Implant-Abutment Screw Joint Preload of 7 Hex-top Abutment Systems

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This study measured the screw joint preload of the implant-abutment interface for 7 common hex-top abutment systems. Increasingly, prosthetic designs are utilizing a direct prosthetic connection to the implant, placing the implant–abutment screw joint under direct functional loads and moments. Sufficiently high screw joint preloads are required to maintain screw joint integrity and confer clinical longevity to implant prosthetic components to prevent such complications as abutment screw loosening and screw fracture. Strain-gauged abutment load cells were calibrated to measure screw joint preload at the implant-abutment interface. Torque delivery by electronic torque controller was varied at low- and high-speed settings. At manufacturer's recommended torques, the overall mean preload measured was 181.6 ± 60.0 N for the Nobel Biocare Standard abutment, 291.3 ± 41.2 N for the Nobel Biocare EsthetiCone abutment, 456.5 ± 44.0 N for the Nobel Biocare MirusCone abutment, 369.7 ± 32.9 N for the 3i Titanium Abutment post, 643.4 ± 143.1 N for the Nobel Biocare CeraOne abutment, 536.3 ± 68.6 N for the Nobel Biocare "Gold Cylinder to Fixture" abutment, and 556.9 ± 145.6 N for the Nobel Biocare TiAdapt abutment. Analysis of variance revealed significant differences between abutment systems (P < .001) and between torque driver speed settings (P < .001). Implant–abutment screw joint preload of external-hex implants is dependent on abutment design, screw diameter, material, tightening torque, and torque controller speed. (INT J ORAL MAXILLOFAC IMPLANTS 2001;16:367–377)

Key words: *abutment screw, biomechanics, bone screw, dental implants, strain gauge, torque controller*

The desirability of a "passive fit" of implant prostheses is generally recognized.[1–4] Long-term clinical studies of implant-supported prostheses have reported the occurrence of prosthetic complications, which include gold screw failures, abutment screw failures, gold cylinder fractures, framework fractures, implant fractures, and possible delayed loss of integration between bone and implant.[5–7]

Implant prosthodontic procedures have been developed from traditional prosthodontic clinical and laboratory procedures. The level of distortion inherent in clinical and laboratory procedures for the fabrication of conventional fixed partial dentures does not conform to the level of fit required for osseointegrated implants anchored in bone. The periodontal ligament in natural teeth has a 100- to 200-μm movement potential, as compared to the 17- to 66-μm "mobility" of osseointegrated implants reported by Sekine and coworkers.[8] This discrepancy in allowable distortion has been implicated as a possible cause of these delayed component failures.[3,4,9–11] However, there is insufficient understanding of the exact etiology of component failure, other than to blame it on a "poor fit."

One approach to determining the etiology of these prosthetic complications is to analyze the stress in the screw joints involved in implant prosthodontics. Overall stress in the screw joint in clinical function can be viewed as the summation of screw joint preload, stress from distortion (from fabrication of the prosthesis), and stress from functional loading (which is intermittent and varying in magnitude).

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Screw joint preload is the "clamping" force necessary to maintain screw joint integrity.[10] The torque delivered to the fastening screw is converted into tensile stress in the screw shank and into an equal and opposite compressive force holding the 2 implant components together. Opening of the screw joint between a gold cylinder and abutment, or its loosening, has been implicated as the primary cause of gold screw breakage.[10] For implant prosthetic connections in general, 2 screw joints are of concern: the prosthetic gold cylinder/abutment screw joint and the abutment/implant screw joint. For the gold cylinder/abutment screw joint, held by the prosthetic gold screw, the optimal preload has been suggested to be 300 N.[10,12,13] Using calibrated strain gauges, Tan and Nicholls[14] (unpublished data) determined the mean preload obtained by hand torque drivers set at a torque setting of 10 Ncm to be 326 N. However, poorly calibrated electronic torque drivers were shown to induce excessive preloads of up to 597 N, and defective drivers induced preloads as low as 88 N (unpublished data). No authors have yet reported on strain gauge load cell measurements of the preload at the implant-abutment screw joint.

Studies have measured strain in implant frameworks as a means of indicating levels of distortion.[15,16] However, strain measurements were made at locations on the framework or on a simulated resin mandible and could not be directly related to the abutment screw joints. Strain gauge location was arbitrary and led to difficulties in interpreting the data. The raw strain measurements were not related to actual stress levels, nor was there a conclusion on the level of strain that would be clinically unacceptable. Rodriguez and coworkers[16] subjected their model to simulated functional cantilever loading. However, the faciolingual and mesiodistal orientation of the strain gauges between abutments did not allow conclusions to be made about the magnitude and direction of maximum stress and bending moments in the abutment screw joints themselves.

