Preload Loss in Gold Prosthesis-Retaining Screws as a Function of Time

Andrew Cantwell, BDentSci, MClinDent, MSc, FDSRCS[1]/
John A. Hobkirk, PhD, BDS, FDSRCSEng, FDSRCSEd, DrMed HC[2]

Purpose: *Screwed joints are widely used in implant dentistry, and their failure is a significant problem that may be related to loss of preload. Preload is the compressive force generated across a joint when a screw is tightened and is responsible for keeping a joint closed. For a given torque, preload is limited by the frictional resistance of the contacting screw threads, flange, and opposing joint surfaces. This study tested the hypothesis that following correct placement, prosthetic gold screws lose preload over time.* ***Materials and Methods:*** *The study used standard Nobel Biocare components. Strain gauges mounted on a standard abutment formed a transducer to measure preload. Five sets of new prosthetic gold screws, gold cylinders, and standard abutment screws were assembled in turn on the top of an implant body, using the transducer abutment. The gold screws were tightened with a Nobel Biocare Torque Controller set to 10 Ncm, when it had an output of 12.06 ± 0.8 Ncm with 95% repeatability. Preload was monitored for 15 hours; then the screws were removed and examined under a scanning electron microscope.* ***Results:*** *Preload ranged from 157.5 to 488.9 N (mean 319.6 N), with a mean reduction over 15 hours of 24.9%, with 40.2% of this occurring within 10 seconds of tightening.* ***Discussion:*** *Torsional relaxation of the screw shaft, embedment relaxation, and localized plastic deformation of the gold alloy and opposing titanium threads were the most likely explanation for this phenomenon.* ***Conclusions:*** *New prosthetic gold screws suffer significant loss of preload following placement.*
INT J ORAL MAXILLOFAC IMPLANTS 2004;19:124–132

Key words: *biomechanics, dental implants, mechanical stress, prosthesis, screw joint, torque*

Most implant systems currently available rely on screws of one form or another to connect vertically stacked components, so that a prosthesis can be directly or indirectly joined to the top of the implant body. The compressive force generated by tightening a threaded fastener is referred to as *preload*. The mechanics of such a system are highly complex, and very little is known about the exact nature of the interface or the interactions that occur during and after the tightening procedure. It is accepted in engineering that a loss of preload is to be expected after a joint is tightened because of subsequent plastic deformation of contacting surfaces.[1]

While one of the most commonly reported prosthetic complications in the dental implant literature to date is the loosening of individual prosthetic components relative to each other and to the implant body, especially in single-tooth restorations,[2–6] little fundamental work on the problem has been published. The amount of compression or preload that is created by a given system is governed by multiple variables. These include the elastic moduli of the materials used for the screw joint and the material being clamped, the coefficient of friction between surfaces with sliding contacts, component fit, lubrication, the applied torque and its velocity, and the temperature of the system. McGlumphy and coworkers[7] added screw head design to this list, and Jörnéus and associates[8] demonstrated that flathead gold screws provided the highest values for a given torque.

[1]Specialist Prosthodontist, Eastman Dental Institute for Oral Health Care Sciences, University College London, United Kingdom.
[2]Professor and Head, Department of Prosthetic Dentistry, Eastman Dental Institute for Oral Health Care Sciences, University College London, United Kingdom.

Correspondence to: Professor John Hobkirk, Department of Prosthetic Dentistry, Eastman Dental Institute for Oral Health Care Sciences, University College London, 256 Grays Inn Rd, London WC1X 8LD, United Kingdom. Fax: +44-020-7915-1246. E-mail: j.hobkirk@eastman.ucl.ac.uk

Monitoring of the performance of a bolted joint over time has demonstrated that preload is dissipated to some degree, even without the application of strain to the joint. Where the threads of a fastener contact in compression, localized plastic deformation and burnishing of surface imperfections occur in both the dynamic and static states. [1,9] This has the effect of reducing surface friction within the system and also results in loss of preload with time. This may partly explain what has been referred to as "settling" of the joint.[10]

Shigley and Mischke[9] estimated that up to 10% of the initial preload created by the single application of a torquing moment in a threaded fastener system may be lost because of embedment relaxation of the contacting surfaces. This was also observed by Hagiwara,[11] while Bickford[1] estimated that it is possible for this to fall by between 5% and 40% as a result of embedment relaxation. Bickford suggested that the number of times a joint has been tightened and loosened strongly influences this figure.

