RESEARCH

THE RELATIONSHIP BETWEEN IMPLANT PRELOAD AND SCREW LOOSENING ON IMPLANT-SUPPORTED PROSTHESES

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KEY WORDS

Implant
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Preload
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Untightening torque

The purpose of this study was to determine whether varying the preload on the implant-abutment complex would affect screw loosening under simulated loading conditions. Abutment screws in sample models were tightened to 25, 30, 35, and 40 N-cm. One group of samples was allowed to stand for 3 hours after being torqued and then loosened. Another group of samples was retorqued after 10 minutes with the same initial torque value and then allowed to stand for 3 hours before loosening. For the load group of samples, the abutments were torqued into place, retorqued after 10 minutes, and a load applied for 3 hours before loosening. Cyclic loading was carried out using a servo-hydraulic testing machine with the values cycled between 1 and 26 pounds and the load applied directly to the abutments. Analysis of variance, analysis of covariance, and linear regression analysis was performed. Within the parameters of this in vitro investigation, the following recommendations can be made: (1) retightening abutment screws 10 minutes after the initial torque applications should be routinely performed and (2) increasing the torque value for abutment screws above 30 N-cm can be beneficial for abutment-implant stability and to decrease screw loosening.

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INTRODUCTION

The successful treatment of dental patients with implants during the past 25 years has significantly influenced restorative dentistry treatment planning. Osseointegrated implants were originally introduced as a treatment modality for edentulous patients but later were utilized to replace individual missing teeth and for fixed partial dentures.

A common problem associated with the prosthetic application of dental implants is loosening and fracturing of screws that retain the prosthesis to the implant.[1–11] Fracture of abutment screws is more prevalent than fracture of prosthesis-retaining screws.[1,6,9,11–13] Although loosening of screws is not a serious complication in itself, it is very inconvenient for the patient and the dentist.[14] Usually simple tightening or replacing of the gold retaining or abutment screws is required, but occasionally, more extensive repair is indicated.[15] Sones[10] reported that the failure of components, especially if abutment screws cannot be retrieved, might necessitate the disuse of the involved implant and require conversion or remake of the prosthesis.

Zarb and Schmitt[16] examined 274 implants and noted 9 abutment retaining screw fractures and 53 gold alloy screw fractures during a 4 to 9 year period of observation.

In a study by Jemt et al,[5] 10 of 23 abutment screws in single implant restorations were reported to be unstable during the first year of follow-up.

Naert et al[8] reported 5% of all gold retaining screws were loose in a group of 564 implants placed in 91 patients. In a 6-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism, Naert et al[9] reported a loosening of 6% of the gold screws.

In a retrospective single-tooth replacement investigation by Becker and Becker[17] using nonrotational abutments secured with gold screws, screw loosening was reported in 38% of the 21 restored implants. During the average 24 months of function, 9.5% of the screws loosened twice and 14.3% loosened 3 times.

Balshi et al[18] reported molar replacement with single hexagonal implants experienced a screw loosening incidence of 33% in 21 patients followed for 3 years. Forty-eight percent of the prostheses ''became mobile, including completely loose and fractured screws.''

In a prospective study for single-tooth implant replacement by Jemt et al,[19] 26% of the screws retaining the crowns were retightened during the 1-year period of observation. A higher incidence of loosening was reported for retaining screws in the premolar region compared with those in the incisor region. The frequency, however, tended to decrease as the study progressed. The authors attributed their results to the settling effect and the higher occlusal load when posterior teeth were considered. In a continuance of the same multicenter study, the investigators reported that abutment screw loosening continued, although it was significantly reduced.[20] After 5 years, the same authors reported that the most frequent complication recorded during the follow-up period continued to be loosening of the abutment fixation screws.[21]

In a retrospective study of 93 implants for single-tooth replacements placed in 77 patients, Ekfeldt et al[22] reported that the predominant complication involved loose abutment screws, which occurred in 40 (43%) of the restorations. In 28 restorations, the screws were loose once, and in 12 restorations, 2 or more times.

Schmitt and Zarb,[23] in a study of 40 single-tooth implant replacements, reported that maintenance requirements were minimal and consisted mainly of screw tightening.