The screw joint preload at the implant-abutment interface level has not been measured directly. Previous work has focused on measuring the screw joint preload at the transmucosal abutment/gold cylinder interface.[17,18] This is because classical implant prostheses with screw retention had their fabrication procedures focused on this joint. More recently, alternative prosthetic designs favored by clinicians have moved the prosthetic connection from the abutment-cylinder interface to a direct connection between the implant and abutment. Some examples include the UCLA abutment, which is incorporated in screw-retained multiple-unit prosthesis directly connected at the implant level, and prefabricated titanium abutments or custom cast abutments for cemented prostheses. Prosthetic complications reported for these prostheses now increasingly include fractures of the abutment screw[7,19–26] and of the implant body itself.[6,19,23,24,27,28] It has also been speculated that the "stacked screw" arrangement of implant prosthetic connections confers some degree of "mobility" or stress attenuation,[12] and in these newer designs, the single screw joint at the implant-abutment interface is forced to bear the entire load.

Various abutment systems each have specific abutment screws that vary in constituent material (eg, commercially pure titanium, titanium alloys, gold alloys) and mechanical configuration (eg, pitch of threads, head design, shank diameter, configuration, shank length, and contact area of mating surfaces between abutment screw head and internal ledge of abutment), as well as machining quality (tolerance levels). Burguete and associates[29] concluded that every screw design can be expected to have different preload-torque relationships. Manufacturers claim that their abutment and abutment screw designs are superior to those of competitors, but these claims have not been substantiated scientifically, and there has been a dearth of reported data on specific implant/abutment screw joint characteristics. Various abutment systems would all be expected to possess different mechanical properties, anti-rotation properties, and fatigue resistance to screw joint opening. Thus, current knowledge of the pattern of stress transmission and the mechanical properties of the implant-abutment screw joint is incomplete. Values for preload of this joint are lacking in the literature. Further investigations of the preload levels at this screw joint would aid in the prediction of clinical adequacy of such prosthetic abutment systems.

Therefore, the aim of this study was to measure and compare the implant/abutment screw joint preload of several commonly used hex-top abutment systems. A definition of the level of preload would add to the current understanding of the overall stress in the screw joint at the implant-abutment interface. This would be of importance in the prediction of clinical longevity and selection of implant-abutment systems.

MATERIALS AND METHODS

Test Abutment Groups

The 7 abutment systems studied are listed in Table 1. These abutments were selected for comparison between older "traditional" abutment designs and

Table 1 Test Abutment Groups and Working Vertical Dimensions

Group	Abutment	Component part no.	Manufacturer*	Abutment screw material	Working vertical dimension, h (mm)	Notes
A	Standard regular platform 5.5 mm	SDCA 005	Nobel Biocare	Commercially pure titanium	1.7	This abutment does not have a flat internal ledge, but a tapering internal conical ledge
B	EsthetiCone regular platform 3.0 mm	SDCA 136	Nobel Biocare	Commercially pure titanium	4.7/3.0	Because of the offset instep, the available external vertical surface for strain gauge attachment is 3.0 mm
C	MirusCone regular platform 3.0 mm	SDCA 425	Nobel Biocare	Commercially pure titanium	3.9/3.0	Because of the offset instep, the available external vertical surface for strain gauge attachment is 3.0 mm
D	Titanium Abutment Post 2 mm	APNU2	Implant Innovations	Titanium alloy	2.1	
E	CeraOne regular platform 2.0 mm	SDCA 333	Nobel Biocare	Gold alloy	2.1	
F	Gold Cylinder to Fixture (GCTF)	DCA498	Nobel Biocare	Gold alloy	1.8	
G	TiAdapt regular platform 5×8 mm	DCA 1016	Nobel Biocare	Gold alloy	1.8	

*Nobel Biocare, Yorba Linda, CA; Implant Innovations Inc, West Palm Beach, FL.

some more recently introduced abutments used in prosthetic designs that are directly connected to the implant (for single-tooth replacements) or to multiple implants.

Close scrutiny of the test abutments indicated that the vertical dimension available for strain gauge placement was very limited. A critical working vertical dimension (h) was defined as the vertical distance between the bottom mating surface of the abutment and the top of the internal ledge on which the abutment screw head bottoms out. The active grid dimensions of the strain gauges used (Measurements Group EA-05-050AH-120 Option LE, Raleigh, NC) are 1.02 mm width × 1.27 mm height, which meant that with care, the gauge tab could be trimmed and bonded such that the active grid could be placed within the compressive strain field to allow measurement of screw joint preload (Fig 1a). The working vertical dimension (h) of the 7 abutment systems ranged from 1.7 mm to 3.0 mm (Table 1).

Abutment Preparation and Gauge Attachment

Each abutment was modified by milling the first 2 to 3 mm of the abutment wall above the implant-abutment interface level to achieve a vertical cylinder wall. Care was taken to ensure that the contact area of the mating surface to the implant was not affected.

Two strain gauges (EA-05-050AH-120, Measurements Group) were positioned approximately 180 degrees apart on the abutment body and bonded with strain gauge adhesive (M-Bond 200 Adhesive, Measurements Group) within the critical working vertical dimension (h). The exact circumferential position and vertical orientation of the gauges were not critical, as they were later individually calibrated to known loads.

