Abutment Screw Loosening and Bending Resistance of External Hexagon Implant System after Lateral Cyclic Loading

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ABSTRACT

Background: Rigorous efforts to reduce the recurrence of abutment screw loosening in single-tooth implant restorations have recently been made. However, the behavior of the implant/abutment joint components with respect to critical bending force is still unclear.

Purpose: This study investigated the effect of different cyclic loading periods on abutment screw loosening and bending resistance of a single-tooth external hexagon implant system.

Material and Methods: Fifteen Brånemark implant assemblies were divided equally into groups A, B, and C. Each assembly consisted of a Brånemark System® Mk IV 4 × 10 mm implant (Nobel Biocare AB, Gothenburg, Sweden) mounted in a brass block, a CeraOne® 3 mm abutment (Nobel Biocare AB), and an experimental cement-retained superstructure. For groups A and B a cyclic load of 50 N was applied centrally and perpendicular to the long axis of the implant. Targets of 1.0×10^6 cycles (40 months of simulated function) and 0.5×10^6 cycles (20 months of simulated function) were defined for groups A and B, respectively. Group C (control) was left unloaded for the same loading time period as was group B. Reverse torque was recorded before and after loading, and the difference was calculated. After cyclic loading, specimens were mounted in a testing machine, and the yielding and bending strengths were measured. The data were analyzed with one-way analysis of variance and were compared by means of the Tukey test ($p < .05$).

Results: There were statistically significant differences ($p < .001$) in the reverse torque difference values of group A ([–5.6 to –3.4] ± 0.86 Ncm) as compared to those of group B ([–2.4 to –1.6] ± 0.32 Ncm) and group C ([–0.7 to 0.0] ± 0.26 Ncm). Likewise, group B showed a significant difference compared to group C ($p = .002$). On the other hand there was no statistically significant difference in the mean values among the test groups in regard to the yielding and bending strengths ($p > .050$).

Conclusion: Within the limitations of this study, long-term fatigue significantly affected the reverse torque values under centric lateral load ($p < .001$) whereas it had no significant effect on the resistance of the implant/abutment joint to static bending.

KEY WORDS: abutment screw, bending strength, external hexagon implant, implant-abutment interface, lateral cyclic loading, screw loosening, yielding strength

Screw joint instability, specifically the loosening or fracture of the abutment screws, is the most commonly reported mechanical problem related to single-tooth implant replacements.[1–5] In regard to Brånemark System® implants (Nobel Biocare AB, Gothenburg, Sweden), a 5-year prospective study reported that tightening of the new gold alloy abutment screw (which replaced the titanium screw) to 32 Ncm in the CeraOne® system (Nobel Biocare AB) has reduced the problem of screw loosening and has eliminated fracture.[1–3] Another prospective

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study, which presented the results after 5 years of loading of 65 CeraOne abutments, concluded that the CeraOne system has eliminated the problem of screw loosening and presented virtually no complications.[6] These results were attributed to the higher amount of frictional forces produced between the titanium implant component and the gold alloy screw that replaced the titanium screw. The tensile and yield strengths are higher for the gold alloy than for titanium, and thus a higher preload can be generated in the gold alloy screw.[7]

A recent 5-year multicenter study reported loosening of four (4.1%) abutment screws among 97 single-tooth CeraOne system implants.[8] This might indicate that the introduction of the new abutment screw in the CeraOne abutment had significantly decreased loosening but had not eliminated it.

With the introduction of single-tooth implant applications, the purpose of the implant's external hexagon design shifted to providing prosthesis indexing and an antirotational mechanism.[9,10] Rotational misfit at the implant-abutment hexagon interface has been considered a major factor in screw joint failure.[11–14] In other studies the implant hexagon extension height has been considered important for maintaining the antirotational stability of the screw joint.[9,10] English reported that the external hexagon requires a minimum of 1.2 mm in height to attain optimal antirotational effect.[10]

Another important mechanical factor is screw joint preload, which is defined as the tensile force that is built up in the abutment screw as a product of screw tightening.[7,15–17] It creates a compressive force at the abutment screw head–abutment, abutment-implant, and abutment–implant thread interfaces. It is dependent primarily on the applied torque and secondarily on the component material, screw head and thread design, and surface roughness.[7,18]

