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The effect of the digital manufacturing technique of cantilevered implant-supported frameworks on abutment screw preload

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PURPOSE. The purpose of this study was to investigate the misfit and screw preload at the implant abutment connection of implant supported fixed dental prosthesis with cantilever (ICFDP) manufactured using different digital manufacturing techniques and to compare the screw preload before and after cyclic loading. **MATERIALS AND METHODS.** Mandibular jaw model with four intra-foraminal implants was scanned using digital scanner. Stereolithography file was used to design a framework with nonengaging (NE) abutments and 10 mm cantilever distal to one terminal implant. Five frameworks were constructed using combined digital-conventional techniques (CAD-cast), and five frameworks were constructed using three-dimensional printing (3DP). Additional CAD-cast framework was constructed in a way that ensures passive fit (PF) to use as control. Scanning electron microscope (SEM) measured the implant abutment connection misfit. Sixty screws were used on the corresponding frameworks. Screws were torqued and pre-cyclic loading reverse torque value (RTV) was recorded. Frameworks were subjected to 200,000 loading cycles with a loading point 9 mm from the center of terminal implants adjacent to the cantilever and post-cyclic loading RTVs were recorded. **RESULTS.** Microscopic readings showed significant differences between frameworks. PF demonstrated the lowest measurements of 16.04 (2.6) µm while CAD-cast demonstrated the highest measurements of 29.2 (3.1) µm. In all groups, RTVs were significantly lower than the applied torque. Post-cyclic loading RTV was significantly lower than pre-cyclic loading RTV in PF and 3DP frameworks. Differences in RTVs between the three manufacturing techniques were insignificant. **CONCLUSION.** Although CAD-cast and three-dimensionally printed (3DP) both produce frameworks with clinically acceptable misfit, 3DP might not be the technique of choice for maintaining screw's preload stability under an aggressive loading situation. [J Adv Prosthodont 2022;14:22-31]

KEYWORDS

Dental implant; Preload; Reverse torque value (RTV); Screw loosening; Cyclic loading

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INTRODUCTION

Incorporating a cantilever extension in full-arch implant supported fixed dental prostheses (ISFDPs) allows reconstructions to be performed in anatomically compromised areas with reduced complications, cost and complexity of surgical procedures.[1,2] Implant supported cantilevered fixed dental prosthesis (ICFDPs) demonstrated high survival rates in many reviews.[2,3] According to the 5th Consensus Conference of the European Association of Osseointegration (EAO), ICFDPs can be a reliable treatment alternative with high survival rates of prostheses and implants.[3,4] Despite the advantages that ICFDPs offer, many complications might arise. One systematic review reported that prosthetic complications can be as high as 39.46% in ICFDPs.[3] Cantilever extension overloads the terminal implant adjacent to the cantilever,[3,5] causes unequal distribution of masticatory forces, and leads to loss of preload and screw loosening.[6,7] Many studies have evaluated the effect of cantilever extension on the stability of implant abutment connections and it was found that screw loosening is one of the most common complications of ICFDPs with an estimated rate of 5.01% in 5 - 10 years.[1,5,8-10] Loss of preload is a major cause of screw loosening as it is stated that only 10% of the initial torque is transformed to preload while the other 90% is used to overcome the friction between the irregular surfaces of the implant abutment connection.[11,12] Achieving adequate preload results in a clamping force that secures the implant abutment connection.[13,14] With time, screw loosening leads to an unstable superstructure that irritates soft tissues and causes unequal force distribution.[15-17] It also leads to gap formation at the implant abutment connection, bacterial leakage and biological complications.[16,18] Studies were conducted to monitor changes in the screw preload of ISFDPs with different designs, implant numbers and materials. Al-Otaibi *et al*.[19] compared the RTV of ISFDPs under different torque applications and found that RTV is improved in prosthesis group that had retorquing of the abutment screws after the initial torque. Siadat *et al*.[20] evaluated the effect of two implant abutment connection designs on screw loosening before and after cyclic loading and found that the RTV decreased after loading. The manufacturing technique of ICFDPs was reported to have a significant effect on the stability of implant abutment connections.[16,17] The conventional lost wax casting technique is considered the gold standard for the fabrication of implant-supported prostheses, as it produces prostheses with acceptable accuracy.[21] Over the years, conventional casting has shown variable shortcomings; it is highly technique sensitive, has a high incidence of fabrication errors, requires a long fabrication time and expense, and produces frameworks with inferior mechanical properties compared to digital manufacturing.[22-24] Computer-aided design and computer-aided manufacturing (CAD-CAM) systems offer a variety of materials, advanced precision, a high level of customization, and a simpler fabrication protocol.[25,26] They also create a fixed superstructure with greater accuracy and decreased implant-abutment misfit.[27,28] Although digitalized manufacturing has shown promising results, few studies have been conducted to investigate the effect of digital manufacturing techniques on the implant abutment connection misfit and screw preload.[29,30] Ramalho *et al*.[31] compared the fit of abutments manufactured using digital, partial digital, and conventional methods and showed higher implant abutment connection misfit in fully digitalized abutments. In contrast, Bae *et al*.[32] conducted a systematic review to compare the reliability of the marginal fit of 3DP and conventional casting, and they concluded that compared to conventional casting, 3DP techniques are reliable for the construction of fixed dental prostheses with an accurate marginal fit. To the best of our knowledge, there are no studies in the literature that compared the effect of different digital manufacturing techniques of ICFDPs on abutment screw's preload. The aim of this study was to evaluate the effect of different digital manufacturing techniques of ICFDPs on the fit of implant abutment connections and on abutment screw's preload before and after cyclic loading. The null hypothesis is that there is no statistically significant difference in the fit of implant abutment connections and RTVs among ICFDPs manufactured using different digital manufacturing techniques before and after cyclic loading.