SCREW MECHANICS

In order to understand how screws can be safely kept tight, the clinician must understand why screws loosen. When 2 parts are tightened together by a screw, the unit is called a screw joint. The screw loosens only if outside forces trying to separate the parts are greater than the force keeping them together. Forces attempting to disengage the parts are called joint separating forces. The clamping force keeps the parts together. Joint separating forces do not have to be eliminated to prevent screw loosening. The separating forces must only remain below the threshold of the established clamping force. If the joint does not open when a force is applied, the screw does not loosen. Hence, the 2 primary factors involved in keeping implant screws tight are maximizing the clamping force and minimizing joint separating forces.[24]

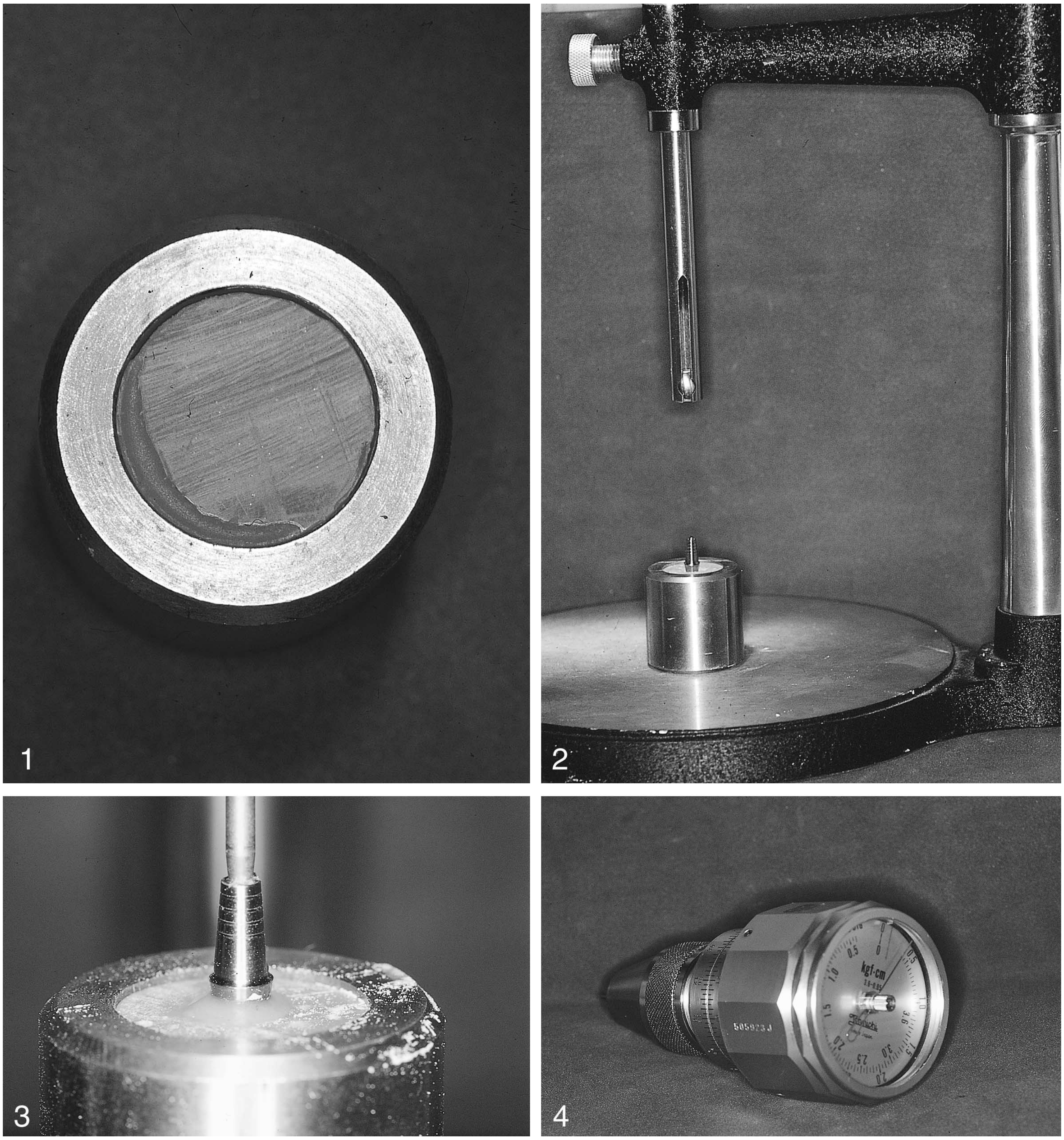
To achieve secure assemblies, screws should be tensioned to produce a clamping force greater than the external force tending to separate the joint. In the design of a rigid screw joint, the most important consideration from a functional standpoint is the initial clamping force developed by tightening the screw. Joint strength is affected more by clamping force than by tensile strength of the screws. Clamp load is usually proportional to tightening torque. Torque is a convenient, measurable means of developing desired tension. Too small a torque may allow separation of the joint and result in screw fatigue, failure, or loosening. Too large a torque may cause failure of the screw or stripping of the screw threads.

