https://doi.org/10.4047/jap.2021.13.3.152

Pull-off resistance of a screwless implant-abutment connection and surface evaluation after cyclic loading

Vasilios Alevizakos[1]*, Richard Mosch[1], Gergo Mitov[2], Ahmed Othman[1], Constantin von See[1]
[1]Department of CAD/CAM and Digital Technologies in Dentistry, Danube Private University, Krems, Austria
[2]Department of Prosthodontics and Biomaterials, Danube Private University, Krems, Austria

ORCID
Vasilios Alevizakos
https://orcid.org/0000-0002-3541-5404
Richard Mosch
https://orcid.org/0000-0002-9550-795X
Gergo Mitov
https://orcid.org/0000-0002-0599-0344
Ahmed Othman
https://orcid.org/0000-0003-1381-7944
Constantin von See
https://orcid.org/0000-0001-6272-7326

PURPOSE. The aim of this study was to investigate to what extent cyclic load affects the screwless implant-abutment connection for Morse taper dental implants. **MATERIALS AND METHODS.** 16 implants (SICvantage max) and 16 abutments (Swiss Cross) were used. The screwless implant-abutment connection was subjected to 10,000 cycles of axial loading with a maximum force of 120 N. For the pull-off testing, before and after the same cyclic loading, the required force for disconnecting the remaining 6 implant-abutment connections was measured. The surface of 10 abutments was examined using a scanning electron microscope 120× before and after loading. **RESULTS.** The pull-off test showed a significant decrease in the vertical force required to pull the abutment from the implant with mean 229.39 N ± 18.23 before loading, and 204.30 N ± 13.51 after loading ($P<.01$). Apart from the appearance of polished surface areas and slight signs of wear, no visible damages were found on the abutments. **CONCLUSION.** The deformation on the polished abutment surface might represent the result of micro movements within the implant-abutment connection during loading. Although there was a decrease of the pull-off force values after cyclic loading, this might not have a notable effect on the clinical performance. [J Adv Prosthodont 2021;13:152-9]

KEYWORDS
Dental implant-abutment connection; Dental implant; Wear; Morse taper dental implant-abutment connection

INTRODUCTION

The most commonly used implants in dentistry are the two-part titanium implants. The reasons for this are the possibility of wound closure, better maintenance during the healing process and the use of temporary restorations, which form a wound dressing in addition to the temporary dentures and restorative advantages.[1]

Corresponding author
Vasilios Alevizakos
Department of CAD/CAM and Digital Technologies in Dentistry, Danube Private University
Steiner Landstraße 124, 3500 Krems, Austria
Tel +49173 8 299 399
E-mail vasileios.alevizakos@googlemail.com

Received October 3, 2020 / **Last Revision** April 20, 2021 / **Accepted** May 28, 2021

The type of connection between the implant and the abutment can be ensured with or without retaining screws which engage in an internal thread in the implant.[2,3] Screwable connections are usually equipped with internal or external rotation protection for single tooth restorations. In addition, there are different types of connection, an inner cone or a butt joint. The advantages and disadvantages of these systems have already been examined.[4]

Looking at the biological effects, the conical connection between the implant and the abutment should prevent mechanical gaps from the outset. The abutment is pressed into the implant through the cone and fixed with the retaining screw. If a force is applied to that system, the two parts always move in one or more directions. Gehrke and Pereira Fde[5] were able to show with four Morse taper implants that under cyclical loading of 80 N there was a significant reduction in the gap, but the gap was not completely closed. Surface defects, which can occur during the milling process, can lead to increased gap formation.[6] Furthermore, mechanical inaccuracies are also the reason for an increased gap formation.[5,6] Due to such displacements, deformations could be recognized in a surface analysis within the implant-abutment connection, and a loss of holding force could be observed.[7]

Morse taper implants were designed for the fabrication of single-tooth implant-supported crowns where the abutment and the crown are one unit. Some manufacturers provide solutions where the abutment-crown complex is connected to the implant without screw to a locking taper.[8] This technique does not use cement to retain the crown or screws to retain the abutment. On the one hand, the clinical outcome of this screwless and cementless system for single implant restorations is favorable, compared with the results for the screw- and cement-retained single implant restorations.[9] On the other hand, the mechanical resistance of the screwless Morse taper implant system is lower than that of the regular implant systems and might result in more frequent clinical complications.[10]

In order to clarify those contradictions the aim of this study was to investigate the extent to which cyclic load affects the implant facing surface of the abutment and the connection of a screwless implant-abutment connection.

