Effect of Serrating Abutment-Implant Mating Surface on Torque Stability of Implant-Abutment Connection, Before and After Cyclic Loading

Vida Rezayani, DDS, MS[1]*
Marzieh Alikhasi, DDS, MS[2]
Abbas Monzavi, DDS, MS[3]

This study evaluated the effect of adding serration to the abutment-implant connection on torque maintenance before and after loading. Two implant systems with the same dimensions and connection design (internal 8° Morse taper octagon) were selected: one with nonserrated abutments (Simple line II) and the other one with serrated abutments (F & B). The removal torque value (RTV) was measured in 2 groups for each system: one group with one-piece abutments and the other group with 2-piece abutments, before and after cyclic loading (n = 10 in each group). The initial RTV of the abutment screw was measured with a digital torque meter. Each abutment received a cement-retained metal crown with 30° occlusal surface. Cyclic axial peak load of 75 ± 5 N was applied to the implants for 500 000 cycles at 1 Hz. The post-load RTV was then measured. Two-way and repeated-measures analysis of variance (ANOVA), and independent *t* test were applied to assess the effects of cyclic loading, connection design, abutment type, and their interaction on the percentage of torque loss ($\alpha = .05$). Two-way ANOVA showed that serration of mating surfaces had a significant effect on torque maintenance before ($P < .001$) and after ($P = .004$) cyclic loading. Repeated-measures ANOVA also showed that loading had a significant effect on the torque loss percentage ($P < .01$). Comparison of the groups with *t* test showed that the torque loss of the serrated groups was lower than that of non- serrated groups. Despite the limitations of this study, the stability of the implant-abutment connection in the serrated design was higher than that of non-serrated group.

Key Words: implant-abutment connection, torque loss, cyclic loading, removal torque value, screw loosening, torque stability

INTRODUCTION

Titanium dental implants are widely used because of their benefits such as optimal mechanical properties and great anchorage in the jawbone. The suitable choice of a particular type of a prosthetic restoration (cement-retained or screw-retained), and an appropriate implant-abutment connection system (external hexagon, internal hexagon, or internal taper) are critical for successful outcomes.[1,2] However, mechanical complications such as fracture or mobility of the superstructure or abutment screw have been frequently reported.[3,4] These complications may occur due to several reasons, such as the errors accumulated during the multiple steps of prosthesis fabrication, characteristics of the materials, or the surface irregularities of the mating surfaces of implant, abutment, and screw.[5–9] Factors such as the connection design, screw design, screw settling, adequate preload by proper tightening torque, precision of mating implant components, and implant diameter are also important in screw joint stability.[10–16] Recent studies have reported that the positional stability of the implant-abutment connection is a determinant factor for prosthesis misfit and mechanical complications.[17–19]

A number of studies have compared the efficacy of different connection mechanisms securing the implant-abutment connection stability, which determines the mechanical integrity, strength and stability of the assembly.[9,20–23] Currently, there are over 20 different commercially available geometrical variations of implant-abutment interface, and all manufacturers claim that their designs greatly contribute to implant connection stability.[24,25] Most current designs have been derived from 2 basic designs namely the "butt-joint" with an external connection, and internal "cone-in-cone" connection. According to some recent studies, the latter design shows higher resistance against the bending forces applied to the implant-abutment connection and minimizes the risk of screw loosening and fracture that typically occur in use of external butt-joint connections.[1,26–28] On the other hand, some studies claim that the abutment screw characteristics, such as the screw material or surface, are the main determinant factors in this respect, and neither the internal nor the external design

[1] Assistant Professor, Department of Prosthodontics, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[2] Associate Professor, Dental Research Center, Implant Research Center, Laser Research Center, Dentistry Research Institute, Tehran University of Medical Sciences and Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.
[3] Professor, Department of Prosthodontics and Implant, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.
* *Corresponding author,* e-mail: vida_rezayani_cg@yahoo.com
https://doi.org/10.1563/aaid-joi-D-19-00029

