Does Ferrule Effect Affect Implant-Abutment Stability?

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Authors

Dr Maryam Mohajerfar §
(DDS, MSc)

Dr Elaheh Beyabanaki §
(DDS, MSc)

Prof. Allahyar Geramy ‡
(DDS, MS)

Prof. Hakimeh Siadat ^
(DDS, MSc)

Dr Marzieh Alikhasi *
(DDS, MSc)

Address for Correspondence

Dr Marzieh Alikhasi *

Email: m_alikhasi@yahoo.com, malikhasi@razi.tums.ac.ir

* *Dental Research Center, Dental Implant Research Center, Dentistry Research Institute, Department of Prosthodontics, Tehran University of Medical Sciences, North Amirabad, Tehran, Iran.*

§ *Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*

‡ *Department of Orthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.*

^ *Dental Research Center, Dental Implant Research Center, Dentistry Research Institute, Department of Prosthodontics, Tehran University of Medical Sciences, North Amirabad, Tehran, Iran.*

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ABSTRACT

Purpose: This study investigated the influence of placing implant-supported crowns on the torque loss of the abutment screw before and after loading. Material and methods: Twenty implant-abutment assemblies were randomly assigned to two groups. The first group was consisted of abutments with abutment-level finishing line (abutment-level), and in the second group the crown margin was placed on the implant shoulder (implant-level). Initial torque loss was recorded for all specimens. After 500000 cyclic load of 75 N and frequency of 2 Hz, post loading torque loss was recorded. Finite element model of each group was also modeled and screw energy, and stress were analyzed and compared between two groups. Results: ANOVA for repeated measurements showed that the torque loss did not change significantly after cyclic loading (P=0.73). Crown margin also had no significant effect on the torque loss (P=0.56). However, the energy and stress of screw in abutment-level model (4.49 mJ and 22.74 MPa) was higher than implant-level model (3.52 mJ and 20.81 MPa). Conclusion: Although embracing the implant with crown produced less stress and energy in the abutment-implant screw, it did not have any significant influence on the torque loss of the screw.

INTRODUCTION

One of the most common mechanical complications reported with single implant-supported restorations is abutment and/or prosthetic screw loosening.[1] Abutment screw loosening has been detected in 6 % of the prostheses and is reported to be as high as 45 % with single implant-supported crowns.[2] The screw loosening importance is arisen from its biologic and mechanical complications. It could result in misfit and micro-gap at the implant-abutment interface.[3-8] It is known that bacterial leakage may occur both into and from the inner part of dental implants.[9] This migration of bacteria is probably facilitated by the unavoidable presence of gaps between the implant and the abutment components of the assembled system. In clinical settings, these gaps may be further widened when bending forces loosen the screw joint during function.[10] This problem could result in microbial colonization, tissue inflammation and bone loss, and even failure of the implants.[10] Several factors have been suggested to affect screw joint stability.[11-18] The screw loosens only if separating forces are greater than clamping forces.[19] Preload, which is the axial load generated in the screw upon tightening, induces clamping force acting at the interface between the abutment and the implant-bearing surfaces.[14-18] This force holds the joint closed and also counteracts any load applied on the joint.[19,20] Preload is influenced by applied torque, screw alloy, abutment alloy, screw head design, abutment surface and lubricants.[19,16-18] Goodacre *et al* [2] reported that early screw designs had average loosening of 25 %, while the mean incidence of screw loosening for newly designed screws was as small as 8 %, indicating substantial improvement with new screw designs. However, it has been shown that regardless of the screw design, adequate applied torque and existing anti-rotational features are crucial factors for preventing screw loosening.[21]

Today by introduction of various implant systems, dentists have to select among various implant-abutment designs. One of the different features of implant designs is the location of cervical margin of the restoration. In other words, the prepared finishing line for the restoration, whether on the abutment or implant shoulder, is different among various implant systems. Some implant systems permit to alter finishing line position on the abutment according to the esthetic needs. However, in others and mostly in tissue level implants, crown margin is imposed by implant position, and changing the finishing line location is not feasible. These various designs among implant systems not only could affect esthetics, but also might have mechanical effects (*Figure 1*).