Recently the fatigue resistances to a lateral cyclic load of 100 N were compared in two implant-abutment combinations: a 4 mm Brånemark System with a hexagon-mediated butt joint and a 4.1 mm ITI Dental Implant System® (Straumann AG, Waldenburg, Switzerland) with an 8° internal conical interface design (taper joint).[19] All abutment screws in the butt joint design fractured between 1.2×10^6 and 1.7×10^6 cycles whereas the taper joint design had no failure until a defined target of 1.8×10^6 cycles. It was concluded that the axial preload of the screw in the butt joint was the determining factor for joint stability. In particular the presence of play at the joint interface might allow micromovement of the abutment screw, leading to the increase of its tensile stress and thus to the decrease of its preload.[19]

Khraisat and colleagues[20] investigated the influence of eccentricity of lateral cyclic loading on the loosening of the abutment screw in a hexagon-mediated butt joint system. They concluded that the lateral eccentric rather than centric load affected abutment screw loosening insignificantly. The explanation of their results is that the eccentric lateral load made the implant hexagon engage with the abutment counterpart and supplied a lock effect, which dispersed bending forces away from the abutment screw and preserved the screw torque.[20]

In another recent study that investigated the influence of eccentricity of lateral cyclic loading on the static bending resistance of the implant/abutment joint, it was found that specimens that were eccentrically loaded had the lowest mean yielding and bending strengths.[21] It was concluded that eccentric rather than centric lateral cyclic loading affected negatively the resistance of the implant/abutment joint to static bending.[21]

The aim of this study was to investigate the effect of long-term fatigue on abutment screw loosening and bending resistance of a single-tooth external hexagon implant system after two periods of lateral cyclic loading. For this purpose, the reverse torque of the abutment screw was measured before and after lateral cyclic loading, and the decrease in reverse torque was then compared. After that, the specimens were then quasi-statically bent to investigate the yielding and bending strengths.

MATERIALS AND METHODS

Fifteen implant assemblies obtained from a previous study[20] were used in this study; each consisted of a Brånemark Mk IV implant (4 × 10 mm) mounted in a brass block, a CeraOne abutment (3 mm), and an experimental cement-retained casting (7 × 10 × 7 mm) (Figure 1). Specimen preparation, casting fabrication, and cementation were described in the report of the previous study.[20]

Recording the Initial (Preload) Reverse Torque

The implant assembly was held in place by a bench vice attached to a solid board. A torque gauge (Model BTG60CN, Tonichi Mfg. Co., Tokyo, Japan) was used to ensure an accurate application of reproducible force to each abutment screw.[22,23] The handle for the abutment

