Critical Bending Moment of Implant-Abutment Screw Joint Interfaces: Effect of Torque Levels and Implant Diameter

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Purpose: Critical bending moment (CBM), *the moment at which the external nonaxial load applied overcomes screw joint preload and causes loss of contact between the mating surfaces of the implant screw joint components, was measured with 2 types of implants and 2 types of abutments.* **Materials and Methods:** *Using 4 test groups of 5 implant-abutment pairs, CBM at the implant-abutment screw joint was measured at 25%, 50%, 75%, and 100% of the manufacturer's recommended torque levels. Regular Platform (RP) Nobel Biocare implants (3.75 mm diameter), Wide Platform (WP) Nobel Biocare implants (5.0 mm diameter), CeraOne abutments, and Multiunit abutments were used. Microstrain was measured as loads were applied to the abutment at various distances from the implant-abutment interface. Strain instrumentation logged the strain data dynamically to determine the point of gap opening. All torque applications and strain measurements were repeated 5 times.* **Results:** *For the CeraOne-RP group, the mean CBMs were 17.09 Ncm, 35.35 Ncm, 45.63 Ncm, and 62.64 Ncm at 25%, 50%, 75%, and 100% of the recommended torque level, respectively. For the CeraOne-WP group, mean CBMs were 28.29 Ncm, 62.97 Ncm, 92.20 Ncm, and 127.41 Ncm; for the Multiunit-RP group, 16.08 Ncm, 21.55 Ncm, 34.12 Ncm, and 39.46 Ncm; and for the Multiunit-WP group, 15.90 Ncm, 32.86 Ncm, 43.29 Ncm, and 61.55 Ncm at the 4 different torque levels. Two-way analysis of variance (ANOVA) ($P < .001$) revealed significant effects for the test groups (F = 2738.2) and torque levels (F = 2969.0).* **Discussion:** *The methodology developed in this study allows confirmation of the gap opening of the screw joint for the test groups and determination of CBM at different torque levels.* **Conclusion:** *CBM was found to differ among abutment systems, implant diameters, and torque levels. The torque levels recommended by the manufacturer should followed to ensure screw joint integrity.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:648–658

Key words: *abutment screw, bending moment, dental abutments, dental implants, strain gauges, torque*

Reported complications with implant-supported prostheses include gold screw loosening, abutment screw failure, implant component fracture, framework fracture, and loss of integration between bone and implants.[1,2] The degree of mechanical integrity at the implant-abutment interface is dependent on abutment screw preload, abutment design, screw design, component fit, and dynamic loading conditions.[3]

In a study reported by Jemt and associates,[4] one of the most frequently encountered problems during the first year implant-supported fixed partial prostheses were in function was loose gold screws and related complications. After final tightening, 13.6% of maxillary prostheses demonstrated loose screw joints. The same problem was also noted in partial implant-supported prostheses and single-tooth prostheses.[5,6] Binon and associates[7] concluded

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that factors contributing to screw joint instability include poor tightening, inadequate prosthesis fit, poorly machined components, excessive loading, settling of the screws, inadequate screw design, and the elasticity of bone.

The screw loosens only if the forces attempting to disengage the joint are greater than the force keeping the 2 parts together. Screws should be tensioned to produce a clamping force greater than the external forces tending to separate the joint. Clamping load is usually proportional to tightening torque. However, excursive contacts, off-axis centric occlusal contacts (eg, those in angled abutments and wide occlusal tables), interproximal contacts, and cantilever contacts are joint-separating forces.[8] Nonpassive frameworks also cause joint-separating forces. Rangert and coworkers[9] stated that as soon as opening of the screw joint occurs, the external tension load has to be taken up entirely by the screw shank. The opening of the screw joint, or screw loosening, is the primary cause of gold screw breakage.[9,10] For restorative procedures, tightening abutment and prosthetic screws to recommended torque specifications would more effectively control screw-joint integrity during function.[8]

Screw joint preload is the clamping force necessary to maintain the integrity of the screw joint. Preload is determined by the applied torque, screw alloy, screw head design, abutment alloy, machining tolerances of the abutment, and lubricant.[8,11–14] Screw joint preload at the implant-abutment interface was recently measured directly by Tan and Nicholls[15] using strain gauge methodology. The definition of the level of these preloads has added to current understanding of functional stress distribution in the implant prosthesis screw joint and is of great importance in the prediction of clinical longevity and selection of an implant system by clinicians. Optimal preload confers screw joint stability. Previous analyses have primarily focused on vertical loads, eg, tension or compression. A third type of load on these screw joints that needs to be resisted by optimal preload is bending moment. Clinical overload situations, which lead to excessive bending moment, have been reported as the cause of prosthetic and osseointegration failure.[16]

Rangert and colleagues[16] defined "bending overload" as a situation in which occlusal forces on an implant-supported prosthesis exert a bending moment on the implant cross section at the crestal bone, leading to marginal bone loss and/or eventual implant fatigue fracture. In a retrospective analysis of 39 patients with implant fracture, overload situations were associated with risk factors related to geometric load (in-line implant position, leverage-load magnification, cantilever loading, abutment height of > 7 mm, 15-degree buccal-lingual offset deviation, and large occlusal table dimensions) and elevated occlusal functional forces (parafunction leading to increased load magnitude and frequency). Eighty-five percent of the failures were in fixed partial or single-tooth prostheses; only 10% were in full-arch prostheses. The average period from the time function began until failure was 32 months.

