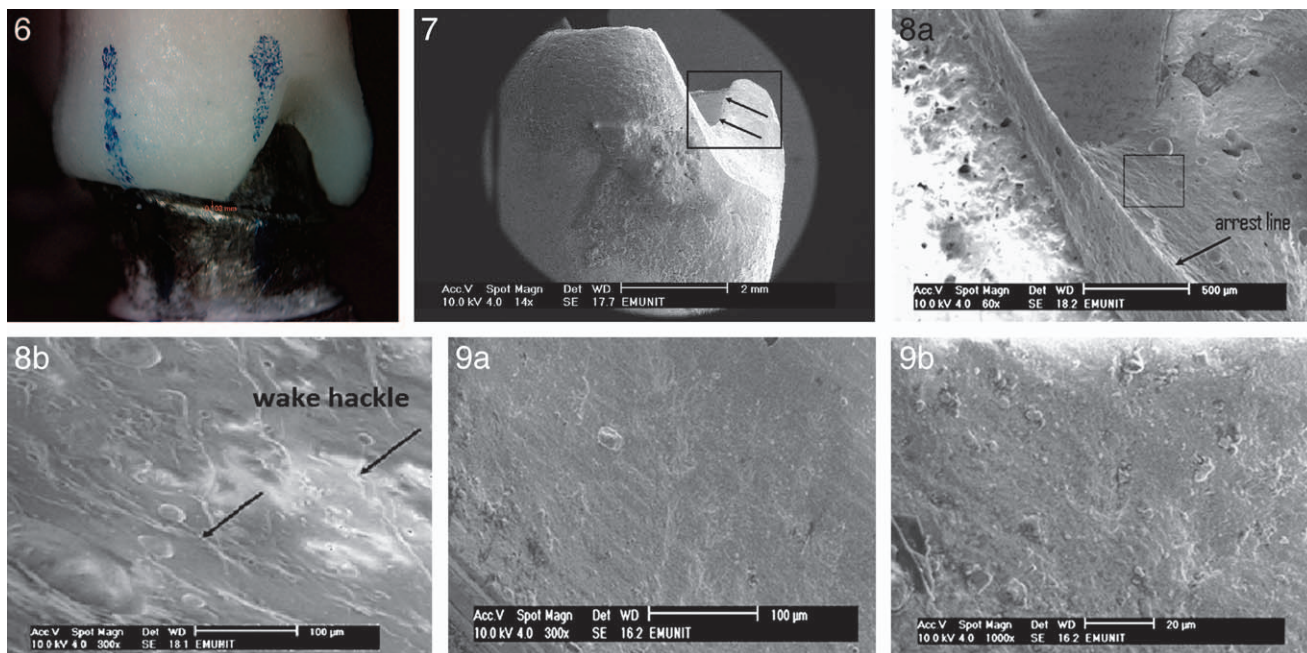
TABLE 4

Two-way ANOVA test of significance comparing variables affecting marginal gap mean values†

Source of Variation	df	SS	MS	F	P Value
Fabrication technique	2	6441	3220	37.24	.0001*
Cyclic loading	1	2304	2304	26.65	.0001*
Interaction	2	691.7	345.8	3.999	.0306*

*Significance is set at $P < .05$.

†SS indicates sum of squares; df, degree of freedom; MS, mean squares.



FIGURES 6–9. **FIGURE 6.** Stereomicroscopic photograph (50 \times) showing the vertical marginal gap and a minor chip at the gingival margin of the computer-aided design/computer-aided manufacturing (CAD/CAM) sample. **FIGURE 7.** Scanning electron microscopy (SEM) photograph (at 14 \times) of one of the CAD/CAM samples showing a minor chip at the gingival margin of the buccal side. **FIGURE 8.** The SEM photographs of the failure site of the CAD/CAM sample showed at (a) 60 \times arrest line. A higher magnification (300 \times and 1000 \times) of the squared area pictured in (a) shows (b) a wake hackle and (c) a hackle indicating the direction of the crack propagation toward the margin. **FIGURE 9.** The SEM photographs of the Zirkozahn sample at (a) 300 \times and (b) 1000 \times showed no fractographic features.

less complicated process that uses a manual rather than a computer program computation.⁵⁰ The higher contraction cooling of the nonprecious material used to fabricate the conventional FPD frameworks may have influenced the accuracy achieved in these restorations.⁵¹

Once a prosthesis is in function, it is likely that wear will occur at the interface of the prosthetic and implant components.⁵² In the present study, cyclic loading did not significantly affect the marginal adaptation of the all-ceramic zirconia samples constructed with both techniques, although it significantly decreased the marginal adaptation of the control group samples. This may be attributed to the high hardness and brittle nature of zirconia. Subjecting ceramics to cyclic stress of a maximum value below their proportional limit will result in interaction between these constant stresses and structural flaws over time, which result in sudden fracture or chipping rather than yielding of this brittle material by plastic straining (a phenomenon known as “dynamic fatigue failure”). In contrast, when ductile materials such as metals and alloys are stressed beyond their proportional limit, disloca-

tions move and pile up along grain boundaries, producing a noticeable plastic deformation rather than sudden fracture or chipping of the metals.⁵³ These findings were in accordance with other laboratory testing of cyclically loaded implant frames, which demonstrated change in fit dimensions and distortion of the mating surfaces.⁵² However, a study by Hecker et al⁵⁴ showed that in spite of the wear there was no deterioration of fit, and in some situation there was an improvement in fit.

The SEM analysis revealed no failure features in the Zirkozahn frameworks (Figure 9) but a small chip was observed in the cervical margin of the CAD/CAM framework (Figures 7 and 8). According to Lawn et al,⁵⁵ this was explained by the introduction of flaws into the surfaces of ceramic framework, which may have degraded strength. Such flaws may arise from sandblasting, machining, or shaping (CAD/CAM) or from diamond bur adjustments by the dentist in final seating. Also, repetitive loadings may have initiated a crack, which resulted in failure of the restoration.⁴³ The failure mode in this study was comparable to the findings

of other in vitro studies.^{55–58} In all-ceramic restoration, compressive and tensile stresses have been reported to accumulate on heavy load bearing areas, such as cervical finish lines where high torque and stress concentration occur by the levering effect. This was overcome in the Zirkozahn samples by the excellent marginal fit in contrast to the CAD/CAM samples, which showed less marginal fit.

CONCLUSIONS

Within the limitations of the present study, fabrication techniques have a direct influence on the vertical marginal fit of implant-supported frameworks. The CAD/CAM milled implant-supported frameworks showed the highest vertical marginal gap compared with that of the Zirkozahn and PFM frameworks. Cyclic loading did not significantly affect the vertical marginal fit of the all-ceramic zirconia frameworks, whereas it negatively affected that of the PFM frameworks.

ABBREVIATIONS

ANOVA: analysis of variance

CAD/CAM: computer-aided design/computer-aided manufacturing

FPD: fixed partial denture

SEM: scanning electron microscopy

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