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MATERIALS AND METHODS

Four parallel implant holes were drilled in acrylic resin human mandibular model at the interforaminal area (clear orthodontic resin; Dentsply International, New York, NY, USA) with their centers approximately 15 mm apart using an acrylic bur (Dentsply Sirona, New York, USA), twist drill (∅4.1 mm) (Straumann, Waldenberg, Switzerland) and a handpiece mounted on a parallelometer (Paramax II paralleling device WhaleDent, Altstätten, Switzerland). Four tissue-level implants (4.1 mm × 10 mm, Tapered effect; Straumann, Basel, Switzerland) were temporarily stabilized parallel to each other inside the holes using a long implant driver (TE profile drill; Straumann, Waldenberg, Switzerland) mounted on a parallelometer (Paramax II paralleling device WhaleDent, Altstätten, Switzerland) and hand-mixed heavy-body polyvinylsiloxane (PVS) material (Express STD putty; 3M ESPE, St. Paul, MN, USA). The implants were numbered from 1 to 4, where 1 was the most distal implant in quadrant three (Fig. 1). A passive fitting framework was constructed using the combined CAD-cast method. Scan bodies (048.068; Straumann, Basel, Switzerland) were attached to the implants and scanned using a digital scanner (CERamill Map 300, Amann Girrbach, Vorarlberg, Austria). The obtained stereolithography (STL) file was used to design a (5 mm height and 3 mm width) CAD framework with nonengaging (NE) abutments and a 10 mm cantilever distal to implant number 4 using Ceramill Mind software (Amann Girrbach AG; Herrschaftswiesen, Austria). The designed framework was milled from wax material (Dima Mill wax; Kulzer, GmbH, Wasserburg, Germany) using a milling machine (Ceramill Motion 2; Amann Girrbach, Koblach, Austria). The cobalt-chromium (Co-Cr) alloy (StarLoy C; DeguDent, Hanau-Wolfgang, Germany) framework was cast following standardized laboratory procedures in which the wax-up was invested with phosphate-based investment and paper liner soaked in water for 1 minute (K&B investment; YETI Dental, Engen, Germany); the rings were burned out in an oven following the thermal cycle in which the investment was heated to 650 - 700 degrees centigrade in 1 hour and maintained at this temperature for 15 minutes using a centrifugal casting machine (Centrifico; KavoKerr, Berlin, Germany). The investment was quenched, and the casting underwent a pickling process that removed oxides and tarnish. To ensure passive fit of the framework, the implants were removed from the master model then reassembled and screwed into the framework using implant screws (048.350; Straumann, Basel, Switzerland).[19] The assembly was then cemented into the master model using clear acrylic resin (Orthodontic resin clear; Dentsply international, New York, NY, USA). This framework was used as a control and labeled as PF (Fig. 2). Five additional (CAD-cast) frameworks were constructed using the same materials and laboratory procedures. With the previously obtained CAD design, another five frameworks were three-dimensionally printed (3DP) from Cr-Co alloy material (Remanium Star CL, powder 10 - 40 mm; concept laser GmbH, Lictenfels, Germany) using a selective laser melting (SLM) device in a layer-by-layer manner (Concept laser; GE Additive, Lictenfels, Germany). The frameworks were

Fig. 1. Mandibular model with temporarily stabilized implants.