MATERIALS AND METHODS

The examined implants (SICvantage max, Schili Implants, Basel, Switzerland; 4.7 mm × 13 mm) have an engaging design and a conical connection between the implant and the abutment. The cone inhibits the removal of the abutment placed on it by means of friction. According to the manufacturer and the literature, the retentive stability of the conical design used is sufficient to attach prosthetic restorations without a retaining screw.[11] The inner cone has an angle of 2.8°, which is also known as Morse Taper. The rotation protection is a groove-nub connection, which holds the abutment (Swiss Cross, Schili Implants, Basel, Switzerland) with 4 grooves precisely in position. Due to the equal connection between the abutment and the implant it is intended to achieve an optimal distribution of the pressure and bending forces over the connective surface. The conical section is tightened for the long- term by tapping gently or with the fixation screw at a torque of 20 Ncm. After removal of the fixation screw, the (Morse taper) conical connection can only be removed with a special instrument - the extractor.

Dense polyurethane (PU) block (Solid rigid polyurethane foam, 50PCF, Sawbones Europe AB, Malmö, Sweden) was used for the tests. The bone blocks (13 cm × 18 cm × 4 cm) were produced using a 5-axis milling machine (U5-620, SPINNER Werkzeugmaschinenfabrik GmbH, Sauerlach, Germany) with swivel table, so that the opposite sides were exactly parallel to each other. Thus, the implant or abutment could be subjected to precise axial statical loading (Fig. 1).

In order to set a reproducible implant position, the implant bed preparation was carried out with the 5-axis milling machine U5-620 - equipped with implants drills - without changing the position of the table of the parallelometer. The implants were inserted by 35 Ncm.

The abutments were fixated according to the manufacturer's recommendations. The abutment was introduced into the cone and seated in intermediate position with the "Swiss Cross". The index was found

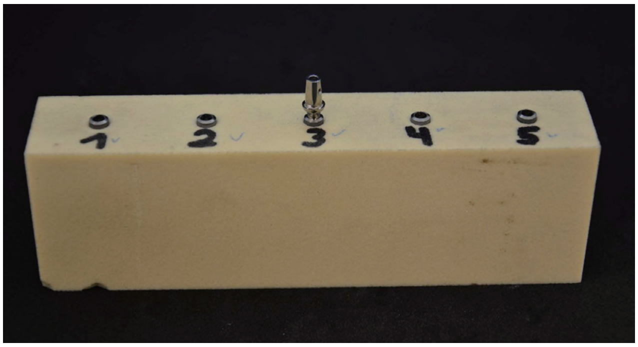

Fig. 1. Five implants have been placed in the artificial bone block. In implant no. 3 a morse taper abutment has been inserted.

by turning it to the right or left. The fixation screw was then tightened with 20 Ncm with a torque wrench and removed before testing.

The mechanical loading setup is presented in Fig. 2. The artificial bone block was placed inside the universal testing machine (ProLine Z100TN, ZwickRoell GmbH & Co. KG, Ulm, Germany). A working stamp with a horizontal working surface was used. The plate and working stamp, as well as artificial bone and the abutment were consequently parallel to ensure the best possible axial force transmission and prevent angulation errors. Cyclical loading was performed as follows:

- preload of 0.2 N
- cross-speed of 0.2 mm/min
- loading magnitude 120 N
- 10,000 cycles of loading

During testing the machine did not completely relieve the load as this could result in a spatial offset or rotation of the bone (Fig. 2).

Pull-off tests were performed before and after cyclical loading using the universal testing machine. Thus, initial and post-loading pull-off force could be detected.

The force required to separate the implant and abutment was evaluated in pull-off tests before and after cyclic loading, using the universal testing machine (Fig. 3). Thus, initial and post-loading pull-off force was detected.

The scanning electron microscope (TM-1000, Hitachi Ltd. Corporation, Chiyoda, Japan) examination was performed in a standardized manner under 120 × magnification. Therefore, the abutments were set upside-down in a customized holder. The first SEM examination focused orthogonally on the Swiss Cross retraction (Fig. 4). The second SEM examination focused in approximately 35° angulation on the Swiss Cross retraction (Fig. 5). The images were assigned to the respective implant and could be direct visually compared.