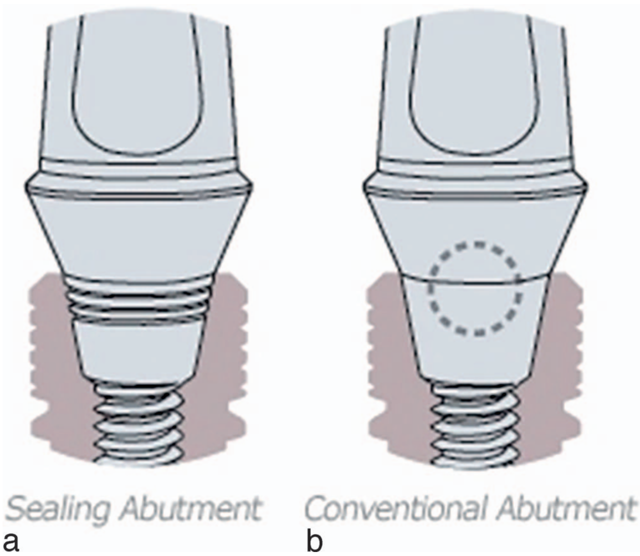

Figure 1. (a) Adding the serration feature to the implant-abutment connection. (b) Conventional implant-abutment internal connection.

had any important effect on implant-abutment connection.[29,30] An abutment with internal taper connection may have directly machined threads on the abutment body (1-piece abutment), or it may be fixed to the implant by a separate screw (2-piece abutment).[1,2] The preference for one type of the abutment over the other (1- or 2-piece) depends on different factors such as the clinical and laboratory procedures, and the location of implant in dental arch (eg, esthetic zone).[1,2] Type of abutment also affects the stress distribution, which can be related to the number of components the abutment is made of.[31,32]

The torque applied to a new screw causes elongation, and the subsequent elastic recovery results in generation of a compressive clamping force between the screw head and the abutment, and also between the screw threads and the internal implant threads.[33,34] The contact force that clamps the implant and abutment together is called the preload.[33–35] Within the elastic limits, a higher preload increases the resistance to loosening.[34] Direct measurement of preload is preferable but not practical since it requires a strain gauge or load cell. However, for estimation of preload, indirect methods such as measuring the torque, angle of rotation of the screw head, or both can be used. Measuring the torque value is the most commonly used method for this purpose.[36]

The possibility of cold welding of the abutment inside the implant is a concern in internal taper systems, which could lead to clinical difficulties if the abutment needs to be retrieved.[37,38] Sutter et al reported 10% to 15% higher removal torque values (RTVs) of abutment compared with the respective initial torque values.[38] However, some other studies found that cold welding is probably counteracted by a phenomenon known as the settling effect (embedment relaxation),[39–41] which works on the threads of the screw part of the abutment, and decreases the initial torque.[1,5,18,42] Therefore, it has been shown that the RTVs of abutment screws immediately after screw tightening are frequently lower than the initial tightening torque values.[30,38,39] Another possible cause is permanent/plastic deformation of the mating surfaces.[26] During tightening of an abutment screw, the screw is damaged by friction, which may cause creeping, and decrease the tightening torque by 2%–10%.[40]

Dynamic loading in a chewing simulator is often used to simulate the clinical loading conditions.[41,42] Realistic simulation of intraoral conditions could improve clinical relevance of the results.[42,43] Generally, it is believed that screw loosening or torque loss would occur more after loading. Different studies have shown controversial results in this respect.[26,40,42,44–47]

Adding serration to the abutment connection is one strategy that has been claimed to enhance stability and better stress distribution at the implant-abutment connection, and subsequently decrease the rate of mechanical complications such as screw loosening (Figure 1a and b). The objective of this study was to evaluate the effects of cyclic loading on the RTV of internal taper abutments by comparing the percentage of torque loss of loaded and unloaded abutments. Two types of internal taper abutments of two implant systems, one system with serration feature on the implant-abutment connection and the other one with conventional mating surfaces were assessed. The null hypothesis of the study was that there would be no significant difference in RTVs of the 2 implant-abutment connection types.

Materials and Methods

Twenty implants of one implant system (4.8 × 10 mm; F&B, Busan, Korea) were divided into 2 groups. The first group (F_1) included 1-piece abutments (F&B, SESA455) with serrated design (F&B 1-piece abutment, F_1 group; Figure 2a) while the second group included 2-piece abutments (F&B, SEOA4305 O) with serration on the neck (F&B 2-piece abutment, F_2 group; Figure 2b). Twenty implants of another implant system (Dentium, Simple line II, Seoul, Korea) with the same dimensions (4.8 × 10 mm) and connection design (internal 8° morse taper octagon) were selected and divided into 2 groups of 1-piece (D_1) (SOSAB4855, Dentium 1-piece abutment; Figure 2c) and 2-piece (D_2) abutments (SODAB4855O, Dentium 2-piece abutment; Figure 2d).

