Load Fatigue Performance of a Single-Tooth Implant Abutment System: Effect of Diameter

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Purpose: *This study investigated the load fatigue performance of narrow-, regular-, and wide-diameter CeraOne (Nobel Biocare) single-tooth implants and abutments.* ***Materials and Methods:*** *Five samples of each implant-abutment combination in 3 different widths were tested at 3 applied screw torque levels (recommended torque, recommended torque +20%, and recommended torque −20%). A rotational load fatigue machine was used to apply a 21-N load, at an angle of 45 degrees to the long axis of the specimens. This loading produced an effective bending moment of 35 Ncm at the abutment-implant interface. An upper cyclic limit was set at* 5×10^6 *load cycles for all specimens.* ***Results:*** *Two-way analysis of variance revealed a significant difference between narrow-diameter and wide-diameter implant test groups but no significant difference between the 3 torque levels for each implant diameter. In the narrow-diameter group, 6 of the 15 specimens failed (5 abutment screw failures and 1 implant failure). In the regular-diameter group, 3 of the 15 specimens failed (2 implant failures and 1 abutment screw failure). There were no failures in the wide-diameter group.* ***Discussion:*** *The results of this study indicate that the abutment screw is not the only potential failure location. The possibility of implant fracture clinically has been previously reported for prostheses supported by both single- and multiple-implant prostheses.* ***Conclusion:*** *The wide-diameter CeraOne single-tooth implant system demonstrated superior load fatigue performance. For clinical situations with significant functional loading, the narrow-diameter implants would be at a greater risk of fatigue failure.* (Basic Science) INT J ORAL MAXILLOFAC IMPLANTS 2006;21:929–936

Key words: *implant diameter, implant failure, implant fracture, load fatigue, single-tooth replacement, torque*

Broadly classified, there are 3 implant diameter categories: small or narrow diameter (3 to 3.4 mm), regular diameter (3.75 to 4 mm), and wide diameter (5 to 6 mm). Narrow-diameter implants have been indicated for the thin alveolar ridges or mesiodistal spaces of less than 7 mm. Block and Kent[1] reported a 99% success rate over an 8-year evaluation period for 238 narrow-diameter (3.25 mm) Integral implants. Spiekermann and associates[2] studied 127 narrow-diameter (3.3 mm) IMZ implants used with overdentures over a 5-year period and reported a 95% success rate. Saadoun and Le Gall[3] published clinical data on 306 narrow-diameter (3.25 mm) Steri-Oss implants over an 8-year period; they had a success rate of 89%. In a 5-year retrospective multicenter study of 202 narrow-diameter (3.3 mm) 3i implants, Lazzara and colleagues[4] showed a 96% success rate. Polizzi and associates[5] reported on a clinical study involving 30 narrow 3.0-mm-diameter Brånemark System implants in 21 patients for single-tooth restorations that had been followed up for 3 to 7 years. One implant fractured at 66 months, and a crown had to be replaced. However, information on the long-term clinical performance of the Brånemark narrow-diameter (3.3 mm) implant is lacking, and no biomechanical testing of this system has been reported.

There is not an abundance of clinical studies of wide-diameter implants. In 1993, Langer and coworkers[6] described a new 5-mm-diameter self-tapping implant and recommended its use in poor quality (type 4) bone,[7] in situations where there was inadequate bone height, for immediate replacement of

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Table 1 Implant Components Tested

Component	Size	Article no.
Nobel Biocare MKIII	Ø3.3 × 15 mm NP	26982
Nobel Biocare MKIII	Ø3.75 × 15 mm RP	25980
Nobel Biocare MKIII	Ø5 × 15 mm WP	26977
Nobel Biocare NP CeraOne abutment and Unigrip screw	3 mm	27206
Nobel Biocare RP CeraOne abutment and Unigrip screw	3 mm	27198
Nobel Biocare WP CeraOne abutment and Unigrip screw	3 mm	27203

nonosseointegrated regular implants, and for the immediate replacement of fractured implants. Due to the larger surface area of this implant, it was also suggested for use in areas of compromised bone quantity and quality. In 1996, Bahat and Handelsman[8] reported an overall success rate of 97.7% for a total of 133 wide-diameter Brånemark implants in 90 patients in the posterior jaw. Ivanoff and associates,[9] reporting on the influence of variations in Brånemark implant diameter in a 3- to 5-year retrospective clinical study, found the highest osseointegration failure rate (18%) for 5.0-mm-diameter implants compared with 3% for the 4.0-mm-wide implants and 5% for the 3.75-mm-diameter implants.