This study introduces the bioengineering term *critical bending moment (CBM)* to implant dentistry. This is the bending moment at which the nonaxial load applied overcomes screw joint preload and causes loss of contact between the mating surfaces of the implant screw joint components. Junker and Wallace[17] showed that when the screw joint opens asymmetrically from an eccentrically applied load, the additional external load will be resisted by the screw shank. This additional load on the shank increases nonlinearly with progressive joint opening. The stress is not uniformly distributed across the screw shank; higher stress is induced on the tensile side. This asymmetric stress predisposes the screw shank to earlier failure.

The aim of this study was to measure and compare the critical bending moments of the implant-abutment screw joint interfaces of 2 abutment systems and 2 implant diameters. The 4 different implant-abutment test groups were measured at 25%, 50%, 75%, and 100% of manufacturer's recommended torque levels in the screw joint.

MATERIALS AND METHODS

Nobel Biocare Regular Platform (RP) implants, Wide Platform (WP) implants, CeraOne abutments, and Multiunit abutments (Nobel Biocare, Göteborg, Sweden) were used in the study (Tables 1 and 2). Four implant-abutment combinations (CeraOne-RP, CeraOne-WP, Multiunit-RP, and Multiunit-WP) were tested. The Multiunit abutments, which were screw retained, were premounted in a plastic holder (20 mm in height for all platforms). They had a nonhex configuration and a 20-degree convergence angle. They were suitable for all sulcus depths and platforms and for use with multiple units. The CeraOne abutments were designed to receive prefabricated ceramic or gold caps. They had a hex configuration and were suitable for all platforms. They were intended for use with single-tooth restorations.

For each combination, 4 levels of torque (25%, 50%, 75%, 100% of the manufacturer's recommended torque) were applied (Table 3). A new screw was used for each test group. Five samples of each

Table 1 Characteristics of Test Implants

Implant	Width (mm)	Length (mm)	Component part no.	Manufacturer	Material
Mk III RP	3.75	15	25980	Nobel Biocare	Strengthened grade 1 titanium
Mk III WP	5.00	15	26977	Nobel Biocare	Strengthened grade 1 titanium

Table 2 Characteristics of Test Abutments

Abutment	Component part no.	Manufacturer	Abutment screw material	Driver	MRT (Ncm)
CeraOne RP 2.0 mm	SDCA 333	Nobel Biocare	Gold alloy	Square PSQD1N	32
CeraOne WP 3.0 mm	27203	Nobel Biocare	Gold alloy	Unigrip DIA 932-0	45
Multiunit RP 5.0 mm	26264	Nobel Biocare	Commercially pure titanium	External hexagonal DIB 038	20
Multiunit WP 5.0 mm	26279	Nobel Biocare	Gold alloy	External hexagonal DIA 371	32

MRT = manufacturer's recommended torque.

implant-abutment combination were tested, and 5 measurement repetitions were done (Table 3).

A pilot study verified instrumentation, program data capture by a desktop PC interface, and linearity of strain output. The elastic range was also determined in the pilot study using an RP implant and a standard abutment 5.5 mm wide (SDCA 005, Nobel Biocare). The same experimental concept was then applied to the experimental variables.

Table 3 Applied Torque Levels for the 4 Implant-Abutment Combinations

	Applied torque (Ncm)			
Group	25%*	50%*	75%*	100%*
CeraOne RP	8.00	16.00	24.00	32.00
CeraOne WP	11.25	22.50	33.75	45.00
Multiunit RP	5.00	10.00	15.00	20.00
Multiunit WP	8.00	16.00	24.00	32.00

*Percentage of the torque recommended by the manufacturer.

Strain Gauge Measurement of Gap Opening

Experimental Setup. L-shaped aluminum implant holders were machined for each test group. The test implant was secured in the holder. The test abutment was then connected to the implant with an abutment screw using the driver recommended by the manufacturer.

Under 10× magnification, a pretrimmed strain gauge (type EA-05-050AH-120, option LE; Measurements Group, Raleigh, NC) was bonded with adhesive (M-Bond 200, Measurements Group) such that the active grid (length = 1.27 mm) was within the vertical critical working dimension (h) of the selected abutment (Fig 1). For the CeraOne-RP group, h = 2.25 mm; for the CeraOne-WP group, h = 1.92 mm; for the Multiunit-RP group, h = 5.95 mm; and for the Multiunit-WP group, h = 6.00 mm. For the CeraOne-RP combination, in which the abutment was only 2.0 mm wide, epoxy resin (DP-460; 3M, St Paul, MN) was used to support the strain gauge. In this case, the active grid was still attached to the abutment body within h.

The prepared implant holder was then secured under the testing load jig. The loading site was marked with articulating paper to ensure even contact between the loading indenter and the abutment surface.

Strain gauge output was recorded with an HP 75000 Series B VXI Multimeter and an HP E1357 Strain FET Multiplexer (Hewlett-Packard, Loveland, CO). Custom-written HP VEE Pro 6.0 graphical instrument control software (model H2327G, Hewlett Packard) data-logged strain dynamically on a personal computer to determine the point of gap opening. The software program allowed calibration prior to each measurement sequence. Readings were taken only when ambient temperature and strain circuitry conditions were stabilized. The screw joint was then disconnected before the next measurement.