For the fabrication of standardized full-metal crowns for each abutment, the occlusal surface of one abutment of each system was waxed up with the slope of 30° to simulate the direction of oral forces applied to the cusp.[18] Then, 38 duplicates were prepared by silicone material, and molten wax (blue inlay casting wax; GC Corp, Gyeonggi-do, South Korea) was used to fabricate the wax pattern of each duplicate. Each wax pattern was removed, and minor imperfections in the wax were corrected. Next, spruing, investing, burn out, and casting with a base metal alloy (Vera Bond V, Alba Dent, Fairfield, Calif) were performed.[18,26] The implant-abutment assemblies were fixed in a special jig to avoid any rotation or movement. The abutments of each group were torqued to the value recommended by the manufacturer, which was 30 Ncm for D groups and 35 Ncm for F groups using an electronic torque meter (Lutron Enterprise, Coopersburg, Penn). According to the protocol suggested by Dixon et al,[40] Breeding et al,[48] and Deben et al,[46] the abutment screw was retightened to the same torque 10 minutes later, to minimize embedment relaxation between the mating threads and help in achieving

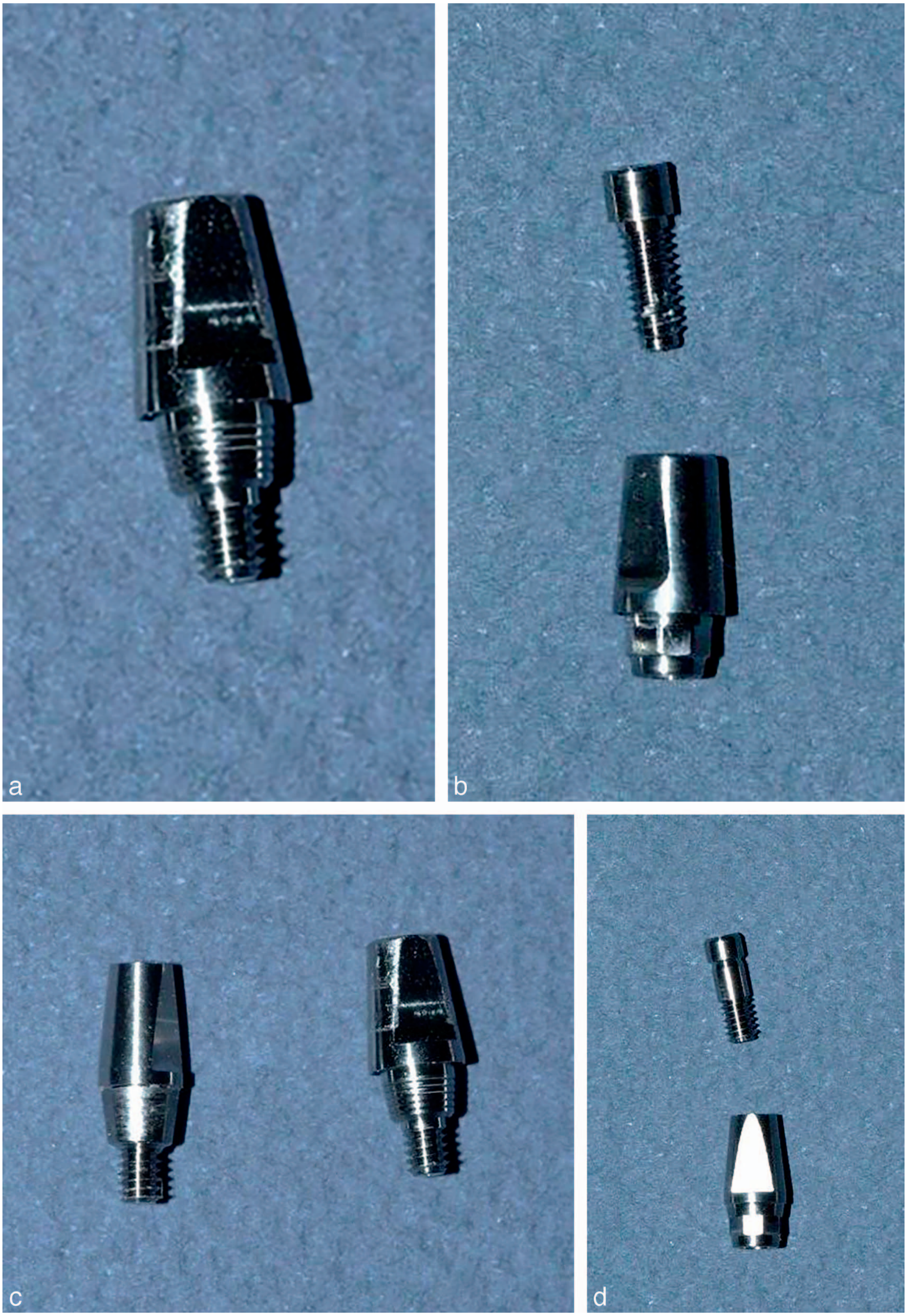

Figure 2. (a) F&B 1-piece abutment with serration on connection (F_1). (b) F&B 2-piece abutment with serration on connection (F_2). (c) Dentium 1-piece abutment (D_1). (d) Dentium 2-piece abutment (D_2).

Table 1

Torque loss percentage of different groups before and after cyclic loading

Groups	Before Cyclic Loading		After Cyclic Loading	
	Mean	SD	Mean	SD
Simple surface				
One-piece (D_1)	19.43	11.77	38.03	8.90
Two-piece (D_2)	21.85	14.40	45.11	9.54
Serrated				
One-piece (F_1)	6.18	3.72	31.33	8.13
Two-piece (F_2)	7.99	3.27	33.26	10.96