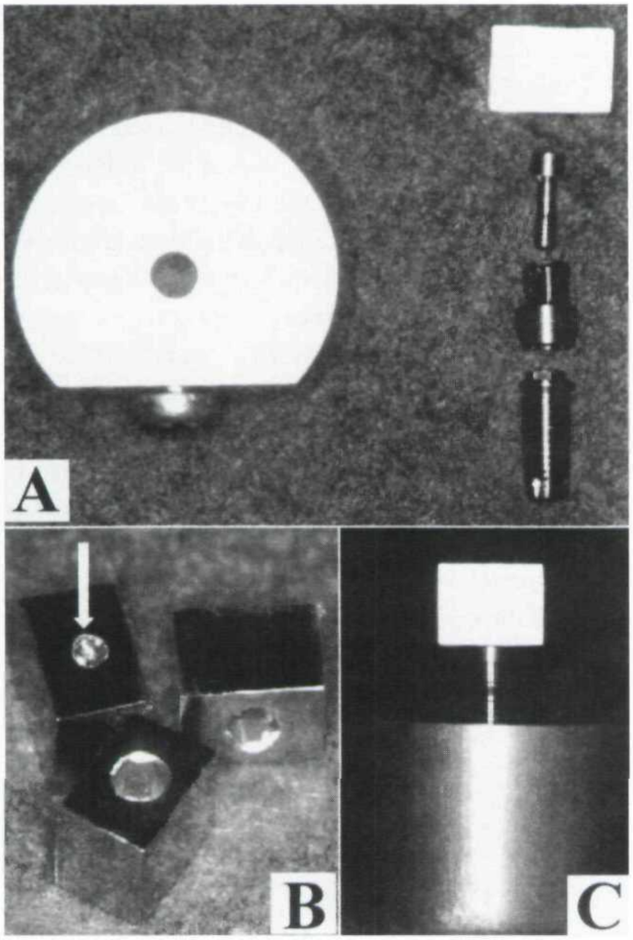

Figure 1 Experimental implant assembly components. *A*, Top view of the implant-supporting brass block (*left*) and the experimental crown, abutment screw, abutment, and implant (*right*). *B*, Multiple views of the experimental crowns; the *arrow* indicates the occlusal-screw access hole through which the torque was measured. *C*, The assembled experimental specimen.

screwdriver (UniGrip,™ Nobel Biocare AB) was mounted in the three-jaw chuck of the torque gauge, and then the corresponding machine driver (UniGrip) was attached. The torque gauge was held firm, carefully oriented in the long axis of the implant with the driver seated in the screw head, and rotated clockwise until the abutment screw was tightened to 32 Ncm as recommended by the manufacturer for clinical applications. In accordance with a protocol suggested by Dixon and colleagues[24] and Breeding and colleagues,[22] the screw was retightened to the same torque 10 minutes later to minimize embedment relaxation between the mating threads and thus to assist in achieving the optimum preload. Five minutes later the preload reverse torque was measured with the same torque gauge and recorded. Subsequently the screw was tightened and then retightened as described previously.

Loading Machine and Loading Approach

Each specimen was firmly mounted in a brass holder of a custom-made lever-type fatigue testing machine that was used in previous fatigue testing studies.[19–21,25] A cyclic load of between 0 and 50 N was applied perpendicularly to the flat surface of the underlying abutment (Figure 2). In each load cycle the force value increased (with time) from 0 N to a peak of 50 N and then decreased again to 0 N before the next cycle started. The peak load was equivalent to the lateral component of a 100 N vertical force on a 30° cuspal inclination to the longitudinal axis of the implant.[19,20] The latter was within the average of maximal posterior occlusal force for fixed prostheses supported by implants (35–330 N).[26] The loading point was at a longitudinal distance of 11.5 mm from the brass block surface (lever arm length). A marked bone resorption, similar to that in this study, would increase the lever arm length and thus contribute to a bending overload of the implant.[27] Since the bending moment is the product of the lateral force component (50 N) and the lever arm length (11.5 mm),[19,20] the generated bending moment was 575 Nmm (57.5 Ncm) at the implant fixed point for the two loaded groups. The loading rate was 75 cycles per minute, similar to the reported human masticatory frequency.[28] The machine was equipped with an automatic counting device to count the loading cycles. Before the beginning of each test, a small amount of grease was used to reduce friction and wear at the loading point.

The prepared assemblies were divided into groups A, B, and C, with five specimens in each group. For group A the load was applied perpendicular to the implant long axis (0 mm off-axis) at 11.5 mm from the

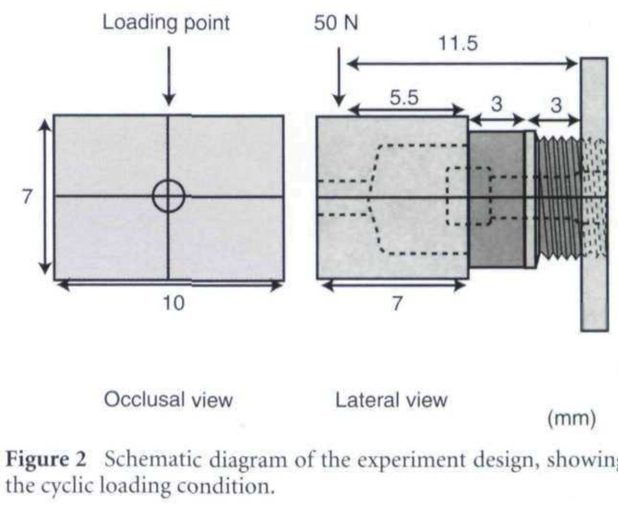

Figure 2 Schematic diagram of the experiment design, showing the cyclic loading condition.

block surface. A target of 1.0×10^6 cycles, representing 40 months of simulated function, was defined.[29] For group B the same load was applied for 0.5×10^6 cycles, which represented 20 months of simulated function. For group C (the control group) the specimens were left unloaded for the same loading period as for group B.