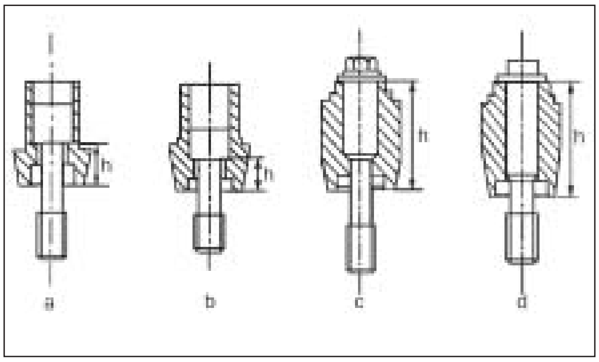


Fig 1 Cross-sectional views of the test abutments. *(a)* CeraOne RP; *(b)* CeraOne WP; *(c)* Multiunit RP; *(d)* Multiunit WP. h = critical working dimension.

Fig 2 Mechanical torque gauge (model 6 BTG, Tohnichi Manufacturing, Tokyo, Japan) with the selected driver tip.

Measurement Sequence. For each test abutment sample, the following measurement sequence was used:

1. After initialization of the strain measurement instrumentation, torque was applied with a mechanical torque gauge (Model 6 BTG; Tohnichi Manufacturing, Tokyo, Japan) (Fig 2) to connect the test abutment to the test implant. The driver tip was fully seated under pressure directly in line with the screw axis. The abutment screw was then tightened with the torque gauge to the relevant torque.
2. Known vertical loads were applied to the test abutment at loading point C (Fig 3) to induce a bending moment in the implant-abutment screw joint. As the strain output approached a linear plateau (Fig 4), the load was increased in 100-g increments.
3. Dynamic strain output during torque-down, load-on, and load-off revealed the changes in compressive and tensile stresses at the implant-abutment screw joint interface. Applied torque induced a clamping force in the screw joint. As loading progressed, the screw joint preload was gradually lost. When the applied load on the abutment exceeded the clamping force, the screw joint disengaged at the superior point of the mating interface—point S (Fig 5). The unresponsiveness of strain output to further incremental load increase therefore represented the gap opening of the screw joint.
4. The loading site was marked with the loading indenter and a 25-μm articulating paper after the test. The moment arm was then measured with a measuring microscope (Measurescope MM-11; Nikon, Tokyo, Japan). Measurement of the moment arm length was repeated 3 times. CBM was calculated as load (N) × moment arm.

Strain measurement with loading to CBM (steps 1 to 4) was repeated 5 times for each applied torque level and the 4 implant-abutment test groups. A total of 400 measurements were conducted. One operator performed all measurements for standardization.

Verification of Gap Opening. The strain gauge measurement of CBM was verified by visual evaluation (Fig 6). The unresponsiveness of strain output was confirmed to be the "end point" which represented the gap opening of the screw joint. One sample for each test group was tested, and visual verification was repeated twice.

The 4 different implant-abutment combinations were loaded with the same loading jig setup but without strain gauge application (Fig 6a). The loading site was captured by a stereomicroscope (BX 51; Olympus, Tokyo, Japan) with a color video digital camera (ExwareHAD; Sony, Tokyo, Japan) connected and recorded by imaging software (Micro-Image; Olympus). Two operators performed all the tests for this portion. One operator (the same operator who conducted the strain gauge study) applied the recommended torque (100%) to the test specimen and gradually increased the load to the test assembly without observing the captured digital image. The second operator watched the captured digital image on the computer screen until the gap opening was detected. Once the second operator detected the gap opening, loading was stopped and recorded. The moment arm was measured with the measuring microscope 3 times.

Statistical Analysis

All critical bending moment data were subjected to 2-way analysis of variance (ANOVA) for the variables implant diameter–abutment system and torque level. Abutments for each torque level were compared with multiple 1-way ANOVA. Group means

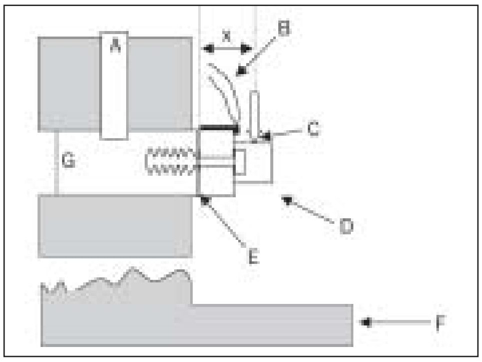


Fig 3 Strain gauge location and loading site on the test abutment. A = set screw; B = strain gauge; C = loading site with applied load *(white arrow)*; D = abutment; E = implant-abutment interface; F = L-shaped holder; G = implant; x = moment arm.

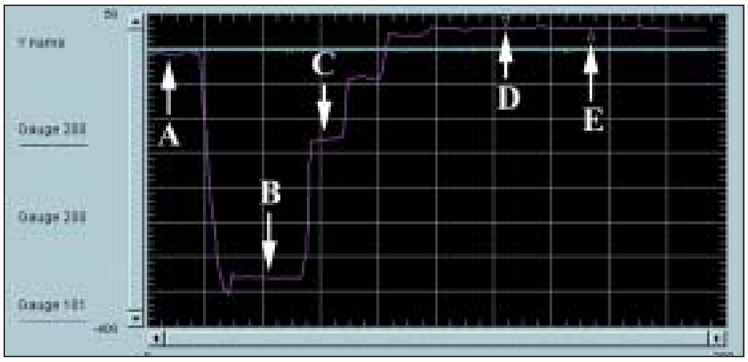


Fig 4 Representative strain output diagram. Arrows show strain output at A (no torque applied), B (torque applied to impart preload within screw joint), C (incremental loads applied until the bending moment was reached), D (the recorded load at point of joint opening), and E (further load increments [100 g] with no strain change observed).

