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CAD/CAM fabrication accuracy of long- vs. short-span implant-supported FDPs

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Abstract

Objective: To compare the precision of fit of long-span vs. short-span implant-supported screw-retained fixed dental prostheses (FDPs) made from computer-aided-design/computer-aided-manufactured (CAD/CAM) titanium and veneered with ceramic. The null hypothesis was that there is no difference in the vertical microgap between long-span and short-span FDPs.

Materials and methods: CAD/CAM titanium frameworks for an implant-supported maxillary FDP on implants with a flat platform were fabricated on one single master cast. Group A consisted of six 10-unit FDPs connected to six implants (FDI positions 15, 13, 11, 21, 23, 25) and group B of six 5-unit FDPs (three implants, FDI positions 21, 23, 25). The CAD/CAM system from Biodenta Swiss AG (Berneck, Switzerland) was used for digitizing (laser scanner) the master cast and anatomical CAD of each framework separately. The frameworks were milled (CAM) from a titanium grade V monobloc and veneered with porcelain. Median vertical distance between implant and FDP platforms from the non-tightened implants (one-screw test on implant 25) was calculated from mesial, buccal, and distal scanning electron microscope measurements.

Results: All measurements showed values <40 μm. Total median vertical microgaps were 23 μm (range 2–38 μm) for group A and 7 μm (4–24 μm) for group B. The difference between the groups was statistically significant at implant 21 (P = 0.002; 97.5% CI −27.3 to −4.9) and insignificant at implant 23 (P = 0.093; −3.9 to 1.0).

Conclusions: CAD/CAM fabrication including laboratory scanning and porcelain firing was highly precise and reproducible for all long- and short-span FDPs. While all FDPs showed clinically acceptable values, the short-span FDPs were statistically more precise at the 5-unit span distance.

While computer-aided-design and computer-aided-manufacturing (CAD/CAM) technology to fabricate implant-supported fixed dental prostheses (FDPs) has become feasible in daily practice using various systems (Beuer et al. 2008; Kapos et al. 2009), conventional manual casting technology for the fabrication of the metal framework may no longer be considered the golden standard due to different problems during casting process (time consuming, costs, material inhomogeneity, FDP misfit due to casting distortion) (Hjalmarsson et al. 2010; Paniz et al. 2013; Katsoulis et al. 2014). The accuracy of CAD/CAM titanium bars and FDP frameworks was shown to be highly accurate even for full-arch implant-supported reconstructions using the latest scanners and CAD/CAM systems from some of the most frequently used implant companies such as Nobel Biocare AG (Katsoulis et al. 2013b; Katsoulis et al. 2014) and Institut Straumann AG (Katsoulis et al. 2013a). Recently, new CAD and milling centers have come on the market providing the dentists and laboratories with alternative fabrication possibilities other than the established ones. However, independent scientific investigation of these new systems on the precision of fit and the reproducibility are mainly missing. There is an urgent need to provide evidence before clinical use on a standard basis can be recommended. The biodenta® CAD/CAM system (Biodenta Swiss AG, Berneck, Switzerland) is a new CAD/CAM system that was introduced recently allowing for the fabrication of zirconia and titanium frameworks. To our knowledge, no *in vitro* or *in vivo* study investigated yet the precision of fit of FDPs made with this specific CAD/CAM system. Thus, the primary aim of this study was to analyze the precision of fit of implant-supported,

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screw-retained, porcelain-veneered CAD/CAM titanium FDPs fabricated with the specific system (scanner and CAD/CAM). Secondary, a comparison of the misfit between long- and short-span FDPs was aimed to show possible impact of the FDP length and the number of implants included.

Material and methods

Master cast

An *in vitro* study with a single master cast of an edentulous maxillary jaw made from polyester resin (EFCO Produkte GmbH, Düren, Germany) was performed as described in previous similar studies (Katsoulis et al. 2013a, b, 2014). Six implant analogs with a flat platform (Replace Select Tapered Regular Platform, Nobel Biocare, Gothenburg, Sweden) were placed in the FDI positions 15, 13, 11, 21, 23, and 25. The axes of the four posterior implants were in parallel and vertical alignment, while the implants 11 and 21 were angulated by 10 degrees in the sagittal plane. The linear distance between the center points was 11 mm between the implants 25 and 23, 22 mm between implant 25 and 21, and 40 mm between implant 25 and 15. This single master cast was stored for 6 weeks before fabrication of the 12 FDPs.