Statistical analysis was performed with SPSS (27, IBM, Armonk, NY, USA). Kolmogorow-Smirnow test was used to examine normal distribution and t-test for differences between means. The significance-level was set at 0.05.

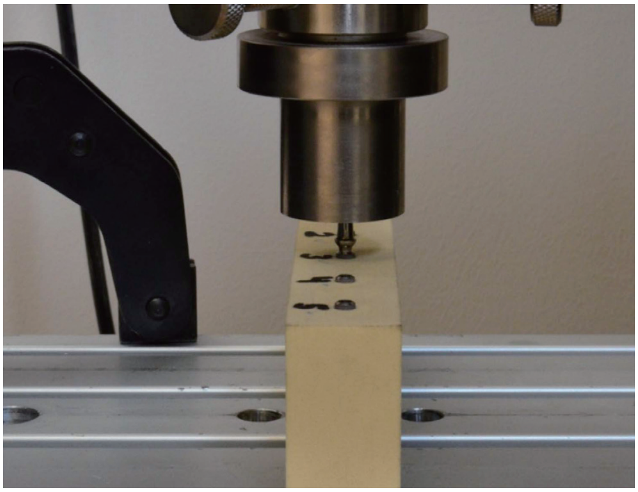

Fig. 2. Cyclic loading test - the stamp of the testing machine presses on the abutment.

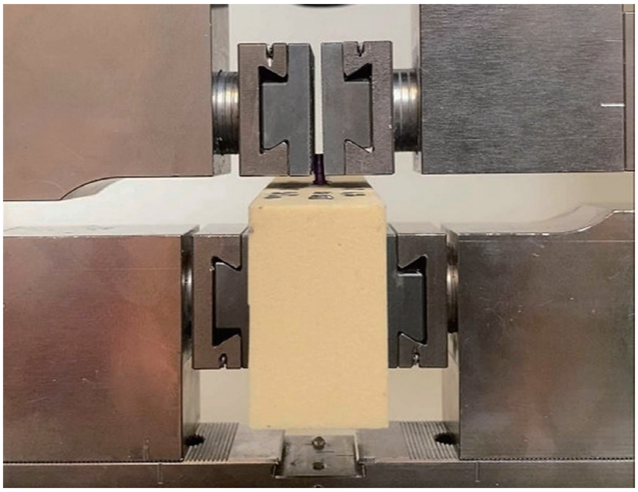

Fig. 3. After cyclical loading test - the clamps of the testing machine pull the abutment.

RESULTS

No implant has been dislodged from the polyurethane block and the clamps of the testing machine have caused no distortion of the abutment. The results of mechanical testing showed a significant decrease of the pull-off-forces after cyclical loading ($P < .002$). Before the cyclic loading, the mean value of the required withdrawal force was 229.39 N ± 18.23 and after 204.30 N ± 13.51.

Fig. 4 and Fig. 5 show SEM of implant facing surface of the abutment before and after cyclic loading.

SEM images of the implant facing surface of the abutment with its twist protection, the Swiss Cross are shown in Fig. 4. Minor damage - wear of the edges - could be detected as a result of screwing in or the cyclic loading. No other changes on the surface could be observed. In particular, the surface structure in the unloaded implants appears very similar to that. The same situation was shown for all other implants. The edges of the twist protection also seemed not affected during testing and showed no signs of grinding.

This was different when looking at the pictures with an inclination of approximately 30 - 35° (Fig. 5). Before loading, a clear grinding pattern could be seen, which extended to the upper edge of the twist protection. Also some finely drawn lines were visible that run constantly through the magnified area. After the testing, they were not visible anymore. Apart from a few fragments, the surface was smooth from the border between the twist protection and the implant. No grooves or striations were visible. The same situation could be observed on all other abutments tested.

DISCUSSION

The aim of the present study was to investigate the extent to which cyclic load affects the implant facing surface of the abutment and the connection of the implant-abutment connection for Morse taper dental implants. SEM-examination showed only minor changes in the abutment surface in the form of minor smoothening of edges and polished surface. After mechanical loading, the pull-off testing showed a statistically significant decrease of the required pull-off force ($P < .002$).