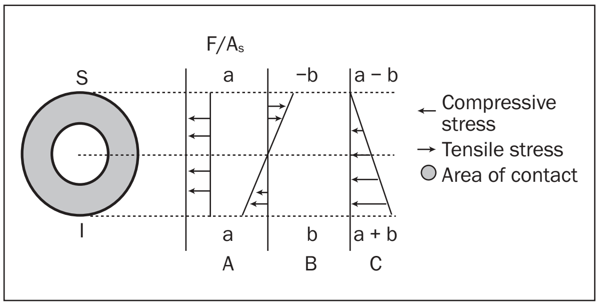
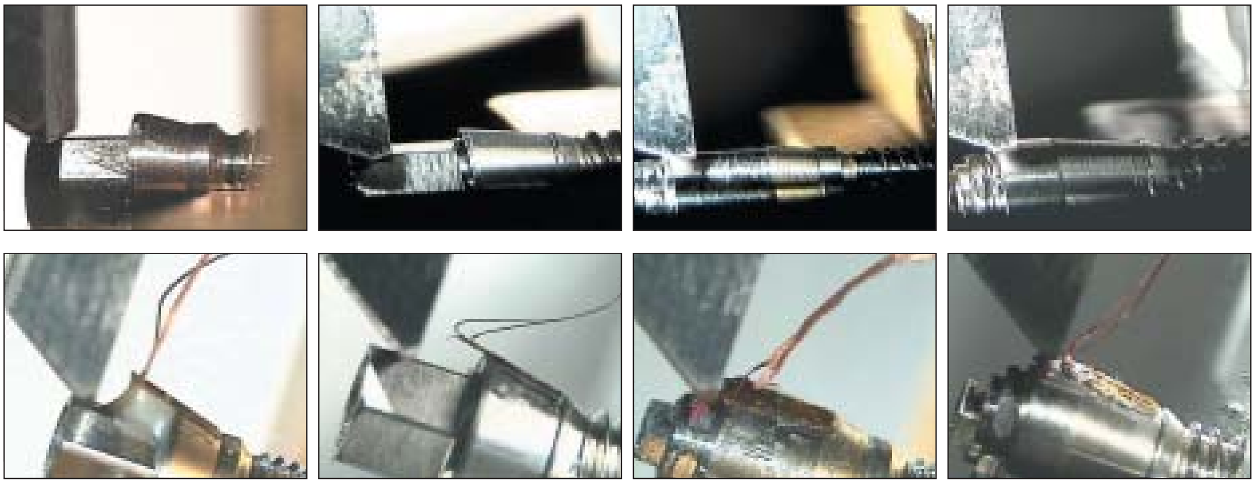


Fig 5 Change in stress at the implant-abutment mating interface during loading. A = overall stress on the interface during torque application. B = reduction in compressive stress at superior point of mating interface (point S) and increase at inferior point of mating interface (point I). C = at the critical bending moment, stress on point S (a − b) becomes 0 and stress at point I becomes a + b. a, b = stress magnitude; F = load ; A_s = surface area.



a

b

Fig 6 *(a)* Visual verification of CBM for *(left to right)* a CeraOne-RP sample, a CeraOne-WP sample, a Multiunit-RP sample, and a Multiunit-WP sample. *(b)* Strain gauge measurement *(left to right)* of a CeraOne-RP sample, a CeraOne-WP sample, a Multiunit-RP sample, and a Multiunit WP sample.

Table 4 Implant-Abutment Screw Joint Mean Critical Bending Moment (Ncm)

	Torque level							
	25%*		50%*		75%*		100%*	
Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CeraOne RP	17.09	2.11	35.35	3.75	45.63	5.82	62.64	6.44
CeraOne WP	28.29	2.01	62.97	4.62	92.20	7.27	127.41	8.35
Multiunit RP	16.08	1.11	21.55	2.06	34.12	2.21	39.46	1.81
Multiunit WP	15.90	1.38	32.86	2.42	43.29	3.46	61.55	1.73

*Percentage of the torque recommended by the manufacturer.

Table 5 Two-Way ANOVA for Variables Abutment System/ Implant Diameter (Abut) and Torque Level (Torque)

Source	Type III sum of squares	df	Mean square	F	*P*
Corrected model	339870.474	15	22658.032	1302.629	.000
Intercept	847282.786	1	847282.786	48710.989	.000
Abut	142885.110	3	47628.370	2738.194	.000
Torque	154929.079	3	51643.026	2969.000	.000
Abut × Torque	42056.285	9	4672.921	268.650	.000
Error	6679.326	384	17.394		
Total	1193832.587	400			
Corrected total	346546.800	399			

R^2 = .981 (adjusted R^2 = .980).
Dependent variable = CBM.

were compared with the multiple comparisons (Tukey honestly significant difference [HSD]) post hoc tests. SPSS 10.0 software was used for the statistical analysis (SPSS, Chicago, IL). All statistical tests were determined at the 95% significance level.

