BASIC SCIENCE RESEARCH

Preloads Generated with Repeated Tightening in Three Types of Screws Used in Dental Implant Assemblies

Declan Byrne, MSc, MA;[1] Stuart Jacobs, BDS, MSD;[2] Brian O'Connell, BDS PhD;[3] Frank Houston, BDS;[4] and Noel Claffey, BDS, MDentSc[3]

Purpose: **Abutment screw loosening, especially in the case of cemented single tooth restorations, is a cause of implant restoration failure. This study compared three screws (titanium alloy, gold alloy, and gold-coated) with similar geometry by recording the preload induced when torques of 10, 20, and 35 Ncm were used for fixation.**

Materials and Methods: **Two abutment types were used—prefabricated preparable abutments and cast-on abutments. A custom-designed rig was used to measure preload in the abutment–screw–implant assembly with a strain gauge. Ten screws of each type were sequentially tightened to 10, 20, and 35 Ncm on ten of the two abutment types. The same screws were then loosened and retightened. This procedure was repeated. Thus, each screw was tightened on three occasions to the three insertion torques. A linear regression model was used to analyze the effects on preload values of screw type and abutment type for each of the three insertion torques.**

Results: **The results indicated that the gold-coated screw generated the highest preloads for all insertion torques and for each tightening episode. Further analysis focused on the effects of screw type and abutment type for each episode of tightening and for each fixation torque. The gold-coated screw, fixed to the prefabricated abutment, displayed higher preloads for the first tightening at 10, 20, and 35 Ncm. Conversely, the same screw fixed to the cast-on abutment showed higher values for the second and third tightening for all fixation torques. All screws showed decay in preload with the number of times tightened. Given the higher preloads generated using the gold-coated screw with both abutment types, it is more likely that this type of screw will maintain a secure joint when tightened for the second and third time.**

Conclusion: **All screw types displayed some decay in preload with repeated tightening, irrespective of abutment type and insertion torque. The gold-coated screw showed markedly higher preloads for all insertion torques and for all instances of tightening when compared with the uncoated screws.**

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SCREW LOOSENING is a recognized complication in implant restorations.[1-4] The small retaining screws, which fasten restorations to abutments, are susceptible to loosening, though these screws are usually accessible and readily retightened or replaced. The loosening of abutment screws can be more problematic as it is necessary to remove the overlying restoration to gain access to the screw.[5] Cement-retained restorations may be damaged or destroyed in this process. In addition, movement at the deep implant–abutment interface due to screw loosening often causes irritation and pain. As such, screw loosening is at the very least an unpleasant experience for patients and time-consuming for dentists.

The maintenance of a screw joint is achieved when the clamping force exerted by the screw exceeds the joint separating forces acting on the assembly.[6] To reduce the possibility of screw loosening, potential joint separating forces should be

[1]*Lecturer, School of Dental Science, Trinity College, Dublin, Ireland.*

[2]*Private Practice, London, England.*

[3]*Professor/Consultant, School of Dental Science, Trinity College, Dublin, Ireland.*

[4]*Senior Lecturer/Consultant, School of Dental Science, Trinity College, Dublin, Ireland.*

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Correspondence to: Noel Claffey, BDS, MDentSc, School of Dental Science, Trinity College, Dublin 2, Ireland. E-mail: nclaffey@dental.tcd.ie

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minimized by optimal positioning and angulation of the implants. Joint separating forces may exceed clamping forces when implant assemblies are subject to nonaxial loading because of implant position or angulation, or excessive occlusal forces.[7] Cantilever designs may amplify forces on screw joints due to the lever effect and should, when possible, be avoided.[8]

Preload is the term given to the tension generated in the screw upon tightening and is a direct determinant of clamping force. The elasticity of the material used in screw manufacture is important in the development and maintenance of preload.[9] Optimal preload for a screw is achieved when the screw is elongated but not to a point where the yield strength is exceeded. Implant abutment screws are most often made from titanium alloys or gold alloys. Friction on screw threads can result in lower preloads generated in screws for any given insertion torque. To minimize friction, dry lubricant coatings have been developed such as pure gold (Gold-Tite®, 3i Implant Innovations, Inc., West Palm Beach, FL) and amorphous carbon (TorqTite®; Nobel Biocare UK, Ltd., County Wicklow, Ireland).

