ORIGINAL RESEARCH

In Vitro Comparison of Loss of Torque between Gold and Titanium Alloy Abutment Screws in Dental Implants without Any Cyclic Loads

Nithyapriya Selvamani[1], Ramesh Ardhanari Shanmugasundaram[2], Anand Selvaraj[3], Gayathri Ranganathan[4], Sonia Abraham[5], Kirubakaran A[6]

Abstract

Aim: To find and compare the amount of screw loosening in gold and titanium alloy abutment screws without any cyclic load, this study was performed.

Materials and methods: A total of 20 implant fixture screw samples with 10 gold abutment screws from Osstem and 10 titanium alloy abutment screws from Genesis. Implant fixtures were placed into the acrylic resin using a surveyor to maintain the same path of insertion. Using a hex driver and calibrated torque wrench, initial torque was given according to the manufacturer's recommendation. One vertical and other horizontal lines were drawn over the head of the hex driver and resin block. Acrylic block position was standardized using a putty index in a fixed table and using a tripod stand a digital single-lens reflex camera (DSLR) camera was positioned with its horizontal arm facing the floor, as well as perpendicular to the acrylic box. Photographs were taken immediately after the application of the initial torque given as per the manufacturer's recommendation and 10 minutes after the initial torque. Re-torque of 30 and 35 N cm was given to gold and titanium alloy abutment screws respectively. Photographs were taken again in that same position immediately after re-torquing and 3 hours after re-torquing. The photographs were uploaded into the Fiji-win64 analysis software and the angulations were measured in each photograph.

Results: Both the gold and titanium alloy abutment screws exhibited screw loosening after initial torquing. There was a significant difference in the amount of screw loosening between gold and titanium alloy abutment screws after initial torquing and no change in the abutment screw position after three hours of re-torquing.

Conclusion: Re-torquing of both gold and titanium alloy abutment screws after 10 minutes of initial torquing should be performed routinely for retaining the preload and minimizing the screw loosening even before loading the implant fixture.

Clinical significance: Gold abutment screws may have the ability to retain the preload better than the titanium alloy abutment screws after initial torquing, re-torquing may be necessary after 10 minutes to reduce the settling effect in a routine clinical procedure.

Keywords: Loss of torque, Preload loss, Screw loosening.

The Journal of Contemporary Dental Practice (2022): 10.5005/jp-journals-10024-3388

Introduction

The dental implant is a successful treatment option for replacing missing teeth in edentulous patients. Abutment screw loosening, abutment screw fracture, gingival bleeding and enlargement, purulent discharge, pain, fracture of prosthetic components, and angular bone loss are some of the reasons for implant failure. One of the major reasons for implant failure is screw loosening[1] and fracture of the abutment screws that hold the prosthesis. The major cause for the loosening of the abutment screw is loss of preload.[1] Preload is the axial force in the neck of the abutment screw, which is between the first mating thread and the head of the abutment screw. The tensile force is the one that clamps the abutment to the implant thereby improving the locking effect and fatigue strength of the screw.[2] The force that keeps the abutment screw tight is the friction force between the threads of the implant and the abutment. At micro-level friction, the interlocking and welding together of minute peaks are called the asperity of the opposing surfaces.[3] If any movement even micro-movement occurs parallel to the plane of friction, then the asperity is sheared off and produces an abrasive powder between the two surfaces.[4] This leads to the reduction in the preload and friction force thereby reducing the rigidity of the assembly and making it more prone to lateral loads. Torque is a convenient measurable means of developing the desired tension.

[1,3,5,6]Department of Prosthodontics, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Tamil Nadu, India

[2]Department of Prosthodontics and Implantology, Sai Poly Clinic, Chennai, Tamil Nadu, India

[4]Department of Oral Medicine and Radiology, Ora Care Dental Clinic, Ranipet, Tamil Nadu, India

Corresponding Author: Nithyapriya Selvamani, Department of Prosthodontics, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Tamil Nadu, India, Phone: +91 9080096491, e-mail: nithul219@gmail.com

How to cite this article: Selvamani N, Shanmugasundaram RA, Selvaraj A, *et al.* *In Vitro* Comparison of Loss of Torque between Gold and Titanium Alloy Abutment Screws in Dental Implants without Any Cyclic Loads. J Contemp Dent Pract 2022;23(8):801–806.