Long-span and short-span FDPs

The long-span (15-x-13-x-11-21-x-23-x-25, group A) and the short-span FDPs (21-x-23-x-25, group B) were fabricated on the same master cast with identical dimensions and distances between the corresponding implants 21, 23, and 25. Group A consisted of six 10-unit FDPs connected to six implants (FDI positions 15, 13, 11, 21, 23, 25) and group B of six 5-unit FDPs (three implants, FDI positions 21, 23, 25) (Fig. 1a and b).

Scanning and CAD/CAM fabrication

Each of the 12 FDPs was fabricated separately included all steps in scanning, CAD/CAM, and veneering. One trained operator fabricated consecutively all the 12 FDPs. Specific scan bodies were manually screwed on the implants for digitization with a laser scanner (D800; Biodenta Swiss AG). CAD (DentaSwiss 3D Design Software; Biodenta Swiss AG) was based on a scanned resin pattern for dimensional reproducibility of the anatomically shaped FDP frameworks. The CAD information of each FDP framework was electronically transmitted to the production center for the milling procedure (CAM) with a computer numeric controlled (CNC) machine of 5 axes. The CAM software calculated the milling path from a homogenous block of titanium grade V (composition in % weight: titanium 0.896, aluminum 0.060, vanadium 0.041, other <0.003).

Veneering

The veneering was performed with the same materials for all FDPs and according to the manufacturer's instructions. A duplicate of the master cast was created to protect the master model during veneering procedure. With the application on titanium frameworks, the newly developed titanium opaquer (Biodenta Swiss AG) was used to insure bonding between the substructure. The frameworks were sandblasted with aluminum oxide (100 μm) at 1 bar of pressure from a distance of 3–5 cm. The opaquer powder was mixed with the opaquer liquid to a creamy consistency. The liner was applied onto the clean framework with a flat brush until an optimal coverage of the framework was attained. The opaquer was applied and firing performed (preheated oven 400° Celsius (C), 6 min, heating 55°C/min, 7 min, 800°C, 2 min). Then, the marginal ceramic was applied and firing performed (preheated oven 400° C, 4 min, heating 45°C/min, 7 min, 1st firing temp. 800°C, 1 min, 2nd firing temp. 800°C, 1 min). Thereafter, two layers of dentin and one layer of incisal porcelain (Dentin/Incisal; Biodenta Swiss AG) were baked at a temperature of 740°C (preheating 400°C, 4 min, heating 45°C/min, 7.5 min, 1st firing temp. 740°C, 1 min, 2nd firing temp 730°C, 1 min). Finally, one glaze (400°C, 4 min, heating 45°C/min, 7 min, 710°C, 1 min) was applied and fired in the oven. The thickness of the ceramic veneering was depending on the area between 1.5 and 2.5 mm. The frameworks were finished in the same manner as a clinical case for the patient try-in appointment (Fig. 1a and b).

Assessment of the precision of fit

One trained investigator performed all measurements. The one-screw test was applied using the original master cast (Jemt 1991; Tan et al. 1993). The FDPs were put on the master cast with the screws 21 and 25 first tightened by hand to avoid horizontal shift. Then, the screw at implant 25 was tightened with a torque of 30 Ncm using a calibrated hand wrench, and thereafter, the other screw (21) was removed. The vertical distance between FDP platform and the implant shoulder in the master cast was measured for all the unretained interfaces (group A: 15, 13, 11, 21, 23 and group B: 21, 23) with a calibrated scanning electron microscope (SEM) (FEI Quanta 600 FEG Mark II, Hillsboro, OR, USA). The SEM was in a room with standard temperature of 24°C and 35% humidity. A large field view detector and a low vacuum environment allowed collection of the electrographs with the quality of photographs below the optical range and direct imaging of the uncoated FDP (Danilatos et al. 2011). The PENN Regional Nanotechnology Facility staff (School of Engineering and Applied Science, University of Pennsylvania, PA, USA) provided maintenance and calibration of the SEM. The mobile SEM platform and large chamber allowed for perpendicular view on the buccal interface of each implant. SEM images of the whole implant–FDP complex and focused close-ups of the buccal, mesial, and distal interfaces (Fig. 2) were taken at a magnification of up to 2000×. The mean misfit per implant was calculated from three