Two fatigue testing protocols have been addressed in the dental literature; namely, unidirectional bend-release fatigue testing[10–17] and rotational fatigue testing.[18–27] Unidirectional testing is carried out on asymmetric dental restorations such as post and core crowns,[12,13,15] bridge connectors,[10] and dentin bonding systems.[14,16] In rotational testing, symmetrical specimens can be tested at a much faster rate. This testing methodology has been used to test fatigue life of porcelain repair systems,[18] dental connectors with both soldered[19,20,24] and laser-welded joints,[23] crowns with different convergence angles luted with various cements,[21] and various implant and abutment systems.[22,25–27]

In a review of clinical implant studies, Goodacre and colleagues[28] reported on the clinical complications associated with osseointegrated implants. The most common complication reported with single crowns was abutment and/or prosthetic screw loosening. A higher frequency of screw loosening was reported for single crown replacements in the premolar and molar areas.[29–32]

This study investigated the load fatigue performance of narrow, regular, and wide-diameter single-tooth implant-abutment systems when tightened at 3 torque levels: *(1)* 20% less than the recommended torque, *(2)* the recommended torque, and *(3)* 20% more than the recommended torque.

MATERIALS AND METHODS

The single-tooth implant-abutment system investigated was the CeraOne abutment system (Nobel Biocare, Göteborg, Sweden) with the Brånemark MkIII implant (Nobel Biocare). The 3 different diameters used were *(1)* the narrow 3.3-mm diameter (NP), *(2)* the regular 3.75-mm diameter (RP), and *(3)* the wide 5.0-mm diameter (WP), and the implant length was 15 mm (Table 1). All the components were received in their original packaging.

Implant Holder Setup

A hollow brass implant holder (outer diameter = 12.0 mm, length = 28.0 mm, inner diameter = 10.0 mm) was machined (Fig 1). A narrower-diameter part (9.0 mm) was machined at the closed end to allow the implant holder to be clamped in the 3-jaw chuck of the rotational load fatigue machine (Fig 1).

Embedding the Assembled Specimen in Resin

The implant holder was filled with PL-2 epoxy resin (Measurements Group, Raleigh, NC), which was allowed to cure for 4 hours at 70°C. The PL-2 filled implant holder was then mounted to a miniature engineering lathe (Emco Unimat 4, Hallein, Austria). A central concentric hole was drilled into the PL-2 resin: a 3.3-mm-diameter hole, a 3.75-mm-diameter hole, and a 5.0-mm-diameter hole. The hole depth allowed each implant to be embedded into the PL-2 epoxy resin up to the second thread, which defined supporting bone level. Additional uncured PL-2 epoxy resin was used to secure the implant. This was also cured for 4 hours at 70°C. This procedure ensured that all implants were placed concentrically, with a standardized embedment depth.

The PL-2 epoxy resin used simulated trabecular bone supporting the implant.[22,33] This resin has a Young's modulus of 0.21×10^9 N/m^2; by comparison, human bone[34] has a modulus of 0.14×10^9 N/m^2.

Rotational Load Fatigue Machine

A custom rotational load fatigue machine applied a sinusoidally varying stress to each test specimen. This rotation was in a direction that would tighten the abutment screw. The stress fluctuation varied from tensile to compressive. The abutment-implant test specimen was angled at 45 degrees to the horizontal. Fig 1 shows an assembled test specimen in the load fatigue testing machine. The total test load of 21 N was thus angled at 45 degrees to the long axis of the test specimen, which induced a bending moment on the test specimen of 35 Ncm at the abutment-implant interface. The load fatigue machine had an automatic cycle counter and an automatic shut-off switch placed

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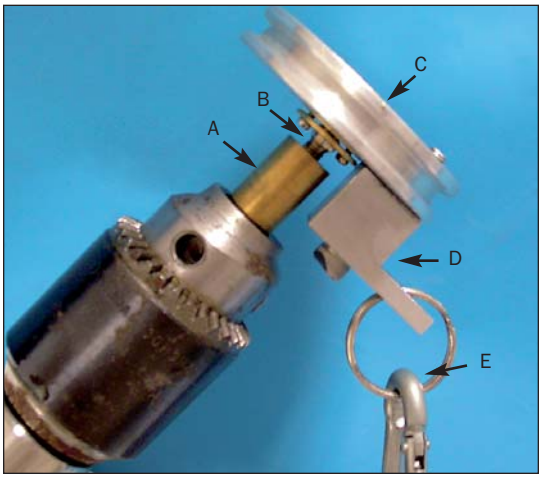

Fig 1 Profile view of the assembled test specimen setup. *(a)* Implant holder, *(b)* implant specimen, *(c)* bearing housing, *(d)* L-bracket, and *(e)* applied load.