Source of support: Nil

Conflict of interest: None

When the applied torque is too small it may lead to screw loosening, failure, or fatigue. When it is larger it may cause stripping of the threads and failure of the abutment screws.

Screw loosening may occur by settling the screw. This phenomenon depends on the presence of surface irregularities that prevent maximum contact of the screw with the abutment and become worn during a function which leads to loss of preload.[5] Repeated loosening and tightening of uncoated abutment retaining screws will result in a progressive decrease in removal torques.[1–6] A total of 75–90% of the preload may be required to prevent loosening under moderate lateral loads. The principle that affects preload is embedment relaxation (settling). This occurs due to high spots or micro-roughness in the screw thread that were flattened during initial torquing and thereby produces friction between the threads.[7–10] This leads to loss of initial torque and preload. By applying the additional torque after embedment relaxation, the roughened parts of the screw threads are pulled together by the clamping force.[11,12] The embedment relaxation depends on the number of rough spots or irregularities, the surface hardness of the implant and screw, and also the amount of load applied. Torque application after embedment relaxation would help in regaining the preload.[13–15] In a review article by Nithyapriya et al., type of material, torque method, torque sequence, abutment connection type, the influence of lubrication, and abutment collar length are discussed as various factors that cause loss of preload.[6] When comparing titanium alloy material to gold, titanium alloy material is very resistant to scratch, bending, and cracking whereas gold has good durability, and can bend if stressed moderately but usually never cracks.[7] Since there is no study regarding a comparison of torque loss between the gold and titanium alloy abutment screws before cyclic loading, this study was performed to find the amount of screw loosening and preload loss in gold and titanium alloy abutment screw after initial torquing and re-torquing.

Materials and Methods

This study was performed in Adhiparasakthi Dental College and Hospital, Melmaruvathur, Chennai, Tamil Nadu, India, and the study components were obtained from two manufacturers, 10 implants and gold abutment screws from Osstem, 10 implants, and titanium alloy abutment screws from Genesis. To obtain the results, 7 hours and 10 minutes were spent on each sample. A hollow plastic box with a dimension of 3.5 cm × 3.5 cm was filled with orthodontic clear resin (Dentsply International) and placed in the surveyor flat platform perpendicular to the arm of the surveyor. The implant carrier was attached to the arm of the surveyor to position the implant into the acrylic. To ensure straight and parallel placement of implants each resin-filled box was placed on a dental surveyor so that the top surface of the box was perpendicular to the arm of the surveyor (Fig. 1). The implant was now embedded into the orthodontic resin using a surveyor's arm and allowed it to cure for 4 hours at room temperature. Each abutment was screwed into the corresponding implants to a finger-tight stage. As per the recommended manufacturer instructions, subsequent tightening of the abutment screws was done using a torque wrench. Over the head of the hex driver one vertical and one horizontal line were drawn along with the top surface of the resin block and extended to the implant platform. A tripod stand with a horizontal arm facing the floor was positioned and the acrylic box was placed perpendicular to the camera. The camera was positioned using a tripod stand. A DSLR Camera (EOS Canon 1200D) was used for taking photographs. The image was taken without flash, with a fixed shutter speed of 1/125 s, automated white balance, aperture F/22, and ISO 100. There was a fixed distance of 37 cm between the acrylic box and the camera. This study has done in Tamil Nadu, India for about 60 hours. Initial torque was given according to the manufacturer's recommendation of 30 and 35 N for gold and titanium alloy abutment screws, respectively, then photographs (A1) were taken. After 10 minutes of initial torquing, photographs (A2) were taken once again in that same position. Then re-torquing once again of 30 and 35 N was given for gold and titanium alloy abutment screws as per the manufacturer's instruction and photographs (A3) were taken. After 3 hours of re-torquing, one last photograph (A4) was taken in that same position. These photographs were uploaded into the photometric analysis software (Fiji-win64). The horizontal line in the acrylic block and the vertical line in the head of the hex driver were taken as standard lines for measuring the angulation. The angulation between those two lines was measured in all four photographs and repeated for all the samples (Fig. 2). The values measured are calculated as follows: A5 = (A2 − A1), recorded loss of torque after 10 minutes of initial torquing, that is, self-loosening of the screw, A6 = (A1 − A3); recorded loss of torque immediately after re-torquing, A7 = (A5 + A6) The actual loss of torque after re-torquing and A8 = (A3 − A4), loss of torque after 3 hours of re-torquing (Fig. 3). Photometric analysis was done using "Fiji-win64 software" for all the samples and the data obtained were given in Tables 1 and 2.