the optimal preload. Five minutes later, the reverse torque was measured using the same torque gauge and recorded.[9,21] Next, the implant-abutment assemblies were mounted in acrylic resin (Acropars, Iran) vertically by a dental surveyor in the loading pot of the chewing stimulator. Then, all metal castings were cemented with temporary cement (Temp Bond, Kerr, Salerno, Italy) mixed with petroleum jelly in 50:50 ratios to ensure easy retrieval of the crowns. The full metal casting was seated on the abutment with finger pressure for 10 seconds followed by a sustained pressure of 5 kg for 10 minutes.[1,9,21] The cement was allowed to set at room temperature. Upon setting and removing the excess cement, dynamic axial peak loads of 75 ± 5 N with a compressive sine wave were applied to the crowns for a duty of 500 000 cycles at 1 Hz. This loading regimen was applied by a chewing stimulator machine (S-D Mechatronic, Germany), and corresponded to 20 months of chewing in the clinical setting.[1,9,21] After cyclic loading, the castings were removed and the RTV of each abutment was measured by an electronic torque meter. The reverse torque loss percentage values were measured based on the difference between the preload values of each system.

A power analysis was performed to determine the minimum sample size necessary to test the null hypothesis considering the different experimental groups. The Kolmogorov-Smirnov test was applied to verify the normality and homoscedasticity of the insertion torque and removal torque data.

Three factors were involved in this study: the abutment type (1- or 2-piece), the connection design (with or without serration), and cyclic loading. Therefore, the data were analyzed using 2-way ANOVA; paired *t* test was used to compare the insertion torque and the RTV in each group before and after cyclic loading. The effect of cyclic loading and its interaction effects with the implant system and abutment type were

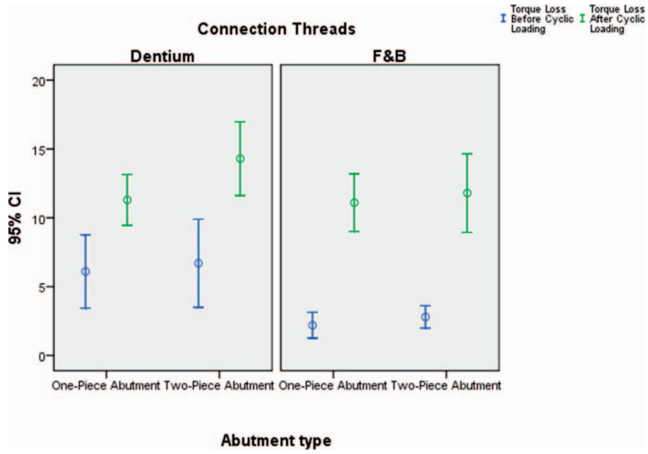

Figure 3. Torque loss percentage before and after cyclic loading in each group.

analyzed by repeated measures ANOVA. A probability level (*P* value) of less than .05 was considered statistically significant. All statistical analyses were performed using SPSS version 20.0. The methodology of the study was reviewed by an independent statistician.