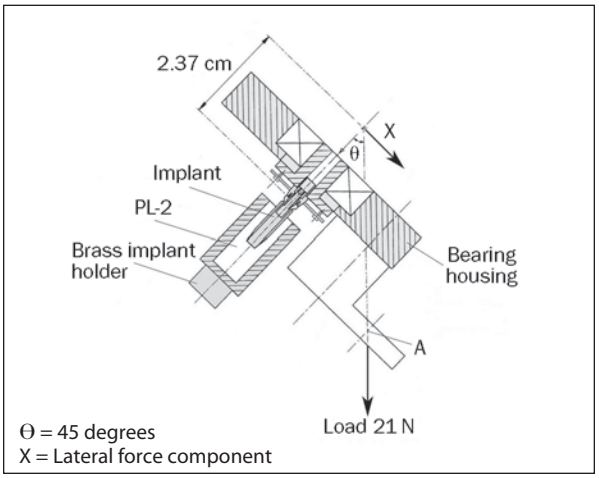

Fig 2 Schematic drawing of fatigue load applied to a specimen. Point A = Applied load. The moment arm is taken from the abutment-implant interface to the load point along the long axis of the specimen (2.37 cm). The lateral force component was calculated as x = 21cos45° and was 14.8 N. Bending moment = force × perpendicular distance; therefore the generated bending moment in this setup was 14.8 N (force) × 2.37 cm (perpendicular distance), which gives a value of 35 Ncm.

underneath the test load basket. When the test specimen failed, the load basket fell and depressed a shut-off switch. This stopped both the load fatigue machine and load cycle counter.

Fixture to Ball-Bearing Connections

The 21-N load was applied through point A on the L-bracket, as shown in Fig 2. This L-bracket was connected to the bearing housing. The bearing allowed the test specimen to rotate while the applied load remained vertical.

To strengthen the cemented connection between the brass cap and the abutment, a flat brass disk with a centrally located hole was placed beneath the abutment, as shown in Fig 2. This disk was connected to the brass cap through four screws. Tightening these four screws compressed the cemented connection between the abutment and brass cap, thus eliminating a cement failure at this location. The steps needed to assemble a test specimen were:

1. The brass cap was cemented into the bearing in the bearing housing using zinc phosphate cement (Super Cement; Shofu, Kyoto, Japan) with a force of 1 kg for 15 minutes.
2. The abutment was cemented into the brass cap using zinc phosphate cement.
3. With the brass disk on the lower side of the abutment, the 4 screws connecting the brass disk and brass cap were tightened to create an assembly containing the bearing, bearing housing, abutment, brass cap, brass disk, and L-bracket.
4. This assembly was placed over the implant in the PL-2 resin, and a torque driver (Model 6 BTG; Tonichi Manufacturing, Tokyo, Japan) and a Unigrip screwdriver (article no. 29149, Nobel Biocare) were used to achieve the desired torque. The hole in the brass cap allowed this torque to be applied. Table 2 shows the torque levels used. Fig 2 shows the assembled specimen.

Upper Cycle Limit on Fatigue Testing

The US Food and Drug Administration, Centre for Devices and Radiological Health specifications for rotational load fatigue testing of dental implants were followed.[35] These specifications state that test abutment-implant specimens not undergoing corrosion fatigue testing should be subjected to fatigue loading conditions in air at 20°C and at a frequency of 3 to 15 Hz for a minimum of 5×10^6 cycles. This exceeds the minimum of 1×10^6 cycles recommended by Wiskott and associates[36] for fatigue testing, which was postulated to be equivalent to a service life of 4 to 20 years.

The implant components were visually examined for gross defects when they were removed from their packaging. The fatigue testing was done at 20°C in an air-conditioned room. The rotational load fatigue testing machine was run at 14 Hz, with 5×10^6 cycles set as the upper limit. The same operator performed specimen preparation and testing for the entire study. There were 5 test samples per test group (n = 5).