Strain Measurement

Strain measurement instrumentation used was a HP 75000 VXI Multimeter (Hewlett-Packard, Loveland, CO) with 8-channel HP E1357 Strain FET Multiplexer (Hewlett-Packard) using quarter-bridge strain measurements. Through a HPIB Bus-to-PC interface, a custom-written HP VEE 3.12 program (Hewlett-Packard) sampled each strain gauge for a specified time interval. The program's virtual multimeter function was used to visualize strain output over time. All strain data and plots were digitally logged into a personal computer for later analysis.

Calibration Procedure

A 3.75×15-mm implant (SDCA 019, Nobel Biocare AB, Göteborg, Sweden) was modified by having its internal thread removed and then held vertically in an engineering rotary table (Model MCL-HHV-150, Michilin, Taipei, Taiwan). This modification was necessary to allow the various abutment screws to bear down on the abutment body only and not be held up by the internal threads of the implant when

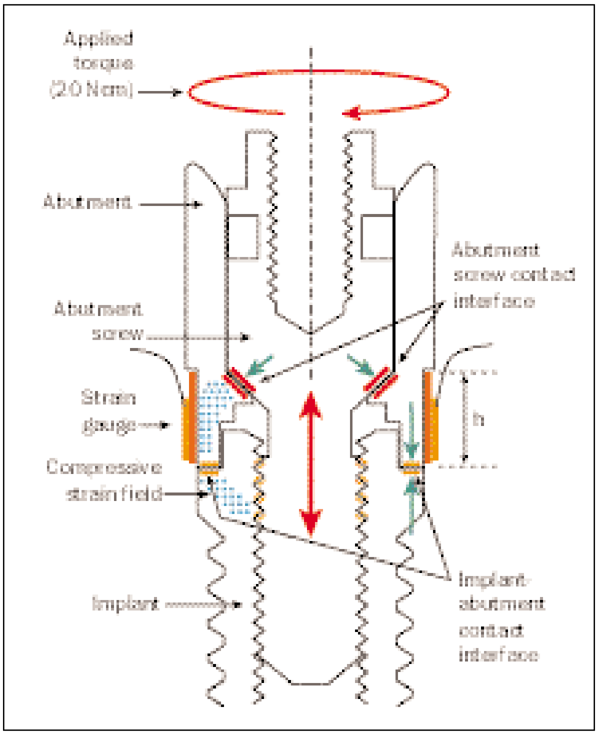


Fig 1a Compressive strain field at implant-abutment interface with tightening torque application. Shown here is the Nobel Biocare Standard 5.5-mm abutment. Critical working vertical dimension (h) is defined as the vertical distance between the bottom mating surface of the abutment and the top of the internal ledge on which the abutment screw bottoms out. Arrows indicate the compressive load at the implant-abutment interface, and double-headed arrows indicate the tensile load in the abutment screw.

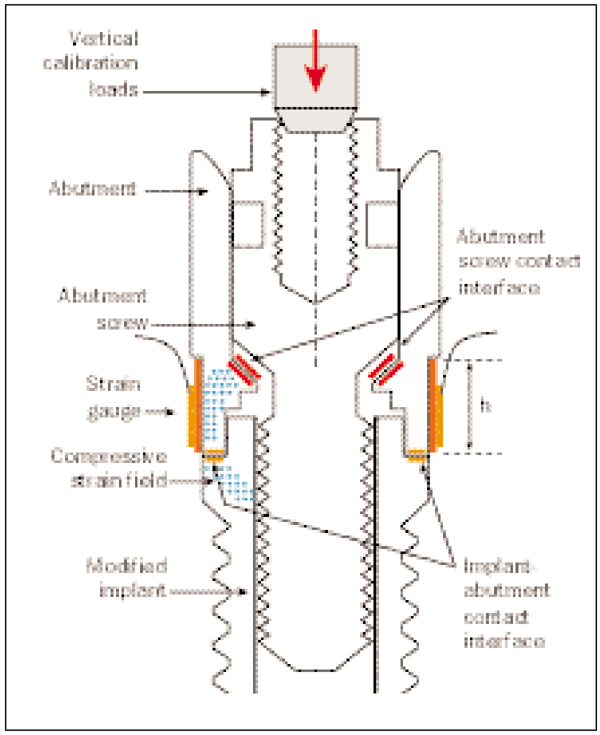


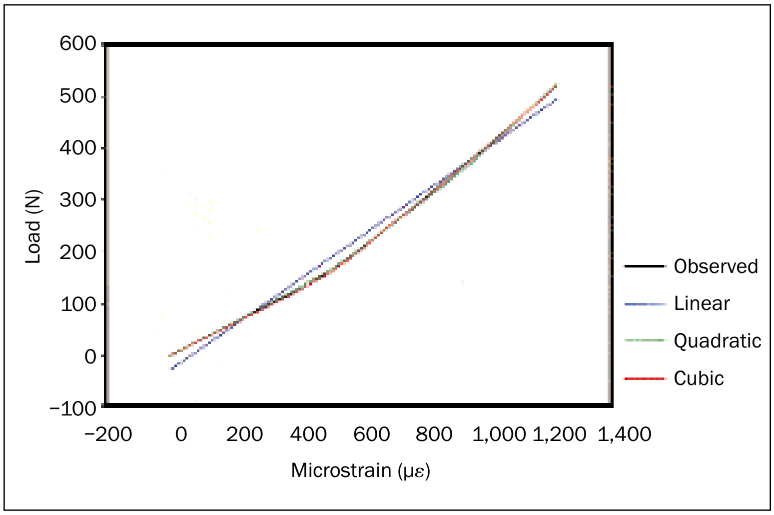
Fig 1b Abutment calibration using modified implant. Note modification of internal threads of implant.