Clinically, an abutment may be placed on the implant several times during the fabrication of a prosthesis, for example, to check its emergence profile or to verify the fit of an overcasting. Repeated tightening and loosening of uncoated abutment retaining screws has been shown to result in a progressive decay in removal torques.[10] To date, little or no data exist on the effect of repeated tightenings of abutment screws with coated (dry lubricated) surfaces, to either prefabricated abutments or custom cast-on abutments. The main purpose of this study was to compare the preloads induced by three abutment screws (titanium alloy, gold alloy, and gold alloy coated with gold) when repeated insertion torques of 10, 20, and 35 Ncm were used for fixation.

Screw loosening may also occur by settling of the screw. This phenomenon depends on the presence of surface irregularities that prevent maximum contact of the screw with the abutment. These irregularities become worn during function, and a loss of preload may result.[9] It is possible that those abutments onto which the alloy has been cast have irregularities resulting from distortion during the casting process. The second objective of this study was to compare the preloads generated with prefabricated abutments and cast-on abutments for the different screw types and insertion torques.

Materials and Methods

An apparatus was developed to record preload in the abutment screw (Fig 1). The rig consisted of a strain gauge (Revere Transducer) fixed to a heavy metal baseplate by means of a threaded bolt. A standard diameter 13 mm long implant (3i Implant Innovations, Inc.) was screwed into a threaded receptacle, and this in turn was screwed into the transducer. An upper metal plate was placed on two upright bolts so the abutments could be suspended over the implant heads. The height of the plate was adjustable by means of two nuts and secured with two wing nuts. The upper plate also had a cutout to allow visibility of the implant–abutment joint.

The abutments were placed into a countersunk hole in the center of a small plate secured to the top plate with four screws (Fig 1). The small plate could be adjusted in the horizontal plane to align the abutments with the underlying implants. The abutment was secured to the implant with an abutment screw. A torque driver (Tohnichi, Tokyo, Japan) was used to deliver the desired torques to the abutment screw. The abutment and implant interfaces were not allowed to come into contact, as this would result in an aberrant registration for screw preload. The preload developed in the screw was measured by the strain gauge and recorded via a digital readout (Mark-10 Corporation, Hicksville, NY). The torque driver and strain gauge were calibrated independently before the study.

Three types of screw were tested: titanium alloy screw, gold alloy screw, and gold alloy screw coated with gold (Gold-Tite™, 3i Implant Innovations, Inc.). The titanium alloy screws had a composition of 90% Ti, 6% Al, and 4% V. Both gold alloy screws were composed of 80% Pd, 10% Ga, and 10% Cu/Au/Zn; the Gold-Tite screws were coated with 0.76 μm of pure gold. All screws had similar geometry and were placed using a square driver.

Two abutment types were used with each of the three different screws: prefabricated abutments (Prep-Tite Post™, 3i Implant Innovations, Inc.) and cast-on abutments, consisting of a machined gold alloy cylinder to fit the implant hex and a castable plastic sleeve (UCLA abutment, 3i Implant Innovations, Inc.). The unaltered plastic sleeves of the UCLA abutments were cast with a gold alloy, following standard procedures (Mettigold Brittanica, Cookson Precious Metal Ltd., Providence, RI).