RESULTS

The pooled mean CBMs of the test implant-abutment screw joints at the 4 different torque levels are summarized in Table 4. At the 100% torque level, the lowest CBM measured was 39.46 ± 1.81 Ncm (for the Multiunit-RP combination; recommended tightening torque 20 Ncm), and the highest CBM measured was 127.41 ± 8.35 Ncm (for the CeraOne-WP combination; recommended tightening torque 45 Ncm). The mean CBMs of the CeraOne-RP and the Multiunit-WP combinations at 100% torque were similar (62.64 ± 6.44 Ncm and 61.55 ± 1.73 Ncm, respectively); the recommended tightening torque was 32 Ncm for both abutments.

Two-way ANOVA ($P < .01$) revealed significant effects for the variables implant diameter–abutment system (F = 2738.2) and torque level (F = 2969.0) (Table 5). Subsequent Tukey HSD post hoc tests and 1-way ANOVA of torque levels found significant differences between all torque levels for each group. One-way ANOVA of the implant diameter-abutment systems confirmed that significant differences existed between the implant-abutment groups (Table 6). CBM was found to differ by implant diameter–abutment system and torque level.

Generally, a linear relationship was observed for the mean CBM of the 4 different applied torque levels for each of the test implant-abutment groups. A significantly higher critical bending moment was observed with the WP implants compared to the RP implants for the same abutment system. The CeraOne abutment gave significantly higher CBMs than the Multiunit abutment for the same implant diameter (Fig 7).

Table 6 and Fig 7 further illustrate that at the 25% recommended tightening torque level, the mean CBM for the CeraOne-RP combination (17.09 Ncm), the Multiunit-RP combination (16.08 Ncm), and the Multiunit-WP combination (15.90 Ncm) were not statistically different ($P < .05$), with the test tightening torque of 8 Ncm for the CeraOne-RP and Multiunit-WP groups and 5 Ncm for the Multiunit-RP group. With the higher applied torques (50%, 75% or 100% of the recommended tightening torque), the lowest mean CBMs were measured for the Multiunit-RP samples, followed by the

Table 6 One-Way ANOVA of Implant Diameter–Abutment Systems by Torque Level*

Torque level	Statistically significant subsets†
25%	[MUWP, MURP, CORP] [COWP]
50%	[MURP] [MUWP, CORP] [COWP]
75%	[MURP] [MUWP, CORP] [COWP]
100%	[MURP] [MUWP, CORP] [COWP]

*Tukey HSD post hoc test for statistical subsets.
†Groupings within brackets are not significantly different from each other ($P < .05$).
MUWP = Multiunit wide platform; MURP = Multiunit regular platform; CORP = CeraOne regular platform; COWP = CeraOne wide platform.

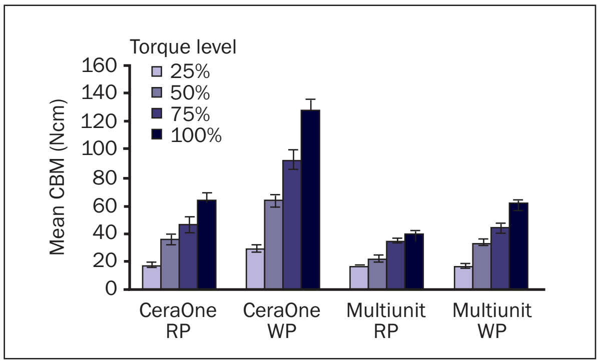


Fig 7 Mean CBM (Ncm) for the 2 abutment systems and 2 implant diameters at each torque level.

CeraOne-RP samples, the Multiunit-WP samples, and finally, the group with the highest mean CBMs, the CeraOne-WP group (Table 6).

DISCUSSION

Strain Gauge Location

Modification of the abutments was not necessary for this study. Careful selection of abutments with the necessary collar height and the active grid length of strain gauge enabled bonding of the strain gauge within the critical working vertical dimension (h) of the selected abutments under magnification (Fig 1). The active grid of the strain gauge used (050AH; active grid length 1.27 mm) was still within the critical working vertical dimension of all abutments, which was 2.25 mm for the 2-mm CeraOne-RP combination and 1.92 mm for the 3-mm CeraOne-WP combination.

There is a difference in the screw shank design between the CeraOne abutment and the Multiunit abutment. The CeraOne abutment screw head seats internally into the abutment, whereas the abutment screw head of the Multiunit abutment stops on top of the abutment (Fig 1). Placement of the active grid of the strain gauge within the vertical length of the screw shank was necessary to obtain measurable strain output. Therefore, bonding of the strain gauge was found to be more technique-sensitive for the CeraOne abutments.

Plastic Deformation

Under the loads applied in this study, there were 3 locations where plastic deformation could occur: *(1)* the superior region of the gold abutment screw shank, *(2)* the inferior region of the implant, and *(3)* the inferior region of the abutment (point I in Fig 5).

Plastic deformation in the gold screw would lower the clamping stress between the abutment and implant. This in turn would lower the strain between the implant and abutment on load removal. Strain data showed that the strain returned to the same level after removal of applied loads. Therefore, it is assumed that no plastic deformation in the screw occurred. For locations 2 and 3, plastic deformation would be discernible as a groove in the titanium implant ledge. A visual examination of this ledge magnified 50× showed no discernible permanent deformation.