Results

After dynamic loading, there was no screw loosening and no sign of mechanical failure in the specimens. During the experiment, loosening of cemented crowns was not noted by tactile or visual inspection, but wear of the occluding surfaces of restorations was detected. Also, following the RTV measurements, it was observed that the abutments did not have any sign of deformation or fracture. The measurements showed that the mean percentage of torque loss had a wide range of variation with a minimum value of 3.27% and maximum value of 38.3% (Table 1, Figure 3).

Two-way ANOVA showed that serration of implant-abutment mating surface had a significant effect on torque maintenance before ($P < .001$) and after ($P = .004$) cyclic loading (Table 2). Repeated-measures ANOVA also showed that loading had a significant effect on the percentage of torque loss ($P < .01$). Comparison of groups with *t* test showed that torque loss in F_2 groups was lower than that in D_2 groups, both before ($P = .008$) and after ($P = 0.19$) loading, and also was lower in F_1 group compared with D_1 before loading ($P = .003$; Table

Table 2

Two-way analysis of variance (ANOVA) results for the removal torque value before and after loading of experimental groups

Source of Variation	df	Sum of Squares		Mean Square		*F*		*P*	
		Before Loading	After Loading	Before Loading	After Loading	Before Loading	After Loading	Before Loading	After Loading
Intercept	1	7689.39	54 566.45	7689.39	54 566.45	6.77	612.31	.000	.000
System (serrated or non-serrated)	1	1836.80	860.32	1836.80	860.32	82.98	9.65	.000	.004
Abutment	1	44.83	203.03	44.83	203.03	19.82	2.28	.49	.14
System * abutment	1	.934	66.26	.93	66.26	.48	.74	.92	.39

TABLE 3

Paired t test results for 1- and 2-piece abutments before and after cyclic loading

	Levene's Test for Equality of Variances		t test for Equality of Means		
	F	Sig.	Significance (2-tailed)	Mean Difference	Standard Error Difference
1-piece abutment					
% of torque loss before loading	20.49	.00	.003	13.25	3.90
			.006	13.25	3.90
% of torque loss after loading	.08	.79	.096	6.70	3.81
			.096	6.70	3.81
2-piece abutment					
% of torque loss before loading	14.81	.001	.008	13.86	4.67
			.014	13.86	4.67
% of torque loss after loading	1.28	.27	.019	11.85	4.59
			.019	11.85	4.59

3). The methodology and the results were reviewed by an independent statistician.

DISCUSSION

In this study, all abutments presented torque loss, indicating that cold welding did not occur at the abutment/implant connection. The effect of cyclic loading on implant-abutment connection, screw loosening, and the RTV has been reported in several studies.[1,21,23,25,26,36,46–49] The present results demonstrated that the torque loss percentage was significantly higher after loading in comparison with the torque loss percentage before loading. This was in accordance with the findings of other studies.[21,23,47] The reduction in RTV after loading conforms with the joint failure mechanisms explained by Bickford.[50] The external forces progressively decrease the preload because of screw vibration, wear of mating surfaces, and settling effect. The greater the abutment micromovements, the more the torque loss would be.[50] Although a high attrition force between the threads would prevent loosening, external loads may decrease the friction by compression of the screw head against the abutment base and result in screw loosening.[19,23]

Each implant system offers different abutment types for clinical use such as 1- and 2-piece abutments. However, the more recent provision of two-piece conical abutments for improved prosthetic flexibility raised a question regarding the stability of these joints, since the abutment screw is considered as the "weak link in the chain" and could affect the joint stability.[20] Joint stability of 2-piece abutments, in comparison with 1-piece abutments, has been studied in different investigations.[1,20,26] These results were in agreement with those of Norton[20] who concluded that the strength of both groups was beyond the clinical loads applied to the implant-abutment connection.[20] In another study, Cehreli et al[1] reported that the fatigue resistance of both types of abutments was extremely high after dynamic loading and both could have convenient function with no clinical complications. However, the RTV of 1-piece abutments was significantly higher than that of 2-piece abutments, which was not in agreement with our results.

