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Comparative Analysis of the Stability of Prosthetic Screws under Cyclic Loading in Implant Prosthodontics: An In Vitro Study

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Abstract: *Background*: To compare the loss of preload in absence of loading and after a fixed number of cyclic loadings on 7-mm distal cantilever in two different connection systems using all-on-four prosthetic model. *Methods*: Two equal models of an edentulous mandible rehabilitated with all-on-four technique with two types of abutment system (MUA and OT-Bridge) supporting a hybrid prosthesis, were used. Initial torque values of the prosthetic fixing screw, after ten minutes from initial screw tightening and after 400,000 repeated loadings were registered using a mechanical torque gauge. Differences between initial and final torque values were reported for each anchoring system and the two systems were finally compared. *Results*: No statistically significant differences regarding the loss of preload between MUA and OT-Bridge system were found after 400,000 cyclic loadings; however, in MUA system it was found between anterior and posterior implant screws. A significant difference in preload loss was found only for MUA system comparing the initial screw torque to that measured after 10 min from the tightening in absence of cyclic loadings. *Conclusions*: Within the limits of the present study, MUA and OT-Bridge may be considered reliable prosthetic anchoring systems able to tolerate repeated cyclic occlusal loads on distal cantilever in all-on-four rehabilitation model without any significant loss of preload in screw tightening.

Keywords: preload loss; conical abutment screw; multi-unit-abutment; OT-Bridge; prosthetic connection; implant-supported prosthesis; loosening torque; tightening torque

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1. Introduction

In the last few decades, the screw-retained prosthesis on implants has become increasingly common for the rehabilitation of the totally edentulous patients [1–3]. Multiple solutions for the rehabilitation of upper and lower jaw were proposed and accepted in literature, basing on the entity of bone atrophy, the pneumatization of maxillary sinus, the quantity of bone available and the position of inferior alveolar nerve and mental foramina [4–7]. The All-On-Four technique for the rehabilitation of completely edentulous mandibles, initially proposed by Malo et al. [8] is nowadays used by several clinicians [9–11] in order to reach the correct masticatory and speech functions, as well as an optimal prosthetic support, and to re-establish an acceptable situation for the patient [12]. In these type of implant-supported rehabilitation, intermediate components between implant fixtures and prosthetic framework are used in order to correct implant misalignment and to achieve a passive fit of the framework. For this technique, one of the most used anchoring systems is the Multi-Unit-Abutment (MUA), which consists of straight or angulated components of different heights that move the implant internal connection to a conical external connection. In this way, a passive prosthetic fit is allowed even in case of implant disparallelism. Furthermore, the occlusal stress is moved from the implant screw to the multi-unit abutment screw, that is smaller than the first one and may be the weak point in case of prosthetic complications.

An alternative to MUA system, recently introduced on dental market, is represented by OT-Bridge® system (Rhein 83, Bologna, Italy). The OT-Bridge system is composed of a low profile attachment for overdenture (OT-Equator), a sub-equatorial component represented by an interchangeable undercut acetal ring (Seeger ring) and a cylindrical titanium abutment with a cavity at the retentive extremity designed for insertion of the acetal ring. In this way, the Seeger ring provides a secure and functioning elastic retention system of the abutment, against the possibility of prosthesis unscrewing. The most frequent mechanical complications in implant supported prosthesis are represented by the chipping of the prosthesis, the fracture of the abutment and the abutment/implant screw fracture and loosening [13–16]. This last complication is always preceded by the reduction of its preload [17–20], defined as the axial force that, during the tightening of the screw, is generated between the threads of the screw and the internal part of the implant in the long axis direction. Screw loosening is influenced by several factors such as screw geometry, material properties particularly stiffness, surface texture and condition of mating surfaces, degree of lubrication, rate of tightening, integrity of joint, prosthetic misfit etc. [17]. The metal alloy composition of the screw and the abutment is an important factor that defines the entity of the friction during the mating threads and then influence the stability of the joint system in terms of absorption of preload [18,19]. Also, the type of abutment (machined or cast), and the surface coating or the implant connection systems could play crucial roles relating to this phenomenon.