Hagiwara and Ohashi[12] demonstrated the variation in preloads that could arise in a standardized threaded fastener system. Repeated tightening and loosening procedures also result in changes in preload for a given applied torque, as friction within the system is reduced with each cycle. The arc of applied rotation of the screw is also seen to increase with subsequent cycles.

The work of Higdon and coworkers[13] suggested that when a screw is tightened to create a clamping force, there will be a residual strain in the shaft of the screw as a result of the friction between the mating components. The screw will then tend to unwind to a passive position when the frictional resistance created by the preload under the head of the screw is overcome by eccentric loading.

Bickford[1] estimated that up to 50% of the reactionary torsion in a steel fastener is dissipated after removal of the torque-generating device. If the frictional resistance at the clamping surfaces is greater than that at the contacting threaded surfaces, then the preload in the system may actually increase. This is probably masked by the effects of embedment relaxation. Bickford[1] divided the process of loosening into 2 phases. The first involves the slippage of the joint surfaces, which is related to the application of transverse and axial forces that are sufficiently large to overcome the frictional and compressive forces that keep the contacting surfaces in a fixed relationship. The second phase occurs when the preload is reduced to such an extent that external forces and vibrations cause the mating threads to "back off." Once this stage has been reached, the screw joint ceases to function and the clamped surfaces separate. In this state the screw is liable to be loaded in flexion and may fracture.[14] This has implications for cantilevered prosthetic situations.

None of these phenomena have been demonstrated in the dental implant situation.[15] However, Carr and colleagues[16] reported that the mean preload that could be generated when using as-received gold cylinders for the cast-on technique was 97 N. However, when the internal surfaces were treated so as to produce a smooth finish, using standard techniques, a mean preload of 322 N could be developed.

The joints between many implant components incorporate a degree of "play," and Ma and coworkers[17] demonstrated a significant machining tolerance between various Nobel Biocare components (Göteborg, Sweden). This can be extrapolated to a significant degree of rotational play, which must be a factor in both of the stages of loosening described by Bickford.[1]

Patterson and Johns[14] have described the possible sequelae of varying preload in a dental implant assembly. If the preload is too great, the screw will break. At a level slightly below this, the screw will plastically deform, resulting in a loss of preload. If the preload of the screw is kept within its elastic limit, it will be able to resist separation of the clamped parts as long as the applied force is less than that of the preload. If the clamped surfaces remain in intimate contact despite loading, the screw is in an optimum state to resist external loading. This protective effect is beneficial to the fatigue resistance of the screw, which is maximal at a point just before the elastic limit of the screw is exceeded.

The question still remains: What is the optimum preload for a given clinical situation that will minimize the possibility of screw fracture caused by overtightening or loosening because of undertightening, while maximizing the fatigue resistance of the various components? Griffith[18] suggested that the optimal preload for a given screw is 75% of the force required to exceed its ultimate breaking strength. This is a totally arbitrary criterion, which in no way takes into consideration material properties or the possibility of the screw having to resist any further external loading.

The purpose of this project was to test the hypothesis that the gold screws in a single implant assembly lose preload after correct tightening when not subject to external loading. This has not been addressed in the literature previously with regard to dental implant components and is important when developing a baseline for further work.

Fig 1 The experimental rig showing the mounting for the handpiece, vertical slides, and the implant body and abutment with the gold cylinder and screw in place.

MATERIALS AND METHODS

A standard 10-mm-long, 3.75-mm-diameter Nobel Biocare (NB) implant was mounted vertically in an acrylic resin block (20×15×2 cm) and carried a 7-mm standard NB abutment. Three resistance strain gauges (Type 2N/120, 120 Ω ± 0.15%; Tinsley Strain Measurement, Londonderry, Northern Ireland, United Kingdom) were bonded to the abutment with cyanoacrylate adhesive (M-Bond 200, Measurements Group, Raleigh, NC). The gauges were arranged parallel to the long axis of the abutment and equidistant from each other and the end of the cylinder. The abutment was secured with a standard abutment screw that was tightened to 20 Ncm using the NB torque driver and carried an NB gold cylinder secured in succession with a series of NB gold screws. The abutment acted as a force transducer, measuring changes in pre-tension in the gold screw that altered the length of the abutment. It was calibrated before and after each set of measurements using a jig, which applied a series of masses via a vertical loading plunger and a 4-mm-diameter ball bearing, which was placed on the gold cylinder.