The mechanical behavior of implants is influenced by the design of implant-abutment mating and retentive properties of the screw joints. In the current study, adding serration to either 1- or 2-piece abutments caused a lower percentage of torque loss that indicates that the type of connection may affect the RTV and this result was in agreement with the findings of many other studies.[2,24,27,37,51,52] Many studies have evaluated the effects of altering the mating surfaces or friction characteristics of implant-abutment connection.[1,9,22–24,26,30,40,49] Application of dynamic loading without considering the thermal alterations cannot simulate the humidity of the oral environment; thus, not simulating the continuous thermal alterations of the oral environment was one limitation of this study.[53,54] Another limitation of this study was the comparison of 2 systems with different recommended applied torque values. Despite these limitations, comparison of 2 different systems—serrated and non-serrated—with the same size of abutments and also evaluation of 1- and 2-piece abutments of each system together and conduction of dynamic loading for better simulation of clinical setting (compared with static loading) were the strength points of this study. Thus, this design might enhance joint stability and decrease mechanical complications such as screw loosening or fracture.

However, further studies are needed to evaluate the fatigue resistance of abutments with the serrated design. Finite element analyses are also required to evaluate stress distribution at the implant-abutment connection, compare screws made of different materials and also angled abutments or customized abutments of this design. For successful oral rehabilitation treatments, attempts should be made to improve the connection systems and increase the implant/prosthetic abutment interface stability to minimize the biological and mechanical complications.[45] Thus, lower drop of torque loss percentage in serrated specimens demonstrated in this study may be helpful to increase the implant-abutment connection stability.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1. Torque loss occurred in all abutments before and after cyclic loading, indicating that cold welding did not occur.

2. Torque loss was greater for the abutment screws after dynamic loading, which highlights the role of mechanical loading in torque loss.
3. The type of implant system significantly influenced the torque loss before and after cyclic loading. Despite the limitations of this study, the stability of the implant-abutment connection of the serrated design was better than that of non-serrated group.
4. In both systems, the torque loss of 2-piece abutments was higher than that of 1-piece abutments; but this difference was not statistically significant.

The methodology and conclusion were reviewed by an independent statistician.

Acknowledgments

We would like to acknowledge Dr Mohammad Javad Kharazifard for reviewing the methodology and statistical analyses as an independent statistician. Dr Kharazifard is Research Advisor for the Dental Research Center at Tehran University of Medical Sciences, Tehran, Iran.

Note

There is no conflict of interests for any of the authors.

References

1. Çeherli MC AK, Iplikçioĝlu H, Şahin S. Dynamic fatigue resistance of implant/abutment junction in an internally notched morse-taper oral implant: influence of abutment design. *Clin Oral Implants Res*. 2004;15: 459–465.

2. Merz BR, Hunebart S, Belser UC. Mechanics of the implant-abutment connection: an 8degree taper compared to a butt-joint connection. *Int J Oral Maxillofac Implants*. 2000;15:519–526.

3. Goodacare CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implant and implant prostheses. *J Prosthet Dent*. 2003;90: 121–132.

4. Bozini T, Petridis H, Garefis P. A meta-analysis dental prosthodontic complication rates of implant-supported fixed dental prostheses in edentulous patients after an observation period of at least 5years. *Int J Oral Maxillofac Implants*. 2011;26:304–318.

5. Davis DM, Packer ME, Watson RM. Maintenance requirements of implant-supported fixed prostheses opposed by implant-supported fixed prostheses, natural teeth, or complete dentures: a 5-year retrospective study. *Int J Prosthodont*. 2003;16:521–523.

6. Nadir R, Bischof M, Szmuller-Moncler S, Belser UC, Samson J. Prosthetic complications with dental implants: from an up-to-8-year experience in private practice. *Int J Oral Maxillofac Implants*. 2006;21:919–928.

7. Nicoll RJ, Sun A, Haney S, Turkyilmaz I. Precision of fit between implant impression coping and implant replica pairs for three implant systems. J Prosthet Dent. 2013;109:37–43.

8. Barbi FC, Camarini ET, Silva RS, Endo EH, Periera JR. Comparative analysis of different joining techniques to improve the passive fit of cobalt-chromium super structures. *J Prosthet Dent*. 2012;108:377–385.

9. Khraisat A, Stegaroiu R, Nomura S, Miyakawa O. Fatigue resistance of two implant/abutment joint designs. J Prosthet Dent. 2002;88:604–610.

10. Norton MR. An in vitro evaluation of the strength of an internal conical interface compared to a butt joint interface in implant design. *Clin Oral Implants Res*. 1997;8:290–298.

11. Selto CB, Sahyun HBS, Santos PH, Delben JP, Assuncao WG. Efficacy of sealing agents on preload maintenance of screw-retained implant-supported prostheses. *Int J Oral Maxillofac Implants*. 2018;33:123–126.