Fig. 2. Passive fit framework implant assembly.

inserted in the furnace at 1500 degrees centigrade for 1 hour followed by bench cooling to relieve accumulated internal stress. All the frameworks were finished using standardized laboratory procedures. The implant abutment linear misfit was recorded using a scanning electron microscope (SEM) (FEI Apreo FEG SEM; Thermo Fisher Scientific, Waltham, MA, USA) at 150× magnification. For each framework, the screws were torqued to 35 N·cm using a digital torque meter (BTGE-G; Tohnichi, Chicago, IL, USA) to which a 046.401 screw driver was attached to the three jaw chuck of the torque meter. The gap was recorded from six marked points (mesiobuccal, midbuccal, distobuccal, mesiolingual, midlingual and distolingual) using a permanent marker (Sharpie; Newell brand, Atlanta, GA, USA) with a total of 24 readings for each framework. A specially designed silicon stand was used to standardize the position of the frameworks during gap measurement. The PF framework received 20 screws (048.350; Straumann, Basel, Switzerland) representing 5 runs. Both CAD-cast and 3DP frameworks received 4 screws for each framework with a total of 40 screws. The total sample size was 60 screws and was determined based on the power calculation of 0.91 at effect size 0.48 and level of significance of 0.05 using the G-power sample power calculator (Universtat Kiel, Kiel, Germany). For measuring the RTV, the digital torque meter (BTGE-G; Tohnichi) was first calibrated to ensure reliable and valid measurements. Each framework with a new set of screws was placed on the implants, and the torque/retorque experiment began with torquing to 35 N·cm for implant numbers 2, 3, 4, and 1. Retorquing was performed 10 minutes later in the same sequence.[33-35] Five minutes after retorquing, detorquing of implant numbers 1, 4, 3, and 2 was performed, and the pre-cyclic loading RTV was recorded. Prior to cyclic loading, each framework with the same set of screws was torqued following the same steps performed in the pre-cyclic loading procedure, after which each framework was subjected to cyclic loading. An indentation on the cantilever extension was marked 9 mm from the center of implant No 4 to standardize the point of loading on the framework (Fig. 3). The frameworks were subjected to cyclic loading at a rate of 1.6 Hz using a chewing simulator (Chewing Simulator CS-4; Mechatronik GmbH, Feldkirchen-Westerham, Germany), each framework was placed in distilled water at room temperature and subjected to 200 N for 200,000 cycles.[18,36] With the presence of opposing stainless steel, the frameworks were positioned at an inclination of 30 degrees following the International Organization for Standardization (ISO 14801:2017) (Fig. 4). After the completion of the cyclic loading protocol, post-cyclic loading RTV was recorded following the same implant sequence using a digital torque meter.

Statistical package for the social science (SPSS; IBM, New-York, NY, USA) software program version 22 was used for the analysis of data. Mean and standard deviation of the gap at implant abutment connection were calculated and the one-way analysis of variance

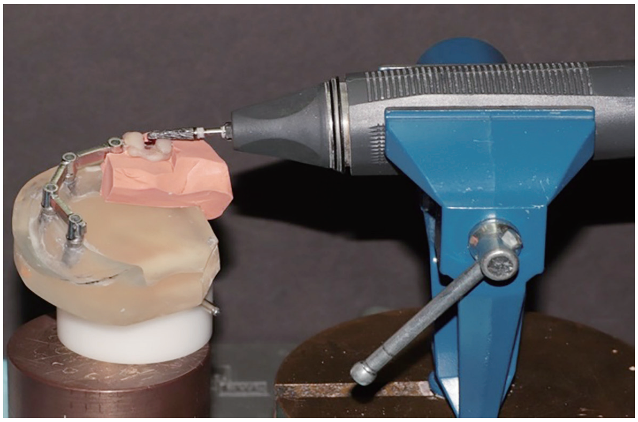

Fig. 3. Indentation on cantilever extension prior to cyclic loading.

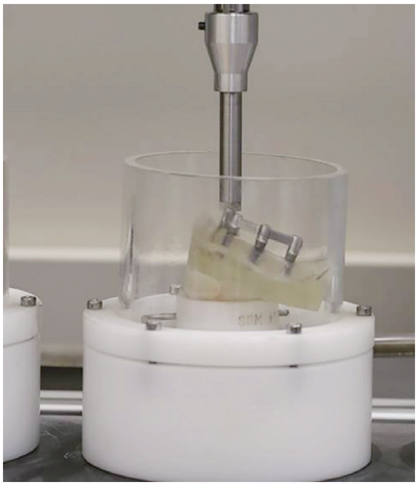

Fig. 4. Positioning of the model in the cyclic loading chewing simulator (CS-4) with 30 degrees angle.