The gold screw was tightened with an electronically controlled NB torque driver. This was mounted in an acrylic resin jig, which could be slid vertically on 3 brass rods mounted in the acrylic resin base plate, such that the chuck in the torque driver was concentric with the central long axis of the implant body (Fig 1).

Before use, the output torque of the driver was measured using a torque gauge (Model 1200 ATG-N; Tohnichi, Tokyo, Japan), which has a measurement range of 0 to 14 Ncm and an accuracy of 2% of full scale deflection (fsd). The handpiece and gauge were rigidly mounted with their chucks and linked by a screwdriver bit, and the driver was activated at low speed while set to a torque of 10 Ncm until rotation was stopped by the torque-limiting circuitry. The torque was then read off the gauge, and the procedure was repeated a total of 20 times. The average recorded torque output was 12.06 Ncm (SD = 0.19), and it was concluded that the torque controller tested had a repeatability of output sufficient for the intended investigation (95% repeatability of 12.06 ± 0.8 Ncm). While the Tohnichi gauge does not have the same force/displacement characteristics as a gold screw assembly, and would thus react differently with the driver's control circuitry, it is a standard test instrument that was used principally to select the driver with the best repeatability from those available in this hospital setting.

The strain gauges were wired in a quarter-bridge configuration and energized with a laboratory bench power supply (PL 310 DC Power Supply Unit; Thurlby Thandar Instruments, Huntingdon, Cambridgeshire, United Kingdom). The output signal from the 3 strain gauges was summated and processed with a Microlink 3000 data logger (Biodata, Manchester, United Kingdom), utilizing an A/D converter and strain gauge board. This was linked to a computer for data storage and subsequent analysis using commercial software packages supplied by Biodata.

Data capture was run at 2 different A/D conversion rates, as shown in Table 1, to permit detailed analysis of the initial loss of pre-tension over the first 10 seconds following tightening, followed by a slower sampling rate for the next 15 hours, based on the results of a pilot study. There was a 15-second gap between the 2 recording sequences (Table 1).

Five sets of NB components, consisting of a prosthetic screw with an internal hexagonal socket, a 4-mm gold cylinder, and a standard abutment screw, were tested. All components were in an as-received condition from the manufacturer. The testing (actual tightening) of each set of components was referred to as tests A through E. So as to minimize temperature fluctuations, all measurements were carried out in a temperature-controlled, air-conditioned room, and the test apparatus was stored in an insulated, draft-proof box.

A new gold cylinder was positioned on top of the abutment, and a gold prosthesis-retaining screw was threaded into place by hand until the first indication was felt of the screw flange contacting the internal flange of the abutment. The external surfaces of the gold cylinder and the standard abutment were marked with a fine felt-tip marker to produce a vertical line, which ensured that the same orientation

Table 1 Variables Used in Data Collection for Calibration and Short-term and Long-term Scans

Program variables	Units	Calibration	Short-term scan	Long-term scan
Sampling frequency	HZ	75	150	0.5
Sampling interval	mS	13.3	6.6	2,000
No. of scans		25,000	15,000	44,000
Channel interval	mS	2	2	2

Table 2 Tightening Time and Mean Peak Preload Generated in Each Test Using a Standard Tightening Torque and Rotational Speed

Test	Tightening time (s)	Peak preload (N)
A	1.75	488.9
B	0.84	261.9
C	1.64	340.7
D	2.36	349.0
E	0.66	157.5

Table 3 Loss of Preload Over Time Expressed as a Percentage of Peak Preload During Short-term Tests

Test	Peak preload (N)	Loss of preload with time (%)			
		1 s	2 s	5 s	10 s
A	488.9	6.4	8.0	9.8	11.5
B	261.9	4.9	5.9	7.2	7.8
C	340.7	5.3	5.8	6.8	7.5
D	349.0	5.1	5.4	5.6	7.1
E	157.5	11.2	11.6	15.2	16.1

between components was maintained. The prosthetic gold screw was in this passive state for both the pre- and posttest calibration measurements. The latter were carried out to confirm that the transducer had a similar performance before and after the tests and thus exclude the possibility of changes in the system contributing to observed effects (these could arise, for example, from degradation of the bond between the gauge and the substrate).