The number of specimens (N) was set at 16. For this, similar studies have been taken into consideration. Other comparable studies set the number of specimens ranging from three to twenty.[4,5,7] The experi-

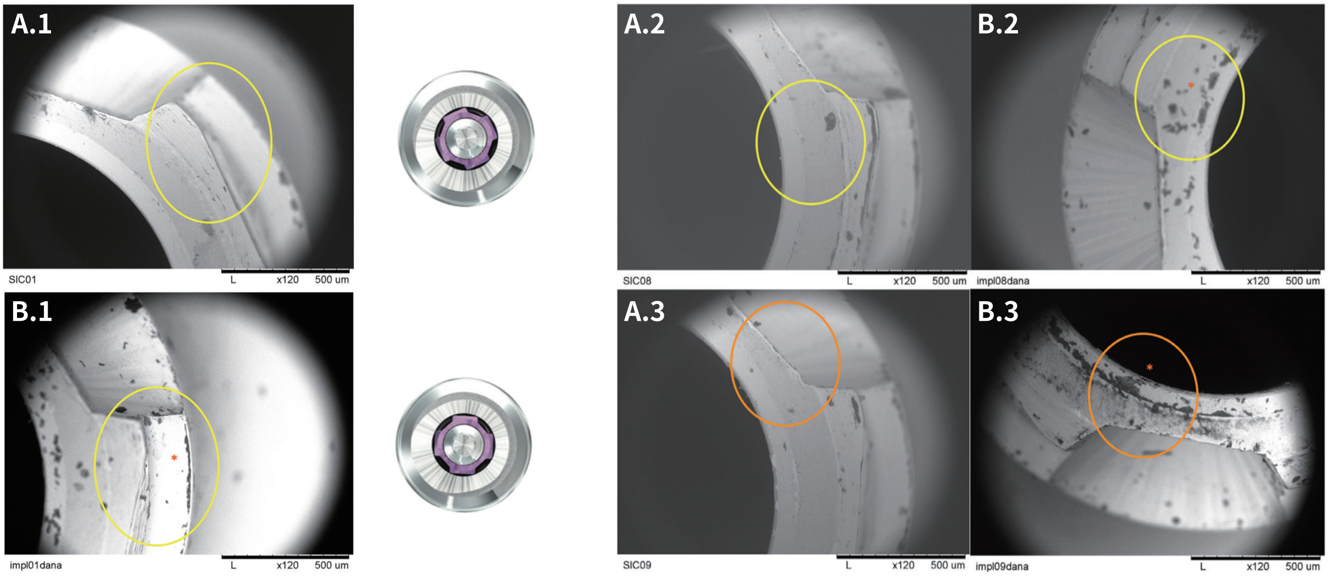

Fig. 4. SEM examination before placing the abutments in the implants (A) and after the cyclic loading (B). After cyclic loading * wear was visible at the abutment's implant facing surface. The circles mark the area of wear. The corresponding pictures A/B.1; A/B.2; A/B.3 focus on the same area in order to show the alteration due to the cyclic loading. In the pictures B.1, B.2 and B.3 alterations in form of wear are visible.