At the best of our knowledge, no studies of comparison for prosthodontic complications between MUA and OT-Bridge are today present in literature. The aim of this in vitro study was to compare the loss of preload in MUA and OT-Bridge connection systems using all-on-four prosthetic model, with and without cyclic loading on 7-mm distal cantilever.

2. Materials and Methods

Ethics approval was not required for this in vitro study. Modified CONSORT checklist of items for reporting in vitro studies of dental materials were followed.

2.1. Models Realization

Two reference models, representing the patients, were obtained from a single silicon oral impression of an edentulous mandible model rehabilitated with four implants in the position of canines and second premolars, following the ideal "all-on-four" concept [8]. Each implant was placed according to a predetermined angulation: the axes of implants in canine position were orthogonal to the occlusal plan, and the axes of implants in second premolar were angulated distally for 30 degrees. The models were made using epoxide resin (Trias Chem Srl, Parma, Italy,) loaded at 300% in order to enhance the mechanical properties and to withstand to the chewing loading without modification, mimicking the mandibular bone. Four implant analogues (3.5 $\times$ 10 mm; NobelBiocare, Kloten, Switzerland) with internal hexagonal connection were used. A calibrated hole was performed at the center of the model to fix it to the machine for the dynamometric control of the loads (Figure 1a,b).

In the model A, MUA (NobelBiocare) were screwed at 35 Ncm on the anterior straight implant analogues and at 15 Ncm on the posterior tilted implant analogues. In the model B, four OT-equator were screwed at 25 Ncm on each implant analogue. A milled cobalt-chrome framework for hybrid prosthesis was created on each model from the same file system. An internal conical attachment with a connection screw hole was realized in the framework for Model A and an extra-grade abutment was used for the model B. The first molars were located distally to the posterior implant platform in order to obtain a distal cantilever 7 mm long, between the central fossa of these elements and the last implant according to the most predictable protocols in the literature [21,22] (Figure 2).

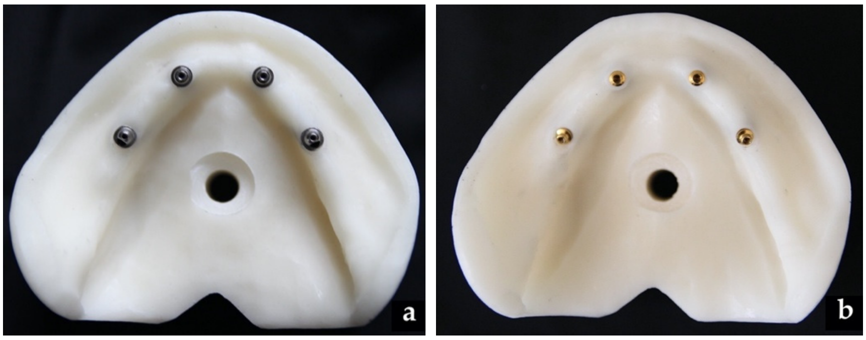

Figure 1. (**a**,**b**). Edentulous model with Multi Unit Abutment system (**a**) and OT-Equator abutment system (**b**).

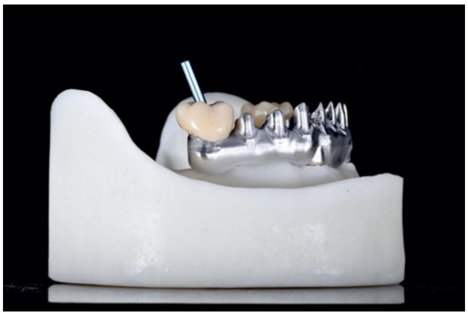

Figure 2. CAD/CAM Cr-Co Milled Framework.

2.2. Simulation of Loading Cycles on Distal Cantilever

Connecting screws were tightened on implant analogues according to manufacturer's indications with a torque-controlled dynamometric micromotor, Implantmed Plus (W&H, Brusaporto—BG, Italy). Torque values were the following: 15 N/cm for angulated posterior implants and 35 N/cm for straight anterior implants on Model A, 25 N/cm for Model B. Implant screws were then retightened 10 min after the initial torque application in order to compensate the settling effect, described by Winkler et al. [18]. After 10 min, screw insertion torque was measured with the same machine. Loading cycles on 7-mm distal cantilever were simulated using MTS-Acumen 1 (MTS Systems S.R.L, Turin, Italy), an electrodynamic testing machine which acted as a presser dynamometer on which was mounted a metal bracket ending with two spherical geometrical tips that were positioned on the central fossa of the first molars of the model (Figure 3).

