Load Fatigue Performance of Four Implant-Abutment Interface Designs: Effect of Torque Level and Implant System

H. C. Quek, BDS, MDS, MRD, RCSEd[1]/Keson B. Tan, BDS, MSD[2]/Jack I. Nicholls, PhD[3]

Purpose: *Biomechanical load-fatigue performance data on single-tooth implant systems with different implant-abutment interface designs is lacking in the literature. This study evaluated the load fatigue performance of 4 implant-abutment interface designs (Brånemark-CeraOne; 3i Osseotite-STA abutment; Replace Select-Easy abutment; and Lifecore Stage-1-COC abutment system). The number of load cycles to fatigue failure of 4 implant-abutment designs was tested with a custom rotational load fatigue machine. The effect of increasing and decreasing the tightening torque by 20% respectively on the load fatigue performance was also investigated.* ***Materials and Methods:*** *Three different tightening torque levels (recommended torque, −20% recommended torque, +20% recommended torque) were applied to the 4 implant systems. There were 12 test groups with 5 samples in each group. The rotational load fatigue machine subjected specimens to a sinusoidally applied 35 Ncm bending moment at a test frequency of 14 Hz. The number of cycles to failure was recorded. A cutoff of* 5×10^6 *cycles was applied as an upper limit.* ***Results:*** *There were 2 implant failures and 1 abutment screw failure in the Brånemark group. Five abutment screw failures and 4 implant failures was recorded for the 3i system. The Replace Select system had 1 implant failure. Five cone screw failures were noted for the Lifecore system. Analysis of variance revealed no statistically significant difference in load cycles to failure for the 4 different implant-abutment systems torqued at recommended torque level. A statistically significant difference was found between the −20% torque group and the +20% torque group (*$P < .05$*) for the 3i system.* ***Conclusions:*** *Load fatigue performance and failure location is system specific and related to the design characteristics of the implant-abutment combination. It appeared that if the implant-abutment interface was maintained, load fatigue failure would occur at the weakest point of the implant. It is important to use the torque level recommended by the manufacturer.* Int J Oral Maxillofac Implants 2008;23: 253–262

Key words: *abutment screw failure, implant-abutment interface, load fatigue, preload, torque*

It is generally held that prostheses supported by multiple implants have better load distribution and hence lower stress concentrations at the implant-abutment interface compared to single-tooth prostheses.[1] Bending moments become more significant in single-tooth prostheses, as the load distribution effect is absent. Prosthetic complications reported for single-tooth implants include abutment screw fracture, abutment screw loosening, and implant fracture.[2]

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Several implant-abutment interface designs are supposedly able to support the single-tooth restoration. These interface designs may be classified as external or internal connection and incorporate features for rotational resistance, indexing, and lateral stabilization. The designs may be described as hexagonal, octagonal, cone screw, cone hex, cylinder hex, spline, cam, cam tube, and pin/slot.[3]

The external hexagonal interface was originally intended to provide a method for engaging the implant during surgical placement. In single-tooth applications, the external hexagon has also been used to provide an anti-rotational mechanism, resulting in the exposure of the implant-abutment interface and abutment screw to greater external loads and bending moments,[4] which can lead to screw joint opening and screw loosening.[4,5] Tan et al[6] showed that the critical bending moment (the moment when the external nonaxial load applied overcomes the screw joint preload and results in the loss of contact between the mating surfaces of the

implant and abutment) varied significantly with abutment design and tightening torque. Loosening of abutment screws has been reported in clinical retrospective studies of the Brånemark and 3i single-tooth implant systems.[7–10] Implant fractures have also been reported in some clinical studies.[11–15] However, clinical studies on the newer TorqTite and Gold-Tite abutment screws and information on their relative performance are needed.

The tapered cone-screw internal connection was first introduced in the Morse taper system. The mating angle between the implant and the abutment taper was 8 degrees, and a retaining-screw component was utilized. Straumann has claimed that 91% of the tightening torque is delivered to the Morse taper. Sutter et al[16] reported that the loosening torque required for the Straumann connection was 124% greater than the tightening torque of 25 Ncm, which may account for the lack of screw loosening in the Straumann implant system. In a bending-to-failure study, Norton[17] found that in the Straumann implant system, the failure occurred at the start of the screw thread just beneath the base of the cone of the abutment. Loosening and fracture of solid Straumann abutments (but no implant fractures) were reported in a retrospective analysis of 675 posterior single-tooth Straumann implant restorations on 4.1-mm solid-screw Straumann implants.[18]

Novel internal designs of the implant-abutment connection are available. The Replace Select implant has a "Trichannel" internal configuration and an abutment that fits within it. The Camlog implant system connection features 3 symmetrical internal grooves (cam cut-outs) in the uppermost cylindric portion of the implant for antirotation. No clinical reports on possible prosthetic complications have yet been reported for the Replace Select or Camlog implant systems.