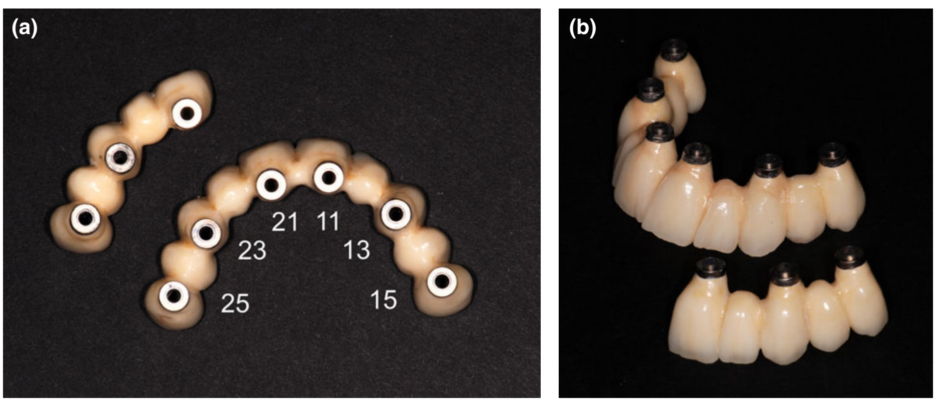

Fig. 1. (a) View on the platforms of the long-span (15-x-13-x-11-21-x-23-x-25, group A) and the short-span FDPs (21-x-23-x-25, group B). They were fabricated on the same master cast with identical dimensions and distances between the corresponding implants 21, 23, and 25. (b) Buccal view of the long-span (10 units, group A) and short-span (5 units, group B) implant-supported FDPs each made from a CAD/CAM titanium framework and conventionally veneered (bonder, opaquer, porcelain, and glaze).

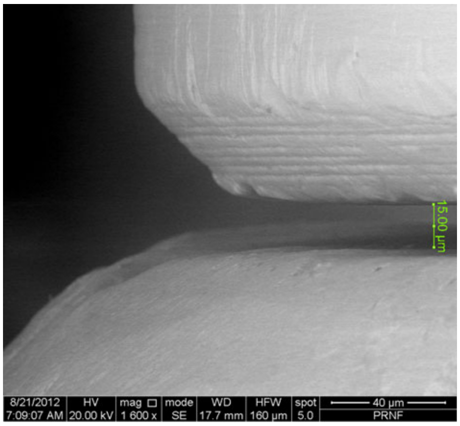

Fig. 2. SEM image at a magnification of 1600× showing a veneered FDP at the distal implant framework interface of implant 15 (10-unit FDP).

mesial, three buccal, and three distal measurements.

Statistical analysis

The R software (version 2.15.1; The R Foundation for Statistical Computing, 2012) with the packages coin (version 1.0-21) and the SPSS software (SPSS 21, Chicago, IL, USA) were used for data analysis (mean, median, standard deviation (SD), confidence intervals (CI) of the median, minima, and maxima) and graphic illustrations. The CI's were indicated for the specific implant positions. The Friedman test (Monte Carlo approximation of exact test) was performed to test within-group differences.

At the implant positions 23 and 21, the values were compared between short- and long-span FDPs using a two-sided exact Wilcoxon–Mann–Whitney test. As two hypotheses were tested, p-values below 0.05/2 = 0.025 were considered significant according to the Bonferroni correction for multiple testing. Corresponding 97.5% confidence intervals for the difference between the two groups were also calculated.

Results

The analysis showed values <40 µm for all vertical microgap measurements performed (Table 1). Total median vertical micrograps were 23 µm (range 2–38 µm) for group A (long-span FDPs) and 7 µm (4–24 µm) for B (short-span FDPs).