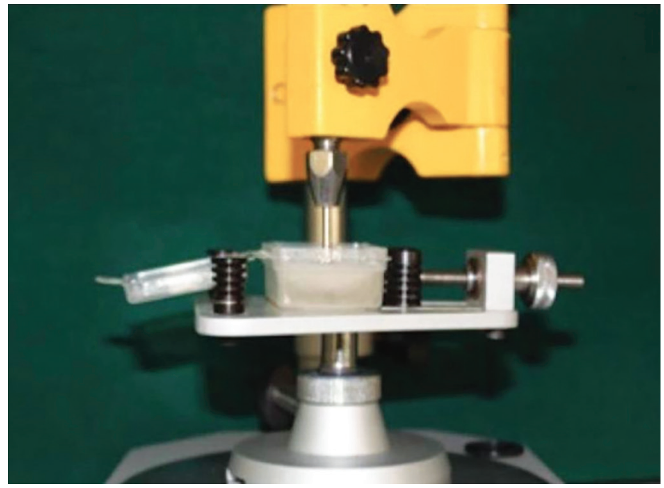

Fig. 1: Vertical positioning of the implant using surveyor

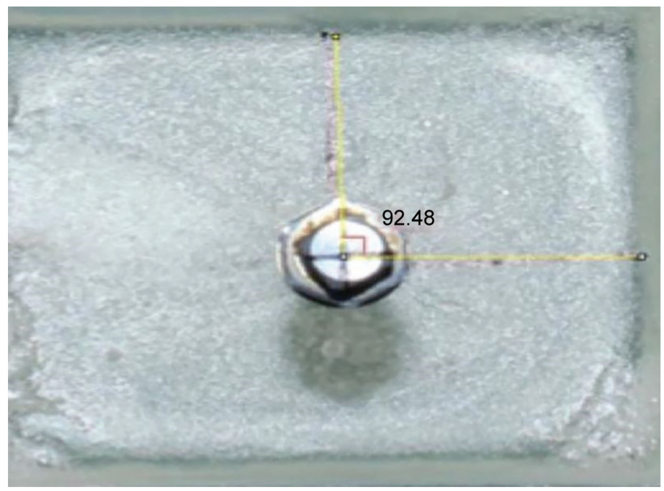

Fig. 2: Measuring the angulation over the head of hex driver using Fiji-win64 software

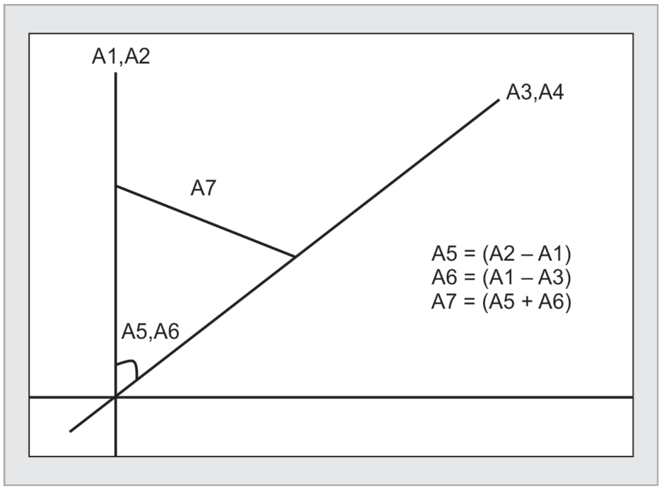

Fig. 3: Geometric diagram of each value

Results

In A1, A2, A6, A7, A6%, and A7%, it shows that there is a difference in mean ranks between gold and titanium alloy abutment screw, titanium alloy abutment screw seems to have more highest torque loss without any cyclic load, whereas in A3 and A4, the gold abutment screw has the highest torque loss. In A5, A8, and A5%, the mean ranks are equal. The calculated test statistics value is greater than the critical value; also, the *p*-value is lesser than 0.05 which rejects the null hypothesis and shows that there is a significant difference between the amount of screw loosening in gold and titanium alloy abutment screws after torquing.

Since $p < 0.05$ for A1–A4, A6, A7, A6%, and A7%, we reject the null hypothesis; $p > 0.05$ for A5, A8, and A5%, so we retain the null hypothesis. As a result, gold abutment screws retain the preload much more than titanium alloy abutment screws (Tables 3 to 5).