12. Schmitt J HS, Eitner S, Schegel A, Wichmann M, Hamel J. Prosthetic screw detorque values in implant retained as cast bar superstructures or bars modified by the Cresco Ti precision technique-a comparative in vivo study. *Int J Prosthodont*. 2009;22:193–200.

13. Bulaqi HA, Mousavi Mashhadi M, Safari H, Samandari MM, Geramipanah F. The dynamic nature of abutment screw retightening: finite element study of the effect of retightening on the settling effect. *J Prosthet Dent*. 2015;113:412–419.

14. Assuncao WG, Delben JA, Tabata LF, Barao VAR, Gomes EA, Garcia IR. Preload evaluation of different screws in external hexagon joint. *Implant Dent*. 2012;21:47–50.

15. Lee JH, Huh WH, Park CJ, Cho LR. Effect of the coronal wall thickness of dental implants on the screw joint stability in the internal implant-abutment connection. *Int J Oral Maxillofac Implants*. 2016;31:1058–1065.

16. Lee JH, Lee W, Huh WH, Park CJ, Cho LR. Impact of intentional overload on joint stability of internal implant-abutment connection system with different diameter. *J Prosthodont*. 2017;28:1–8.

17. Semper W, Kraft S, Mehrohf J Nelson K. Impact of abutment rotation and angulation on marginal fit: theoretical considerations. *Int J Oral Maxillofac Implants*. 2010;25:725–758.

18. Barbosa GA, das Neves FD, de Mattos Mda G, Rodrigues RC, Ribiro RF. Implant| abutment vertical misfit of one-piece cast frameworks made with different materials. *Braz Dental J*. 2010;21:515–519.

19. Theoharidou A, Petridis HP, Tzannas K, Garefis P. Abutment screw. Loosening in single implant restorations: a systematic review. *Int J Oral Maxillofac Implants*. 2008;23:681–690.

20. Norton MR. An in vitro evaluation of the strength of a 1-piece and 2-piece conical abutment joint in implant design. *Clin Oral Implants Res*. 2000;11:458–464.

21. Khraisat A, Hashimoto A, Nomura S, Osama Miyakawa BE. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. *J Prosthet Dent*. 2004;91:326–334.

22. 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;33:75–78.

23. Jorge JRP, Barao VAR, Delben JA, Assuncao WG. The role of implant/abutment system on torque maintenance of retention screws and vertical misfit of implant-supported crowns before and after mechanical cycling. *Int J Oral Maxillofac Implants*. 2013;28:415–422.

24. Tang CB, Liu SY, Zhou GX, et al. Nonlinear finite element analysis of three implant – abutment interface designs. *Int J Oral Sci*. 2012;4:101–108.

25. Yao KT, Kao HC, Cheng CK, Fang HW, Yip SW, Hsu ML. The effect of clockwise and counter clockwise twisting moments on abutment screw loosening. *Clin Oral Implants Res*. 2012;23:1181–1186.

26. Coppede AR, Matos MDA G, Rodrigues RC, Ribeiro RF. Effect of repeated torque/ mechanical loading cycles on two different abutment types in implants with internal tapered connections: an in vitro study. *Clin Oral Implants Res*. 2009;20:624–632.

27. Perriard J, Wiskott WA, Mellal A, Scherrer SS, Botsis J, Belser UC. Fatigue resistance of ITI implant – abutment connections- a comparison of the standard cone with a novel internally keyed design. *Clin Oral Implants Res*. 2002;13:542–549.

28. Pjetrusson BE, Zarauz C, Strasding M, et al. A systematic review of the influence of the implant-abutment connection on the clinical outcomes of ceramic and metal implant abutments supporting fixed implant reconstructions. *Clin Oral Implants Res*. 2018;29:160–183.

29. Tsuge T Hagiwara Y. Influence of lateral-oblique cyclic loading on abutment screw loosening of internal and external hexagon implants. *Dent Mater J*. 2009;28:373–381.

30. Piermatti J, Yousef H, Luke A, Mahevich R, Weiner S. An in vitro analysis of implant screw torque loss with external hex and internal connection implant system. *Implant Dent*. 2006;15:427–435.

31. Mendes JP, Melo RM, Borges ALS. Mechanical behavior of different micro conical abutments in fixed prosthesis. *Int J Oral Maxillofac Implants*. 2018;33:1199–1205.

32. Peixoto HE, Bordin D, Del Bel Cury LL, da Silva WJ, Faot F. The role of prosthetic abutment material on the stress distribution in a maxillary single implant –supported fixed prosthesis. *Mater Sci Eng C Mater Biol Appl*. 2016;65:90–96.