Ten of each screw type were secured to each abutment type, resulting in 60 abutment–screw–implant assemblies. A torque of 10 Ncm was first applied to each assembly and the preload was measured. The torque

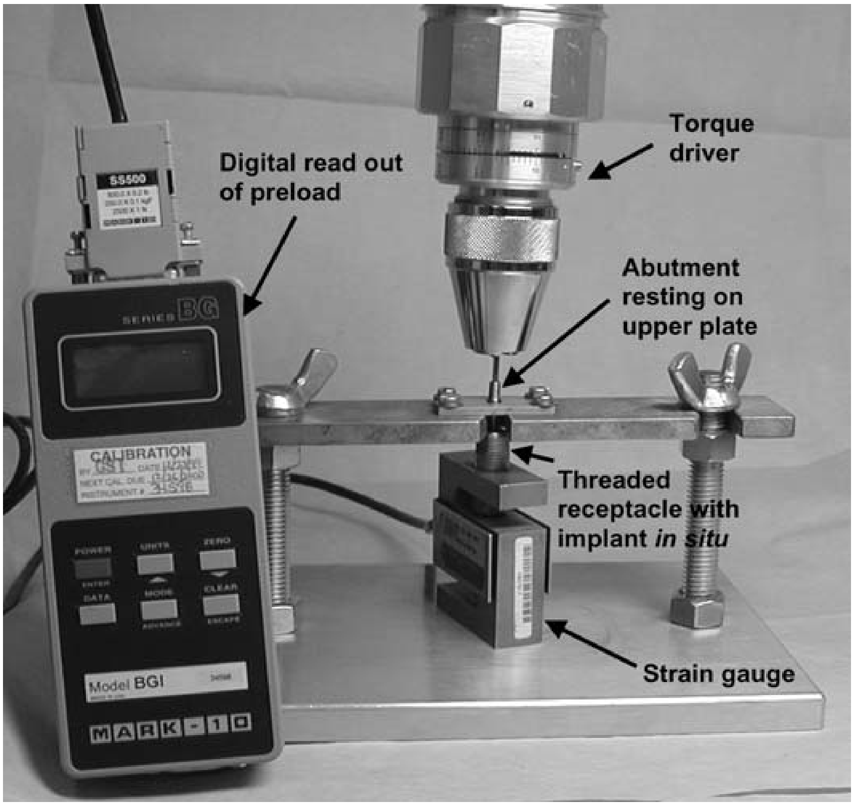

Figure 1. The apparatus used to measure preload in the implant–screw–abutment assemblies. The custom rig allowed for each abutment to be centered and suspended above the implant platform, by resting on the upper plate. As each screw was tightened using a calibrated torque driver, the preload was read from the output of the strain gauge.

was increased to 20 Ncm on each assembly and the preload was measured again. The torque was further increased to 35 Ncm and the preload recorded once more. The screws were then loosened completely, the sequence of tightening to the three ascending torque levels repeated, and the preloads recorded as above. This procedure was carried out for the third time. The components of each abutment–screw–implant assembly were used for only one series of three tightenings in order to avoid wearing of the components or carry over of lubricant from one assembly to another.

Data Analysis

The experimental procedures resulted in preload values for six groups of ten assemblies, representing each of the three screw types fastened to each of the two abutments. The preload of each assembly was measured using insertion torques of 10, 20, and 35 Ncm and for the first, second, and third tightening sequences. A preliminary analysis of variance was carried out with tightening instance as the independent variable and preload as the dependent variable. This preliminary analysis did not include screw type as an independent variable, thus exploring only the effect of repeated tightening. Following this, linear regression analysis was used to analyze the effects on preload values of screw type and abutment type for each of the three insertion torques.

Results

The initial analysis of variance with the number of times tightened as the independent variable indicated that the number of times the screws were tightened was significant ($p \leq 0.0001$).

Effect of Repeated Tightening on Each Screw Type

In general, the preload lessened with the number of times the screws were tightened; this was consistent at each insertion torque used (Table 1, Fig 2). It was observed that each screw type behaved differently in this respect.