The steel ball bearing was removed from the gold cylinder, and the acrylic resin block that held the torque-controller handpiece was then positioned on the vertical rods and slid into position, with the hexagonal driver in the handpiece chuck fitting into the socket in the prosthetic gold screw. A plastic disk engaged the squared outer surface of the gold cylinder and the vertical surface of the acrylic resin block held the handpiece so as to prevent rotation of the cylinder (Fig 1). The vertical orientation lines were seen to be coincident.

The torque controller was set to 10 Ncm. Data collection started, and the screw was tightened until the torque-limiting circuitry was triggered. Short-term data collection was then run for 10 seconds after peak preload was generated, followed by long-term data collection for 15 hours. The zero time point was defined as the moment that peak preload was reached. Posttest calibration of the measurement system was then immediately carried out.

The first thread of each prosthetic gold screw used in this project was observed under a scanning electron microscope (SEM) (Stereoscan 90; Cambridge Instruments, Crawley, United Kingdom), so that initial surface asperities and, later, burnishing effects could be observed for descriptive purposes. Magnifications of ×300 and ×1,200 were used. It was not intended to correlate surface roughness with test results, as it would have been impossible to effectively qualify and quantify the surface geography of each screw with a 2-dimensional view of only a very small area of the thread surfaces. Furthermore, none of the many other surfaces involved were viewed using the SEM. The untightening process would have also superimposed its own effects over those of the initial tightening sequence.

RESULTS

All the data were stored electronically and are presented in tabular and graphic form.

Calibration

The calibration data for the transducer showed it to perform consistently with a linearity of ± 2.9% of fsd over the course of the project.

Short-term Results

The time taken to generate the maximum preload in each test varied greatly, with a mean of 1.45 seconds (SD = 0.58) (Table 2). The mean peak preload generated in the 5 samples tested was 319.6 N, with a standard deviation of 88.0 N (Table 3). Test A had

Table 4 Loss of Preload Over 15 Hours, Expressed as a Percentage of Peak Preload

Test	Peak preload (N)	Loss of preload with time (%)				
		30 min	1 h	5 h	10 h	15 h
A	488.9	16.4	18.0	22.6	24.9	25.9
B	261.9	10.0	10.1	11.7	16.6	17.7
C	340.7	11.4	12.8	16.6	18.5	19.5
D	349.0	10.2	11.1	14.1	15.9	16.7
E	157.5	24.7	28.4	36.7	41.8	44.5

Table 5 Peak Preload of Prosthetic Gold Screws Compared to Residual Preload After 15 Hours

Test	Peak preload (N)	Residual preload (N)
A	488.9	362.1
B	261.9	215.5
C	340.7	274.3
D	349.0	290.9
E	157.5	87.4

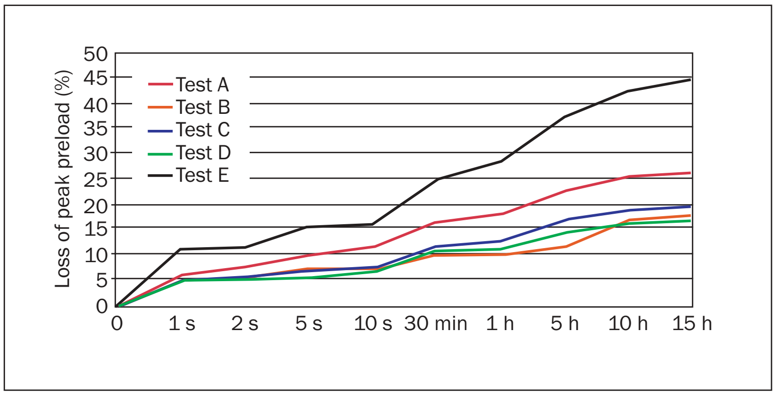


Fig 2 Change in preload over time. Note that the x-axis is not linear.

the highest peak preload (488.9 N) and Test E had the lowest preload (157.5 N).

Loss of preload occurred in all tests. The greatest and most rapid rate of change occurred within the first 2 seconds of the short-term tests (Table 3). The greatest loss of preload at the end of the first 10 seconds, measured as a percentage of the peak preload, occurred in test E (16.1%). Test E also had the lowest recorded peak preload (157.5 N). Test A had the second highest percentage loss over the same time interval (11.5%). Test A also had the highest recorded peak preload (488.9 N). Tests B, C, and D showed similar losses (7.1% to 7.8%) over the same time span.