Applied torque develops a force within the screw called preload. Preload is the initial load on the screw. A specific torque is recommended for each screw for different implant systems from different manufacturers.[25] Preload is induced in a screw when torque is applied during tightening. Preload keeps the screw threads tightly secured to the screw's mating counterpart and holds the parts together by producing a clamping force between the screw head and its seat. The screw elongates, placing the shank and threads in tension. The elastic recovery of the screw creates the clamping force that pulls the prosthesis and the implant together.[3]

Preload must be maintained and fluctuate as little as possible to prevent joints from separating.[26] Several implant manufacturers have marketed mechanical and automatic torque drivers to apply exact torque levels to abutment and prosthetic screws. At the time of introduction of torque drivers, no published research existed to substantiate the optimal preload. The definitive optimum preload level to which retaining and abutment screws should be tightened is still unknown.[27]

There are several factors that can play critical roles in screw joint stability, including settling effects, preload, and screw geometry. The implant interface geometric design and precision of fit of mating components serve to resist mastication forces.[28]

These are 2 main mechanisms of



FIGURES 1–4. FIGURE 1. A hollow stainless steel cylinder was filled with autopolymerizing clear resin and allowed to cure for 4 hours at room temperature. FIGURE 2. Each resin cylinder was placed on a surveyor so that the upper surface of the cylinder was perpendicular to the arm of the surveyor. FIGURE 3. The implants were embedded in the clear resin up to the level of the second thread from the implant head. FIGURE 4. Tohnichi torque gauge. (Tohnichi America Corporation, Northbrook, Ill).

screw loosening for implant-supported restorations: excessive bending on the screw joint and settling effects. If a bending force on a single-tooth restoration causes a load larger than the yield strength of the screw, a plastic permanent deformation of the screw results, with a loss of tensile force in the screw stem. This results in reduced contact forces between the abutment and the implant, and consequently, the screw joint more easily loosens.

The other mechanism of screw loosening is based on the fact that no surface is completely smooth. Even a

TABLE 1
Groups of specimens

	25 N-cm	30 N-cm	35 N-cm	40 N-cm
No load–no set	n = 2	n = 2	n = 2	n = 2
No load–set	n = 2	n = 2	n = 2	n = 2
Load	n = 6	n = 6	n = 6	n = 6

carefully machined implant surface is slightly rough when viewed microscopically. Because of this microroughness, no 2 surfaces are completely in contact with one another. When the screw interface is subjected to external loads, micromovements occur between the surfaces. Wear of the contact areas might be a result of these motions, thereby bringing the 2 surfaces closer to each other. The magnitude of settling depends on the initial surface roughness and surface hardness as well as the magnitude of the loading forces. Rough surfaces and large external loads increase the settling. When the total settling effect is greater than the elastic elongation of the screw, the screw works loose because there are no longer any contact forces to hold the screw.[28]

It has been hypothesized that 2% to 10% of the initial preload is lost because of the settling effect.[29] Thread friction is higher for the first tightening and loosening of a screw; after repeated tightening and loosening cycles, friction decreases.[30] The result of the settling effect is that the torque necessary to remove a screw is less than the torque used to initially place the screw.[31] It has therefore been suggested that the implant-abutment joint be tightened after initial screw insertion and periodically thereafter.[27]

One of the simplest methods to prevent screw loosening is to ascertain screws are tight. Dellinges and Tebrock[32] reported that the average torque placed with a screwdriver is only 10 N-cm. Most titanium components available to the profession can easily be tightened to twice that amount without any consequences.[33] For torque levels greater than 20 N-cm, a torque wrench is usually required.

The purpose of this study was to determine whether varying the preload on the implant-abutment complex would affect screw loosening under simulated loading conditions.