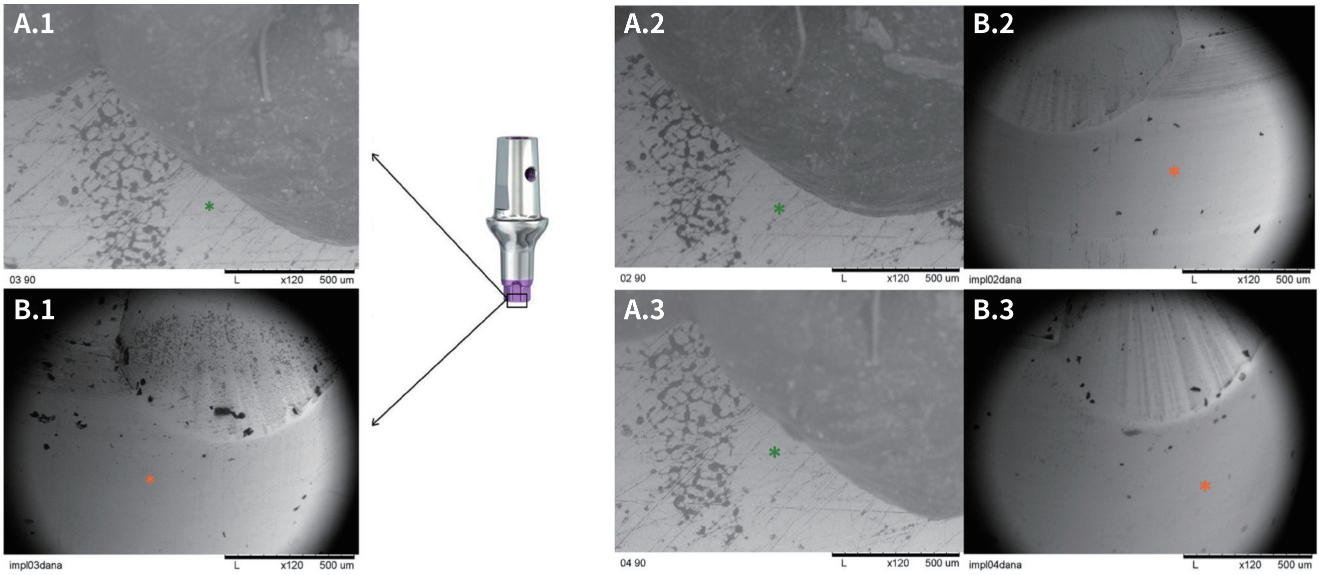

Fig. 5. SEM examination of the abutments before placing the abutments in the implants (A) and after the cyclic loading (B) at transition from implant facing surface to lateral site (30 - 35° to the abutment axis). (A) Before cyclic loading the surface shows * finely drawn lines. (B) After cyclic loading * no finely drawn lines are visible.

mental setup was similar to the study by Prado *et al*.[7]. Care was taken to ensure that as many sources of bias and errors as possible could be excluded in order to be able to confirm or reject the hypothesis. Therefore, every consumable component was replaced for every trial. This included the implant, drill hole, abutment and retaining screw.

The number of cycles was set at 10,000. The preliminary test showed that with this number of cycles there was already a clearly visible change in form of wear in the material. An increase in cycle number or dynamic loading in a chewing simulator could make further statements about material and its behavior. A similar study was carried out with a simulated chewing cycle number of 300,000.[12] The maximum force of 120 N, which was reached once per cycle, corresponds to the chewing forces that occur when chewing hard food.[10]

The artificial bone used in the present work consists of bone-like polyurethane foam. It is validated in several further studies[13-15] as a homogeneous material allowing reproducible results. However, human bone does not have this homogeneity, which should affect the transfer of the study to the clinical site and should be taken into account. Implant placement could be performed using a parallelometer.[5,16] Several implants were placed in an artificial bone block. As they were loaded in sequence, this could lead to a deformation of the polyurethane block that interferes with the movement of the assembly and a change in the incidence of load applied to a specific implant. Although the pull-out testing results showed a high consistency within the groups, this fact should also be regarded as a possible limitation of the study design. To avoid mechanical deformation during testing, a dense artificial bone (no spongious area) with high mechanical resistance was chosen. Furthermore, not holding the blocks in position while loading might have resulted in dislocation and thus non-axial loading of the abutments. Nevertheless, this was not observed during testing.

The stamp acting in the loading test was lowered onto the edge of the abutment and the force was transferred to it directly. Clinically the abutment is fully covered from the prosthetic restoration. The resulting force was therefore not the same as in clinical use. However, since the force in the experimental setup acted purely axially, the implant abutment surface behaves as if the forces were acting on the entire abutment.

Consistency as *in-vitro* in humans is not to be expected. In clinical practice, the nature of implant loading is dynamic. The number of 10,000 chewing cycles is reached relatively quickly *in vivo*. It is assumed that humans make around 1500 antagonistic tooth contacts every day, for example by chewing or swallowing, thus the number of chewing cycles examined is reached fairly quickly.[17] The temperature at which the trials were carried out was also constantly lower than *in vivo*. Whereas relatively constant 37°C can be found in the oral cavity, the study was carried out at significantly lower temperatures.

A criticism could be that the abutment only loads axially, always with the same force. In the studies by Mangano *et al*. as well as by Geckili *et al*. the inserted implant construction was loaded with forces from all different directions and with various, compressive forces.[8,18,19] Axial loading might favor the system.

A polish of the surface was clearly visible after cyclic loading (Fig. 5B). Slight signs of wear were seen during SEM-examination. No material failure such as breakage or deformation could be identified. No damage was found when looking at the twist protection. Due to the polishing and wear of the surface of the abutment, there was the presumption that pulling off the abutment might require less effort than with an unstressed implant-abutment connection. This presumption was confirmed by the following pull-off test. We focused on the area of the index portion because that area secures the stable position of the abutment. If that area is getting damaged during loading the implant-abutment connection might loosen.