vertical loads were applied during calibration. Thus, there would be no resistance to the seating of the screws, and, when calibrating vertical loads were applied, the imparting of compressive load was entirely to the abutment body seated on the implant mating contact surfaces.

The strain-gauged abutments were placed on top of the modified implant and engaged the external hex. Known vertical loads were applied to the top of respective abutment screws of each abutment system using a servo-hydraulic testing machine (Model 858 Mini Bionix, MTS Systems Corporation, Eden Prairie, MN). This induces a compressive stress field in the cylinder of the abutment body between the bottom of the abutment screw head (seated on the internal ledge) and the abutment-implant interface (Fig 1b). The calibrating load range was 0 to more than 500 N, and strain gauge output was recorded. The calibration run was repeated 3 times for each abutment. The strain readings from the 2 gauges were summed to balance out slight moment effects. These summed strain readings were plotted against applied loads.

Curve fitting was performed with the SPSS regression procedure (SPSS 8.0, SPSS Inc, Chicago, IL), and the data were fitted to linear, quadratic, and cubic equations. In all cases, quadratic equations of the form $y = cx^2 + bx + a$ were found to yield fitted calibration curves with regression coefficients (R^2) ranging from 0.997 to 1.000 (Fig 2); this indicated a very high degree of confidence in the subsequent computation of loads from the measured strain. With these calibration curves, coefficient terms for the quadratic calibration equations were obtained and used to compute compressive load from the strain readings obtained during the abutment screw torque-down procedure. The calibrations were specific only to that particular strain-gauged abutment; that is, each test abutment needed to be calibrated separately and the curve-fitting procedure performed.

Fig 2 Example of a calibration plot for the TiAdapt abutment (DCA 1016) showing applied load versus microstrain, calculated against the equation $y = cx^2 + bx + a$. Observed values are shown in black and values from the fitted quadratic equation appear in green.



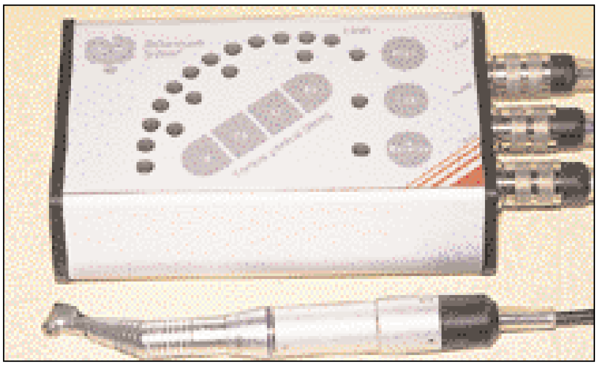


Fig 3a Electronic torque controller (Nobel Biocare DEA 020).

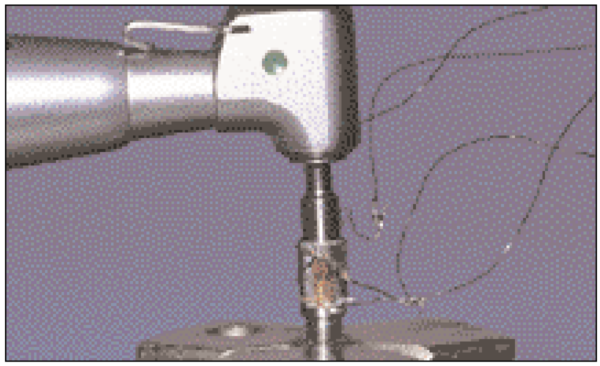


Fig 3b Application of tightening torque by electronic torque controller to implant-abutment load cell (example shown is the Nobel Biocare Standard 5.5-mm abutment).

Torque-Down Procedure and Preload Measurement

For measurement of the implant/abutment screw joint preload, each previously calibrated abutment was placed on a 3.75×15-mm implant base (SDCA 019, Nobel Biocare AB) held vertically in the rotary table. The specific abutment screw was then torqued down using an electronic torque controller (DEA 020, Nobel Biocare AB) (Figs 3a and 3b). Dynamic strain output was measured digitally and logged (Fig 4). Each torque-down and strain measurement procedure was repeated 5 times and performed by a single operator. In addition, the following experimental variables were investigated: *(1)* electronic torque controller speed setting, *(2)* implant-to-abutment hex position, and *(3)* different implant bases.