Table 1: Values of gold abutment screws

	Gold									
A1	90	90	82.66	90.46	80.26	88.01	82.56	85.69	88.02	90.54
A2	90	90	82.66	90.46	80.26	88.01	82.56	85.69	88.02	90.54
A3	77.05	77.4	69.86	77.46	67.56	75.51	69.76	72.59	75.86	77.86
A4	77.05	77.4	69.86	77.46	67.56	75.51	69.76	72.59	75.86	77.86
A5	0	0	0	0	0	0	0	0	0	0
A6	12.95	12.6	12.8	13	12.7	12.5	12.8	13.1	12.16	12.68
A7	12.95	12.6	12.8	13	12.7	12.5	12.8	13.1	12.16	12.68
A8	0	0	0	0	0	0	0	0	0	0
	Expressing the values as loss of torque (in %)									
A5%	0	0	0	0	0	0	0	0	0	0
A6%	3.5972	3.5	3.5555	3.6111	3.5277	3.4722	3.5555	3.6388	3.3777	3.5222
A7%	3.5972	3.5	3.5555	3.6111	3.5277	3.4722	3.5555	3.6388	3.3777	3.5222

Table 2: Values of titanium alloy abutment screws

	Titanium alloy									
A1	92.48	91.09	94.65	90.99	89.19	84.29	87.38	87.01	90.99	91.09
A2	92.48	91.09	94.65	90.99	89.19	84.29	87.38	87.01	90.99	91.09
A3	72.43	71.49	75.1	70.94	69.39	64.49	67.48	67.41	70.94	71.49
A4	72.43	71.49	75.1	70.94	69.39	64.49	67.48	67.41	70.94	71.49
A5	0	0	0	0	0	0	0	0	0	0
A6	20.05	19.6	19.55	20.05	19.8	19.8	19.9	19.6	20.05	19.6
A7	20.05	19.6	19.55	20.05	19.8	19.8	19.9	19.6	20.05	19.6
A8	0	0	0	0	0	0	0	0	0	0
	Expressing the values as loss of torque (in %)									
A5%	0	0	0	0	0	0	0	0	0	0
A6%	5.5694	5.4444	5.4305	5.5694	5.5	5.5	5.5277	5.4444	5.5694	5.4444
A7%	5.5694	5.4444	5.4305	5.5694	5.5	5.5	5.5277	5.4444	5.5694	5.4444

Table 3: Mean ranks of the variables

Group	*N*	*Mean rank*	*Sum of ranks*
A1			
Gold	10	7.80	78.00
Titanium	10	13.20	132.00
Total	20		
A2			
Gold	10	7.80	78.00
Titanium	10	13.20	132.00
Total	20		
A3			
Gold	10	13.50	135.00
Titanium	10	7.50	75.00
Total	20		
A4			
Gold	10	13.50	135.00
Titanium	10	7.50	75.00
Total	20		
A5			
Gold	10	10.50	105.00
Titanium	10	10.50	105.00
Total	20		
A6			
Gold	10	5.50	55.00
Titanium	10	15.50	155.00
Total	20		
A7			
Gold	10	5.50	55.00
Titanium	10	15.50	155.00
Total	20		
A8			
Gold	10	10.50	105.00
Titanium	10	10.50	105.00
Total	20		
A5%			
Gold	10	10.50	105.00
Titanium	10	10.50	105.00
Total	20		
A6%			
Gold	10	5.50	55.00
Titanium	10	15.50	155.00
Total	20		
A7%			
Gold	10	5.50	55.00
Titanium	10	15.50	155.00
Total	20		