33. Wang R, Kang B, Lang LA, Razoog ME. The dynamic natures of implant loading. *J Prosthet Dent*. 2009;101:359–371.

34. Gumus HO, Zortuk M, Albyrak H, Dincel M, Kocaagaoglu HH, Kilinc

HI. Effect of fluid contamination on reverse torque values in bone level implants. *Implant Dent*. 2014;23:582–587.

35. Sabouri A, Neshandar Asli A, Vaziri SH. The effect of repeated torque in small diameter implants with machined and pre-machined abutments. *Clin Implant Dent Relat Res*. 2012;14:e224–e230.

36. Cardoso M, Torres MF, Lourenco EJV, Telles DM, Rodrigues RCS, Ribeiro RF. Torque removal evaluation of prosthetic screws after tightening and loosening cycles: an in vitro study. *Clin Oral Implants Res*. 2012;23:475–480.

37. Norton M. Assessment of cold welding properties of the internal conical interface of two commercially available implant system. *J Prosthet Dent*. 1999;81:159–166.

38. Sutter F, Weber HP, Sorensen J, Belser U. The new restorative concept of the ITI dental implant system: design and engineering. *Int J Periodont Rest Dent*. 1993;81:409–431.

39. Bozkaya D, Müftü S. Mechanics of the taper integrated screwed-in (TIS) abutments used in dental implants. *J Biomech*. 2005;38:87–97.

40. Dixon DL, Breeding LC, Sadler JP, McKay ML. Comparison of screw loosening, rotation and deflection among three implant designs. *J Prosthet Dent*. 1995;74:270–278.

41. Weiss EI, Kozak D, Gross MD. Effect of repeated closures on opening torque values in seven abutment-implant systems. *J Prosthet Dent*. 2000;84:194–199.

42. Bickford JH. *An Introduction to the Design and Behavior of Bolted Joints*. 3rd ed. New York: Marcel Dekker; 1995:515–564.

43. Bozkaya D, Müftü S. Mechanics of the tapered interface fit in dental implants. *J Biomech*. 2003;11:1649–1658.

44. Asvanund P, Morgano SM. Photoelastic stress analysis of external versus internal implant-abutment connections. *J Prosthet Dent*. 2011;106:266–271.

45. Guzaitis KL, Knoernschild KL, Viana MA. Effect of repeated screw joint closing and opening cycles on implant prosthetic screw reverse torque and implant and screw thread morphology. *J Prosthet Dent*. 2011;106:159–169.

46. Delben JA, Gomes EA, Barao VAR, Assuncao WG. Evaluation of the effect of retightening and mechanical cycling on preload maintenance of retention screws. *Int J Oral Maxillofac Implants*. 2011;26:251–256.

47. Bhering CL, Takahashi JMFK, Luthi LF, Henriques GEP, Consani RLX, Mesquita MF. Influence of the casting technique and dynamic loading on screw detorque and misfit of single unit implant-supported prostheses. *Acta Odontol Scand*. 2013;71:404–409.

48. Breeding LC DD, Nelson EW, Tietge JD. Torque required to loosen single-tooth implant abutment s crew before and after simulated function. Int J Prosthodont. 1993;6:435–439.

49. Kim ES, Shin SY. Influence of implant abutment types and dynamic loading on initial screw loosening. *J Adv Prosthodont*. 2013;5:21–28.

50. Oliveira Silva TS, Alencar SMM, Silva Valente V, Moura CDVS. *J Prosthet Dent.* 2017;117:621–627.

51. Ugurel CH SM, Steiner M, Ozkol GI, Kutay O, Kern M. Mechanical resistance of screwless Morse taper and screw retained implant-abutment connections. *Clin Oral Implants Res*. 2015;26:137–142.

52. Steinbrunner L W, Ludwig K, Kern M. Implant-abutment interface design affects fatigue and fracture strength of implants. *Clin Oral Implants Res*. 2008;19:1276–1284.

53. Yeo IS, Lee JH, Kang TJ, et al. The effect of abutment screw length on screw loosening in dental implants with external abutment connections after thermocycling. *Int J Oral Maxillofac*. 2014;29:59–62.

54. Jalalian E, Hashemi E, Naser Mostufi S, et al. Effect of abutment connection type and cyclic loading on removal torque value. *J Res Dentomaxillofac Sci*. 2019;4:36–40.