Most laboratory studies compare implant-abutment interfaces using monotonic tensile or bending load-to-failure testing methodology. Load fatigue from functional chewing loads is considered a more physiologically relevant biomechanical failure mode. Wiskott et al[19] propose that rotational load fatigue testing is a fast and cost-effective means to generate relevant data and provides a more realistic selection basis for prediction of clinical longevity. Several investigators[20–22] have used rotational load fatigue testing of implant-abutment interfaces to elucidate their relative performance. The Center for Devices and Radiological Health of the US Food and Drug Administration recommends that fatigue testing of implants and abutments of various designs be carried out in air at 200°C, at a frequency of 3 to 15 Hz for at least 5 × 106 cycles.[23]

In the absence of long-term clinical studies, these newer implant-abutment interface designs require investigation. An understanding of the relative performance of single-tooth implant systems of different implant-abutment interface designs under load fatigue testing would enable the clinician to select and utilize each implant system optimally.

The aim of this study was to evaluate the load fatigue performance of 4 regular-diameter implant-abutment interfaces (2 external hexagonal, 1 cam tube, and 1 cone screw) subjected to 3 different tightening torques. The following were investigated:

1. The number of load cycles required to result in load fatigue failure and the corresponding mode of failure
2. The effect of decreasing the recommended tightening torque by 20% and increasing the tightening torque by 20% on the load fatigue performance

MATERIALS AND METHODS

This study evaluated the load fatigue performance of four implant-abutment interface designs:

1. Brånemark-CeraOne abutment system (BR; Nobel Biocare, Göteborg, Sweden); external hexagon
2. 3i Osseotite-STA abutment system (3i; Biomet/3i, Palm Beach Gardens, FL); external hexagon
3. Replace Select-Easy abutment system (RS; Nobel Biocare, Göteborg, Sweden); cam tube
4. Lifecore Stage-1-COC abutment system (LC; Lifecore Biomedical, MN); cone screw

The 4 implant-abutment systems used are described in Table 1 and shown in Figs 1a and 1b. The same operator performed all sample preparation and testing, which was done in random order.

A hollow cylindric brass specimen holder with an outer diameter of 12.0 mm, a length of 28.0 mm, and an inner diameter of 6.0 mm was fabricated to hold the test specimens (Fig 2). One end of this holder was machined to a diameter of 9.0 mm. This end was clamped in the load fatigue machine. The hollow end of this holder was filled with PL-2 epoxy resin (Vishay Measurements Group, Raleigh, NC), and the resin was allowed to set for 4 hours at 21°C. The PL-2 resin was used to simulate trabecular bone supporting the implant. PL-2 resin has a modulus of elasticity of 0.21 $\times$ 10^9 N/m,^{2} which is close to that of trabecular bone (0.14 $\times$ 10^9 N/m^2).[24] A central hole was drilled into the PL-2 resin, and the test implant was secured in this hole with additional PL-2 resin. This hole allowed the

Table 1 Implant Components Tested

System	Component	Ref code
Nobel Biocare Brånemark	Mk III Regular Platform 3.75 wide, 15 mm long	28888
	CeraOne abutment Regular Platform 3 mm	29647
3i	Osseotite implant 3.75 wide, 15 mm long	OSS315
	STA abutment 4.1 mm wide, 5 mm platform, cuff height of 3 mm	STA 453
Nobel Biocare Replace Select	Replace Select Straight TiUnite RP 4.3 × 15 mm	28954
	Easy Abutment Select RP 1.5 mm	29471
Lifecore Stage-1	Stage-1 RBM Single-Stage Implant RDS 4.1 × 14 mm	RSR4114-2
	RDS COC abutment	S2432-70-1

Fig 1a Components of 4 implant systems tested. *(From left)* Brånemark MkIII RP implant with CeraOne abutment and TorqTite screw; 3i standard Osseotite implant with STA abutment and Gold-Tite screw; Replace Select TiUnite RP implant with Easy abutment and TorqTite screw; and Lifecore RBM Single-Stage implant with RDS COC abutment.

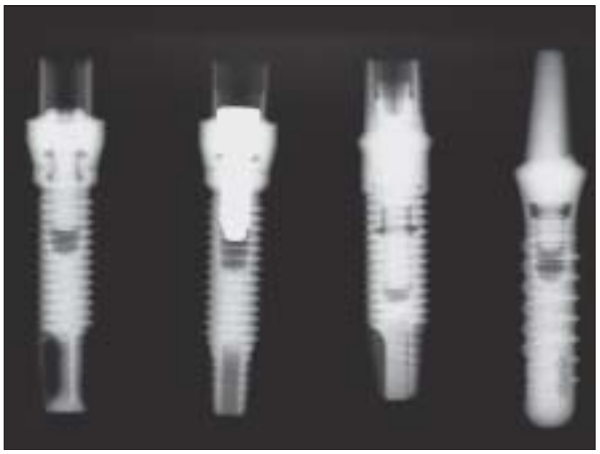


Fig 1b Radiograph of 4 implant systems shown in the same order as described for Fig 1a.