Long-term Changes in Preload

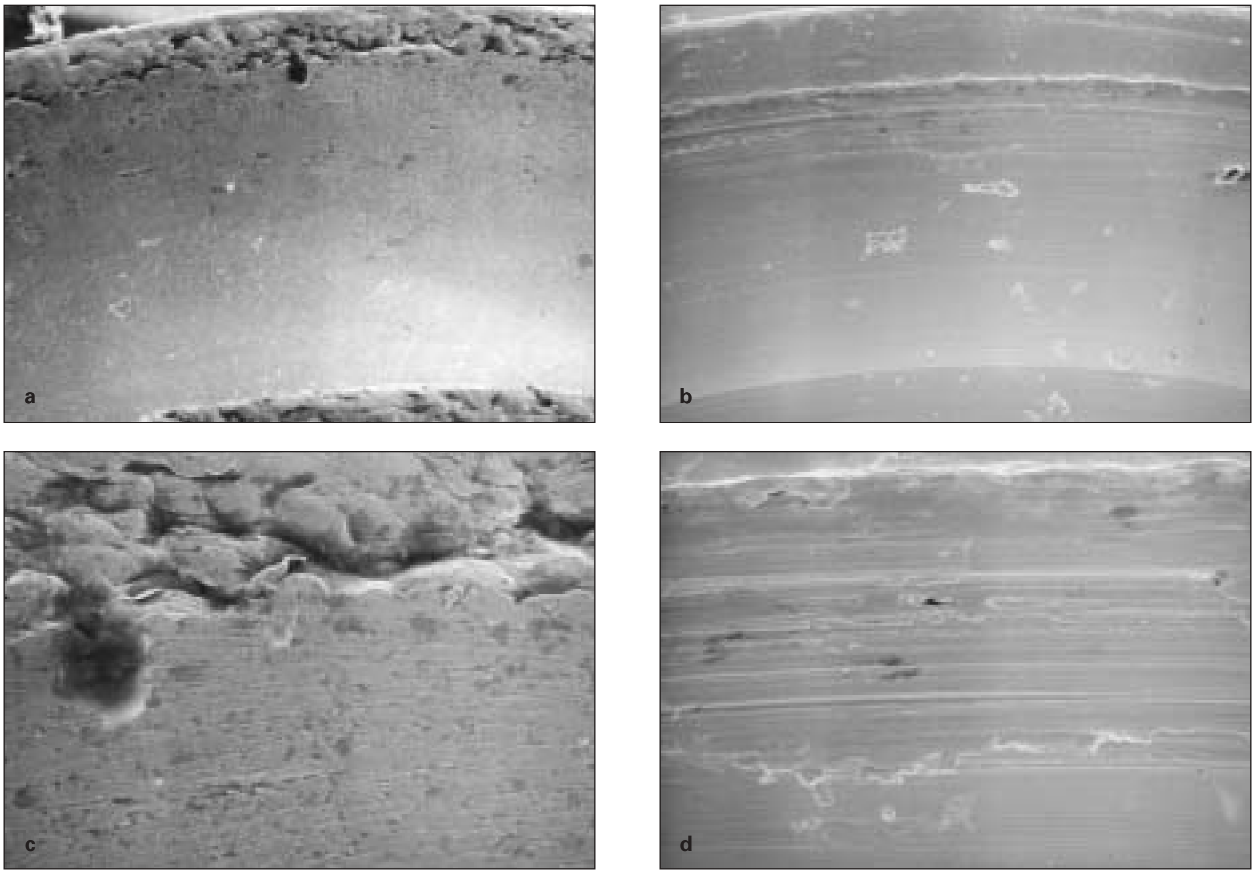
The changes in preload over the entire 15-hour period were derived by combining the short-term test results with those of the long-term tests (Table 4). Test A had a peak preload of 488.9 N; after 15 hours this value had dropped by 25.9%, to 362.1 N. Test B had a peak preload of 261.9 N, which dropped by 17.7% to 215.5 N at 15 hours. Tests C and D had similar peak preloads of 340.7 N and 349.0 N, respectively, and both dropping by similar amounts (19.5% and 16.7%) to 274.3 N and 290.9 N, respectively. Test E had the lowest recorded peak preload of 157.5 N and the greatest percentage and rate of loss over the 15 hours (44.5%). When loss of preload is presented graphically, it is evident that even at 15 hours posttightening gradual loss was still occurring, particularly in Test E (Fig 2).