Every 10,000 cycles, the loading machine was stopped for a visual and tactile inspection of the specimen for any deformation, decementation, and/or abutment loosening. On test completion, the specimen was fixed again in a rigid holding vice, and the postload reverse torque for the abutment screw was measured with the torque gauge and recorded.

Upon completion of the dynamic test and measurement of the abutment screw reverse torque, all specimens underwent preparations for the static bending test. The implant assembly was held in place by a bench vice attached to a solid board, and the abutment screw was tightened to 32 Ncm with a torque gauge (Model BTG60CN). To minimize embedment relaxation between the mating threads, the screw was retightened to the same torque after 10 minutes.[22,24]

Static Bending Test

Each specimen was fixed in a holder on an AG-1000E™ testing machine (Shimadzu Corporation, Kyoto, Japan). Bending force perpendicular to the implant long axis was centrically (0 mm off-axis) applied at 11.5 mm from the block surface, at a crosshead speed of 1 mm per minute (Figure 3). The force-deflection curve of the abutment-implant assembly was recorded on chart paper at a speed of 30 mm per minute. The yielding strength and corresponding deflection at the loading point were determined on the chart (Figure 4). Although the yield point is theoretically defined as the point at which the assembly component starts to deform plastically, it is difficult to practically determine. In the present study the yield point was expediently defined as the point at which the curve intersects with a line parallel to its straight part at a distance of 1 mm (see Figure 4). If the assembly were unloaded at this point, it could show a permanent deflection of 0.033 mm (1/30 mm) because the deflection was recorded on the chart at ×30 magnification. The bending strength was determined as the peak value of the force-deflection curve.

In this study, specimen preparation and testing were performed by the same operator and completed in

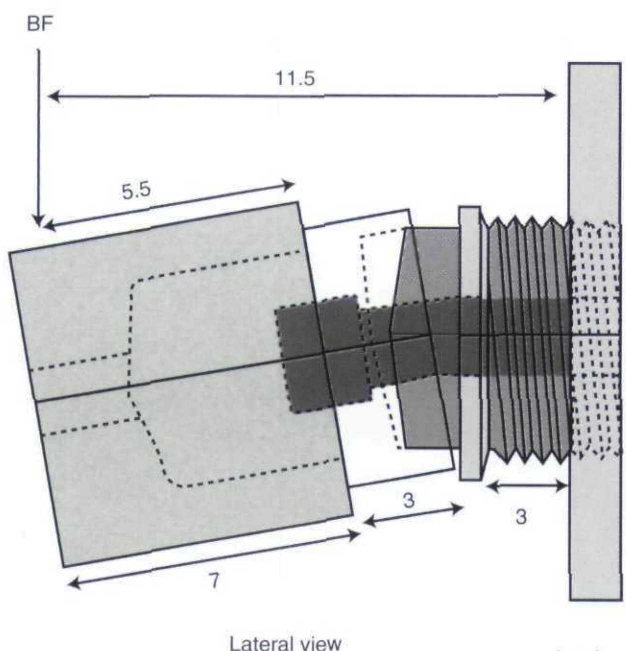

Figure 3 Schematic diagram of the experiment design, showing the static loading condition. (BF = bending force)