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Table 2 Applied Torque Level for the 3 Implant-Abutment Diameters

	Recommended torque level – 20% (Ncm)	Recommended torque level (Ncm)	Recommended torque level + 20% (Ncm)
Narrow diameter (3.3 mm) (NP)	16	20	24
Regular diameter (3.75 mm) (RP)	25.6	32	38.4
Wide diameter (5 mm) (WP)	36	45	54

Table 3 Load Fatigue Performance of the NP Group by Torque Level

Applied torque/ Sample ID*	Cycles to failure	Type of failure
16 Ncm (–20% recommended torque)		
N/–/1	> 5,000,000	No failure
N/–/2	459,129	Gold screw fracture
N/–/3	> 5,000,000	No failure
N/–/4	271,852	Gold screw fracture
N/–/5	> 5,000,000	No failure
Mean	3,146,196.2	
SD	2,539,288.8	
20 Ncm (recommended torque)		
N/0/1	> 5,000,000	No failure
N/0/2	> 5,000,000	No failure
N/0/3	1,657,703	Gold screw fracture
N/0/4	> 5,000,000	No failure
N/0/5	95,916	Gold screw fracture
Mean	3,350,723.8	
SD	2,324,888.7	
24 Ncm (+20% recommended torque)		
N/+/1	> 5,000,000	No failure
N/+/2	4,803,830	Implant fracture
N/+/3	854,493	Gold screw fracture
N/+/4	> 5,000,000	No failure
N/+/5	> 5,000,000	No failure
Mean	4,131,664.6	
SD	1,833,962.9	

* N = narrow diameter; – = –20% recommended torque; 0 = recommended torque; + = +20% recommended torque

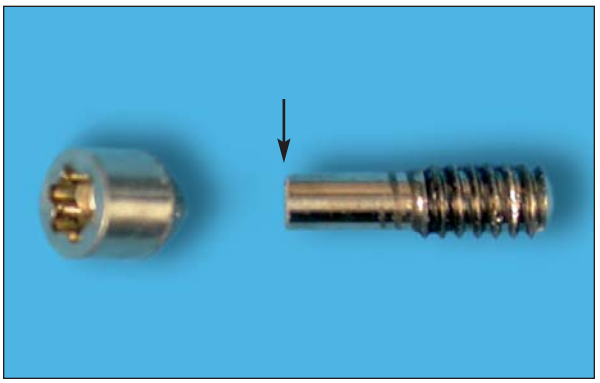

Fig 3 Failed abutment screw (sample N/+/3) at the junction of the screw head and the screw shank *(arrow)*.

Scanning Electron Microscopy

The fractured surfaces of all failed specimens were examined with a scanning electron microscope (SEM). These surfaces were uncoated to preserve surface detail and were observed under a Jeol JSM-5800LV SEM (JEOL USA, Peabody, MA) at 15 kV.

Statistical Analysis

The independent variables were the different implant diameters and the varying torque levels. The dependent variable was the number of load cycles required before failure of the assembly. All data were subjected to a 2-way analysis of variance (ANOVA), and group means were compared with 1-way ANOVA and Tukey highly significant difference (HSD) post-hoc test at the 95% significance level (SPSS 11.0; SPSS, Chicago, IL).

RESULTS

Narrow Diameter

Table 3 shows the results for the narrow diameter (3.3 mm) abutment-implant combinations for the 3 different applied torque levels. There were 5 abutment screw fractures and 1 implant fracture. The 5 abutment screw fractures occurred in the range of 95,916 to 1,657,703 load cycles. Four abutment screws failed at the first thread (2 at the 16-Ncm torque level and 2 at the 20-Ncm torque level). The fifth abutment screw failed at the junction between the screw head and screw shank (24-Ncm torque level; Fig 3). The single implant fracture occurred after 4,803,830 cycles, at the start of the self-tapping thread notch (24-Ncm torque level). The fractured implant remnant was firmly embedded in the PL-2 resin. For each torque level group, there was a 60% (3 of 5 samples) survival rate.

Regular Diameter

Table 4 presents the data for the regular diameter (3.75 mm) abutment-implant combinations with the 3 different applied torque levels. Of the 15 specimens, 3 failed (2 implant fractures and 1 abutment screw fracture). The abutment screw failed in the first thread, at 1,207,260 load cycles (25.6 Ncm torque

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level). This is shown in Fig 4. The 2 implant fractures occurred at 4,623,283 cycles (32 Ncm torque level) and 4,349,565 cycles (38.4 Ncm torque level). Both implants fractured at the start of the self-tapping thread notch (Figs 5a to 5c).