The studies of the literature research showed that the Morse taper abutments could be compared very well with the screwed abutments and that the designs differ only slightly regarding clinical failure.[8,9,20] None of the studies showed a greater loosening or even a loss of the abutment. During the last decades, in literature two different assumptions have appeared: the first possible explanation is that the abutment tends to be cold welded to the implant due to the high pressure, which in turn leads to the abutment being firmly anchored in the implant. The second possibility might be that despite or because of the various external influences, there might be no great changes, and if so, only minimal ones.[21,22]

Cold welding requires sufficient pressure on one point. In an *in-vitro* study, Merz *et al*. examined the pressure distribution of conical connections.[23] When tightening the retaining screw with 35 Ncm, the cone of the abutment was pressed into the implant. Loading this connection showed stress values in the conical connection. According to finding of Norton *et al*., those stress values are not enough for initializing cold welding. They reported that cold welding was only apparent in high torque series when torques of 100 Ncm and more were applied.[22] Thus, cold welding might not be the reason for higher pull-off forces after loading. Bozkaya and Müftü could show that elastic straining in the implant increases the pull-off force due to higher interference values.[24] In contrast, a plastic deformation leads to a decrease of interference values resulting in lower friction and thus lower required pull-off forces. In addition, according to the Coulomb's law of friction the surface roughness influences proportionally the increase of friction, thus increasing the required external forces to disengage both surfaces.

In the present study, a decrease of required pull-off force to separate the abutments from the implants was observed after axial static loading. The initial pull-off force of 229.39 N ± 18.23 decreased slightly to 204.30 N ± 13.51 after loading. These results do not correspond to the findings of further studies on the impact of loading on the implant-abutment connection.[24,25] In a similar set up, on Ankylos implants with a conical connection, Hsu *et al*. measured an increase of pull-off values after loading.[26] It should be taken into consideration that even after static axial loading, the resulting mean pull-off force (77.6 N) was substantially lower than the results of the present study. From this point of view, the increase of connection strength might not be of clinical relevance.

It can only be carefully assumed that the polish and slight deformation within the index area could have led to a decrease in surface roughness and congruence and thus a decrease in friction. This decrease in friction decreases the required external forces to disengage those two surfaces. The results of the SEM examination showed signs of polish or slight wear in the index area of the abutment after cyclic loading -

consequences of possible minimal movements in the implant-abutment connection. It might be assumed that this might be the reason for the decrease in the required pull-off force after loading.

CONCLUSION

From the present results and within the limitations of this *in-vitro* study, following conclusions were drawn:

Axial static loading of the abutments resulted in minimal signs of wear within the implant-abutment connection, leading to a slight decrease of the force values needed to separate them. The hypothesis, that cold welding occurs, could be rejected.

The clinical relevance of the changes caused by mechanical loading is negligible. Further studies are needed for a full understanding of the biomechanical behavior of Morse taper systems.