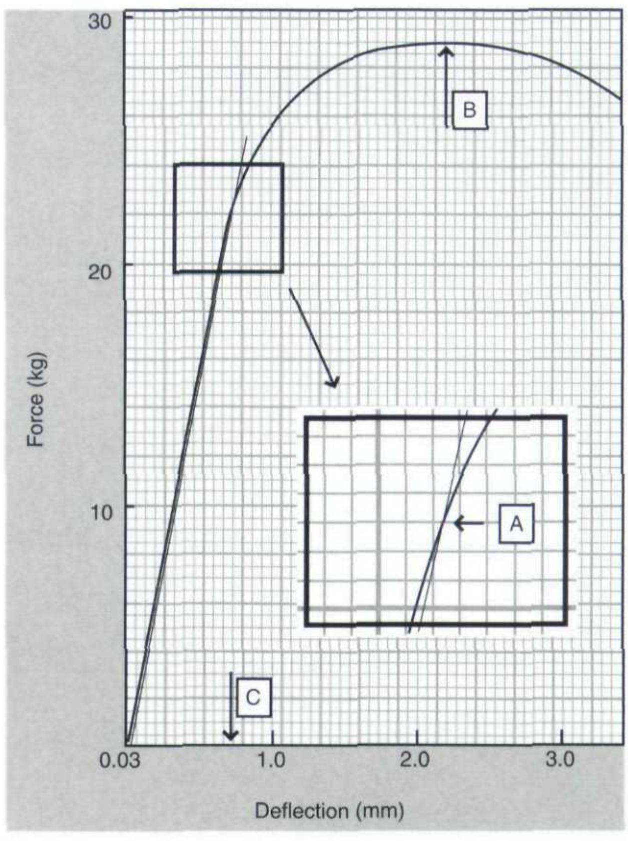

Figure 4 Force-deflection graph of a tested specimen, showing an expediently defined yield point (A), bending strength (B), and deflection at yield point (C). The straight line was drawn parallel to the straight part of the curve; the distance corresponds to a deflection of 0.033 mm.

random sequence to avoid potential errors due to increase in operator's skill.

Statistical Analysis

It was hypothesized that under lateral cyclic loading, neither the reverse torque values of the abutment screw nor the resistance of the implant/abutment joint to static bending force is affected by different loading periods. The preload reverse torque of each abutment screw was subtracted from the postload reverse torque, and the resulting difference was referred to as reverse torque difference (RTD). Mean values of RTD, standard deviations (SDs), and standard errors of means (SEMs) were calculated. Mean values of yielding strength, deflection at yield point, bending strength, hexagon abraded area, and their respective SDs and SEMs were calculated. The data were then analyzed with one-way analysis of variance (ANOVA) at the 95% confidence level. Accordingly all pairwise multiple comparison procedures using the Tukey test ($p < .050$) were performed for the comparisons among individual means of the experimental groups.

RESULTS

After dynamic testing, no decementation or screw loosening was noticed for any of the specimens by tactile or visual inspection during loading or upon the completion of cyclic loading.

Negative RTD values listed in Table 1 indicate that the loaded abutment screws required less loosening torque. Group A had the highest mean RTD value (–4.260 Ncm) while the control group (group C) had the lowest (–0.380 Ncm) (Table 2). The results of one-way ANOVA are summarized in Table 3; there was a statistically significant difference ($p < .001$). This primary analysis rejected the null hypothesis as a significant effect was found between the three groups. The results of the Tukey test indicated that group A had a statistically significant difference in RTD values as compared to groups B and C ($p < .001$) (Table 4). Likewise, group B showed a significant difference compared to group C ($p = .002$).

Upon the completion of static loading, the abutment screw was plastically bent in the unthreaded part without fracture in all test specimens (Figure 5). No decementation was noticed on tactile or visual inspection.

TABLE 1 Preload and Postload Reverse Torque Values, Means, and Differences

Specimen No.	Preload RT (Ncm)	Mean Preload RT and SD (Ncm)	Loading Point (Off-Axis)	Cycles No. ($n \times 10^6$)	Postload RT (Ncm)	Mean Postload RT and SD (Ncm)	RT Difference (Ncm)
Group A							
1	22.0		0 mm	1	18.6		–3.4
2	25.5		0 mm	1	21.8		–3.7
3	23.6	24.5, 2.0	0 mm	1	18.0	20.2, 2.2	–5.6
4	27.2		0 mm	1	23.1		–4.1
5	24.0		0 mm	1	19.5		–4.5
Group B							
1	24.2		0 mm	0.5	22.4		–1.8
2	25.4		0 mm	0.5	23.2		–2.2
3	28.4	24.0, 3.2	0 mm	0.5	26.0	22.0, 3.0	–2.4
4	22.0		0 mm	0.5	20.0		–2.0
5	20.0		0 mm	0.5	18.4		–1.6
Group C							
1	21.5		—	*	20.8		–0.7
2	27.0		—	*	26.5		–0.5
3	24.5	24.6, 2.1	—	*	24.2	24.2, 2.2	–0.3
4	26.0		—	*	25.6		–0.4
5	24.0		—	*	24.0		0.0

RT = reverse torque; SD = standard deviation.
*Left unloaded for 1×10^6 cycles time period.