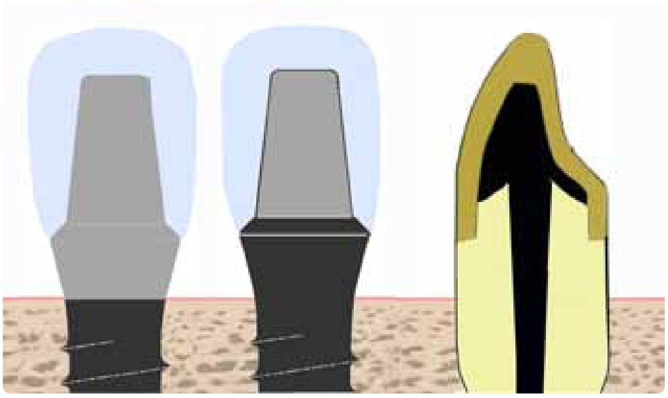

Figure 1: Schematic representation of two implant designs. (grey: abutment, black: implant, blue: crown). The left design shows abutment-level finishing line location. The middle figure depicts implant-level finishing line location of crown margin. The right figure compares embracing the ferrule effect of tooth-supported crown with implant-supported restoration.

One of the factors influencing the position of finishing line for fixed tooth-supported restorations is the ferrule. There is a well-documented theory that a ferrule or encircling band of cast metal around the coronal aspect can improve the integrity of the endodontically treated teeth.[22-26] Finite element studies on teeth have proved the importance of this parameter in the stress distribution within the tooth and the surrounding bone.[27,28] However, no data exists on the influence of the crown margin location (either on implant or abutment) on the abutment screw torque loss and consequently screw loosening. The purpose of this study was to determine the effect of finishing line location on the torque loss of abutment screw before and after cyclic loading. Also, the effect of the embracing the implant with prosthetic crown on the screw stress and energy was assessed with three-dimensional finite element analysis. The study was initiated to examine the null hypothesis of no differences between screw joint stability after fatigue testing either in abutment-level or implant-level finishing line designs.

MATERIALS AND METHODS

Twenty implant-abutment assemblies each consisted of an internal hex implant with 4.8 mm platform diameter and 10 mm in height were used for this study. Specimens were randomly assigned to two groups. In the first group the implants were screwed to the straight abutments with finishing line for seating the crowns (Abutment-level group) (*Figure 2*), whereas in the second group with different abutments, the crown margin ended on the implant shoulder (Implant-level group) (*Figure 2*).

Figure 2: The abutments of two groups. Left, abutment with finishing line on it (abutment-level specimen). Right, abutment without finishing line for crown margin placement (implant-level specimen).

Twenty identical metal crowns were fabricated by duplicating a plastic template in wax. Molten wax was flowed in the cavity inside the plastic pattern, then each solidified wax pattern was removed, and minor defects in the wax were corrected. The occlusal part of each coping was built up with 30 relative to the horizontal plane.[29] Wax patterns were individually sprued and invested in phosphate bonded investment. Castings were made with a base-metal alloy. To achieve acceptable fit, crown fitness was verified using fit checker medium. Also, a probe was used for checking the marginal integrity under 5x magnification.

Each specimen was mounted in a transparent self-cured acrylic resin block, and rigidly held in place by a custom-made jig during abutment screw tightening to ensure solid fixation without rotation during the tightening. An electric torque wrench was used to ensure an accurate application of reproducible force to each abutment screw. Each abutment screw was tightened to 30 Ncm, as recommended by the manufacturer. Ten minutes after first torque application, the screw was retightened to the same torque value to ensure achieving the optimal preload.[30,31] Initial torque loss (ITL) for each specimen was measured after five minutes of screw tightening[3,32] and its percent was calculated for each group (ITL %).

Full metal crowns were cemented with a temporary cement under 5 kg of static loading.[33] Acrylic resin blocks were firmly mounted in a holder of chewing simulator machine for 500,000 cycles of loading.[4,5,34] A 75 N load[4,6,32,35-37] was applied perpendicular to occlusal surface of each crown. Based on the size of specimen, the distance between the loading point and the abutment screw for both groups was set about 9.8 mm. The contact time between the rod and crown was adjusted to 0.2 seconds with a frequency of 1 Hz, simulating tooth contact duration in each masticatory cycle.[38] After cyclic loading, the removal torque value of each abutment was measured with an electric torque wrench, and the percent of secondary torque loss (STL%) was calculated for each group.