Implant, Abutment, and Abutment Screw Design

The results suggest that the abutment type and abutment screw design as well as the tightening torque applied are relevant to screw joint stability. A significantly higher mean CBM was obtained with the CeraOne abutment than with the Multiunit abutment (Table 4 and Fig 7). The hex configuration of the CeraOne abutment provided a reduced abutment rotation during tightening compared to the nonhex Multiunit abutment. Also, a higher recommended tightening torque was applied to the CeraOne abutment (32 Ncm for RP and 45 Ncm for WP) compared to the Multiunit abutment (20 Ncm for RP and 32 Ncm for WP). The highest CBM measured was that of the CeraOne-WP abutment, due to the combined effect of implant diameter, the hex configuration of the abutment design, the applied torque, and the positive engagement feature of the abutment gold screw.

The Multiunit abutment was developed to replace the Standard, EsthetiCone, and MirusCone abutments for multiple-unit prostheses. Simplified selection, simplified connection, and increased performance are the main advantages claimed for this new abutment. Clinical reports of prosthetic complications have been reported for the Standard and EsthetiCone abutments. Naert and associates[18] reported an abutment screw fracture incidence of

0.6%, and Gunne and coworkers[19] reported an abutment screw fracture incidence of 0.2% for the Standard abutment. A 3-year prospective multicenter study of the EsthetiCone abutment by Kastenbaum and associates[20] reported an abutment screw loosening incidence of 1.0% and an abutment screw fracture incidence of 0.5%. No relevant clinical reports are available for the MirusCone and the Multiunit abutments.

To mitigate the problem of screw loosening, screw design has been modified to improve performance.[21] The optimum screw design in most systems has not been fully established. Current abutment screw designs generally consist of a flat head seat (for less frictional resistance and higher preload), long stem length (for optimal elongation and preload), and 6 thread lengths (to reduce friction, because the first 3 threads carry most of the load).[22] The yield strength of the screw material has a significant influence on the clamping force. Seventy-five percent of the yield strength of a grade 1 titanium screw allows a preload of 120 N; a torque of 35 Ncm to a titanium alloy screw generates a preload of 400 N.[22] Gold alloy abutment screws were introduced to overcome the "galling" effect that occurs during the intimate sliding contact of 2 similar materials as well as to take advantage of the higher preload of 890 N at 75% of its yield strength. The CeraOne gold abutment screw has a reported yield strength of 1,370 N.[10] Recently, based on theoretical calculations and in an effort to reduce frictional resistance, abutment screws with dry lubricant coatings such as TorqTite (Nobel Biocare) and Gold-Tite (3i/Implant Innovations, Palm Beach Gardens, FL) have been introduced. Martin and colleagues[23] reported that the Gold-Tite and TorqTite screws, with their reduced coefficient of friction, achieved a greater preload than gold alloy and titanium screws. However, the effectiveness of these designs has not been demonstrated conclusively, and concerns relating to the wear of the coated screw require further investigation.[22]

One screw was used for each test group at the 4 applied torque levels, and no screw fracture was observed. Mitrani and coworkers[24] tested 1 CeraOne gold abutment screw at 3 torque levels (10, 20, and 32 Ncm) and reported no observed influence on their results. The consistency of the strain data indicated that the screws used in each test group in this study could withstand all 4 applied torque levels.

To date, abutment screws have either slotted, square, star, or hexagonal driver engagement designs.[22] A guiding effect can be achieved with the UniGrip driver (Nobel Biocare), which makes it easier to connect the abutment screw and minimizes the slippage of the driver during screw tightening to the recommended tightening torque. This study suggests that the UniGrip design performs better than other designs. Its deep geometric engagement appears to allow more positive seating and efficient torque transfer. However, the potential differences need to be explored further.

Gold abutment screws were used for the CeraOne-RP samples at the recommended tightening torque of 32 Ncm, while the recommended tightening torque of 20 Ncm was applied to the titanium abutment screws of the Multiunit-RP group. The use of a higher recommended tightening torque for a gold screw was supported by previous studies. A gold screw can attain higher preload, more than twice that of a titanium alloy screw.[22] Jorneus and coworkers[10] suggested that gold screws with a flat head and high tightening torque (35 Ncm) resulted in a stable screw joint. In 2 clinical studies in which the CeraOne gold abutment screw was used,[21,25] no abutment screw loosening was reported after 5 years. Haack and associates[11] showed that induced stresses in the screw shank of UCLA abutment screws at the recommended torque values were 57.5% of the yield strength for gold alloy screws and 56% of the yield strength for titanium screws. However, the superiority of a single screw material could not be determined because different torques were applied.

A significantly higher CBM was observed with the WP compared to the RP implant for the same abutment system (Fig 7). A WP system increases the available surface for osseointegration, decreases off-axis load transfer, increases abutment stability, and permits a more favorable emergence profile for molar replacement.[26] It has been hypothesized that the WP screw joint assembly would have better screw joint stability than the RP because of its greater platform surface area. However, little variation in mean CBM was observed between the CeraOne-RP (62.6 Ncm) and Multiunit-WP (61.5 Ncm) combinations at the same applied torque level (32 Ncm). The differences in abutment design may account for this finding. Hoyer and coworkers[27] reported that the 3.75-mm-diameter and 6.0-mm-diameter externally hexed implants gave a similar joint opening after a period of dynamic loading on UCLA-type abutments. No comparison could be made to the present study, since the authors used a Gold-Tite central abutment screw torqued to 32 Ncm for the 3.75 mm implant and a titanium central abutment screw torqued to 25 Ncm for the 6.0-mm-diameter implant. From these 2 studies, applied torque appears to be a major factor for screw joint stability.