Within-group comparison revealed significant differences only in the long-span FDPs (group A: $P < 0.0001$, group B: $P = 0.2188$). The anterior implants 13, 11, and 21 of all FDPs in group A showed higher values than the most distant implant 15. In group B, five of six FDPs had increased microgap values for the distant implant 21 compared to closest implant 23 (Fig. 3).

The difference between the long- and short-span groups was statistically significant at the implant 21 ($P = 0.002$) and insignificant at implant 23 ($P = 0.093$) (Table 2). All short-span FDPs (group B) reached smaller values at the specific positions 21 and 23 compared with long-span FDPs (group A).

Table 1. **Data analysis for the specific implant FDP interfaces of groups A and B**

	FDI position (N_x = 6)					
	15	13	11	21	23	Total
A (Long-span)						
Median	3.5	29.6	27.0	30.5	7.7	22.7
95% CI (median)	2.0–7.8	16.0–36.1	18.3–36.2	24.7–37.6	7.1–8.4	7.9–29.4
Mean	4.2	27.5	27.0	30.1	7.8	19.3
SD	2.1	6.9	6.5	4.7	0.6	12.0
Minimum	2.0	16.0	18.3	24.7	7.1	2.0
Maximum	7.8	36.1	36.2	37.6	8.4	37.6
B (Short-span)						
Median				9.4	5.2	6.9
95% CI (median)				6.6–23.6	3.8–9.0	5.1–10.3
Mean				12.7	5.8	9.2
SD				7.4	1.9	6.3
Minimum				6.6	3.8	3.8
Maximum				23.6	9.0	23.6

Table 2. **Comparison of long-span (group A) and short-span FDPs (group B) at the specific FDI positions 21 (5-unit FDP) and 23 (3-unit FDP)**

	97.5% CI	*P* value
Implant 23	−3.86; 1.03	0.0931
Implant 21	−27.3; −4.89	0.0022*

*Statistically significant difference $P < 0.025$.

Discussion

The aim of the present laboratory study was to evaluate the precision of fit of CAD/CAM titanium frameworks for an implant-supported screw-retained ceramic-veneered full-arch FDP and to compare them with short-span FDPs using the specific CAD/CAM system from Biodenta AG. The transfer of the clinical situation to the master cast using conventional or digital impression techniques was not part of this investigation as the focus was to be on the fabrication accuracy of the specific CAD/CAM system. The method applied to assess the gap at the interface was the one-screw test. This method allows for a realistic measurement similar to the clinical and laboratory conditions. Only the vertical misfit may be measured while the horizontal or 3D distortion is difficult to measure even with other techniques (Abduo et al. 2010; Jemt & Hjalmarsson 2012). With the one-screw test (implant 25 screw retained*), the short-span 5-unit

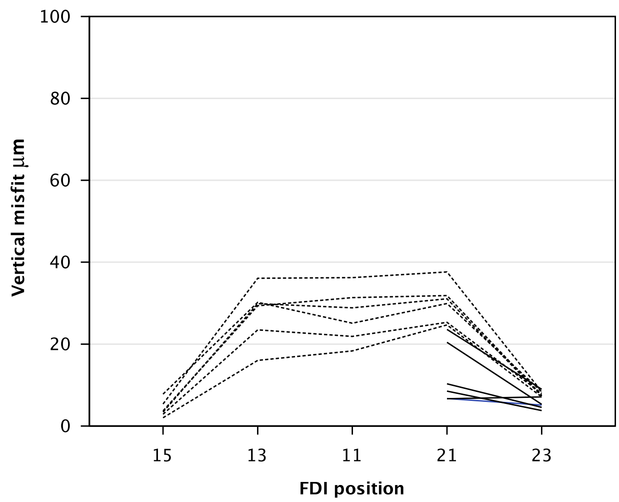

Fig. 3. Vertical microgap at the specific implant positions for the individual specimen of group A (long span) and group B (short span).