implant to be embedded to the depth of the second thread, which simulated bone level. These procedures were used by Basten et al[20] and Quek et al.[21]

For the CeraOne, STA, and Easy abutments, the connection between the abutment and bearing housing was similar to that described by Quek et al.[21] A brass cap was machined to fit over the Lifecore COC abutment. This cap was held in place with a screw threaded perpendicular to the abutment and cemented to the bearing housing with zinc phosphate cement. For all abutments, the load was applied at point A on the L-bracket, at a 45-degree angle to the long axis of the test sample (Fig 2).

Following connection of the abutment to the bearing housing, the abutment screw was tightened with a torque gauge (Model BTG60CN-S; Tonichi, Tokyo, Japan). The torque gauge was factory calibrated to be accurate to within 0.6 Ncm. Table 2 shows the tightening torques (recommended, +20% recommended, and –20% recommended) applied to the various samples. Altogether there were 12 test groups with 5 samples (n = 5) per test group.

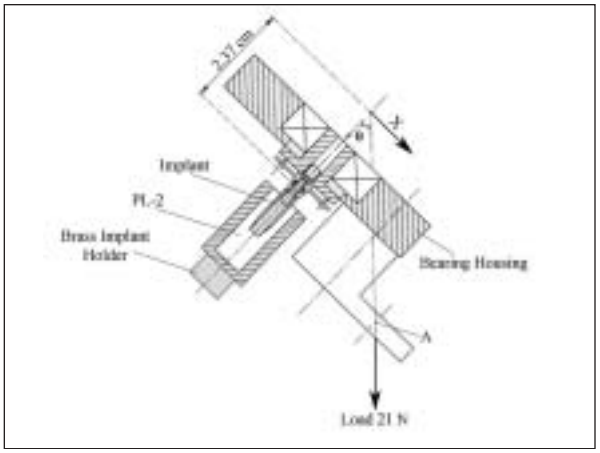


Fig 2 Schematic drawing of fatigue load applied to a sample. The moment arm is taken from the implant-abutment interface to the load point along the long axis of the sample (2.37 cm). The lateral force component, x, was calculated as 21cos45°, which was 14.8 N. Bending moment = force × perpendicular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

Table 2 Applied Torque Levels (Ncm) for the 4 Implant-Abutment Systems

System	Test group ID	Recommended torque level –20% (Ncm)	Recommended torque level (Ncm)	Recommended torque level +20% (Ncm)
Brånemark	BR	28	35	42
3i	3i	25.6	32	38.4
Replace Select	RS	28	35	42
Lifecore Stage-1	LC	24	30	36

Table 3 Load Fatigue Performance of Brånemark Implant Group by Torque Level

Applied torque/ sample ID	Cycles to failure	Type of failure
28 Ncm (–20% recommended torque)		
BR/1/–	> 5,000,000	No failure
BR/2/–	> 5,000,000	No failure
BR/3/–	> 5,000,000	No failure
BR/4/–	> 5,000,000	No failure
BR/5/–	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	
35 Ncm (Recommended torque)		
BR/1/0	4,878,023	Implant fracture
BR/2/0	> 5,000,000	No failure
BR/3/0	> 5,000,000	No failure
BR/4/0	2,049,628	Implant and TorqTite screw fracture
BR/5/0	> 5,000,000	No failure
Mean	4,385,530.0	
SD	1,306,876.8	
42 Ncm (+20% Recommended torque)		
BR/1/+	>5,000,000	No failure
BR/2/+	>5,000,000	No failure
BR/3/+	>5,000,000	No failure
BR/4/+	1,264,237	TorqTite screw fracture
BR/5/+	>5,000,000	No failure
Mean	4,252,847.0	
SD	1,670,684.0	

BR = Brånemark system.

Table 4 Load Fatigue Performance of 3i Implant Group by Torque Level

Applied torque/ sample ID	Cycles to failure	Type of failure
25.6 Ncm (–20% recommended torque)		
3i/1/–	619,454	Gold screw fracture
3i/2/–	38,998	Gold screw fracture
3i/3/–	21,958	Gold screw fracture
3i/4/–	54,692	Gold screw fracture
3i/5/–	207,775	Gold screw fracture
Mean	188,575.4	
SD	252,034.0	
32 Ncm (Recommended torque)		
3i/1/0	2,318,653	Implant fracture
3i/2/0	> 5,000,000	No failure
3i/3/0	> 5,000,000	No failure
3i/4/0	209,858	Implant fracture
3i/5/0	> 5,000,000	No failure
Mean	2,760,998.0	
SD	2,145,367.1	
38.4 Ncm (+20% Recommended torque)		
3i/1/+	> 5,000,000	No failure
3i/2/+	> 5,000,000	No failure
3i/3/+	893,486	Implant fracture
3i/4/+	592,849	Implant fracture
3i/5/+	> 5,000,000	No failure
Mean	3,297,267.0	
SD	2,333,984.7	

3i = 3i implant system.