Wide Diameter

Table 5 shows the data for the wide diameter (5 mm) abutment-implant combinations with the 3 different applied torque levels. All 15 samples survived 5×10^6 load cycles without failure.

Statistical Results

A 2-way ANOVA (Table 6) revealed significant differences ($P < .05$) in the number of cycles to failure between abutment-implant diameters. Consequently, a 1-way ANOVA with Tukey's HSD post-hoc test showed a significant difference between the narrow-diameter groups and wide-diameter groups. There were no significant differences between the 9 torque groups.

DISCUSSION

Abutment Screw Failure

For the narrow implants, there was 1 fracture at the abutment screw head (recommended +20% torque level) and 4 fractures at the first thread of the abutment screw (2 at the recommended –20% torque level and 2 at the recommended torque level). In cases where the abutment screw fractured at the first thread, the abutment screw heads were badly damaged. This type of damage suggests screw loosening as the first stage of failure. When an abutment screw loosens, surface damage occurs. This leads to fatigue fracture at the first thread, which is a high-stress location. Screw loosening was also most likely to occur with the lower torque levels applied to the abutment screws, as opposed to the highest torque

Table 4 Load Fatigue Performance of the RP Group by Torque Level

Applied torque/ Sample ID*	Cycles to failure	Type of failure
25.6 Ncm (–20% recommended torque)		
R/-/1	> 5,000,000	No failure
R/-/2	> 5,000,000	No failure
R/-/3	> 5,000,000	No failure
R/-/4	> 5,000,000	No failure
R/-/5	1,207,260	Gold screw fracture
Mean	4,241,452.0	
SD	1,696,164.9	
32 Ncm (recommended torque)		
R/0/1	4,623,283	Implant fracture
R/0/2	> 5,000,000	No failure
R/0/3	> 5,000,000	No failure
R/0/4	> 5,000,000	No failure
R/0/5	> 5,000,000	No failure
Mean	4,924,656.6	
SD	168,473.0	
38.4 Ncm (+20% recommended torque)		
R/+/1	>5,000,000	No failure
R/+/2	>5,000,000	No failure
R/+/3	4,349,565	Implant fracture
R/+/4	>5,000,000	No failure
R/+/5	>5,000,000	No failure
Mean	4,869,913.0	
SD	290,883.4	

* R = regular diameter; - = –20% recommended torque; 0 = recommended torque; + = +20% recommended torque

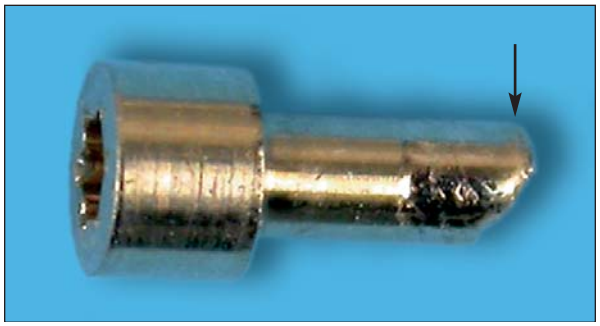

Fig 4 Failed abutment screw (sample R/–/5) at the first thread *(arrow)*.

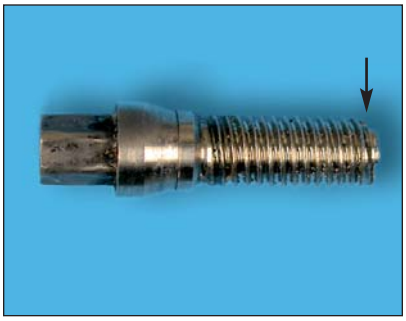

Fig 5a Fractured implant (sample R/0/1). The fracture occurred at the level of the start of the self-tapping notch *(arrow)*.

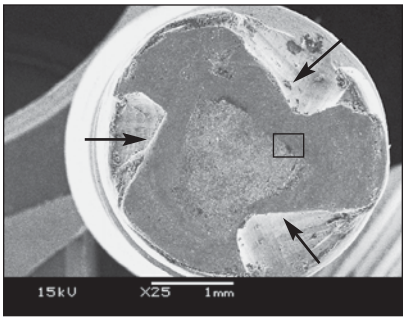

Fig 5b The surface of fractured implant R/0/1 under SEM. Fracture occurred at the start of the self-tapping notch *(arrows)*.