Torque-down and Measurement Procedure

Manufacturer-recommended abutment screw torques vary from 18 to 45 Ncm, depending on the system and the components. Binon[22] classified screw-torque requirements as system-, material-, and design-dependent. In the present study, the manufacturer's recommended tightening torque levels were followed in one series of tests (the 100% applied torque), and the same mechanical torque gauge was used for all measurements. The strain measurement instrumentation allowed calibration of strain output, and the consistency of the mechanical torque gauge was demonstrated by the consistency in preload obtained at each applied torque level throughout the investigation.

A shift in baseline was noted over the course of the study. Torque-down strain and gap opening strain were corrected against the initial zero strain. In most cases the variability in the total gap opening strain did not vary significantly with the load measured. The strain gauge orientation, operator manipulation of the mechanical torque gauge, and the loading procedure were the main causes for the measurement variability (standard deviations ranged from 1.11% to 8.35% for all torque levels). During loading, the loading indenter and the loading site were aligned to achieve even contact during all measurements.

Torque Level

A linear relationship was observed between the mean CBMs at the 4 different applied torque levels for each of the test implant-abutment groups. Very little difference in mean CBM was found between the CeraOne-RP (17.09 Ncm), Multiunit-RP (16.08 Ncm), and Multi-unit WP (15.90 Ncm) groups at 25% of the recommended tightening torques of 8 Ncm for the CeraOne-RP and Multiunit-WP groups and 5 Ncm for the Multiunit-RP group, despite the differences in implant diameters and abutment systems. Therefore, to achieve adequate preload for a selected abutment, tightening abutment and prosthetic screws to recommended torque specifications for screw-joint integrity during function is important. Gratton and coworkers[3] reported that a minimally tightened screw joint exhibited significantly increased micromotion at the implant-abutment interface. Patterson and Johns[28] suggested that extended fatigue life of screw can be achieved with adequate preload.

Defective torque drivers may deliver lower tightening torque, thus resulting in a lower level of CBM than appropriate.[29] Jorneus et al[10] suggested that inadequate tightening led to unintentional screw loosening. Tan and Nicholls[29] recommended regular calibration and monitoring of the electronic torque controller. Gutierrez and colleagues[30] reported reduced torque delivery accuracy of torque wrenches in clinical service from 1 month to 3 years. Annual calibration is suggested if the variable torque output from inaccurate wrenches is of concern.

Clinical Significance of Bending Moments

Rangert and associates[9] modeled the loading of the cantilevered complete prosthesis and, based on the assumption that the weak link was the prosthetic gold screw (ultimate tensile strength of 600 N), calculated that the gold cylinder–abutment screw joint would be opened up by a bending moment of 50 to 60 Ncm. They concluded that the majority of clinical situations do not place the prosthetic stack at risk of overload. However, when the fixed partial and single-tooth prosthesis situations are considered, the load distribution effect of the full-arch prosthesis is absent, and bending moment becomes significant. Jorneus and coworkers[10] calculated that some single-tooth implant recipients may exert up to 1,027 N on the abutment screw with a bending moment of 49 Ncm. This led to the adoption of the CeraOne gold abutment screw, which has a yield strength of 1,370 N to resist overload failure and screw loosening. The mean CBMs measured in the present study at 100% of the manufacturer's recommended torque level were 62.64 ± 6.44 Ncm for CeraOne-RP test group and 127.41 ± 8.35 Ncm for CeraOne-WP test group, which is sufficient to ensure screw joint integrity based on the clinical overload conditions estimated by Jorneus and coworkers.

The use of single-tooth restorations with predictable clinical success has been reported in several studies.[25,31,32] The use of CeraOne abutments[33] and UCLA abutment[34] has also been described. Significant differences among system combinations exist in terms of screw preload levels, area of component interface contact, and screw joint characteristics, and these need further investigation. The methodology developed in this study would be useful in the study of other implant-abutment and abutment-cylinder combinations. Differences can also be expected between the narrow-, regular-, and wide-diameter implant system families and between different applied torque levels. Knowledge of the level of bending moment at which critical overload occurs for a particular abutment system would be of great significance in designing and specifying biomechanical situations that minimize risk for prostheses in function.

CONCLUSIONS

This study evaluated the CBM at the implant-abutment interface using 2 implant diameters and 2 abutment systems at 4 different applied torque levels. Strain gauges were used to determine the CBM at which gap opening occurred at the screw joint interface. Within the limitations of the present study design, the following conclusions were made:

1. For each of the 4 implant-abutment test groups, a linear increase of mean CBM was observed at the 4 different applied torque levels.
2. CBM was significantly higher with the WP implant than with the RP implant for the same abutment system.
3. With the same implant diameter, CBM was significantly higher with the CeraOne abutment than with the Multiunit abutment at the recommended tightening torque.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Nobel Biocare for supplying the test components used in this study and Mr Chan Swee Heng (senior laboratory officer) for his technical assistance. This study was supported by National University of Singapore Research Grant R-224-000-010-112.