The rotational load fatigue machine has been described by Quek et al.[21] The test load used was 21 N, at an angle of 45 degrees to the long axis of the sample (Fig 2). This created a bending moment of 35 Ncm at the implant-abutment interface. The fatigue testing machine was run at 14 Hz, and the upper limit for specimen cycling was set at 5×10^6 cycles.[23] All the samples were examined for concentricity during the initial 1,000 cycles. If there was eccentric rotation, the samples were mounted again in new PL-2 resin and retested. All concentric samples were run continuously until failure or for 5×10^6 cycles. When the sample failed, the load basket fell and activated a shut-off button, stopping the load fatigue machine immediately. The number of load cycles to sample failure was recorded by the automatic cycle counter.

The failed samples were analyzed under light microscope at 40×. Scanning electron microscopy (SEM) was used to examine the fractured surfaces of the failed samples (JEOL JSM-5600LV; JEOL USA, Peabody, MA). The samples were uncoated to preserve all surface features.

Statistical Analysis

All data were subjected to 2-way analysis of variance (ANOVA), and group means were compared with subsequent 1-way ANOVA and Tukey highest significant difference post-hoc test at the 95% significance level (SPSS 12.0; SPSS, Chicago, IL).

Table 5 Load Fatigue Performance of Replace Select Implant Group by Torque Level

Applied torque/ sample ID	Cycles to failure	Type of failure
28 Ncm (−20% recommended torque)		
RS/1/−	> 5,000,000	No failure
RS/2/−	> 5,000,000	No failure
RS/3/−	> 5,000,000	No failure
RS/4/−	> 5,000,000	No failure
RS/5/−	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	
35 Ncm (recommended torque)		
RS/1/0	> 5,000,000	No failure
RS/2/0	> 5,000,000	No failure
RS/3/0	3,679,822	Implant and TorqTite screw fracture
RS/4/0	> 5,000,000	No failure
RS/5/0	> 5,000,000	No failure
Mean	4,735,964.0	
SD	590,401.6	
42 Ncm (+20% recommended torque)		
RS/1/+	> 5,000,000	No failure
RS/2/+	> 5,000,000	No failure
RS/3/+	> 5,000,000	No failure
RS/4/+	> 5,000,000	No failure
RS/5/+	> 5,000,000	No failure
Mean	5,000,000	
SD	NA	

RS = Replace Select implant system.

Table 6 Load Fatigue Performance of Lifecore Stage-1 Implant Group by Torque Level

Applied torque/ sample ID	Cycles to failure	Type of failure
24 Ncm (−-20% recommended torque)		
LC/1/−	> 5,000,000	No failure
LC/2/−	> 5,000,000	No failure
LC/3/−	> 5,000,000	No failure
LC/4/−	1,375,768	Cone screw fracture
LC/5/−	> 5,000,000	No failure
Mean	4,275,154.0	
SD	1,620,805.8	
30 Ncm (recommended torque)		
LC/1/0	> 5,000,000	No failure
LC/2/0	107,901	Cone screw fracture
LC/3/0	3,137,178	Cone screw fracture
LC/4/0	> 5,000,000	No failure
LC/5/0	553,777	Cone screw fracture
Mean	2,759,771.0	
SD	2,349,388.9	
36 Ncm (+20% recommended torque)		
LC/1/+	> 5,000,000	No failure
LC/2/+	> 5,000,000	No failure
LC/3/+	> 5,000,000	No failure
LC/4/+	> 5,000,000	No failure
LC/5/+	156,598	Cone screw fracture
Mean	4,031,320.0	
SD	2,166,035.2	

LC = Lifecore Stage-1 implant system.

RESULTS

The results for the load fatigue testing of the 4 implant-abutment interfaces with the 3 different applied tightening torque levels are shown in Tables 3 to 6.

Brånemark System

Three of the 15 samples failed. There were 2 implant fractures and 2 TorqTite abutment screw fractures. For implant failures, sample BR/1/0 fractured apically at the level where the self-tapping threads began (Fig 3), and sample BR/4/0 fractured at the commencement of the threads (Fig 4). The TorqTite abutment screw of this specimen also fractured at a level slightly below the implant fracture level. The TorqTite abutment screw of sample BR/4/+ fractured at the first thread region (Fig 5). None of the test samples in the –20% recommended torque group failed.