For electronic torque controller speed, the low setting was compared to the high setting. The manufacturer-recommended speed setting for final

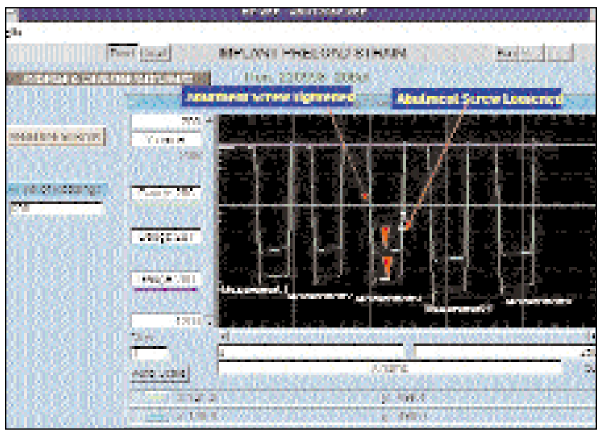


Fig 4 Dynamic strain data logging. Example shown is for the TiAdapt abutment (DCA 1016) at the low-speed setting. Strain output for the 2 gauges is shown in blue (Gauge 206) and yellow (Gauge 207). Negative microstrain values indicate compressive strain at the interface. Note the steady strain state attained immediately in both gauges after the screw has been torqued and the immediate return to zero baseline when the screw is loosened. Five consecutive measurements are shown.

Table 2 Implant-Abutment Screw Joint Mean Preload by Abutment System

Group	Abutment	Manufacturer	Machine driver tips	Final torque tightening levels (Ncm)	Mean preload (N) (SD)		
					Low setting	High setting	Overall
A	Standard regular platform 5.5 mm	Nobel Biocare	DIA 272	20	180.6 (56.6)	182.6 (62.4)	181.6 (60.0)
B	EsthetiCone regular platform 3.0 mm	Nobel Biocare	DIA 272	20	293.0 (36.1)	289.7 (46.1)	291.3 (41.2)
C	MirusCone regular platform 3.0 mm	Nobel Biocare	DIA 272	20	454.9 (46.5)	458.2 (40.9)	456.5 (44.0)
D	Titanium Abutment Post 2 mm	Implant Innovations	DIA 187	20	373.9 (32.1)	365.5 (33.7)	369.7 (32.9)
E	CeraOne regular platform 2.0 mm	Nobel Biocare	DIA 265	32	666.4 (151.2)	620.5 (132.5)	643.4 (143.1)
F	Gold Cylinder to Fixture (GCTF)	Nobel Biocare	DIA 187	20	527.9 (60.6)	544.8 (75.3)	536.3 (68.6)
G	Ti Adapt regular platform 5×8 mm	Nobel Biocare	DIA 922	32	638.5 (142.2)	475.3 (110.8)	556.9 (145.6)

Sample size n = 45 for the low and high groups.

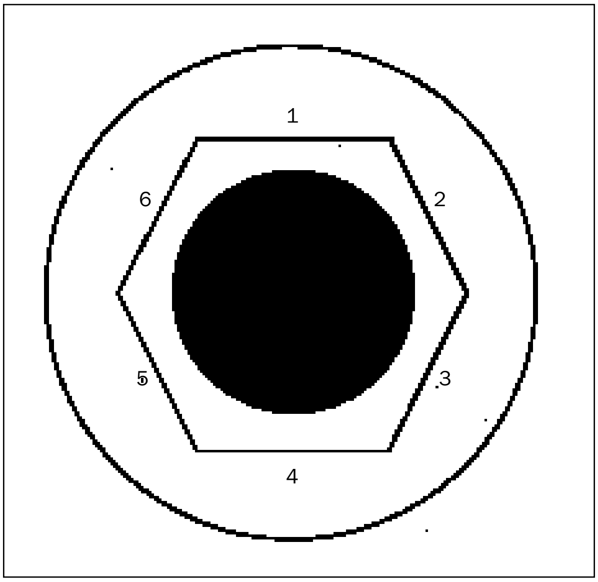


Fig 5 Paired hex positions of hex-top implant: Flats 1 and 4, Flats 2 and 5, and Flats 3 and 6.

torque tightening of abutment screws is low. The appropriate driver tips for each abutment system were used and the abutments were torqued to manufacturer-recommended levels (Table 2).

Theoretically, different component mating positions could give rise to variation in the compressive strain produced. Microscopic surface discrepancies at the mating interface surfaces can have an influence on the strain output. Although the external-hex implant has 6 flats to the hex top, the paired arrangement of the strain gauges meant that the compressive strain field at the implant-abutment interface needed to be verified for 3 paired hex orientations only. These paired hex positions were designated Flat 1/4; Flat 2/5; and Flat 3/6 (Fig 5). Strain measurements were taken at all 3 positions. Furthermore, all strain measurements for the 7 test abutments were repeated on 3 separate 3.75×15-mm implant bases (SDCA 019, Nobel Biocare AB).

Statistical Analysis

All data were subjected to 3-way analysis of variance (ANOVA) for the experimental variables abutment system (ABUTMENT), torque driver speed (TRQSPEED), and base implant (BASE_IMPL). Group means were compared with the Tukey HSD post-hoc test at $P = .01$ significance level (SPSS 8.0, SPSS Inc).