The mean percentage loss of preload at 15 hours for all tests was 24.9%, with a standard deviation of 8.28%. The most rapid and extensive loss in both the short- and long-term tests occurred in tests A and E (Table 5, Fig 2).

SEM Study

The first thread of each prosthetic gold screw used in this project was observed with an SEM, so that initial surface roughness and later burnishing effects could be observed. Magnifications of ×300 and ×1,200 were used. The first thread was chosen because it is the area of the prosthetic gold screw that experiences the most prolonged contact during the tightening procedure and hence was the most likely to demonstrate wear effects.

Before tightening, the surfaces of the prosthetic gold screws demonstrated a varied range of topography (Figs 3a to 3d). The most undulating and deeply pitted areas were consistently at the outer edges of the prospective contact areas, and the remaining surfaces were more evenly granular and scratched.



Figs 3a to 3d SEM views of the thread of a prosthetic gold screw *(above left)* before and *(above right)* after a single tightening/un-tightening sequence (original magnification ×300), and a second screw *(below left)* before and *(below right)* after tightening (original magnification ×1,200).

On retrieval, the same areas were devoid of the deep pits and furrows previously noted and demonstrated a more homogenous surface, with parallel ridges where burnishing of the metal surface had taken place. In general, a much smoother and uniform surface was evident (Figs 3a to 3d). However, this surface had to be retrieved for examination, so these effects were also the result of the untightening process.

DISCUSSION

Experimental Procedure

The modified abutment functioned well as a force transducer, as demonstrated by its linearity and consistency during the study, and effectively measured force associated with the gold prosthetic screw. It is probable that some of the variation in output was caused by the imperfect fit between the gold cylinder and abutment, which would have caused uneven distortion of the abutment and hence surface strain. While it would have been ideal to have had a single strain gauge that completely covered the external surface of the abutment, this was not feasible and the 3 gauges used appeared to perform satisfactorily. The use of 2 sample rates created a 15-second gap in the recording sequence; however, this was considered acceptable since it enabled early precision of data collection and longer-term observations while keeping file sizes to manageable levels.

Short-term Test Results

The calibration exercises and tightening of the prosthetic gold screws with the NB torque driver placed the standard abutment in compression, resulting in an increase in surface strain. Some of the short-term tests (tests C, D, and E) displayed a transient positive microstrain reading once the tightening sequence began. This may be explained by an initial disparity in joint geometry, which caused the gold cylinder to momentarily shift and create an uneven pattern of loading of the abutment. There was significant variation in tightening time for the prosthetic gold screws (Table 2). The mean was 1.45 seconds, with a standard deviation of 0.58 second. Individual times were measured from the first indication of a negative change in microstrain to the peak microstrain and were identical for each of the 3 strain-gauge outputs. The variation in time intervals gives an indication of the disparity in alignment of the individual components, joint geometry, and the extent of frictional resistance involved. The more centered the individual components are relative to each other, the less time it will take to tighten the joint.

Variations in the frictional resistance encountered as the threads and contacting surfaces engage will influence the time interval before the torque-limiting circuitry operates. The faster the increase in frictional resistance, the shorter the time interval. Test A demonstrated the longest tightening time (1.75 seconds) and the highest peak preload, and test E showed the shortest tightening time and the lowest peak preload. With the given components and their intended degree of fit, it is impossible to differentiate between the influence of geometry and friction. However, the results do point to the difficulty of obtaining consistent results in the clinical situation.

The peak preloads generated within the 5 tests differed markedly. The mean preload was 319.6 N, and the maximum and minimum were 488.9 N (test A) and 157.5 N (test E), respectively (SD = 88.0 N). It was these same 2 tests that resulted in the greatest percentage and rate of preload loss with time (Tables 3 and 4).

Many of the known variables that influence preload were effectively constant in this study, with the exception of individual frictional coefficients and the added variable of joint geometry. The surface finish of the individual prosthetic gold screws was seen to vary greatly under SEM examination. The internal threads of the abutment screw could not be examined because of limited access; however, it is probable that these surfaces were rougher than those of the gold alloy screws, as the latter are easier to machine than titanium. The abutment screw had to be milled internally, which would tend to increase surface roughness.