SEM of the fractured surfaces of sample BR/1/0 revealed fatigue striations (Figs 3b and 3c), which are an absolute indication of fatigue failure.[19] The depth of the striations is related to stress intensity. SEM of sample BR/4/0 showed radially directed fatigue striations on the fracture surface (Figs 4b and 4c). The width and depth of these fatigue striations suggested that this sample had been subjected to a regular stress of high amplitude and low frequency. The TorqTite screw of specimen BR/4/+ did not present with fatigue striations under SEM, suggesting that rapid catastrophic failure had occurred.

3i System

There were 9 failures among the 15 samples tested; 4 implant fractures and 5 abutment screw fractures. In the 4 cases where the implant failed, the fractures did not involve the abutment screw (Fig 6a). All the 5 samples in the group where –20% recommended torque was applied had abutment screw fractures that left the implant intact. The 4 implant failures were distributed equally between the other 2 torque groups. SEM of these 4 implant failures revealed fatigue striations (Figs 6c and 6d).

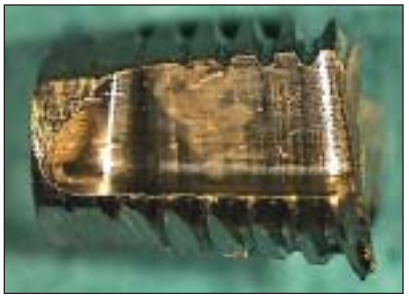


Fig 3a Apical portion of a failed implant at the start of the self-tapping threads. Sample BR/1/0.

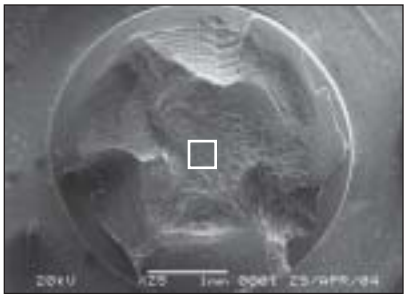


Fig 3b SEM of the implant surface at the site of fracture. Sample BR/1/0.

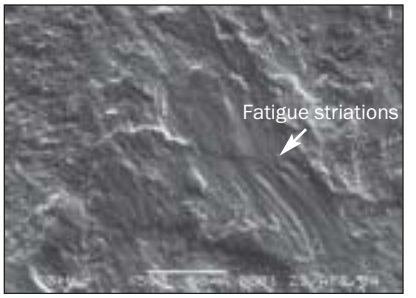


Fig 3c SEM of boxed area in Figure 3b at higher magnification. Sample BR/1/0.

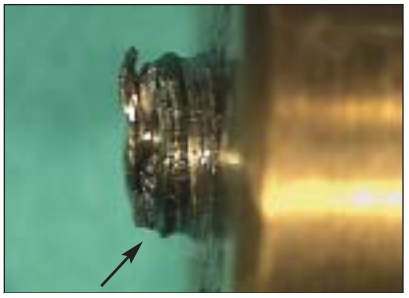


Fig 4a Implant fracture at the first thread *(arrow)*. Sample BR/4/0.

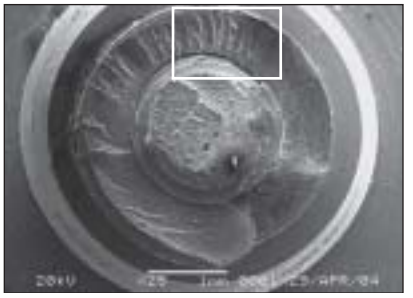


Fig 4b SEM of implant fracture surface at first thread. Sample BR/4/0.

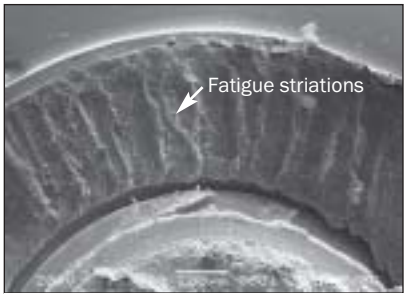


Fig 4c SEM of boxed area in Fig 4b at higher magnification showing fatigue striations. Sample BR/4/0.

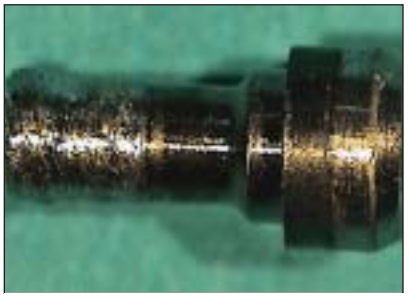


Fig 5a Failed TorqTite screw at first thread region. Sample BR/4/+.

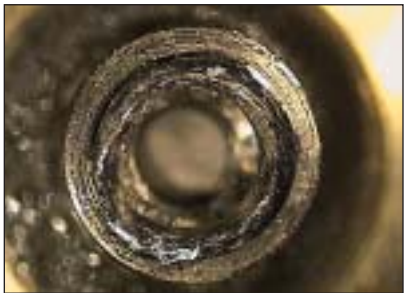


Fig 5b Damaged external hexagon of implant; severe wear is evident. Sample BR/4/+.