RESULTS

The lowest preload measured was 180.6 N for the Nobel Biocare Standard 5.5-mm abutment at the low setting, and the highest preload measured was 666.4 N for the CeraOne 2.0-mm abutment at the low setting. Strain readings among the 3 paired hex positions (1/4, 2/5, and 3/6) showed very little variation, so data for the 3 paired hex positions were pooled and used in subsequent computations. For the 7 test abutment systems, Table 2 and Figure 6 summarize the mean preloads measured for both low and high machine torque driver speed settings, as well as pooled means.

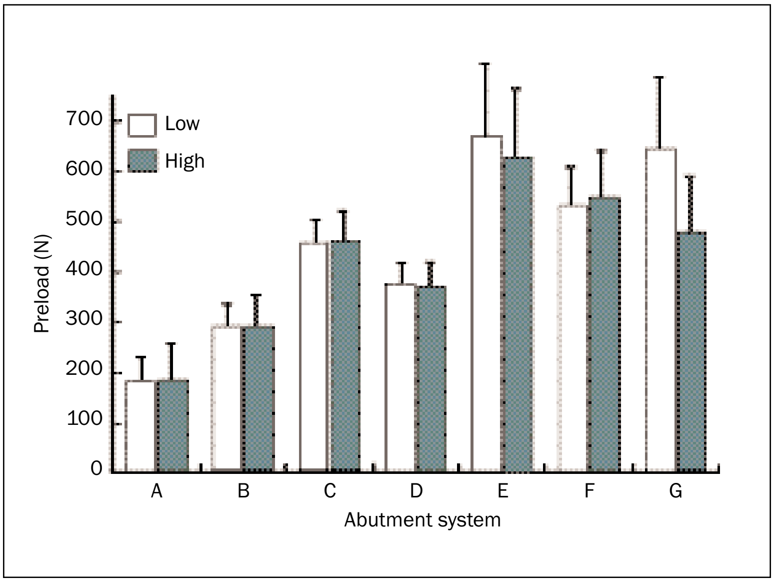


Fig 6 Implant-abutment screw joint preload (N) for 7 abutment systems. Error bars represent ± 1 standard deviation. A = Nobel Biocare Standard 5.5 mm; B = EsthetiCone 3.0 mm; C = MirusCone 3.0 mm; D = Titanium Abutment Post 2 mm; E = CeraOne 2.0 mm; F = GCTF; G = TiAdapt 5×8 mm.

Table 3 Three-Way ANOVA for Abutment System, Base Implant, and Torque Speed

Source	Sum of squares	df	Mean square	F	*P* value
Model	5739985.6	41	139999.6	297.7	.000
Intercept	39382072.8	1	39382072.8	83755.7	.000
ABUTMENT	4747871.8	6	791311.9	1682.9	.000
BASE_IMPL	21060.0	2	10530.0	22.4	.000
TRQSPEED	40939.1	1	40939.1	87.1	.000
ABUTMENT*BASE_IMPL	725611.8	12	60467.6	128.6	.000
ABUTMENT*TRQSPEED	177208.3	6	29534.7	62.8	.000
BASE_IMPL*TRQSPEED	33348.3	2	1674.1	3.6	.031
ABUTMENT*BASE_IMPL* TRQSPEED	27155.0	12	2262.9	4.8	.000
Error	78993.9	168	470.2		
Total	45317686.6	210			
Corrected total	5818979.5	209			

ABUTMENT = abutment system; BASE_IMPL = base implant; TRQSPEED = torque speed.

Three-way analysis of variance (Table 3) revealed significant differences ($P < .01$) in preloads between abutment system (ABUTMENT; F = 1682.9), torque driver speed (TRQSPEED; F = 87.1), and base implant (BASE_IMPL, F = 22.49). Tukey's post hoc test showed statistically significant differences ($P < .01$) in mean preloads between all test abutment groups (Fig 7).

Generally, most of the abutment systems gave slightly higher preloads at the low setting compared to the high setting, but not all these differences were statistically significant. Only the TiAdapt abutment (DCA1016) gave a significantly higher preload with the low setting compared to the high setting. If the abutment systems are grouped according to abutment screw material, then of the titanium abutment screws, the lowest preload was measured for the Nobel Biocare Standard 5.5-mm abutment (181.6 ± 60.0 N) and the highest was seen in the MirusCone

[E] > [G] > [F] > [C] > [D] > [B] > [A]

Fig 7 One-way ANOVA of abutment systems showing statistically significant subsets (Tukey HSD post hoc test for statistical subsets). Groupings within brackets are not significantly different from each other ($P < .05$).

3-mm abutment (456.5 ± 44.0 N). Of the gold alloy abutment screws, the lowest preload was measured for the "Gold Cylinder to Fixture" (GCTF) abutment (536.3 ± 68.6 N), as the recommended tightening torque is 20 Ncm. Of the gold abutment screws with recommended tightening torque of 32 Ncm, the highest preload was measured for the CeraOne 2-mm abutment (643.4 ± 143.1 N).