TABLE 2 Mean Reverse Torque Differences, Standard Deviations, and Standard Errors of Means for Experimental Groups

Group	*N*	Mean RTD	SD	SEM
A	5	−4.260	0.856	0.383
B	5	−2.000	0.316	0.141
C	5	−0.380	0.259	0.116

RTD = reverse torque difference; SD = standard deviation; SEM = standard error of the mean.

Values of yielding strength, deflection at yield point, and bending strength are shown in Table 5. Table 6 displays the calculated data for each of the three tested groups. Group C (the control) had the highest means in the three variables among the tested groups whereas group A, which had undergone 1.0×10^6 lateral loading cycles, had the lowest yielding and bending strengths. The null hypothesis was rejected for the yielding strength, the bending strength, and the deflection at yield point because one-way ANOVA proved that the differences in the mean values among the test groups were greater than would be expected by chance ($p < .050$) (Table 7).

DISCUSSION

In this in vitro study the load was applied on a single implant post in a high magnitude and critical vector for a considerably long time. Since occlusal forces are complex in vector and magnitude, the load applied in this study simulated the lateral component of intraoral forces that may have critical effects on joint instability.[19,20,27] However, clinically the occlusal forces are distributed over the prosthesis and remaining teeth, and cyclic forces vary in intensity.

Upon the centric lateral loading applied in this study, the abutment screw might be allowed to intensively bend at the implant–abutment hexagon interface.

TABLE 3 One-Way Analysis of Variance* for the Experimental Groups

Source of Variation	*df*	SS	MS	*F* Value	Probability
Between groups	2	37.977	18.989	63.296	< .001
Residual	12	3.600	0.300	—	—
Total	14	41.577	—	—	—

df = degrees of freedom; MS = mean square; SS = sum of squares.
*$p < .050$.

TABLE 4 All Pairwise Multiple Comparison Procedures Using Tukey Test

Group Comparison	Difference of Means	*p*	$p < .050$
C vs A	3.880	< .001	Yes
C vs B	1.620	< .002	Yes
B vs A	2.260	< .001	Yes

Bending may lead to fatigue of the abutment screw that could result in screw loosening. The difference between groups A and B might be explained by the difference in loading periods. Long-term loading in the present study may have aggravated micromovements of the abutment as well as fatigue of the screw surface, leading to reverse torque reduction, loosening, and subsequent fracture of the screw.[11,19] The absence of misfit at the implant-abutment interface should lead to intimate engagement of joint components and thus to dissipation of the load through the external hexagon in the clamped components as compressive stresses.[13] Moreover, optimal hexagon height might protect the screw from the bending effect by dispersing forces to the other components.[10] Although the external hexagon implants available have heights of 0.7, 0.9, 1.0, and 1.2 mm,[30] the implant hexagon was reported as optimal with the 1.2 mm height.[10]

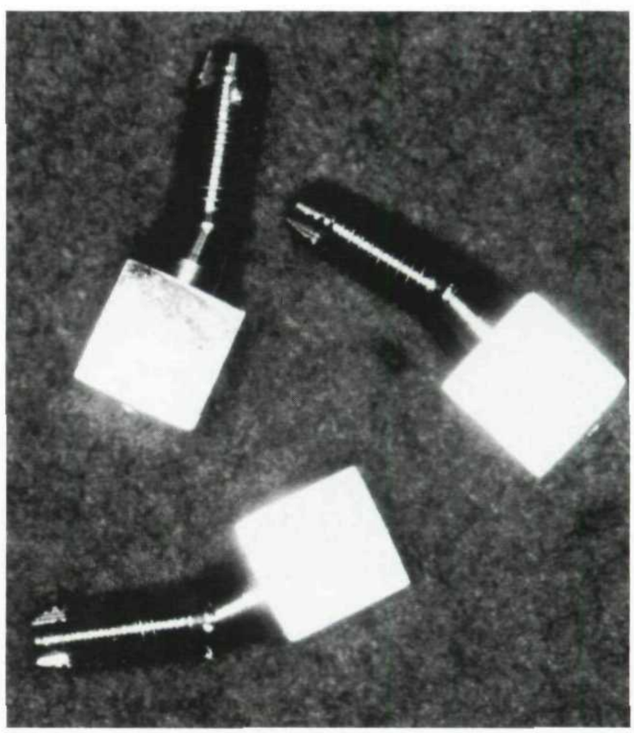

Figure 5 Experimental specimens that were plastically bent in the unthreaded part after static bending.