Fig 6a Fracture of implant at the third to fourth thread region. Gold-Tite screw not involved. Sample 3i/4/0.

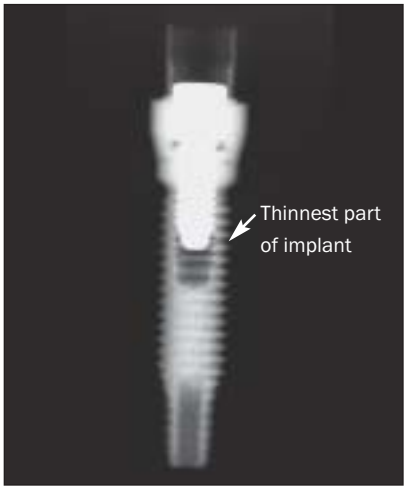
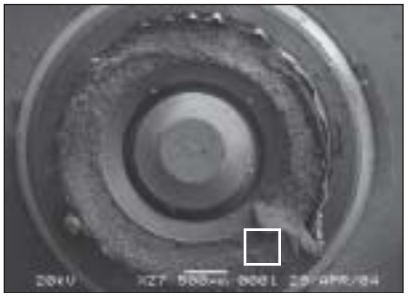


Fig 6b *(Left)* Radiograph of the 3i implant system.

Fig 6c *(Above)* SEM of failed implant at the third to fourth thread region.



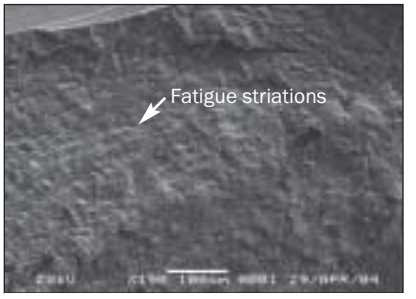


Fig 6d SEM of boxed area in Fig 6c at higher magnification showing fatigue striations. Sample 3i/4/0.

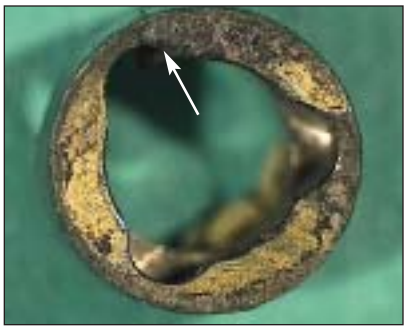


Fig 7a Crack at thinnest section of internal configuration. Sample RS/3/0.

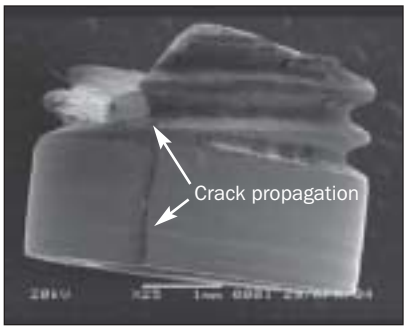


Fig 7b SEM of the side of the fractured implant. Sample RS/3/0.

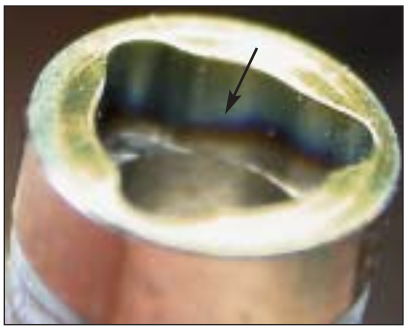
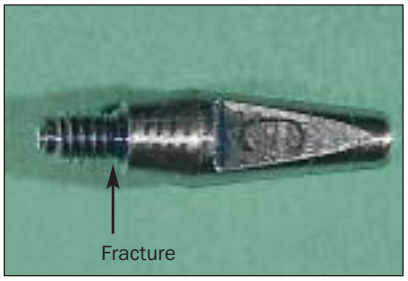


Fig 7c Blue discoloration *(arrow)* within the internal connection of the Replace Select implant.

Fig 8a *(Left)* Cone screw of Lifecore Stage-1 system. Five samples failed at the first thread region at the base of the cone *(arrow)*.

Fig 8b *(Right)* Fractured cone screw at first thread region *(arrow)*. Cone screw is anchored in the brass cap. Sample LC/5/+.