DISCUSSION

Abutment Preparation

Modification of the abutment bodies was necessary to obtain a vertical wall to which the strain gauges could be bonded. A non-vertical configuration would have complicated the compressive stress field and resulted in a non-linear strain output. The slight reduction in abutment wall thickness, on the order of about 0.1 to 0.2 mm, would not be expected to significantly affect the screw joint preload, and hence preload measurements can be assumed to be indicative of the actual clinical situation.

Torque-Down Procedure

One operator performed all measurement runs, and the same electronic torque controller unit was used for all measurements. During a pilot study and all subsequent measurement runs, repeated application of the driver under the same experimental parameters gave consistent preload results of below 5% standard deviation in most cases and a maximum standard deviation of 11.5%. The electronic torque controller unit was checked against a mechanical torque gauge (Model 6BTG, Tonichi Manufacturing, Tokyo, Japan) throughout the measurement runs and was also found to deliver consistent output.

The authors noted that during the torque-down procedure, more variability in preload measured was caused by operator manipulation of the torque controller—specifically, the manner in which the machine driver tip engaged the screw and was applied. It is also postulated that the trend toward more consistent loads after the initial torque and unscrew process was caused by a "flattening out" phenomena of the high spots on the machined surfaces to a more even contact at the implant-abutment interface as well as the thread-contacting surfaces.

Hex Positions

Torque-down and strain measurements were performed at the 3 possible paired hex orientations (designated as Flats 1/4, 2/5, and 3/6) to account for the possibility of differing stress fields at the implant-abutment interface. Theoretically, if the gauge happened to be related to a "high" spot, then higher strain would be recorded. When the 3 paired hex orientations were compared, measurement repetitions revealed standard deviations in preload that ranged from 0.1% to 23.7% for the 7 systems, with an overall mean standard deviation of 11.3%. This can be considered as within experimental error, given the variable nature of strain gauge measurements. Because of the low variability seen between hex orientations, strain data were pooled in all subsequent computations and not subjected to the ANOVA procedure. In addition, the consistency of the load cell was shown by the low standard deviation (range 1.3% to 17.9%; mean 5.9%) during the 5 measurement repetitions at each particular paired hex orientation.

Torque Controller Speed Settings

For 4 of the 7 abutment systems (EsthetiCone 3.0 mm, Titanium Abutment Post, CeraOne 2.0 mm, and TiAdapt 5×8 mm), higher mean preloads were obtained at the low-speed setting than at the high-speed setting. It is postulated that the lower preloads obtained with the high setting could be caused by an overshoot phenomena in the torque controller sensor mechanism. These results support the manufacturer's recommendation to use the low setting for all final abutment screw torque-down operations to achieve more accurate torque delivery levels.

Abutment System Preload

Of the 7 abutments tested in this study, the Nobel Biocare Standard, EsthetiCone, and MirusCone abutments are used in a "screw stack" manner when connected to the implant-supported prosthesis, whereas the Titanium Abutment Post (APNU2), CeraOne, GCTF, and TiAdapt abutments can be classified as "direct to implant" connections. Of the "direct to implant" abutments, the GCTF abutment can be connected directly to the prosthesis by being incorporated into a cast framework, whereas the other 3 abutments would be connected to the prosthesis via a cemented interface. In addition, the GCTF abutment may also be used to develop custom cast abutments and then receive prostheses cemented onto them.

"Screw stack" systems would comprise 2 screw joints in the connection to the prosthesis, and manufacturers commonly claim that the "weaker" screw joint would serve as the "fail safe" and fail first by design. In contrast, the "direct to implant" systems would comprise just the implant/abutment screw joint, and thus higher preloads would be required in clinical function. This has obvious implications in the need for such "direct to implant" abutment systems to be designed to resist higher stress in the implant/abutment screw joint.

The relationship between applied torque and screw preload is affected by many variables, including screw material properties and diameter, screw configuration geometry, and coefficient of friction of the 2 contacting surfaces (thread hardness, surface finishes, lubricant quantity and properties, and tightening speed).[13,29–31] Clinically, several additional variables can affect the abutment screw tightening procedure. Variations in torque delivery system, operator technique, presence of oral fluids, speed of tightening, and the use of hand snug tightening before final torque driver tightening are all possible sources of variation in the achievement of optimal preload at the implant/abutment screw joint.

It is current practice for most manufacturers to state recommended torque tightening levels for abutment screws of abutment systems, but the actual preload that these torques translate into in the screw joint is not known. Also, the yield strength and ultimate tensile strength of abutment screws are not commonly reported by manufacturers.

In the single-tooth implant application, abutment screw joint preload achieved by the abutment and abutment screw design is critical for the maintenance of screw joint integrity and for anti-rotational resistance. The higher the preload, the more stable the screw joint and the greater the resistance to screw loosening. An abutment designed specifically for single-tooth application is the CeraOne. Using load analysis for an anterior single-tooth situation, Jörnéus and coworkers[32] reported the yield strength of the CeraOne abutment screw of 1,370 N as within desired design overload parameters. The mean screw joint preload for the CeraOne abutment screw measured in the present study was 643.4 N, which is well within the safety margin for screw fatigue life.