Analysis of variance for repeated measurements was used to evaluate the differences in torque loss between implant-level and abutment-level group before and after cyclic loading. An agreement for the significance value was defined and set at 0.05.

FINITE ELEMENT MODELS

Two 3D computer models of a segment of mandible in the left first premolar region containing an implant were designed in SolidWorks 2010. CT images of a 50-year-old man were used and were transferred to SolidWorks to create the models. The models contained gingivae, compact and cancellous alveolar bone, implant, and the same design of crowns as in the *in vitro* investigations. The hard tissue models were represented by modeling the trabecular bone as a solid structure in the cortical bone with the peri-implant bone 18 mm in height and 16.4 mm in width. The cortical bone was patterned with 1.4 mm in thickness and the trabecular bone with 16.5 mm in height. The models were transferred to the ANSYS Workbench Version 12.1. Boundary conditions restricted displacements of the nodes at the mesial and distal extremes of the models. The manner of restriction was based on the anatomy of mandible. Contacts were defined to simulate a real situation. To apply the boundary condition, all nodes in the y–z plane at the end of the x-axis in both directions were fixed; no translation was allowed in any direction (*figure 3*).

The superstructure was represented by a metal coping with 8 mm in height and 6 mm in width. The access hole was filled with composite resin. It was assumed that there was a direct contact between the abutment and the crown. Also, all materials were considered isotropic, linearly elastic and homogeneous. Bonded contact was established at implant/cortical bone, cortical/trabecular bone interfaces, while the contact interface between crown and implant was considered as juxtaposed. The cement layer was not modeled. According to literature, the coefficient of friction was considered to be 0.20 between all titanium components of the implant models and 0.26 between gold and titanium.[18, 35-37]

Mechanical properties (*Table 1*) were then applied, and the models were meshed with 44358 nodes and 25507 elements. The force system contained 80N vertical force vector and 8N lateral force vector to the center of the crown. Energy and stress analyses of the abutment screws were conducted in both models (implant-level and abutment-level).

The preload contact force was determined at two interfaces; 1) the interface between the abutment screw base and the base of its bore, and 2) the interface between abutment and implant bearing surfaces. The measured preloads in Newton (N) was delivered from the output file of ABAQUS software.[18]

Table 1. Properties of materials and structures used in the models

Material	Young's modulus (MPa)	Poisson coefficient
Cortical bone	34000	0.26
Spongy bone	13400	0.38
Titanium	110000	0.35
Gingivae	19.60	0.30
Gold alloy	93000	0.39
Composite resin	21000	0.24

RESULTS

The mean and standard deviation (SD) values for ITL and STL and their percentages of the two groups are shown in table 2. Torque loss varied from 0% to 67 %. Crown margin (the between-subjects factor) and cyclic loading (the within-subjects factor) did not significantly influence the torque loss as evaluated by repeated measure analysis of variance. In abutment-level group, ITL was greater than STL values, and in implant-level group, STL was greater than ITL, although it was not statistically significant (P =0.73).

The results of finite element analysis (FEA) showed that the energy of screw was 4.49 mJ in abutment-level model and 3.52 mJ in implant-level model. Also, the highest stress of the screw was recorded in abutment-level model (22.74 MPa) as compared to the implant level group (20.81 MPa) (*Figure 4*).