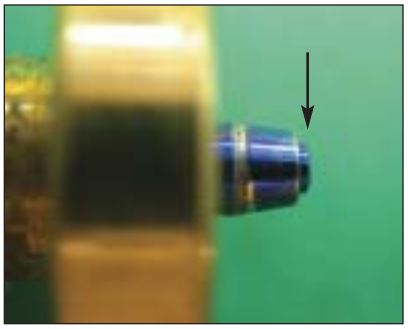


Table 7 2-way ANOVA for Implant System (SYSTEM) and Torque Level (TORQUE)

	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	1.074E+14	11	9.763E+12	4.214	0.000
Intercept	8.697E+14	1	8.697E+14	375.426	0.000
SYSTEM	7.134E+13	3	2.378E+13	10.265	0.000
TORQUE	3.449E+12	2	1.724E+12	0.744	0.480
SYSTEM * TORQUE	3.261E+13	6	5.435E+12	2.346	0.460
Error	1.112E+14	48	2.317E+12		
Total	1.088E+15	60			
Corrected total	2.186E+14	59			

Replace Select System

There was 1 failure among the 15 samples tested. The coronal aspect of the implant in sample RS/3/0 fractured and separated from the main implant body. A crack was noted at the thinnest wall portion at one "channel" of the tri-channel internal configuration, which seemed to have propagated apically to the root of the implant threads and caused failure (Figs 7a and 7b). The TorqTite screw of the same sample also fractured at the screw shank.

Lifecore Stage-1 System

There were 5 abutment cone screw failures but no implant failures among the 15 samples tested. All 5 abutment screws fractured at the start of the screw thread as it emerged from the base of the cone (Figs 8a and 8b). Three of these failures occurred in the group torqued the recommended amount, while the +20% group and the –20% group had 1 failure each. Under SEM, the absence of fatigue striations was noted in all the failed samples. The yield strength of the failed cone screws could have been exceeded, resulting in rapid failure.

Statistical Analysis

Two-way ANOVA indicated a significant difference ($P < .05$) in the number of load cycles to failure between implant systems ($F = 10.265$) but no statistically significant difference between the 3 torque levels (Table 7). No significant differences among the 4 implant systems were revealed with subsequent 1-way ANOVA. One-way ANOVA was per-

formed for the 3 torque levels used in each implant system. Tukey's post-hoc tests showed only statistically significant differences ($P < .05$) in load cycles between the −20% recommended torque group and the +20% recommended torque group for the 3i implant system.

DISCUSSION

Limitations of Study

The sample size of 5, though small, was in compliance with the recommendations of the US Food and Drug Administration for fatigue testing of implants and abutments.[23] The upper limit of 5×10^6 cycles exceeded the minimum recommendation of Wiskott et al[19] of 1×10^6 cycles, which is deemed equivalent to a service half-life of 20 years.

Implant Failure

This study strongly suggests that location of the implant fracture is system-specific and related to the implant design.

For the Brånemark system failures, both implant failures were in the recommended torque group. One implant (BR/1/0) failed at the start of the self-tapping thread region. Quek et al[21] reported that 3 RP implants fractured at the start of the self-tapping thread region. This fracture location is explained by the implant acting as a cantilever beam, and an increase in stress would be expected down the length of the implant. The start of the self-tapping thread presents a change in geometry along the length of the implant and also increases stress. The recommended torque had delivered sufficient preload to maintain the implant-abutment interface integrity; the sample thus failed at the start of the self-tapping thread. The other implant (BR/4/0) fractured at the first thread above the resin embedment level. The thread acted as a stress increase and initiated fatigue fracture.

In the 3i system, all 4 implant failures occurred at the third thread, which coincided with the apical extent of the abutment screw when fully seated. All abutment screws were intact, and the implant-abutment interfaces were maintained at the point of implant fracture. It is noteworthy that the fractures occurred at the implant level which corresponded to the thinnest cross section due to the internal threading (Fig 6b). It appeared that if the Gold-Tite abutment screw did not fail first, the applied stress concentration would be focused on this location, leading to implant fatigue failure.

Morgan et al[12] examined with SEM 5 clinical Brånemark implant fractures that occurred at a level corresponding to the end of the abutment screw. They postulated that at this fracture level, resistance to bending was reduced as the cross-sectional area changed from an effectively solid composite cylinder (implant plus abutment screw) to an annulus (no central screw). Naert et al[13] and Quirynen et al[14] reported that most implant fractures occurred between the third and the fourth thread, corresponding to the end of the abutment screw.

For the 1 sample failure in the Replace Select system, both the implant and screw fractured. Crack initiation probably occurred at the thinnest aspect of the tri-channel implant internal configuration and led to implant and screw fracture. Inspection of the internal aspect of the Replace Select internal connection revealed a blue discoloration (Fig 7c) which was postulated to be the result of the heat generated from the machining of the internal tri-channel configuration leading to possible weakening of the titanium alloy in this location of the thinnest aspect of the implant wall. A finite element analysis study by Nagel et al[25] on the lateral load and torsional behavior of internal abutment connections showed that the Replace Select implant may fail by the fracture of the implant body at the thinnest part of the cut-out area. Long-term clinical performance of single-tooth Replace Select implants has not been reported in the literature.