REFERENCES

1. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated implants: The Toronto study. Part III: Problems and complications encountered. J Prosthet Dent 1990;64:185–194.
2. Tolman DE, Laney WR. Tissue-integrated prosthesis complications. Int J Oral Maxillofac Implants 1992;7:477–484.
3. Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic fatigue properties of the dental implant–abutment interface. J Prosthet Dent 2001;85:47–52.
4. Jemt T, Linden B, Lekholm U. Failures and complications in 127 consecutively placed fixed partial prostheses supported by Brånemark implants: From prosthetic treatment to first annual checkup. Int J Oral Maxillofac Implants 1992; 7:40–44.
5. Jemt T, Laney WR, Harris D, et al. Osseointegrated implants for single tooth replacement: A one-year report from a multicenter prospective study. Int J Oral Maxillofac Implants 1991;6:29–36.
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 checkup. Int J Oral Maxillofac Implants 1991;6:270–276.
7. Binon PP, Sutter F, Beaty K, Brunski J, Gulbransen H, Weiner R. The role of screws in implant systems. Int J Oral Maxillofac Implants 1994;9(suppl):48–63.
8. McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. Dent Clin North Am 1998;42:71–89.
9. Rangert B, Jemt T, Jorneus L. Forces and moments on Brånemark implants. Int J Oral Maxillofac Implants 1989;4: 241–247.
10. Jorneus 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.
11. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. Int J Oral Maxillofac Implants 1995;10:529–536.
12. Sakaguchi RL, Borgersen SE. Nonlinear contact analysis of preload in dental implant screws. Int J Oral Maxillofac Implants 1995;10:295–302.
13. Korioth WP, Cardoso AC, Versluis A. Effect of washers on reverse torque displacement of dental implant gold retaining screws. J Prosthet Dent 1999;82:312–316.
14. Pesun IJ, Brosky ME, Korioth TW, Hodges J, Devoe BJ. Operator-induced compressive axial forces during implant gold screw fastening. J Prosthet Dent 2001;86:15–19.
15. Tan KB, Nicholls JI. Implant-abutment screw joint preload of 7 hex-top abutment systems. Int J Oral Maxillofac Implants 2001;16:367–377.
16. Rangert B, Krogh PHJ, Langer B, Van Roekel N. Bending overload and implant fracture: A retrospective clinical analysis. Int J Oral Maxillofac Implants 1995;10:326–334 [erratum 1996;11:575].
17. Junker GH, Wallace PW. The bolted joint: Economy of design through improved analysis and assembly methods. Proc Inst Mech Eng 1984;198B(14):255–266.
18. Naert I, Quirynen M, van Steenberghe D, Darius P. A six-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism. J Prosthet Dent 1992;67:236–245.
19. Gunne J, Jemt T, Linden B. Implant treatment in partially edentulous patients: A report on prostheses after 3 years. Int J Prosthodont 1994;7:143–148.
20. Kastenbaum F, Lewis S, Naert I, Palmquist C. The Estheti-Cone abutment: Three-year results of a prospective multicenter investigation. Clin Oral Implants Res 1998;9:178–184.
21. Andersson B, Odman P, Lindvall AM, Brånemark P-I. Cemented single crowns on osseointegrated implants after 5 years: Results from a prospective study on CeraOne. Int J Prosthodont 1998;11:212–218.
22. Binon PP. The external hexagonal interface and screw-joint stability: A primer on threaded fasteners in implant dentistry. Quintessence Dent Technol 2000;23:91–105.
23. Martin WC, Woody RD, Miller BH, Miller AW. Implant abutment screw rotations and preloads for four different screw materials and surfaces. J Prosthet Dent 2001;86: 24–32.
24. Mitrani R, Nicholls JI, Phillips KM, Ma T. Accuracy of electronic implant torque controllers following time in clinical service. Int J Oral Maxillofac Implants 2001;16:394–399.
25. Scheller H, Urgell JP, Kultje C, et al. A 5-year multicenter study on implant-supported single crown restorations. Int J Oral Maxillofac Implants 1998;13:212–218.
26. Binon PP. Implants and components: Entering the new millennium. Int J Oral Maxillofac Implants 2000;15:76–94.
27. Hoyer SA, Stanford CM, Buranadham S, Fridrich T, Wagner J, Gratton D. Dynamic fatigue properties of the dental implant-abutment interface: Joint opening in wide-diameter versus standard-diameter hex-type implants. J Prosthet Dent 2001;85:599–607.

28. 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.
29. Tan KB, Nicholls JI. The effect of 3 torque delivery systems on gold screw preload at the gold cylinder-abutment screw joint. Int J Oral Maxillofac Implants 2002;17:175–183.
30. Gutierrez J, Nicholls JI, Libman WJ, Butson TJ. Accuracy of the implant torque wrench following time in clinical service. Int J Prosthodont 1997;10:562–567.
31. 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.
32. Priest G. Single tooth implants and their role in preserving remaining teeth: A 10-year survival study. Int J Oral Maxillofac Implants 1999;14:181–188.
33. Andersson B, Ödman P, Carlsson L, Brånemark P-I. A new Brånemark single tooth abutment: Handling and early clinical experiences. Int J Oral Maxillofac Implants 1992;7:105–111.
34. Lewis SG, Beumer J III, Perri GR, Hornburg WP. Single tooth implant supported restorations. Int J Oral Maxillofac Implants 1988;3:25–30.