Discussion

The torque can be applied by tightening the abutment screw. A force will develop within the abutment screw after the application of torque called the preload. When a screw is tightened, it gets elongated and creates tension thereby causing elastic recovery and pulling the two parts together to produce a clamping force. When the force acts on the screw joint are greater than the clamping force holding the screw assembly, screw loosening occurs. Excessive force will lead to slippage between screw threads, resulting in a preload loss.[16–19] Thus, decreasing separating forces and increasing clamping forces will act to prevent the loosening of the screw.[20–22] A mechanism that results in such loosening of the screw in implant-supported restorations is said to be a settling effect (embedment relaxation). This plays a crucial role in screw stability, as the result of no completely smooth surface. It does not matter how carefully the surface of each implant is built when viewed microscopically it will be micro-rough. Because of this, two surfaces cannot contact completely with one another.[23,24] Sakaguchi and Borgersen discussed that settling occurs as the rough spots get flattened when the load is applied to the contacting surfaces during the initial tightening torque. When it is subjected to external loads, micro-movement occurs between the surfaces[25] and reported that 2–10% of the applied initial preload. It also reported that applying the initial torque values higher than the recommended values by manufacturers for their implant screws may result in stripping, breakage, and other problems.[25] Sones in his research, reported that if failed screws cannot be retrieved from the implant, there might be a necessity to remake the entire prosthesis.[26] The friction of threads is higher in the initial tightening and loosening of a screw and lesser after repeated tightening and loosening cycles.[8] In the study of Luis Eduardo Butingnon, 45 samples were used and were divided into three groups machined titanium, pre-machined gold, and pre-machined zirconia. The results showed that there is no significant difference between the groups before cyclic loading and after load application. The mean preload is reduced significantly in all groups and more significantly in the zirconia group.[21–28]

In this study, the mean value of recorded loss of torque after re-torquing for gold abutment screws is 5.5 and for titanium alloy, abutment screws are 15.5. The mean value for the actual loss of torque after re-torquing for gold abutment screws is 5.5 and for titanium alloy, abutment screws are 15.5. The calculated test statistics value is greater than the critical value; also, $p < 0.05$ which rejects the null hypothesis and shows that there is a significant difference between the amount of screw loosening in gold and titanium alloy abutment screws after torquing. Here, the gold and titanium abutment screws are torqued and analysis was done without giving any load and found that the gold abutment screws can retain the initial torque more than the titanium alloy abutment screws.[29–33] Thereby, to limit the settling effect, the implant–abutment screw complex should be tightened again after 10 minutes of initial torque application in a routine treatment procedure. Mechanical torque instruments should be used to enhance the consistent tightening of implant components till the required torque values are recommended by the manufacturers.

The effectiveness of surface coating and cyclic loading after torque application have not been done in this study. For more relevant results, load application in abutment screws using a cyclic loading machine can be done. The effectiveness of surface coating should be the focus of future studies. In a similar study

Table 4: Test statistic values

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A5%*	*A6%*	*A7%*
Mann–Whitney *U* test	23.000	23.000	20.000	20.000	50.000	0.000	0.000	50.000	50.000	0.000	0.000
Wilcoxon *W*	78.000	78.000	75.000	75.000	105.00	55.000	55.000	105.00	105.00	55.000	55.000
Z	2.043	2.043	2.269	2.269	0.000	3.794	3.794	0.000	0.000	3.794	3.794
Asymptotic significance (2 tailed)	0.041	0.041	0.023	0.023	1.00	0.000	0.000	1.00	1.00	0.000	0.000
Exact significance [2 × (1-tailed significance)]	0.043[b]	0.043[b]	0.023[b]	0.023[b]	1.000[b]	0.000[b]	0.000[b]	1.000[b]	1.000[b]	0.000[b]	0.000[b]

Table 5: Hypothesis test summary

S.No.	*Null hypothesis*	*Test*	*Significance*	*Decision*
1.	The distribution of A1 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.043	Reject the null hypothesis
2.	The distribution of A2 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.043	Reject the null hypothesis
3.	The distribution of A3 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.023	Reject the null hypothesis
4.	The distribution of A4 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.023	Reject the null hypothesis
5.	The distribution of A5 is the same across categories of group A	Independent samples Mann–Whitney *U* test	1.000	Retain the null hypothesis
6.	The distribution of A6 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.000	Reject the null hypothesis
7.	The distribution of A7 is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.000	Reject the null hypothesis
8.	The distribution of A8 is the same across categories of group A	Independent samples Mann–Whitney *U* test	1.000	Retain the null hypothesis
9.	The distribution of A5% is the same across categories of group A	Independent samples Mann–Whitney *U* test	1.000	Retain the null hypothesis
10.	The distribution of A6% is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.000	Reject the null hypothesis
11.	The distribution of A7% is the same across categories of group A	Independent samples Mann–Whitney *U* test	0.000	Reject the null hypothesis

by Doolabh et al., it is inferred that there is a significant change in preload after cyclic loading over the implant–abutment complex. However, in our study, cyclic loading is not done which is one of the limitations of this study. If further studies are done on this domain, where the cyclic loading is applied to the implant–abutment complex, we can substantiate the significance of cyclic loading over the implant–abutment complex and torque loss between the gold and titanium alloy abutment screws in dental implants.