(ANOVA) was used to compare the gap among the three digital manufacturing techniques. The mean and standard deviation of the applied torque and RTVs before and after cyclic loading were calculated. Paired samples *t*-tests were used to compare the applied torque and RTV, and between the RTV before and after cyclic loading under each digital framework manufacturing technique. ANOVA was used to compare the RTV among all digital manufacturing techniques. The level of statistical significant was set to $P < .05$.

RESULTS

One-way ANOVA showed that the manufacturing technique had a statistically significant effect on the implant abutment misfit; higher misfit was present in CAD cast group, followed by 3DP and PF with an average of 29.2 (3.1), 24.5 (1.05), and 16.04 (2.6) µm, respectively (Table 1). The applied torque and RTV means and standard deviations are presented in Table 2. Paired sample *t*-test showed significant mean differences between the applied torque and RTV before and after cyclic loading; the 3DP framework group had the lowest mean difference between the applied torque and RTV before cyclic loading (1.2 N·cm). However, after cyclic loading, the 3DP framework group had the highest mean difference between the applied torque and RTV (5.8 N·cm) (Table 2). In all framework groups, the pre-cyclic loading RTV was higher than the post-cyclic loading RTV (Table 2). Paired sample *t*-tests showed that there were statistically significant differences among RTVs before and after cyclic loading in the PF and 3DP frameworks (P value < .05). However, these differences were statistically insignificant in the CAD-cast group (Table 3). One-way ANOVA comparing pre-cyclic loading RTV in PF, CAD-cast and 3DP frameworks showed that there were no statistically significant differences among groups (P value > .05). There were also no statistically significant differences among groups in post-cyclic loading RTV (P value > .05) (Table 4).

Table 1. One-way ANOVA of the effect of independent variables (framework manufacturing technique) on implant abutment misfit

Group	Mean ± SD (µm)	*P* value
PF	16.04 ± 2.6	.000*
CAD-cast	29.2 ± 3.1	.000*
3DP	24.5 ± 1.05	.000*

PF: passive fit, 3DP: three-dimensional printing.
* statistically significant ($P < .05$)

Table 2. Paired sample *t*-test comparing the applied torque and RTV before and after cyclic loading

Framework		Torque M ± SD	RTV M ± SD	Mean difference	*P*-value
PF	Pre cyclic loading	35.2 ± 0.21	33.6 ± 1.44	1.6	.000*
	Post cyclic loading	35.2 ± 0.17	30.6 ± 4.17	4.6	.000*
CAD-cast	Pre cyclic loading	35.2 ± 0.19	33.3 ± 1.87	1.9	.000*
	Post cyclic loading	35.3 ± 0.19	30.7 ± 5.51	4.6	.001*
3DP	Pre cyclic loading	35.1 ± 0.15	34 ± 1.44	1.2	.001*
	Post cyclic loading	35.2 ± 0.16	29.4 ± 4.9	5.8	.000*

RTV: reverse torque value, PF: passive fit, 3DP: three-dimensional printing.
* statistically significant ($P < .05$).

Table 3. Paired sample *t*-test comparing pre cyclic loading and post cyclic loading RTV in each group

	Mean difference	df	t	*P*-value
PF	3	19	3.3	.004*
CAD-cast	2.6	19	1.87	.076
3DP	4.6	19	3.83	.001*

RTV: reverse torque value, PF: passive fit, 3DP: three-dimensional printing.
* statistically significant ($P < .05$).

Table 4. One-way ANOVA of independent variables (framework manufacturing technique) on pre cyclic loading and post cyclic loading RTV

		df	Mean square	F	Sig.
Pre cyclic loading RTV	Between groups	2	2.813	1.09	.340
	Within groups	57	2.561		
	Total	59			
Post cyclic loading RTV	Between groups	2	10.840	0.448	.641
	Within groups	57	24.195		
	Total	59			

RTV: reverse torque value.