The pattern of preload loss was largely the same for all short-term tests. Once a peak value was reached, which always occurred simultaneously for all 3 gauges, the decrease in preload was described by an inversely proportional reverse curve of varying amplitude, with a continually declining slope over time (Fig 2). Maximum change was always seen to occur over the first 2 seconds; 29.5% of the total loss of preload recorded over 15 hours occurred in this first 2 seconds and 40.2% within 10 seconds.

Long-term Test Results

The mean loss of preload at 15 hours for all tests was 24.9%, with a maximum of 44.5% for test E and a minimum of 16.7% for test D (SD = 8.3%). Tests B, C, and D all showed similar losses over the 15 hours: 17.7%, 19.5%, and 16.7%, respectively. This may be related to fact that the peak preload in all 3 tests was similar to that of the manufacturer's designed preload.

The long-term test graphs demonstrated an inversely proportional reverse curve with a declining slope, which continually approached zero. It is evident that, after 15 hours, preload loss was still occurring, but at a very slow rate (Fig 2). Future studies should take this into account when deciding what time interval to use and the total duration of measurement.

The manufacturer's design preload for the prosthetic gold screw is 300 N. This figure was presumably chosen so as to satisfy 3 important demands: *(1)* clamp the gold cylinder to the standard abutment so as to prevent any relative motion; *(2)* have the ability to accept a further tensile load of up to 300 N and then fracture (with a total tensile load of 600 N), so as to limit the load in the system and effectively protect more vital elements such as the bone-titanium interface; and *(3)* maximize fatigue resistance without limiting the screw's capacity to accept further load, since the nearer the preload is to the ultimate breaking point, the greater is its capacity to resist fatigue fracture.

In the case of the residual preload in the test E prosthetic gold screw (87.3 N), fatigue resistance would have been minimal, and the risk of loosening during function and damage to other areas of the abutment-implant system would have been high. The test A prosthetic gold screw had a residual preload of 316.3 N at 15 hours subsequent to a 25.9% loss over the same time period. Although this gold alloy screw was over-tightened initially by an excess of 126.8 N, the residual figure is just above the design preload of 300 N, and according to the manufacturer would have been in the optimum state to resist functional demands. The gold screws in tests B, C, and D had peak preload values near to the design preload, but after 15 hours all were below this value. For this reason Bickford[1] advocated taking joint relaxation into consideration when choosing a suitable tightening torque.

High magnification, such as that used in the SEM studies carried out in this project, showed that the machined metal surfaces of prosthetic gold screws were rough and undulating, with numerous surface imperfections or asperities (Figs 3a to 3d). The extent and severity of these imperfections are affected by material and technique.

Surface asperities increase frictional resistance of contacting screw threads and opposing flanges, resisting the creation of preload to varying degrees depending on their configuration and extent. In effect this is a major variable in deciding the peak preload generated with a given torque. The surface asperities, together with regions of the contacting thread tips, may also deform plastically with time when compressed by an opposing surface, resulting in closer approximation. This results in loss of preload within the screw and an equal loss of compression within the joint and is probably one of the reasons for the observed loss of preload in this study. This was particularly large immediately after tightening and then reduced over the 15-hour observation period. It is probable that the continued loss of preload represented other reported mechanisms of screw loosening, such as relative movement of contacting surfaces and counter-rotation of the screw related to release of torsional strains.

The tightening process smooths the contacting surfaces and reduces the frictional forces that must be overcome during subsequent reuse of the screw, allowing greater preload production with the same applied torque.[12] This process must also affect the amount of embedment relaxation that occurs as surface asperities are reduced.

The SEM views recorded after a prosthetic gold screw had been tightened and then retrieved clearly demonstrate a reduction of these surface asperities and the burnishing of the screw threads to a more uniform finish, in comparison to the scans of the screw in an as-received condition (Figs 3a to 3d).

In Vivo Considerations

The loss of preload observed in this study occurred in an in vitro situation with no external forces being applied, which was unlike the clinical environment, where the implant and its superstructure are subject to many dynamic forces. Rangert and coworkers,[10] for example, demonstrated that a single application of a physiologic load to a cantilever prosthesis can result in loss of preload in the prosthetic gold screw. The results of this study therefore likely understate the loss of preload that would occur clinically.

As a result of these changes, there may be some justification in tightening screws to a higher peak preload or retightening them at various intervals so as to offset these effects and produce a resultant residual preload that is nearer the desired design preload (300 N). This variability of peak preload generation and its progressive loss over time may partly explain why prosthetic gold screw loosening is such a commonly reported complication of implant treatment.