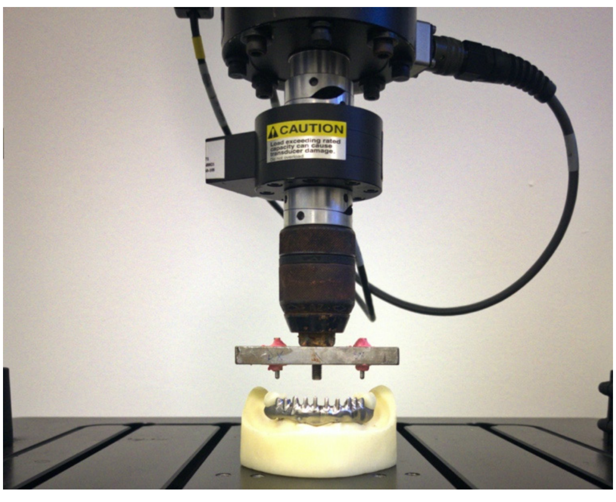

Figure 3. Electrodynamic testing machine (MTS-Acumen 1) simulating loading cycles on the 7-mm distal cantilever of the implant supported prosthesis.

A variable ascending and descending force from 40 to 400 N repeated for 400,000 cycles with a rate of 1.6 Hz was applied on central fossa of the first molars, perpendicular to the occlusal plane and parallel to the axis of the anterior implant analogues. The values of the forces applied, and the number of cycles were established according to literature protocols [8,23] and considering an ideal number of one-year cyclic loading [24–26]. After cyclic loading, the loosening torque was measured and each connecting screw was replaced with a new one and, in the OT-Bridge system, the acetal ring was substituted. Five tests were performed for each system. The accuracy of the loading cycles on the cantilevers and the verification of the absence of errors or collateral movements were verified in real time by the MTS-Acumen 1® software. According to the literature [17], the difference between the initial torque and the torque measured during loosening the screw was assumed as the loss of preload. The torque was measured using the torque-controlled dynamometric micromotor, Implantmed Plus (W&H).

2.3. Statistical Analysis

Analysis of variance (ANOVA) was used to compare the preload loss between the 2 systems, in absence of load and after cyclic loading. ANOVA was also performed to compare preload loss between anterior and posterior implants in both systems. The null hypothesis was that there was no difference in preload loss. The significance level was set to 0.05. SPSS Statistics software for Mac v. 24 was used for statistical analysis.

3. Results

Percentages of preload loss during the five tests for Multi-Unit-Abutment and Ot-Bridge were synthetized in Table 1.

Table 1. Results, % preload loss during 5 tests.

		Multi-Unit-Abutment				Ot-Bridge			
% Preload loss among tests	1° test	33	37	43	47	48	36	44	52
	2° test	40	40	43	47	48	40	44	48
	3° test	47	25	43	33	40	44	44	48
	4° test	40	40	26	47	56	32	40	36
	5° test	40	34.3	34	47	40	36	60	36

On the Model A the overall mean loss of preload was 39% (+/− 16%). The anterior implants reported a 36% (+/− 7%) loss of preload, while the posterior elements reported a 42% (+/− 5%) loss of preload. This difference was statistically significant ($p < 0.005$) therefore the null hypothesis was rejected (Table 2).

Table 2. Comparison between anterior and posterior placed M.U.A. in term of absolute preload loss.

		33–43	35–45
N/cm2 Preload loss in Multi Unit Abutment	**1st test**	14	9
	2nd test	14.5	8.5
	3rd test	13	9
	4th test	11.5	8.5
	5th test	12	8.5

In the absence of cyclic loading, the overall mean loss of preload was 31%, while after cyclic loading the mean loss of preload over the five tests was 39%, with no statistically significant difference ($p = 0.165$). On the Model B the overall mean loss of preload measured in the connecting screws was 43% (+/− 7%). The connecting screws on the anterior implant analogues registered a loss of preload of 42% (+/− 8%), while the posterior elements registered a 45% (+/− 7%) loss of preload. Comparing the values measured between the two pairs of screws there is no statistical significance (p = 0.335) so the null hypothesis was accepted. In the absence of cyclic load, the overall mean loss preload was 41%, following the application of 400,000 chewing cycles the average loss of preload on the five tests it was 43%, the difference being not statistically significant (p = 0.469). Comparing the two models, no statistically significant difference was found in mean loss of preload after cyclic loading (p = 0.202).