Conclusion

By comparing the torque loss between two abutment screw materials prior to and after giving re-torque, it shows that Re-tightening the abutment screws as per the manufacturers' recommendations after 10 minutes of initial torque application should be performed routinely during abutment-implant connections and gold abutment screws can retain the torque greater than the titanium alloy abutment screws. Also, the type of material used as an abutment screw and re-torquing the abutment screws after 10 minutes are the most important factors to decrease the screw loosening.

References

1. Siamos G, Winkler S, Boberick KG. Relationship between implant preload and screw loosening on implant-supported prostheses. J Oral Implantol 2002;28(2):67–73. DOI: 10.1563/1548-1336(2002)028<0067:TRBIPA>2.3.CO;2.
2. Goheen KL, Vermilyea SG, Vossoughi J, et al. Torque generated by handheld screwdrivers and mechanical torquing devices for osseointegrated implants. Int J Oral Maxillofac Implants 19941;9(2):149–155. PMID: 8206549.
3. Kazemi M, Rohanian A, Monzavi A, et al. Evaluation of the accuracy and related factors of the mechanical torque-limiting device for dental implants. J Dentistry (Tehran). 2013;10(2):112–118. PMID: 23724209.
4. Barbosa GS, Silva–Neto JP, Simamoto–Júnior PC, et al. Evaluation of screw loosening on new abutment screws and after successive tightening. Brazilian Dent J 2011;22(1):51–55. DOI: 10.1590/s0103-64402011000100009.