TABLE 5 Yield Strength, Deflection at Yield Point, and Bending Strength in Test Groups

Specimen No.	YS (kg)	DYP (mm)	BS (kg)
Group A			
1	24.75	1.20	30.05
2	21.50	0.70	29.47
3	22.50	0.67	31.55
4	22.75	0.83	32.15
5	25.75	0.80	32.72
Group B			
1	20.00	0.55	30.50
2	26.00	1.00	33.72
3	22.50	0.60	32.07
4	25.00	0.97	32.90
5	24.00	0.90	30.71
Group C			
1	23.75	1.05	30.10
2	24.30	0.82	32.77
3	24.00	0.87	31.92
4	25.00	1.37	33.10
5	27.50	1.77	33.57

BS = bending strength; DYP = deflection at yield point; YS = yield strength.

The present study demonstrated that the initial reverse torque values of the abutment screw are different from one screw to another after tightening to a torque of 32 Ncm. Consequently this would affect the initial preload stored in the abutment screw. However, no detailed evidence for the optimum height was found in the literature. Studies investigating the role of hexagon height in joint stability are still needed.

Although there was a significant decrease in the postload reverse torque values in group A, screw loosening could not be detected tactilely. This may indicate that the remaining tightening torque would serve clinically for a longer period of time. Future investigations are needed to determine the threshold value of the remaining torque below which the abutment screw loosens.

As regards the results of bending tests, the highest bending resistance of the implant/abutment joint was found in group C (the control group). This might be related to the intact joint components, mainly the implant hexagon and abutment screw, which had not been cyclically loaded.

Even though no statistically significant difference was proved in yielding and bending strengths between groups A and B (see Table 7), the results of this study revealed lower mean strengths in group A than in group B (see Table 6). This difference might be explained by the difference in the cyclic loading period that fatigued the implant/abutment joint components of group A. Similarly, no statistical significance was shown when mean yielding and bending strengths or abraded area were compared between groups A, B, and C. A higher number of specimens may possibly clarify the presence of significant differences.

The implant under centric lateral cyclic load showed significantly a reduction in the screw torque.

TABLE 6 Means of Yield Strength, Deflection at Yield Point, and Bending Strength for Experimental Groups

Group	*N*	Mean	SD	SEM
Yield strength (kg)				
A	5	23.450	1.745	0.780
B	5	23.500	2.345	1.049
C	5	24.910	1.522	0.681
Deflection at yield point (mm)				
A	5	0.840	0.212	0.0948
B	5	0.804	0.213	0.0952
C	5	1.176	0.396	0.177
Bending strength (kg)				
A	5	31.188	1.383	0.618
B	5	31.980	1.386	0.620
C	5	32.292	1.365	0.611

SD = standard deviation; SEM = standard error of the mean.

TABLE 7 One-Way Analysis of Variance* for Experimental Groups

Source of Variation	*df*	SS	MS	*F* Value	Probability
Yield strength					
Between groups	2	6.870	3.435	0.949	0.414†
Residual	12	43.437	3.620	—	—
Total	14	50.307	—	—	—
Deflection at yield point					
Between groups	2	0.421	0.210	2.557	0.119†
Residual	12	0.988	0.082	—	—
Total	14	1.409	—	—	—
Bending strength					
Between groups	2	3.239	1.620	0.853	0.451†
Residual	12	22.793	1.899	—	—
Total	14	26.032	—	—	—

df = degrees of freedom; MS = mean square; SS = sum of squares.
*$p < .050$.
†Not significant at $p < .05$.

Probably the misfit at the butt joint would partially void the role of the implant hexagon in resisting lateral forces, leading to repeated bending, loosening,[20] and (finally) fatigue failure[19] of the abutment screw.

CONCLUSION

Within the limitations of this in vitro study, it was concluded that centric lateral loading of 1×10^6 cycles significantly decreased the reverse torque values as compared to a 0.5×10^6 cycle-loading term.

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