4. Discussion

The loss of preload is one of the most frequent complications in implant-supported prosthodontics, belonging to the subcategory of mechanical complications [27–29]. It always precedes the screw loosening, that has an incidence of 5.3% after one year of loading and between 5.8% and 12.7% after 5 years [16,17,29–31]. According to the literature the loss of preload is influenced by several factors [17,27,28], including the type of material used for the fabrication of the abutment and the connecting screw, the fixture geometry connection, the type of prosthesis, the shape of the abutment screw head and the implant screwing method [18–20,24,32–35]. In the present study all these factors, except the metal alloy composition of the screw and the abutment of the two joint systems, were controlled. In particular, in the MUA system used, both the abutment and connecting screw are composed of grade 4 commercially pure titanium while the OT-Bridge system has a titanium nitride coating the low-profile attachment with an anodized titanium anchoring screw. This could be the reason why only in the MUA system a difference was found between initial torque value and the torque value registered after 10 min in absence of loading. Probably the high Young's modulus and the low elastic recovery of grade 4 commercially pure titanium produce an important friction during the mating threads [18,19], resulting in a loss of preload. We can thus hypothesize that the alloy composition of OT-Bridge system prevents this situation. In literature, some studies concluded that the material of the connecting screw plays a great role in the loss of preload, evidencing that Gold-Tite screws better adapt the mating counterpart of the implant bore, thanks to the ductility and malleability properties of this material [18,19,36,37]. An interesting finding of this study was that the two connection systems did not show statistically significant differences regarding the loss of preload following the simulation of 400,000 loadings on distal cantilever, that correspond approximately to 1-year of cyclic loading [24–26]. The application of the occlusal forces on the distal areas, perpendicular to the occlusal plane and parallel to the long axis of the anterior implants, in light of the considerable mechanical stress, produces a statistically significant difference between the connecting screws on anterior and posterior implants only in Model A (MUA system). The absence of this evidence in OT-Bridge system could be due to the presence of the acetal ring, which provides a snap retention opposed to the upward traction force. These results suggest that MUA and OT-Bridge are reliable prosthetic anchoring systems even in unfavorable conditions like the application of occlusal forces on a 7-mm distal cantilever. However, an important difference for the biomechanical comparison of these two systems is the presence of the acetal ring on the OT-Bridge system that stabilizes the prosthetic structure, in case of screw loosening. In other studies, it would be important to assess the behavior of this acetal ring during all the masticatory functions and evaluate the significance of the "snap" retention on the extra-grade abutment of the prosthesis, once the correct tightening of the screw has been lost.

The limits of this work are principally due to the in -vitro nature of the study. The two joint systems were assessed in only one important stress condition, by performing compressive cycles on 7-mm distal cantilever. Other loading conditions were not investigated but occur in the patient's mouth.

As the effects of saliva and food on the longevity of MUA system are well-known in literature, little or nothing is present for OT-Bridge system. However, OT-equator is also used for overdenture rehabilitation and is proved to be effective in the mouth of the patient [14,38]. Also the temperature may influence the preload loss and in this study we do not evaluate this. Furthermore, the models used simulate the strength and plasticity of alveolar bones with limits, despite the use of an epoxide resin model loaded at 300% in order to enhance its mechanical properties to mimic mandibular bone. Also, the construction of the two models may be affected of fabrication defects.

Then, within the limits of this in-vitro study, it can be concluded that MUA and OT-Bridge may be considered a reliable prosthetic anchoring systems able to tolerate cyclic occlusal loads on distal cantilever in all-on-four rehabilitation without any significant loss of preload in screw tightening. However, further in-vitro and in-vivo studies with wider samples and different conditions and especially clinical trials with long follow-up period are required to prove the clinical reliability of this new anchoring system in comparison to the current gold standard.

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