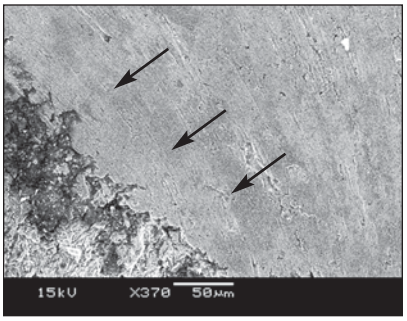

Fig 5c Boxed area of Fig 5b at a higher magnification showing fatigue striations *(arrows)*, indicating fatigue failure.

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level of recommended +20%. For the regular-diameter implant, a single abutment screw fracture occurred at the recommended –20% torque level; this fracture also occurred at the first thread.

For the +20% recommended torque level for the narrow-diameter group, screw failure occurred at the screw head rather than at the first thread, but the screw head was relatively undamaged. This minimal screw head damage indicates that the failure did not include screw loosening. There are 2 possible locations where high stress will develop in the abutment screw: the first thread and the head of the screw. Thus, it is not surprising that this particular screw failed at the head and not the first thread. Jörnéus and colleagues[37] and Jemt[38] have stated that inadequate tightening may be the cause of loosening of the screw while in function. The fact that most screw failures occurred at the 2 lower torque levels is in agreement with this statement. No apparent abutment screw loosening occurred in the +20% recommended torque level groups.

Table 5 Load Fatigue Performance of the WP Group by Torque Level

Applied torque/ Sample ID*	Cycles to failure	Type of failure
36 Ncm (–20% recommended torque)		
W/-/1	> 5,000,000	No failure
W/-/2	> 5,000,000	No failure
W/-/3	> 5,000,000	No failure
W/-/4	> 5,000,000	No failure
W/-/5	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	
45 Ncm (recommended torque)		
W/0/1	> 5,000,000	No failure
W/0/2	> 5,000,000	No failure
W/0/3	> 5,000,000	No failure
W/0/4	> 5,000,000	No failure
W/0/5	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	
56 Ncm (+20% recommended torque)		
W/+/1	> 5,000,000	No failure
W/+/2	> 5,000,000	No failure
W/+/3	> 5,000,000	No failure
W/+/4	> 5,000,000	No failure
W/+/5	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	

*W = wide diameter; - = –20% recommended torque; 0 = recommended torque; + = +20% recommended torque

Implant Failure

It seems surprising that implant failures occurred in this study rather than failures at the first thread of the abutment screw. Yet 3 implants failed at the highest torque levels (at the recommended torque level for 1 RP failure and at +20% recommended for the remaining NP and RP failures). These failures occurred at an expected location, namely, at the plane of the start of the self-tapping notch on the external surface (Figs 5a and 5b). In essence, the implant in the PL-2 resin was a cantilever beam. As a result of the externally applied moment of 35 Ncm, the PL-2 resin applied a resisting stress along the length of the implant. The implant acted as a cantilever beam under these conditions, and this resisting PL-2 applied stress increases down the length of the implant. But at the self-tapping notch on the implant, there would be an increase in stress because of the abrupt change in geometry. This combination would lead to fatigue failure at this location. However, the threads on the external surface would also act as stress risers, and failure could also occur at one of these. So the starting point of the fracture at this location could have been either the top of the notch or 1 of the threads. The fact that implant failure occurred at the 2 higher torque levels suggests that the higher preload in the abutment-implant screw joint forced failure to the lower section of the implant. In addition, since the wide-platform implant did not exhibit implant failure, one can assume that the wider diameter reduced the stress in the implant to a safer level.

Lack of Failure with Wide-Platform Implants

For the wide platform, there were neither screw nor implant fractures. All samples survived to the upper limit of 5×10^6 cycles. These results may be analyzed

Table 6 Two-Way ANOVA for Implant Diameter and Torque Level

Source	Type I Sum of Squares	df	Mean Square	F	*P*
Corrected model	21,728,824,350,087.170	8	2,716,103,043,760.897	1.343	.255
Intercept	874,044,991,667,265.000	1	874,044,991,667,265.000	432.066	.000
DIAM	17,582,863,257,773.750	2	8,791,431,628,886.870	4.346	.020
TORQUE	4,145,961,092,313.469	6	690,993,515,385.578	.342	.910
DIAM * TORQUE	.000	0			
Error	72,825,945,097,320.000	36	2,022,942,919,370.001		
Total	968,599,761,114,673.000	45			
Corrected total	94,554,769,447,407.100	44			

DIAM = implant diameter; TORQUE = applied torque.