Table 2. Descriptive measurements of initial and secondary torque loss (and its percent out of 30Ncm) of implant- and abutment-level groups

Group	Measurement time	Mean	SD	Min	Max
Implant-level	Initial Torque Loss (ITL)	8.70	2.06	6	12
		29.00%	6.96%	20%	40
	Torque Loss after Cyclic Loading(STL)	7.00	4.24	2	16
		23.33%	14.14%	7%	53%
Abutment-Level	Initial Torque Loss(ITL)	6.60	1.43	5	9
		22.00%	4.77%	17%	30%
	Torque Loss after Cyclic Loading(STL)	7.40	7.10	0	20
		24.67%	23.68%	0%	67%

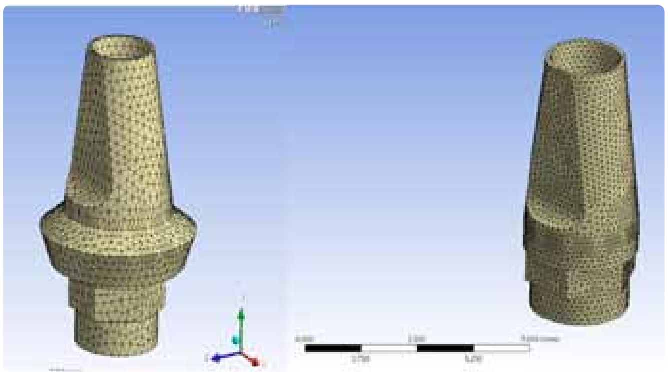

Figure 3: Finite element models of abutment-level finishing line (left), and implant-level finishing line (right).

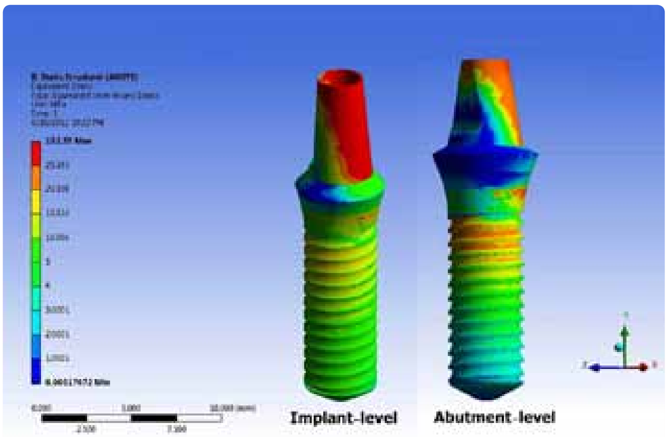

Figure 4: Stress concentration in abutment-level finishing line and implant-level finishing line models.

DISCUSSION

The null hypothesis was supported since there was no difference between screw joint stability after fatigue testing either in abutment-level or implant-level finishing line designs. One of the limitations of this study was that only one implant design (internal hexagon) was tested. However, the advantage of this system was the similarity of all other factors between two groups except crown margin position. Furthermore, the screw movement was not simulated in the present study. The coefficient of friction in the present study was set at 0.20 between all titanium components of the implant models and 0.26 between gold and titanium. The coefficient of friction in the screw thread and joint is determined by many factors such as implant components hardness, surface finish, fit between threads, fit at the abutment-implant connection, tolerance of screw and screw hole.[18] The importance of this parameter is in the preload in the screw joint which would be influenced by any of the mentioned factors.[18]

The ferrule band around the coronal surface of the tooth improves the structural integrity of a pulpless tooth by counteracting the functional lever forces, the wedging effect of tapering posts, and the lateral forces exerted during placement of the post.[25] There is no similar studies in the literature evaluating the effect of ferrule on the stress distribution in the dental implants. However, in finite element studies that the ferrule effect was evaluated in the endodontically treated teeth, it has been shown that the most stress concentration was observed in teeth with no ferrule.[27] Also, increasing ferrule height resulted in more mechanical resistance of a post-core-crown restoration.[28] These models simulated tooth, periodontal ligament (PDL) and the alveolar bone process and evaluated the effect of ferrules with different heights. Then a designated force was applied to the teeth a designated angle. Then the stress values and its distribution were noted. The limitations mentioned in these studies include not modeling the bone, considering the models on the outside surface of PDL, and considering PDL as an elastic material rather than a visco-elastic one.[27,28]

By extrapolating this scheme to the implant-abutment-crown assembly, it could be assumed that there might be a similar effect in implant-level crown margin design. However, the results of this study showed that different positioning of crown margin, either on the abutment or implant shoulder, could not significantly affect the torque loss values before and after cyclic loading. This finding may be related to this fact that anti-rotational features that exist in implant-abutment connection play this role (resistance form) in the implant-supported fixed restorations. In fact, in these restorations, preload[19,20] and resistance form[11,12] are the two factors that resist torquing forces that tend to loosen the interfaces of the implant-abutment. Another hypothesis as shown by some investigators[25,26] is that to achieve the full benefit of the ferrule, it should be a minimum of 1 to 2 mm in height and have parallel facing walls. Therefore, if implant shoulder is supposed to have ferrule effect, it should be designed accordingly.