It should also be noted that this study used new screws; however, there is evidence that repeated loosening and subsequent tightening of the same screw can result in a decrease in the preload in the system from that originally achieved.[19] This is a phenomenon for which there are currently no data in relation to prosthetic components. Similarly, it cannot be assumed that data for one particular screw design are directly transferable to another pattern, even from the same manufacturer.

CONCLUSIONS

It may be concluded from this study that:

- The preload generated within a prosthetic gold screw tightened under standard conditions is variable.
- The mean preload generated for a sample of 5 prosthetic gold screws tightened to 12.06 ± 0.8 Ncm was 319.6 N.
- The maximum peak preload generated was 488.9 N and the minimum was 157.5 N. The components that demonstrated the lowest peak preload also demonstrated the greatest percentage loss of preload over 15 hours (44.5%).
- The mean loss of preload in the 5 prosthetic gold screws over the 15 hours with no external loading was 24.9%.
- A significant component (40.2%) of this mean loss occurred within 10 seconds of tightening.
- Preload loss was still ongoing at 15 hours.
- Embedment relaxation, localized plastic deformation, and torsional relaxation were the most likely causes of this preload loss.

REFERENCES

1. Bickford JH. An Introduction to the Design and Behaviour of Bolted Joints. New York: Marcel Decker, 1981.
2. Naert I, Quirynen M, van Steenberghe D, Darius P. A six year prosthodontic study of 509 consecutively inserted implants in the treatment of partial edentulism. J Prosthet Dent 1992;67:236–245.
3. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int. J Oral Surg 1981;10:387–416.
4. Lekholm U, van Steenberghe D, Herrmann I, et al. Osseointegrated implants in the treatment of partially edentulous jaws: A prospective multicenter study. Int J Oral Maxillofac Implants 1994;9:627–635.
5. Henry PJ, Laney WR, Jemt T, et al. Osseointegrated implants for single-tooth replacement: A prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996;11: 450–455.

6. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: A study of treatment from the time of prosthesis placement to the first annual check-up. Int J Oral Maxillofac Implants 1991;6:270–276.
7. McGlumphy E, Mendel D, Holloway J. Implant screw mechanics. Dent Clin North Am 1998;42:71–89.
8. Jörnéus L, Jemt T, Carlsson L. Loads and designs of screw joints for single crowns supported by osseointegrated implants. Int J Oral Maxillofac Implants 1992;7:353–359.
9. Shigley JE, Mischke CR. Standard Handbook of Machine Design, ed 2. New York: McGraw-Hill, 1996:23.16–23.39.
10. Rangert B, Gunne J, Sullivan D. Mechanical aspects of a Brånemark implant connected to a natural tooth: An in vitro study. Int J Oral Maxillofac Implants 1991;6:177–186.
11. Hagiwara M. Behaviour of thread torque after tightening. J Jpn Soc Precision Eng 1984;50:1278–1282.
12. Hagiwara M, Ohashi N. New tightening technique for threaded fasteners. In: Materials and Engineering Proceedings of the International Offshore Mechanics and Arctic Engineering Symposium, vol 3. New York: American Society of Mechanical Engineers, 1992:371–376.
13. Higdon A, Ohlsen E, Stiles W, Weese J, Riley W. Mechanics of Materials, ed 3. New York: Wiley & Sons, 1978:91–103, 173–175.
14. Patterson EA, Johns RB. Theoretical analysis of the fatigue life of fixture screws in osseointegrated dental implants. Int J Oral Maxillofac Implants 1992;7:26–33.
15. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant screws. Int J Oral Maxillofac Implants 1995;10:529–536.
16. Carr AB, Brunski JB, Labishak J, Bagley B. Preload comparison between as received cast-to cylinders [abstract]. J Dent Res 1993;7(special issue):190.
17. Ma T, Nicholls J, Rubenstein J. Tolerance measurements of various implant components. Int J Oral Maxillofac Implants 1997;12:371–375.
18. Griffith HT. Suggested tightening torques for structural bolts. Fastener Technology/February 1987. In: Torque Tensioning: A Ten Part Compilation. Stow, OH: Fastener Technology, Jan–Dec 1987.
19. Parmley RO. Standard Handbook of Fastening and Joining, ed 3. New York: McGraw-Hill, 1996:1–24.