5. Al-Otaibi HN, Almutairi A, Al Farraj J, et al. Effect of torque application technique on screw preload of implant-supported prostheses. Int J Oral Maxillofac Implants 2017;32(2):259–263. DOI: 10.11607/jomi.4773.
6. Nithyapriya S, Ramesh AS, Kirubakaran A, et al. Systematic analysis of factors that cause loss of preload in dental implants. J Indian Prosthodont Soc 2018;18(3):189–195. DOI: 10.4103/jips.jips_294_17.
7. Doolabh R, Dullabh HD, Sykes LM. A comparison of preload values in gold and titanium dental implant retaining screws. SADJ 2014;69(7):316–320. PMID: 26548212.
8. Tsuge T, Hagiwara Y. Influence of lateral–oblique cyclic loading on abutment screw loosening of internal and external hexagon implants. Dental Mater J 2009;28(4):373–381. DOI: 10.4012/dmj.28.373.
9. Tzenakis GK, Nagy WW, Fournelle RA, et al. The effect of repeated torque and salivary contamination on the preload of slotted gold implant prosthetic screws. J Prosthet Dent 2002;88(2):183–191. DOI: 10.1067/mpr.2002.127604.
10. Winkler S, Ring K, Ring JD, et al. Implant screw mechanics and the settling effect: an overview. J Oral Implantol 2003;29(5):242–245. DOI: 10.1563/1548-1336(2003)029<0242:ISMATS>2.3.CO;2.
11. Khraisat A, Hashimoto A, Nomura S, et al. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. J Prosthet Dent 2004;91(4):326–334. DOI: 10.1016/j.prosdent.2004.01.001.
12. Kitagawa T, Tanimoto Y, Odaki M, et al. Influence of implant/abutment joint designs on abutment screw loosening in a dental implant system. J Biomed Mater Res B Appl Biomater 2005;75(2):457–463. DOI: 10.1002/jbm.b.30328.
13. Piermatti J, Yousef H, Luke A, et al. An in vitro analysis of implant screw torque loss with external hex and internal connection implant systems. Implant Dent 2006;15(4):427–435. DOI: 10.1097/01.id.0000245440.09464.48.
14. Wuo AD. Measurement of the loosening torque of the prosthetic component in a morse-taper connection in dental implants using carbon deposition on the friction surface. Doctoral dissertation, University of São Paulo, Brazil. (In Portuguese).
15. Al Jabbari Y, Fournelle R, Ziebert G, et al. Mechanical behavior and failure analysis of prosthetic retaining screws after long-term use in vivo. Part 2: Metallurgical and Microhardness Analysis. J Prosthodont 2008;17(3):181–191. DOI: 10.1111/j.1532-849X.2007.00265.x.
16. Park JK, Choi JU, Jeon YC, et al. Effects of abutment screw coating on implant preload. J Prosthodont 2010;19(6):458–464. DOI: 10.1111/j.1532- 849X.2010.00595.x.
17. Kim KS, Lim YJ, Kim MJ, et al. Variation in the total lengths of abutment/implant assemblies generated with a function of applied tightening torque in external and internal implant–abutment connection. Clin Oral Implants Res 2011;22(8):834–839. DOI: 10.1111/j.1600-0501.2010.02063.x.
18. Guda T, Ross TA, Lang LA, et al. Probabilistic analysis of preload in the abutment screw of a dental implant complex. The Journal of prosthetic dentistry. 2008;100(3):183–193.
19. Guzaitis KL, Knoernschild KL, Viana MAG. Effect of repeated screw joint closing and opening cycles on implant prosthetic screw reverse torque and implant and screw thread morphology. J Prosthet Dentist 2011;106(3):159–169. DOI: 10.1016/S0022-3913(11)60115-7.
20. Ferreira MB, Delben JA, Barao VA, et al. Evaluation of torque maintenance of abutment and cylinder screws with Morse taper implants. J Craniofac Surg 2012;23(6):e631–e634. DOI: 10.1097/SCS.0b013e318270fe0e.
21. Butignon LE, de Basílio MDA, Pereira RDP, et al. Influence of three types of abutments on preload values before and after cyclic loading with structural analysis by scanning electron microscopy. Int J Oral Maxillofac Implants 2013;28(3):e161–e170. DOI: 10.11607/jomi.2481.
22. Bernardes SR, de Mattos MDGC, Hobkirk J, et al. Loss of preload in screwed implant joints as a function of time and tightening/untightening sequences. Int J Oral Maxillofac Implants 2014;29(1):89–96. DOI: 10.11607/jomi.3344.
23. Siadat H, Pirmoazen S, Beyabanaki E, et al. Does abutment collar length affect abutment screw loosening after cyclic loading? J Oral Implantol 2015;41(S1):346–351. DOI: 10.1563/AAID-JOI-D-D-14-00021.
24. Jörn D, Kohorst P, Besdo S, et al. Influence of lubricant on screw preload and stresses in a finite element model for a dental implant. J Prosthetic Dentist 2014;112(2):340–348. DOI: 10.1016/j.prosdent.2013.10.016.
25. Sakaguchi RL, Borgersen SE. Nonlinear contact analysis of preload in dental implant screws. Int J Oral Maxillofac Implants 1995;10(3):295–302. PMID: 7615325.
26. Sones AD. Complications with osseointegrated implants. J Prosthetic Dent 1989;62(5):581–585. DOI: 10.1016/0022-3913(89)90084-x.
27. Shin HM, Huh JB, Yun MJ, et al. Influence of the implant–abutment connection design and diameter on the screw joint stability. J Adv Prosthodont 2014;6(2):126–132. DOI: 10.4047/jap.2014.6.2.126.
28. Jo JY, Yang DS, Huh JB, et al. Influence of abutment materials on the implant–abutment joint stability in internal conical connection type implant systems. J Adv Prosthodont 2014;6(6):491–497. DOI: 10.4047/jap.2014.6.6.491.
29. Al-Sahan MM, Al Muflehi NS, Akeel RF. The influence of tightening sequence and method on screw preload in implant superstructures. Int J Prosthodont 2014;27(1):76–79. DOI: 10.11607/ijp.3306.
30. Yilmaz B, Gilbert AB, Seidt JD, et al. Displacement of implant abutments following initial and repeated torqueing. Int J Oral Maxillofac Implants 2015;30(5):1011–1018. DOI: 10.11607/jomi.3694.
31. Bulaqi HA, Mashhadi MM, Geramipanah F, et al. Effect of the coefficient of friction and tightening speed on the preload induced at the dental implant complex with the finite element method. J Prosthet Dent 2015;113(5):405–411. DOI: 10.1016/j.prosdent.2014.09.021.
32. Bacchi A, Reglan A, Bhering CL, et al. Loosening torque of universal abutment screws after cyclic loading: Influence of tightening technique and screw coating. J Adv Prosthodont 2015;7(5):375–379. DOI: 10.4047/jap.2015.7.5.375.
33. Kose OD, Karataslı B, Demircan S, et al. In vitro evaluation of manual torque values applied to implant–abutment complex by different clinicians and abutment screw loosening. Biomed Res Int 2017;2017:2017:7376261. DOI: 10.1155/2017/7376261.