The gold-coated screw showed the greatest tendency for decay in preloads with repeated tightening, regardless of abutment type (Fig 2). At 35 Ncm torque, the preload in the gold-coated screw decreased from 369.9 N after the first tightening to 299.5 after the third tightening—a decrease of 19%. A similar loss of preload in the

Table 1. Preloads Generated by Three Screw Types and Two Abutment Types

		Preload (N)					
		Titanium Alloy Screw		Gold Alloy Screw		Gold-Coated Screw	
		Prefabricated Abutment	UCLA Abutment	Prefabricated Abutment	UCLA Abutment	Prefabricated Abutment	UCLA Abutment
First tightening	10 Ncm	34.5	61.8	36.2	53.6	84.7	69.5
	20 Ncm	72.1	130.2	76.2	110.2	187.1	156.2
	35 Ncm	142.5	233.0	134.0	194.0	386.0	353.0
Second tightening	10 Ncm	33.0	61.4	30.0	41.5	68.1	73.8
	20 Ncm	72.4	133.9	69.8	89.8	154.5	181.9
	35 Ncm	140.1	242.9	124.4	173.4	295.0	357.3
Third tightening	10 Ncm	31.9	61.6	29.6	39.6	55.9	65.9
	20 Ncm	70.3	131.3	67.2	89.3	131.7	161.6
	35 Ncm	142.0	242.0	124.5	163.3	266.6	332.4

Preloads were measured at 10, 20, and 35 Ncm insertion torques, for three tightening episodes. Each result represents the mean measurement of preload in ten separate implant–screw–abutment assemblies.

gold-coated screw was observed at 10 and 20 Ncm torque (21% decrease and 16% decrease, respectively). The deterioration in preload with the gold alloy screw was somewhat less than that with the gold-coated screw by the third tightening (15% decrease), while the titanium alloy screw preload was fairly stable over the three tightening episodes. Nonetheless, even with a decay in preload for each tightening, the gold-coated screw was more effective than the other screws in generating preload throughout.

The insertion torques used in this study represent a range from approximately "finger tight" (10 Ncm) to the maximum torque used routinely (35 Ncm) for abutment screws. Many implant systems recommend the use of an intermediate torque (20 Ncm), particularly for internal-fitting abutments. For all screw types tested here, the preload increased at a greater rate than the insertion torque applied. Both the titanium alloy and gold alloy screws yielded a 4.1-fold increase in preload at 35 Ncm compared with 10 Ncm;

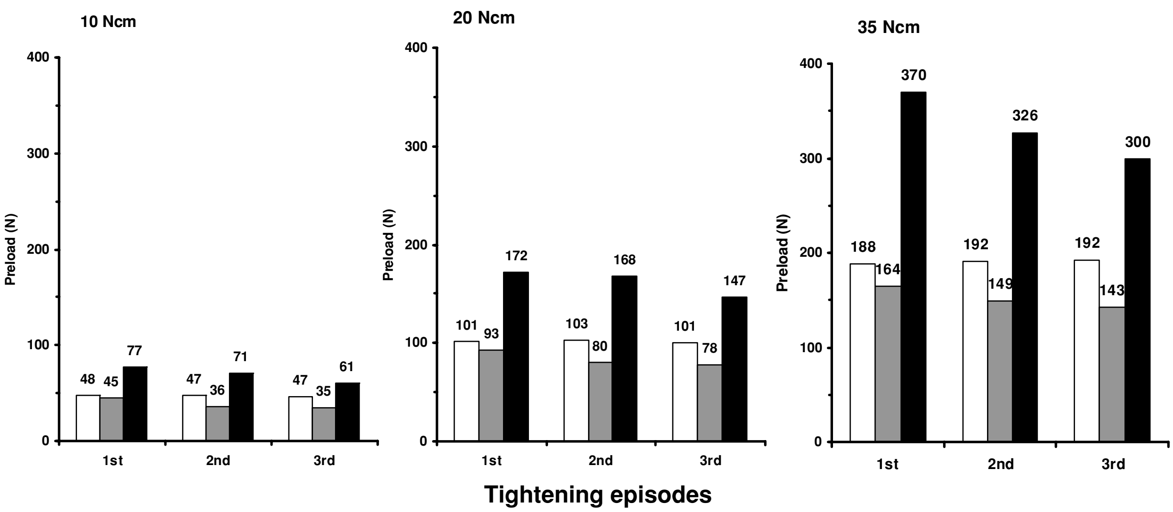

Figure 2. Mean preloads for each of the three screw types following the first, second, and third tightening episodes at 10, 20, and 35 Ncm. Both abutment types were combined, and ten individual abutment–screw–implant assemblies were measured. Titanium alloy screw □; gold alloy screw ■; and gold-coated screw ■.