Using a "preload test device" in a universal testing machine, Miller and associates[30] reported mean preload values of 124.8 N for the Nobel Biocare Standard abutment screw when torqued to 20 Ncm and 145.5 N for the Nobel Biocare EsthetiCone abutment screw when torqued to 20 Ncm. McGlumphy and colleagues[31] reported mean preloads of 539.6 N for the Nobel Biocare CeraOne abutment screw torqued to 32 Ncm and 431.6 N for the Nobel Biocare machined UCLA abutment screw torqued to 32 Ncm (equivalent to the DCA498 GCTF tested in this study). However, specific details on the jig attachments for the preload test device used were lacking. Compared to the current study, the abutment screw preloads in these 2 studies are generally 20% to 50% lower. This difference may be attributed to the different measurement methodology used. However, the relative ranking of the preload levels for the 4 abutments (Standard, EsthetiCone, GCTF, and CeraOne) is the same in these 2 studies as well as in the current study.

Using a screw elongation measurement method, Haack and coworkers[33] reported mean preloads of 468.2 N for gold UCLA hexed abutments (Implant Innovations) using gold abutment screws torqued to 32 Ncm and 381.5 N using titanium abutment screws torqued to 20 Ncm. The equivalent abutment in the current study to which these results can be compared is the GCTF abutment. However, the DCA498 GCTF abutment with gold screw torqued to 20 Ncm used in the current study has been superseded by the AurAdapt Abutment (DCA 1087-0, Nobel Biocare AB), which uses a heavier gold screw to be torqued to 32 Ncm.

The gold UCLA-type abutments are designed for incorporation into patterns and are subjected to "lost wax" casting procedures to develop prosthesis frameworks. Carr and associates[18] have reported that preload at the gold cylinder/abutment interface is reduced by the casting process and other processing manipulations that the gold cylinders undergo during the prosthesis fabrication process. In the present study, the preload for the DCA498 GCTF abutment was measured with the abutment in a pristine state, and a reduction in preload would be expected if the abutment were subjected to the casting and processing manipulations. This expected difference before and after casting would be the subject of further study.

Abutment screw complications have been reported for only a few abutment systems. Of the abutment systems tested in this study, the Nobel Biocare Standard abutment has a reported abutment screw complication rate ranging from 0.9% to 10% in follow-up clinical studies that range from 1 to 15 years duration.[7,19,21–26] These rates are mainly for complete-arch prostheses. When the Standard abutment was applied in partially edentulous situations, Naert and coworkers[34] reported an abutment screw fracture incidence of 0.6%, compared to the 0.2% reported by Gunne and associates.[35] After a 3-year prospective multicenter study for the EsthetiCone abutment, Kastenbaum and colleagues[36] reported an abutment screw loosening incidence of 1.0% and an abutment screw fracture rate of 0.5%. For the CeraOne abutment, Haas and coworkers[37] initially reported 12 cases of abutment screw loosening (in a sample of 76 implants), but this prosthetic complication was eliminated by the introduction of the

CeraOne gold abutment screw, which was developed to achieve higher preloads, and the correct use of torque controllers that delivered 32 Ncm. With use of the properly developed gold abutment screw for the CeraOne abutment, both Scheller and associates[38] and Andersson and associates[39] reported no incidences of abutment screw loosening in separate 5-year multicenter prospective studies. No clinical reports of the prosthetic complication rates of the other 4 abutments in this study could be found in the literature.

Binon[40] has highlighted the trend toward screw designs that afford higher preload levels. This is usually achieved by a change in the screw material from titanium to gold or gold alloy, as well as a change in the geometric configuration of the screw head and shank diameter. The current study clearly confirms this trend, with a comparison of the screw preloads of the older abutments, such as the Standard and the EsthetiCone, with those of the newer MirusCone, CeraOne, GCTF, and TiAdapt.

Also, the proliferation of proprietary interface designs from the original Nobel Biocare 0.7-mm-tall external hex to other innovative interfaces like the internal hex, internal and external spline, internal octagon, cone screw, cam tube, and cam cylinder[40] means that the screw joint preload of these new designs will need to be further investigated.

CONCLUSIONS

This study has shown that screw joint preload at the implant-abutment interface can be measured with strain gauges using a calibration procedure for the individual abutment load cells. Screw preloads measured indicated differences among hex-top abutment systems dependent on abutment design, screw diameter, material, tightening torque, and torque controller speed. This study reports only on the screw joint preload achieved when abutment screws were torque-tightened to the manufacturers' recommended torque levels. The levels of screw joint preload achieved in the different abutment systems give some indication of relative clinical performance in terms of the likelihood of screw joint integrity being maintained in clinical service. However, further studies, including load-fatigue performance testing of these screw joints, are needed to more fully predict the clinical longevity that can be expected from these implant-abutment connections.

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