Cycling fatigue test was also simulated in this experimental study. However, the nature of screw loosening is complex and several factors including oral fluid contamination, thermal changes, number of loading cycles, and the nature of forces could affect the results. One reason for no significant difference between two groups could be attributed to the fact that all of these parameters could not be simulated in one *in vitro* study. Therefore, FEA was performed to measure the energy and stress which was produced in these two models.

The results of FEA showed that despite no significant difference of the reverse torque values of two groups, the energy and stress of screw in abutment-level group (4490.7 mJ and 22.747 MPa) were higher than their corresponding in implant-level group (3523.7 mJ and 20.81 MPa). Therefore, abutment-level model had less capability for preventing screw rotation (screw loosening).[13] Nevertheless, manufacturers do not report data regarding the threshold of stresses at which the screw fails. There are other studies which evaluated the effect of connection design on the screw loosening. However, most of them focused on the different shape of connections, including external hex joint and taper joint, rather than the relation of the prosthesis to the connection.

Another finding of this study was the evaluation of torque loss before and after cyclic loading. In the present study, ITL was smaller than STL in the abutment-level group, and vice versa in the implant-level group. However, their differences were not statistically significant. This result is in accordance with the study of Khraisat and colleagues[32] which showed that despite slight decrease of mean reverse torque values following cyclic loading, there was no significant difference between the reverse torque values before and after cyclic loading. However, there are researchers who found significantly higher preloads than initial ones following cyclic loading.[35] It must be pointed out that applied torque values, applied force, number of cycles, and implant designs have been different in these researches.[19,32,37] The results also showed high SD values in all groups, especially for STL in abutment-level group. Similar studies attributed this finding to some factors including torque meter orientation, operator manipulation of the mechanical torque gauge, screw manufacturing finish, inherent problem in the torque meter itself, and the loading procedure.[7,8,14]

One of the factors that seem to have an influence on the implant-abutment resistance form is the connection type. A systematic review has shown that internal connection designs are more mechanically stable than external flat (hex-type) connections.[7] Considering the limitations of this study, further investigations would be necessary to explore the behavior of these two models under dynamic loading. Therefore, nonlinear dynamic finite element analysis which could simulate screw movement would be a valuable method for this purpose.

CONCLUSIONS

Within the limitation of this study, it can be concluded that although embracing the implant with a crown has no significant influence on the torque loss of abutment-implant screw, the energy and stress of screw in abutment-level group were higher than in implant-level group. It should be noted that relating the results obtained from this *in vitro* study to clinical situations need to be done with caution because of the complex oral environment.

ACKNOWLEDGEMENT

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MANUFACTURERS' DETAILS

- Internal hex implant (Simple line II, Dentium, Seoul, Korea)
- Straight abutments (SOCAB, Dentium, Seoul, Korea)
- Different abutments (SODAB, Dentium, Seoul, Korea)
- Phosphate bonded investment (MC-Vest Micro, Feguramed GmbH, Buchen, Germany)
- Base-metal alloy (VeraBond V, AlbaDent, LA)
- Transparent self-cured acrylic resin block (Rapid repair, Meliodent, Heraeus Kulzer GmbH, Germany)
- Electric torque wrench (Lutron Electronic Enterprice Co, Taiwan)
- Temporary cement (Temp & Bond, Kerr, Salerno, Italy)
- Chewing simulator machine (Chewing simulator, S-D Mechatronic, Germany)
- SolidWorks 2010 (SolidWorks, Concord, Massachusetts)
- MIMICS 10.01 software (Materialize NV, Leuven, Belgium)
- ANSYS Workbench Version 12.1 (Ansys Inc., Southpointe, Canonsburg, PA)

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