MATERIALS AND METHODS

All study components were manufactured by Osteo-Implant Corporation (New Castle, Pa). A 3.75-mm (diameter) × 13-mm (length) implant (manufacturer code 375013), cementable abutment (manufacturer code APH2), and an abutment screw (manufacturer code UCFS) were used for all tests. A sample size of 40 screws (n = 40) was selected.

A hollow stainless steel cylinder (outer diameter 16.5 mm, inner diameter 14.5 mm, height 15 mm) was lubricated and filled with clear resin (Orthodontic Resin; Dentsply International, Inc, Milford, Del) and allowed to polymerize for 4 hours at room temperature (Figure 1). The resin has a modulus of elasticity close to that of bone (trabecular bone of the human mandible has a modulus of 0.14×10^9 N/m^2, while Orthodontic Resin has a modulus of 0.21×10^9 N/m^2). A 5-mm-diameter central hole was drilled in the resin cylinders in which the 3.75-mm-diameter implants were embedded, allowing for centric location of the implants. To ensure straight and parallel placement of the implants, each resin cylinder was placed on a dental surveyor so that the top surface of the cylinder was perpendicular to the arm of the surveyor (Figure 2). A hexagonal screwdriver was attached to the arm of the surveyor to assist in the transfer of the assemblies. Each abutment was screwed into the corresponding implant to a finger-tight stage. The assembly was then secured in the screwdriver on the arm of the surveyor and the implant lowered into the resin cylinder.

The implants were embedded up to the level of the second thread from the implant head. Each implant was then cemented in the holes using additional resin (Figure 3).

A torque gauge (Tohnichi torque gauge, model 3.6 BTG S, Tokyo, Japan) (Figure 4) was used to apply a reproducible force to each abutment screw. The samples were divided into 3 groups (no load–no set, no load–set, and load). Abutment screws were tightened to 30 N-cm (according to the manufacturer's recommendations), 25 N-cm, 35 N-cm, and 40 N-cm (Table 1). For the no load–no set group, the abutments were torqued in place, allowed to stand for 3 hours, and then loosened. For the no load–set group, the abutments were torqued in place, retorqued after 10 minutes with the same torque value, and allowed to stand for 3 hours before loosening. The abutments were torqued in place, retorqued after 10 minutes with the same torque value, and loaded for 3 hours before loosening for the load group.

Cyclic loading was carried out using a servo-hydraulic testing machine (MTS Systems Corporation, Eden Prairie, Minn) at a rate of 2 cycles/s with valves cycled between 1 and 26 pounds. The application of the load was directly to the abutment with the application surface being a point. Cycling data was collected using a dedicated personal computer running LABTECH software (Laboratory Technologies Corp, Wilmington, Mass).

The implants within each group were randomly assigned to the abutments and implants. The abutment screws were tightened to torque values of 25, 30, 35, and 40 N-cm. To account for reduced torque due to the settling effect, the screws were tightened again to the same initial torque after 10 minutes (this procedure was used throughout the investigation whenever the screws were tightened). The controls within each group were set aside at the

Table 2

Abutments torqued and allowed to stand (N-cm)

Initial Torque	Torque After 3 Hours	% Change
25	17.7 ± 0.9	29
30	21.6 ± 0.2	28
35	25.9 ± 0.5	26
40	28.9 ± 1.2	28

Table 3

Abutments torqued, retorqued, and allowed to stand (N-cm)

Initial Torque	Torque After 10 Minute Retorque and 3 Hours Standing	% Change
25	20.7 ± 1.2	17
30	24.5 ± 1.6	18
35	28.5 ± 0.2	19
40	32.8 ± 0.9	18

Table 4

Abutments torqued, retorqued, and loaded (N-cm)

Initial Torque	Torque After 10 Minute Retorque and 3 Hours Loading	% Change
25	19.3 ± 2.3	23
30	20.3 ± 1.7	32
35	25.2 ± 4.2	28
40	28.4 ± 1.9	29

Table 5

Analysis of variance for load groups

Baseline Torque Values (N-cm)	Posttest Torque Values (N-cm)	Standard Error	*P* Value
25	19.3	1.12	
30	20.3	1.12	>.5 (25–30)
35	25.2	1.12	>.006 (30–35)
40	28.4	1.12	>.055 (35–40)