Table 2. Effect Tests of Linear Regression Analyses Using Abutment Type and Screw Type as Independent Variables for the Three Tightening Episodes at 35 Ncm Torque

		Sum of Squares	*F Ratio*	*Prob > F*
First tightening	Abutment	23,760.6	5.7829	0.0196
	Screw	506,232.9	61.6942	<0.0001
	Abutment/Screw	41,261.6	5.02	0.01
Second tightening	Abutment	76,398.02	16.7823	0.0001
	Screw	342,419.63	37.6094	0.0001
	Abutment/Screw	7852.63	0.8625	0.4278
Third tightening	Abutment	69,768.6	17.6932	<0.0001
	Screw	253,874.8	32.1928	<0.0001
	Abutment/Screw	9406.8	1.1928	0.3112

the gold-coated screw gave a fivefold increase in preload under the same conditions.

Further analysis consisted of constructing regression models for each of the 35 Ncm insertion torque with screw type and abutment type as independent variables. The analysis of these regression models for each tightening episode is presented in Table 2.

Preloads Generated by Different Screw Types

Of the three screw types, the gold-coated screw developed the highest preloads for all tightening instances and for all insertion torques (Table 1, Fig 2). The highest preload recorded in this study (386.0 N) was with the gold-coated screw torqued to 35 Ncm. The same gold alloy screw, but without the gold coating, achieved a preload of only 194.0 N under the same circumstances. Even at the finger tight 10-Ncm torque, the gold-coated screw achieved considerably higher preload than its noncoated analogue (84.7 N vs. 53.6 N). Overall, the titanium alloy screw gave preload values approximately 10% higher than the gold alloy screw across the test conditions used here.

Preloads with Different Abutment Types

When all screw types were considered together, higher preloads were generated using the UCLA (cast-on) abutment, compared with the prefabricated abutment, at each insertion torque and each episode of tightening (Table 1); $p = 0.02$. At 35 Ncm torque, the preload using the UCLA abutment was 20% higher than with the prefabricated abutment. The only exception to this trend was in the gold-coated screw after the first tightening, when the preload was greater in the prefabricated abutment—thereafter the preload observed with the UCLA abutment was higher in every case.

Effect of Repeated Tightening on Prefabricated and UCLA Abutments

Figure 3 shows the preloads generated with each abutment type over three episodes of tightening. These data suggest that at 35 Ncm insertion torque the preload with the prefabricated abutment decayed much more over three tightenings (33% decrease) compared with the UCLA abutment (5% decrease); however, it is important to separate the performance of each screw type.

As noted in Table 1, the preloads recorded with the UCLA abutment were higher for each screw type, but the preloads using the titanium alloy screw did not significantly change over the course of three tightenings, regardless of the abutment type. The gold-coated screw also generated higher preloads when combined with the UCLA abutment, and the preload decayed by 6% from the first to the third tightening, whereas the preload with the prefabricated abutment decreased by 31% under the same conditions. This accounts for most of the reduction in preload at 35 Ncm shown in Figure 3.