The lack of implant fractures in the Lifecore Stage-1 system may seem to suggest superior mechanical strength. However, the incidence of cone screw fractures in this system may have directed the failure location to the weak link in the system and spared the implant. In a monotonic load-to-failure study, Norton[17] reported no fractures of the Straumann implant, which is similar to the Stage-1 implant. However, this regular implant had the thickest implant body compared to the other 3 regular implants. This correlates well with Levine et al[18] who reported no implant fractures in 675 solid-screw 4.1-mm Straumann implants at a 5-year recall.

Abutment Screw Failure

Every implant group tested had abutment screw failures. In the Brånemark group, 1 of the TorqTite abutment screws may have failed after the implant fractured (BR/4/0), as the implant-abutment interface integrity was not affected. Abutment screw loosening was a probable cause for the other TorqTite abutment screw fracture (BR/4/+), as both the external hexagon of the implant and the corresponding abutment had severe damage in that sample (Fig 5b). Interestingly, this screw loosening occurred in a sample that had +20% recommended torque application. Surface roughness of the screw threads, misfit, or misalignment of components could have resulted

in loss of clamping force. Fourteen of the 15 Brånemark samples had intact implant-abutment interfaces, and in the –20% torque group, there were no failures. Thus, the performance of the TorqTite abutment screw was equivalent to the performance of the previous CeraOne gold alloy abutment screw, as reported in the study by Quek et al.[21]

For the 3i group, all the 5 samples in the –20% recommended torque group had Gold-Tite screw fractures. Screw loosening was unlikely, as the implant and abutments showed little damage. The reduced application of tightening torque might have resulted in insufficient preload in the implant-abutment interface to survive the testing conditions. However, all the samples in the recommended torque and +20% recommended torque groups had intact implant-abutment interfaces, which demonstrates the importance of application of the recommended torque. Gratton et al[26] showed significantly greater micromotion at the implant-abutment interface of 3i implants when the abutment screws were torqued to 16 Ncm, which was only 50% of the recommended torque.

The one TorqTite screw fracture in the Replace Select group may have occurred after implant fracture. Disregarding this fracture, this group had 100% intact implant-abutment interfaces. As in the Brånemark group, none of the samples in the –20% e group fractured. This suggested that, for the newer TorqTite screw, even –20% of the recommended torque may be sufficient to sustain an intact implant-abutment interface.

In the Lifecore Stage-1 group, all 5 abutment cone screws fractured at the first thread below the cone. The screw portion of the cone screw would take the full brunt of the fatigue loading if the Morse taper effect of the cone screw was reduced because of misfit or inadequate tightening. A nonlinear finite element stress analysis on the implant-abutment complex of a reduced-diameter Straumann solid screw and solid abutment implant by Akca et al[27] found higher von Mises stresses in the first, second, and third threads of the abutment. High stress under oblique loading may result in the failure of the cone screw at those sites. Norton[17] registered ultimate failure of the Straumann implant system at the start of the screw thread just beneath the base of the cone of the solid abutments. However, in a fatigue loading study of the Straumann solid-screw abutment in a single-tooth implant system, Khraisat et al[22] found no failure after 1×10^6 cycles.

Effect of Torque Level

Three different torque levels were used in this study to simulate the clinical application by mechanical or electronic torque drivers of more or less than the manufacturer's recommended torque. Within each implant system, ANOVA revealed no significant difference between groups when the abutment screws were tightened to the manufacturer's recommended torque level. A statistically significant difference was found between the –20% recommended torque group and the +20% recommended torque group ($P < .05$) for the 3i system only.

Clinical Significance

The single-tooth implant situation demands the greatest degree of mechanical integrity in the implant-abutment interface. The manufacturers' recommendation for torque application should be followed. Electronic and manual torque wrenches should be calibrated periodically to ensure delivery of appropriate tightening torque. Proper handling of implant components is important for a stable implant-abutment interface for single-tooth implant restorations. The designs and properties of different abutment screws in the various systems would suggest that the margin for error varies.

CONCLUSIONS

Within the limitations of this study on the 4 implant-abutment systems, the following conclusions can be drawn:

1. There was no statistically significant difference in the number of cycles to failure between the 4 implant-abutment systems when the manufacturer's recommended torque level was used.
2. There was one TorqTite abutment screw fracture out of 15 samples in the Brånemark group. Two implant fractures were noted.
3. There were 5 abutment screw fractures out of 15 samples in the 3i group. Four implant fractures were noted. All 5 abutment screw fractures were from the –20% recommended torque group.
4. There was no TorqTite abutment screw fracture out of 15 samples in the Replace Select Group. One implant failure was noted.
5. There were 5 cone-screw fractures out of 15 samples in the Lifecore Stage-1 group. No implant fracture was noted.
6. Load fatigue performance and failure location is system specific and related to the design characteristics of the implant-abutment combinations. It appeared that if the implant-abutment interface was maintained, load fatigue failure would occur at the weakest point of the implant.

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