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with respect to the width of the platform. First, for the wide platform, the screw diameter is larger, which implies a lower screw shank stress, if one assumes a linear relation between the applied torque and resulting screw shank tensile stress. The screw shank stresses for the 3 platforms would have been in the ratio of narrow = 1, regular = 0.96, and wide = 0.93, if one assumes that the screw shank stress is always a fixed percentage of the applied torque. This indicates that the relative stress in the wide-platform screw would be approximately 93% of that in the narrow-platform screw. Thus, there was a greater possibility of screw fracture occurring in the narrow-platform screws than in the wide-platform screws. This was indeed the case. The fact that the wide-platform implant had a diameter of 5.0 mm; the regular-platform implant, a diameter of 3.75 mm; and the narrow-platform implant, a diameter of 3.3 mm means that stress from implant bending would have occurred in the ratio of wide = 1, regular = 2.4, and narrow = 3.5. This implies that for the same externally applied moment (35 Ncm), the stress induced in the narrow implant would be 3.5 times greater than the stress in the wide implant; the stress induced in the regular implant would be 2.4 times greater. These numbers are in keeping with the results of this study, where implant failures occurred only with the regular and narrow platforms.

Comparison with Other Studies

Basten and associates[22] examined the load fatigue performance of the CeraOne and the EsthetiCone implant systems at 3 torque levels (standard torque, standard torque +20%, and standard torque −20%). Two-way ANOVA showed no significant difference between the 3 torque levels, but a significant difference was observed between the implant systems. Ten of the 15 specimens failed at the implant level between 15,235 and 1,492,048 cycles. One abutment screw fracture in the standard −20% torque group and 3 abutment screw fractures in the standard torque group were reported. No abutment screw fracture occurred in the standard +20% torque group. In the current study, the abutment screw design was the new Unigrip design, while Basten and associates[22] used the old gold-alloy abutment screw. The design change could account for the difference in results.

In a more recent study, Khraisat and associates[25] looked at the fatigue resistance of the CeraOne abutment and the ITI Solid abutment (Straumann, Basel, Switzerland). All 7 CeraOne specimens failed at the abutment screw between 1,178,023 and 1,733,526 cycles. No ITI Solid abutments failed after 1,800,000 cycles. It was observed that the failures occurred at the junction between the unthreaded (1.5 mm diameter) and the threaded parts (2 mm diameter) of the screw. The higher failure rate for the CeraOne abutment screws may have been due to the difference in the study methodology and the higher applied bending moment of 115 Ncm.

Clinical Significance

Polizzi and associates[5] evaluated 30 narrow 3.0-mm-diameter Brånemark implants in 21 patients for single-tooth restorations for 3 to 7 years postplacement. One implant fractured at 66 months, and 1 crown had to be replaced. Eckert and colleagues[39] did a retrospective evaluation of 4,937 implants. For single-tooth restorations, 5 fractured 3.75-mm-diameter implants were observed; all were replacing a missing molar. Screw loosening was observed prior to implant fracture in all cases.

There has been no clinical report of any fractured wide diameter implant to date. These studies show a failure pattern which is consistent with the findings of this research. The current study demonstrated abutment screw fractures which were preceded by a phase of screw loosening. Longitudinal clinical studies have also reported abutment screw loosening. It may be presumed that patients seek management of the prosthetic complication of abutment screw loosening before it can progress to actual screw fracture. It is recommended that loosened abutment screws always be replaced, as these screws could have a fatigue history that could lead to possible screw fracture in the near future.

CONCLUSIONS

In the present study, the brass cap crown analog was compressed against the abutment with the clamping system. This eliminated the possibility of failure at this location. However, the abutment screws and implants used were under applied moment and thus were able to fail. In this study, there were 6 failures of the narrow-diameter implant-abutment specimens tested, 3 failures of the regular-diameter implant-abutment specimens, and 0 failures of the wide-diameter implant-abutment specimens. For clinical situations with significant functional loading, the narrow-diameter implants would be at the greatest risk of fatigue failure.

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