Table 2 shows the probabilities generated in the regression models for the 35-Ncm insertion torque at each tightening episode. Abutment and screw were independent variables and each was significant for all instances of tightening. At the first tightening, a significant interaction was found for abutment/screw. Whereas the preloads for the gold-coated screw were higher with the machined

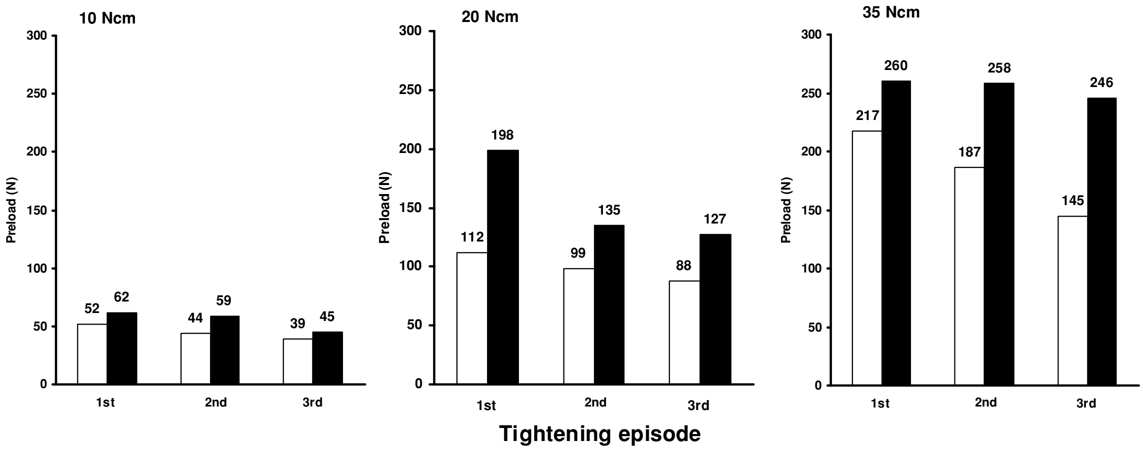

Figure 3. Mean preloads for each abutment type following the first, second, and third tightening episodes at 10, 20, and 35 Ncm. The three screw types were combined for each measurement. Prefabricated abutment □ and UCLA abutment ■.

abutment, this pattern was not obvious for the second and third tightening episodes.

Discussion

For some time, screw loosening has been recognized as a significant problem in dental implant therapy.[11-15] Screws have been extensively studied in the engineering literature and dental implant screws have improved as a result. Jorneus et al noted that screw performance is related to the design, material, and insertion torque of the screw;[9] however, dental implant assembly screws have inherent limitations in size, suitable materials, and the maximum torque applicable, so other strategies must be used to prevent loosening. An example of this limitation is the prosthetic (or retaining) screw, which reports have shown to loosen more readily than the larger abutment screw.[16-18] Because of the increased use of cemented implant prostheses, we decided in this study to focus on the question of abutment screw loosening, and whether a gold-coated screw is superior to an uncoated screw. In addition, we asked whether there was a difference between coated and uncoated screws when the screws were tightened repeatedly.

Screw loosening occurs when the clamping force developed within the assembly is less than the forces which pull the assembly apart. If this happens, for example due to occlusal forces, then the screw will back off and loosen.[19] Screws are usually placed under sufficient tension—termed preload—to resist the separating forces in function.[6] However, substantial preload in the screw may be lost due to a process known as settling.[20] Settling occurs when small irregularities on the screw/receptacle interface wear, so that tension in the screw decreases and the screw is more easily loosened by functional forces.[21] It has been shown that preload decreases over time in implant screws, even when external forces are not applied to the system.[22]

There are significant differences between the screws of various implant manufacturers,[23,24] and it has been demonstrated that screw loosening is inversely proportional to the fit of the implant assembly components.[25] Presumably, any misfit of the components contributes to movement of the assembly and loss of preload. In this study, we used components from one manufacturer to minimize the variations in screw design and avoid the problem of small screw/implant incompatibilities. All the screws used here had the same geometry, though the titanium screw with a square driver is not available commercially.