FDPs on 3 implants (21-x-23-x-25*) showed a statistically better precision of fit only at the implant position 21 compared to the corresponding positions of the long-span FDPs (15-x-13-x-11-21-x-23-x-25*) that were fabricated on the identical master cast. Thus, the hypothesis that no differences in the vertical gap would occur between the long- and short-span FDPs had to be rejected only at implant 21, but not at implant 23. This means that CAD/CAM fabrication was highly accurate for all values measured remained below 37 μm (long span) and 23 μm (short span). Although there was a statistically significant difference between the groups at the implant 21 (Table 2), from a clinical point of view, this would most probably not increase the risk for technical or biological complication of the reconstruction (Jemt & Hjalmarsson 2012). Moreover, in literature, misfit values below 100 μm are considered to be clinically acceptable (McLean & von Fraunhofer 1971; Belser et al. 1985; Beuer et al. 2009). A theoretically perfect passive framework fit is anyway impossible to realize in clinical reality (Sahin & Cehreli 2001). While biology may tolerate a misfit at the implant FDP interface to an unknown degree, the preload stress may even promote bone remodeling at the implant thread tips in immediately loaded implants (Jemt et al. 2000). In an animal study, some adaptation of the implant-bone unit toward the FDP was observed (Duyck et al. 2005). Nevertheless, the impact of the CAD/CAM fabrication has to be added to the errors that occur at each of the steps within the production workflow starting at the impression taking and ending with the polishing of the final FDP. Manual handling and non-digital "mechanical" processes inevitably occur chair side and in the laboratory. These errors accumulation may be very individual and unpredictable. In contrast, CAD/CAM fabrication includes the fewest risks for manual errors within the workflow (Ortorp et al. 2003; Abduo et al. 2011). However, also digital technology may produce hidden errors due to false algorithms and wrong use of the virtual tools.

Thus, screw-retained implant-borne FDPs may induce stress in the implant, bone, FDP, and screw depending on the level of FDP distortion and misfit (Karl & Taylor 2011; Karl et al. 2011; Abduo & Lyons 2012; Abduo & Swain 2012; Abduo et al. 2012; Karl & Holst 2012). Other influencing factors on the stress impact are the number and axes of the implants and the total length of the restoration. An *in vitro* study showed that the framework material itself was not significantly influencing the stress forces created (Karl & Taylor 2011). In a finite element analysis, the effect of the marginal misfit was amplified if a cantilever and excessive occlusal forces were applied (Kunavisarut et al. 2002). Thus, strain-related technical complications may be reduced with precise frameworks and bars as reported in a clinical study with maxillary CAD/CAM titanium reconstructions (Katsoulis et al. 2011).

The present results with the specific CAD/CAM system showed misfit values <40 μm that are comparable to other reports of CAD/CAM titanium frameworks with mean vertical microgaps of approximately 30 μm (Torsello et al. 2008; Paniz et al. 2013). The presented microgaps at the implant FDP interface were all measured after the veneering procedure. Thus, porcelain firing did not lead to a distortion of the FDPs, neither the long-span nor the short-span FDPs. Earlier studies reported on the precision of fit of CAD/CAM FDPs that were made from titanium grade II (Ortorp, et al. 2003) and grade IV (Katsoulis et al. 2013a) comparing before and after porcelain firing. No impact on the FDP accuracy was seen after impact of a baking temperature of 720–740°C and 770–800°C, neither. The precision of fit in the mentioned studies was in agreement with our study results.

The fabrication of two short-span FDPs on each side of the jaw, that is, 15-x-13-x-11 and 21-x-23-x-25, would increase the fabrication accuracy only minimally (although statistically significant at the far implant site 21) compared to a full-arch FDP sectioned between implant 11 and 21. Moreover, these sectioned short-span segments would also fit better on the cast. The treatment strategy is thus depending on other factors (anatomy, number, and position of implant). To order two or more short-span FDPs or one single full-arch FDP (and even section it) before continuing with veneering process includes financial aspects with the milling center. The lower costs for a one-piece long-span framework will in most cases not make a significant difference considering the total treatment costs for a multiple implant approach.

Conclusions

Within this laboratory study limitations, it can be concluded that the investigated CAD/CAM workflow from the Biodenta Swiss AG provides highly accurate screw-retained FDPs made from titanium and veneered with porcelain. The precision of fit was within clinical acceptable levels for each FDP of both groups, the short-span and long-span FDPs. The results do not only show accurate performance of the milling and firing, but show as well a reproducible laboratory scanning and CAD/CAM process. Thus, the risks for potential biological and technical complications due to misfit may be considered minimal for these short- and long-span FDPs.

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