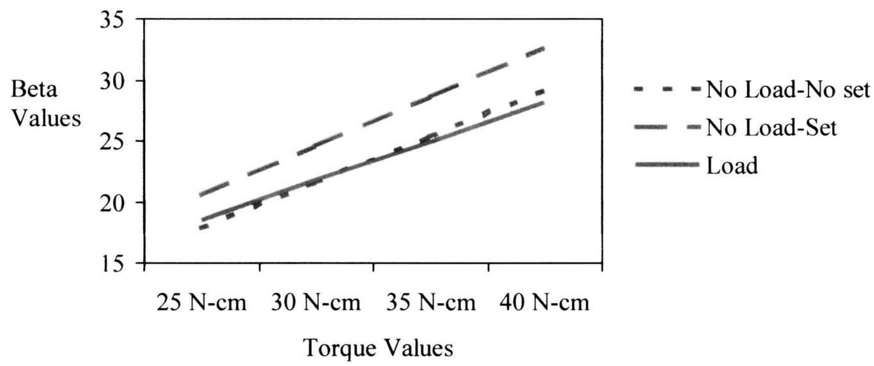


Figure 5. Regression lines for all groups.

same time the experimental groups were loaded. The torque values required to loosen the screws for the exerimental and control groups were then measured.

Analysis of variance was completed to assess the statistical significance among the load groups. Analysis of covariance was completed to assess the statistical significance among the different torque groups. Regressing the tightening torque values on the loosening torque values for all 3 groups was performed with linear regression analysis.

Results

Table 2 lists the mean values and standard deviations measured after the abutments were torqued in place, allowed to stand for 3 hours, and then loosened.

Table 3 presents the mean values and standard deviations measured after the abutments were torqued in place, retorqued after 10 minutes with the same torque value, and allowed to stand for 3 hours before loosening.

Table 4 shows the mean torque values and the standard deviations measured after the abutments were torqued in place, retorqued after 10 minutes with the same torque value, and loaded for 3 hours.

Analysis of variance was completed to assess the statistical significance among the load groups (Table 5).

Linear regression statistical analysis was performed and linear relationship was found between torquing and loosening values for all 3 groups. Proximity to the regression line was similar for the no load groups (R^2 = .974 for the no load–no set group and R^2 = .965 for the no load–set group) but different for the load group (R^2 = .636) (Figure 5).

Analysis of covariance was completed ($P < .0093$) to determine whether the 2 different torque application procedures had any effect on screw loosening within the implant-abutment system.

Analysis of covariance was completed ($P < .001$) to determine whether the loading procedure had any effect on screw loosening within the implant-abutment system.

Discussion

A significant finding of this investigation for all groups (loaded and nonloaded) was that the torque necessary to remove an abutment screw was less than the torque used for initial placement. This is in agreement with the results of Jaarda et al.[34]

The reduction of removal torque varied for the different groups in this study and was related to the method of torque application and the loading or nonloading conditions during the test.

A mechanical engineering principle that affects preload is embedment relaxation (settling). Because the internal threads of the implant and the screw threads that contact these internal threads cannot be machined perfectly smooth, high spots will inevitably occur on both surfaces. These high spots will be the only contacting surfaces when the initial tightening torque is applied to the screw and the preload is developed. Embedment relaxation then occurs, whereby the rough spots actually flatten (or wear) under loading, and 2% to 10% of the initial preload is lost.[35]

The amount of embedment relaxation or settling that occurs depends on the number of rough spots on the contacting surfaces, the surface hardness of the implant and the screw, and the amount of load applied to the system.[29] After embedment relaxation, applying a tightening torque will once again act to regain preload.

The clinical procedure suggested to overcome settling effects by Bakaeen et al[36] is to retorque the abutment screw 10 minutes after the first torque application. The investigators recommended this procedure be used as a routine clinical technique.

A significant finding of this investigation was the necessity of increasing the removal torque when the initial applied torque was increased. This observation suggests that increasing the torque value that is used to connect the abutment to the implant can decrease screw loosening.

CONCLUSION

Within the parameters of this in vitro investigation, the following recommendations can be made:

1. Retightening abutment screws 10 minutes after initial torque applications should be performed routinely during abutment-implant connections.
2. Increasing the torque value above 30 N-cm can be beneficial for abutment-implant stability and to decrease screw loosening. Although the percentage of difference between the applied torque and the counter torque increases as the initial torque increases, greater preload was obtained with higher initial torque values. However, the difference at increased values was statistically insignificant.

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