Screws have been lubricated so that the applied torque will yield more tightening of the screw and result in higher preload. It has been reported that lubrication of implant prosthetic screws with saliva does not increase their fracture load[26] and the ability of saliva to provide any significant lubrication in this type of environment is doubtful. Implant screw manufacturers have used a coating of gold (Gold-Tite) or carbon (TorqTite™) as solid lubricants. These coatings reduce friction upon fastening and allow more turning of the screw for a given torque. In the present study, we found that the gold-coated screw resulted in twice the preload of its noncoated analogue (386 N vs. 194 N) at 35 Ncm torque. At 10 and 20 Ncm insertion torques, the gold-coated screw yielded 58% and 70% greater preload, respectively, than the uncoated gold alloy screw. These results suggest that not only is the gold coating an effective lubricant but also its effectiveness increases at higher insertion torques. This is consistent with the results of Martin and coworkers[27] who found that TorqTite screws gave the highest rotational angle of the screws tested, while the Gold-Tite screw had the highest calculated preload.

The absolute values for preload in implant prosthetic and abutment screws vary considerably among studies, and this may be due to differences in how preload is measured.[28] Experiments have calculated preload from rotational angle,[27] from compression in the implant assembly,[22,29] or from screw elongation.[30] The apparatus used here maintained a gap between the abutment and the implant head, and so more directly measured tension in the abutment screw compared with the other methods. This may be one reason for the generally lower preloads reported here; alternatively it may be that any small misalignment between the abutment and the implant would reduce the preloads generated by the screw.

This study found that repeated opening and closure of implant screws had somewhat different results, depending on screw type. For all three insertion torques, the gold-coated screw lost more preload on the second and third tightenings than either of the uncoated screws (Fig 2). It would seem that the gold coating on the Gold-Tite screw may be damaged during insertion, and so the coating is less effective on subsequent insertions, though it still provides some lubrication compared with the uncoated screws. Preloads generated by the titanium alloy screw were essentially unchanged for the three tightening episodes, while the gold alloy screw lost preload after the first tightening but then remained fairly constant after that. Investigators have suggested that repeated tightening of screws removes small irregularities on the mating surfaces, which in turn reduces the friction at the surface and leads to higher preload. Indeed, Tzenakis and colleagues found that the preload in gold alloy prosthetic screws increased after five or ten tightening episodes;[31] however, a single abutment was used throughout their study, which may have lead to more surface finishing than in our study, where all the components were changed after each series of three tightenings. Weiss and co-workers performed up to 200 closures of implant abutment screws and demonstrated that opening torque values decreased progressively.[10] Though preload was not measured in Weiss's study, these results are consistent with the reduction of friction model outlined above and with the reduced coefficient of friction measured by Haack et al.[30]

The type of implant abutment used may also have a significant effect on the loosening of abutment screws. We have previously shown that fully cast abutments do not fit as accurately as the prefabricated abutments, so only cast-on UCLA abutments and prefabricated abutments were used here. Nevertheless, there was a significant difference in recorded preload between these two abutments, regardless of screw type. The UCLA abutment consistently was associated with higher preloads than the prefabricated abutment. This is similar to the previous findings that, even within one implant system, the preload generated using different abutments may vary severalfold.[32] This variation is thought to be due to an increased tendency of some abutments to cause screw settling or because of variation in the friction between a screw and an implant abutment. Here we noted that the gold-coated screw on the first tightening had a higher preload with the prefabricated abutment (386 N) compared with the UCLA abutment (353 N), but this ranking was reversed on the subsequent tightening episodes. This observation would suggest that there was some finishing of the UCLA abutment by the screw upon tightening, which helped maintain the preload at the second and third tightenings. It was noticeable that there was a relatively small loss of preload with the UCLA abutment over three tightenings (from 260 to 246 N) which would indicate that little settling took place compared with the prefabricated abutment, where the preload decreased from 217 to 145 N.

There is an ongoing need for controlled clinical studies to evaluate the changes in design of implant components. While in vitro testing may suggest improvements in performance, these should be validated in a clinical environment.

Summary

All screw types displayed some decay in preload with repeated tightening, irrespective of abutment type and insertion torque. The gold-coated screw showed markedly higher preloads for all insertion torques and for all instances of tightening, irrespective of abutment type.

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