DISCUSSION

The loss of screw preload is influenced by several factors. In the present study, all these factors, except implant-abutment misfit, were controlled. Based on the results of this study, the first part of the null hypothesis was rejected; that is, implant abutment connection misfit was affected by the different digital manufacturing techniques of the frameworks. The second part of the null hypothesis was accepted since there was no statistically significant effect of different digital manufacturing techniques of the ICFDPs on implant screw's preload before and after cyclic loading. Microscopic readings showed that implant abutment connection misfit is significantly affected by the digital manufacturing technique, which is in agreement with previous literature.[25,32] The 3DP group showed lower implant abutment misfit than the CAD-cast group. One possible reason is that CAD-cast manufacturing technique is affected by the ability and experience of the laboratory technician in casting the CAD-cast frameworks.[37] Another reason is that 3DP manufacturing technique allows reaching 100% of the material density at the final printing procedure.[38,39] In this study, the full density of the material was achieved before introducing post-treatment heat. Another reason that justifies the decreased misfit in the 3DP group is the higher elastic modulus of the Co-Cr alloy that allows more resistance to deformation and improves dimensional precision.[40] Presotto *et al*. compared the marginal fit of 3DP, milled and casted frameworks and found no significant differences among the groups. He also stated that the 3DP group had the highest favorable marginal fit and there was no difference in marginal fit between frameworks in the milled and casted groups. Gonzalo *et al*.[41] conducted an *in vitro* study to compare the marginal fit in milled titanium and laser sintered Co-Cr abutments, and they found that both abutment types had misfit values within the clinically acceptable range. On the other hand, Ramalho *et al*.[25] compared the fit of fully digitalized, prefabricated and casted abutments and found that the full digital workflow had the least favorable internal fit compared to casted and prefabricated abutments. A systematic review evaluated the fit of casted, milled and 3DP abutments and found that 3DP had poor internal fit compared to other manufacturing methods, which would ultimately affect the RTV.[32] Several studies showed that misfit ranging between 10 and 150 µm would be clinically acceptable and tolerated in the long term.[37-39,41-43] RTV describes the amount of force needed to un-torque a screw and it has been used as a measurement of preload in multiple studies to evaluate joint stability.[11,44] The results of the present study reveal that the RTVs before and after cyclic loading were considerably lower than the level of applied torque in all groups. This indicates that loss of screw preload at the implant abutment connection occurs regardless of the manufacturing technique and the level of misfit. The reduction of the RTV can be attributed to the long-span and complex design of the framework or the settling phenomenon and the loss of initial preload due to friction. Furthermore, it can be due to micromovements at the implant abutment connection when the prosthesis is loaded.[11,12,17,18,45] The literature stated that when screw is tightened to the recommended value, the RTV will be lower than the applied torque by 7 to

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10%.[18,46] After cyclic loading, the RTV was lower than the applied torque in most literature, which is in accordance with the results of the present study.[18,46,47] All framework groups presented lower post-cyclic loading RTV compared to the pre-cyclic loading RTV, which was significant in both the PF and 3DP groups. This finding is in accordance with the previous study by Tiossi *et al*.[46] who compared the pre- and post-cyclic loading RTVs of 3DP full arch zirconia prostheses supported by either four or six implants and found that the post-cyclic loading RTV was lower in both implant-supported prostheses. Similar to previous studies, the decrease in RTV after cyclic loading can be attributed to the micromovements at the implant abutment connection, progressive settling effect produced from cyclic loading or presence of a distal cantilever.[18,46] Although there was a reduction in pre and post-cyclic loading RTV, there is no evidence in the literature indicating the cut point of preload loss beyond which the adverse clinical effects might manifest. To the best of our knowledge, there are no literature comparing loss of preload in full arch ICFDPs manufactured using different digital manufacturing techniques. Thus, the present study is the first *in vitro* study that evaluates the effect of CAD-cast and 3DP digital manufacturing techniques of ICFDPs on screws preload. However, several studies have been conducted to compare the preload loss in single implants. Benjaboonyazit *et al*.[18] conducted an experimental study on single implants to compare pre- and post-cyclic loading RTVs at implant abutment connections under 50,000 to 2,000,000 loading cycles and found that all experimental groups showed significantly lower RTV means than the means of pre-cyclic loading RTVs. Yi *et al*.[48] compared pre- and post-cyclic loading RTVs in two different implant systems connected to prefabricated and milled abutments and found that the post-cyclic loading RTV was less than the pre-cyclic loading RTV in all groups. Furthermore, the insignificant differences in the RTVs before and after cyclic loading between the different digital manufacturing techniques indicates that both complete digital or combined digital with conventional manufacturing techniques could be valid methods that produce acceptable prostheses.[37,49] The limitations of the present study include that the frameworks were loaded in one loading point located in the cantilever extension, which does not represent the clinical loading conditions. Additionally, further investigations regarding the effect of subtractive digital manufacturing techniques on the misfit and preload are needed.

CONCLUSION

Within the limitations of the study, although the CAD-cast and 3DP digital manufacturing techniques produce frameworks with a clinically acceptable misfit, the 3DP digital manufacturing technique might not be the technique of choice when it comes to maintaining the stability of the screw's preload under an aggressive loading condition.

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