REFERENCES

1. Barrachina-Díez JM, Tashkandi E, Stampf S, Att W. Long-term outcome of one-piece implants. Part II: Prosthetic outcomes. A systematic literature review with meta-analysis. Int J Oral Maxillofac Implants 2013;28:1470-82.
2. El-Sheikh MAY, Mostafa TMN, El-Sheikh MM. Effect of different angulations and collar lengths of conical hybrid implant abutment on screw loosening after dynamic cyclic loading. Int J Implant Dent 2018;4:39.
3. Lauritano D, Moreo G, Lucchese A, Viganoni C, Limongelli L, Carinci F. The impact of implant-abutment connection on clinical outcomes and microbial colonization: a narrative review. Materials (Basel) 2020;13:1131.
4. Maeda Y, Satoh T, Sogo M. In vitro differences of stress concentrations for internal and external hex implant-abutment connections: a short communication. J Oral Rehabil 2006;33:75-8.
5. Gehrke SA, Pereira Fde A. Changes in the abutment-implant interface in Morse taper implant connections after mechanical cycling: a pilot study. Int J Oral Maxillofac Implants 2014;29:791-7.
6. Lopes PA, Carreiro AFP, Nascimento RM, Vahey BR, Henriques B, Souza JCM. Physicochemical and microscopic characterization of implant-abutment joints. Eur J Dent 2018;12:100-4.
7. Prado AM, Pereira J, Silva FS, Henriques B, Nascimento RM, Benfatti CAM, López-López J, Souza JCM. Wear of Morse taper and external hexagon implant joints after abutment removal. J Mater Sci Mater Med 2017;28:65.
8. Geckili E, Geckili O, Bilhan H, Kutay O, Bilgin T. Clinical comparison of screw-retained and screwless morse taper implant-abutment connections: one-year post-loading results. Int J Oral Maxillofac Implants 2017;32:1123-31.
9. Urdaneta RA, Marincola M, Weed M, Chuang SK. A screwless and cementless technique for the restoration of single-tooth implants: a retrospective cohort study. J Prosthodont 2008;17:562-71.
10. Ugurel CS, Steiner M, Isik-Ozkol G, Kutay O, Kern M. Mechanical resistance of screwless morse taper and screw-retained implant-abutment connections. Clin Oral Implants Res 2015;26:137-42.
11. Bressan E, Lops D, Tomasi C, Ricci S, Stocchero M, Carniel EL. Experimental and computational investigation of Morse taper conometric system reliability for the definition of fixed connections between dental implants and prostheses. Proc Inst Mech Eng H 2014;228:674-81.
12. Moris IC, Faria AC, Ribeiro RF, Rodrigues RC. Torque loss of different abutment sizes before and after cyclic loading. Int J Oral Maxillofac Implants 2015;30:1256-61.
13. Wang TM, Lee MS, Wang JS, Lin LD. The effect of implant design and bone quality on insertion torque, resonance frequency analysis, and insertion energy during implant placement in low or low- to medium-density bone. Int J Prosthodont 2015;28:40-7.
14. Ettinger S, Schwarze M, Yao D, Ettinger M, Claassen L, Stukenborg-Colsman C, Thermann H, Plaass C. Stability of supramalleolar osteotomies using different implants in a sawbone model. Arch Orthop Trauma Surg 2018;138:1359-63.
15. Bischel OE, Nadorf J, Klein SB, Gantz S, Jakubowitz E, Kretzer JP, Arnholdt J, Seeger JB. Modular tumor prostheses: are current stem designs suitable for distal femoral reconstruction? A biomechanical implant stability analysis in Sawbones. Arch Orthop Trauma Surg 2019;139:843-9.
16. Danza M, Carinci F. Flapless surgery and immediately

loaded implants: a retrospective comparison between implantation with and without computer-assisted planned surgical stent. Stomatologija 2010;12:35-41.
17. Hellwig E, Schäfer E, Klimek J, Attin T. Introduction to tooth preservation. 6th ed. Collogne: Deutscher Zahnärzte Verlag; 2013.
18. Mangano F, Bakaj R, Frezzato I, Frezzato A, Montini S, Mangano C. Morse taper connection implants placed in grafted sinuses in 65 patients: a retrospective clinical study with 10 years of follow-up. Int J Dent 2017;2017:4573037.
19. Mangano F, Lucchina AG, Brucoli M, Migliario M, Mortellaro C, Mangano C. Prosthetic complications affecting single-tooth morse-taper connection implants. J Craniofac Surg 2018;29:2255-62.
20. Urdaneta RA, Marincola M. The integrated abutment crown, a screwless and cementless restoration for single-tooth implants: a report on a new technique. J Prosthodont 2007;16:311-8.
21. Arshad M, Mahgoli HA, Rasouli K, Refoua S. A novel technique to retrieve cold-welded implant abutment: a case series. Clin Case Rep 2019;7:1854-7.
22. Norton MR. Assessment of cold welding properties of the internal conical interface of two commercially available implant systems. J Prosthet Dent 1999;81:159-66.
23. Merz BR, Hunenbart S, Belser UC. Mechanics of the implant-abutment connection: an 8-degree taper compared to a butt joint connection. Int J Oral Maxillofac Implants 2000;15:519-26.
24. Bozkaya D, Müftü S. Mechanics of the tapered interference fit in dental implants. J Biomech 2003;36:1649-58.
25. Pintinha M, Camarini ET, Sábio S, Pereira JR. Effect of mechanical loading on the removal torque of different types of tapered connection abutments for dental implants. J Prosthet Dent 2013;110:383-8.
26. Hsu PF, Yao KT, Kao HC, Hsu ML. Effects of axial loading on the pull-out force of conical connection abutments in ankylos implant. Int J Oral Maxillofac Implants 2018;33:788-94.