Screw Preloads and Measurements of Surface Roughness in Screw Joints: An In Vitro Study on Implant Frameworks

Anders Örtorp, LDS, PhD;* Torsten Jemt, LDS, PhD;[†‡] Ann Wennerberg, LDS, PhD;[‡§]
Carina Berggren, MSc;[‖] Mattias Brycke, LDS[#]

ABSTRACT

Background: With the development of milled titanium implant frameworks, new surfaces that have not previously been studied are now being used in screw joints.

Purpose: The aims of the present study were to compare the preload produced in screw-retained titanium and gold alloy frameworks and the preload for titanium frameworks before and after the application of veneers. Another aim was to try to relate the surface roughness of the screw joints to variations in preload.

Materials and Methods: Ten identical titanium and five gold alloy frameworks were fabricated. The gold screws were tightened to 10 Ncm. Preload measurements were made for the gold alloy frameworks and before and after the porcelain or acrylic resin veneers had been applied to the titanium frameworks. Surface roughness measurements were made after preload measurements on the screw joint surfaces of the titanium frameworks and corresponding gold screws.

Results: The preloads for the titanium and gold alloy frameworks were similar. Preload in both types of frameworks decreased after repeated torques ($p < .05$–$.01$) but was unaffected by the application of veneering materials to the titanium frameworks ($p > .05$). No relationship ($p > .05$) between preload and surface roughness characteristics was observed. Loaded titanium framework screw sites, however, had lower mean S_a values than unloaded sites ($p < .001$), whereas the surfaces of loaded gold screws had higher mean S_a values compared with the surfaces of control gold screws ($p < .05$–$.001$).

Conclusion: When using gold screws, milled titanium frameworks have preloads similar to those of gold alloy frameworks and preloads for both decrease after repeated tightening. The preload was similar before and after the veneering of the titanium frameworks. Unloaded milled titanium screw sites had rougher surfaces than loaded, and loaded gold screws had rougher surfaces than unloaded. However, no correlation between screw joint surface and preload was observed for veneered titanium frameworks.

KEY WORDS: CNC, computer numeric controlled, implant frameworks, preload, surface roughness

*Consultant in prosthodontics, The Brånemark Clinic, Göteborg, Sweden; [†]chairman, The Brånemark Clinic, Göteborg, Sweden; [‡]professor, Department of Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, The Sahlgrenska Academy, Göteborg, Sweden; [§]professor, Department of Biomaterials/Handicap Research, Institute for Surgical Sciences, The Sahlgrenska Academy, Göteborg, Sweden; [‖]Product Development, Nobel Biocare AB, Göteborg, Sweden; [#]research fellow, Department of Biomaterials/Handicap Research, Institute for Surgical Sciences, The Sahlgrenska Academy, Göteborg, Sweden

Reprint requests: Dr. Torsten Jemt, The Brånemark Clinic, Public Dental Health Service, Medicinaregatan 12 C, S-413 90 Göteborg, Sweden; e-mail: torsten.jemt@vgregion.se

Computer numeric controlled (CNC)-milled titanium frameworks have been routinely used for the last 5 years as an alternative to conventional gold alloy castings in implant dentistry.[1–5] Several studies on the fabrication of CNC frameworks have been published, and the clinical results with these prostheses have been comparable with those of conventional cast frameworks.[1–4]

Accurate preload in the screw joints is an important factor in maintaining screw stability. Haack and colleagues discussed the risk of plastic deformation of the screws when the implant bridge was secured, a problem that may jeopardize screw stability in the long term.[6] Both Jörneus and Brunski and Skalak suggested that optimal tensile force should be about 300 N for the conventional gold alloy bridge-locking screw in the Brånemark System® (Nobel Biocare AB, Göteborg, Sweden).[7,8] This magnitude of preload was confirmed by Smedberg and colleagues, who determined an internal preload of approximately 300 N for different metallic superstructures in a clinical situation.[9]

Precision of framework fit is an important prerequisite for optimal maintenance of the preload in the screw joint. In a recent study, CNC-milled frameworks had a more precise fit compared with cast frameworks, implying, at least theoretically, a better clinical situation for the screw joints in these titanium frameworks.[10]

Carr and colleagues found that screw preload can vary as a result of differences in the frictional characteristics of the gold cylinder after different laboratory procedures.[11] They concluded that preload in the gold screw–gold cylinder–abutment screw joint could be affected by different manipulations of the frameworks. Most of the studies on preload measurements, however, have been based on conventional gold alloy castings,[7,8,11] with or without separate premachined gold alloy cylinders incorporated. The use of CNC-milled titanium frameworks introduces both new materials in the metal frame and a new surface in the screw joint. The impact of these new surfaces on the preload in the bridge-locking screw joint has not been investigated.

The main objectives of the present study were to compare the preloads of the bridge-locking gold screw for CNC-milled titanium frameworks and for cast gold alloy frameworks and to compare preloads for titanium frameworks before and after the application of veneering materials. The final aim was to determine whether there was any correlation between the surface roughness of selected surfaces in the screw joint and variations in preload.

MATERIALS AND METHODS

Fabrication of Frameworks

Ten titanium frameworks were fabricated according to the standard laboratory protocol for the CNC milling process (Procera® Implant Bridge, Nobel Biocare AB, Göteborg, Sweden)[4] using one master model, as described earlier.[10] When all data from the scanning process of the resin pattern and measurements from the coordinate measuring machine (Zeiss Prismo Vast, Oberkochen, Germany) were collected in the computer, identical frameworks were milled in one piece of grade 2 titanium (Nobel Biocare AB, Karlskoga, Sweden).[10]

Thereafter, the 10 frameworks were divided into two groups of 5 frameworks each. These were provided with either porcelain or acrylic resin veneers.[12] A porcelain veneer (Duceratin®, Titankeramik, Ducera Dental GmbH, Rosbach, Germany) with a final thickness of 2 to 3 mm was applied to one group according to recommended techniques.[10,13,14] A warm polymer acrylic resin (SRChroma Link, Ivoclar, Schaan, Liechtenstein) with a final thickness of 3 to 4 mm was applied to the other group of titanium frames. The thickness of the acrylic was controlled by means of a labial index, as described earlier.[10] During the acrylic veneering process, laboratory screws (DCA 1003-0, Brånemark System) were placed with minimal torque to protect the inside of the cylinders. The cylinders were not protected when veneered with porcelain.

As a control, five gold alloy frames with similar L-shaped designs were cast to fit the master used for the two experimental groups.[10] In brief, the frameworks were cast in one piece using gold alloy (Sjödings D-gold, type 4 casting gold according to ISO 1562, Sjödings, Kista, Sweden). Prefabricated gold alloy cylinders were used in all frameworks (DCA 073, Nobel Biocare AB). The gold frames were not veneered.[10]

Preload Measurements: Measuring Method

The preloads on the screw joints were measured in a testing machine (Figure 1) provided with a load cell (HBM, S2 1000N, HBM, Darmstadt, Germany). Data were collected to read the preload in the gold screw from a display.

One new prosthetic gold screw (DCA 074-0, Brånemark System) and one new abutment screw (SDCA 008-0, Brånemark System) were used for each measured site. The heel above the O-ring on the abutment screw was turned away to make measurements of the preload possible (Figure 2). The abutment screw was secured in a case during measurements. A special holder with a hole in the center was designed to allow access to the modified abutment screw. Two abutment replicas (DCB 175, Brånemark System) were welded to the holder on either side of the test site to stabilize the frameworks during measurements (Figure 3).

Three different holders were constructed to allow measurements in position 2, 3, or 4 in the frameworks.

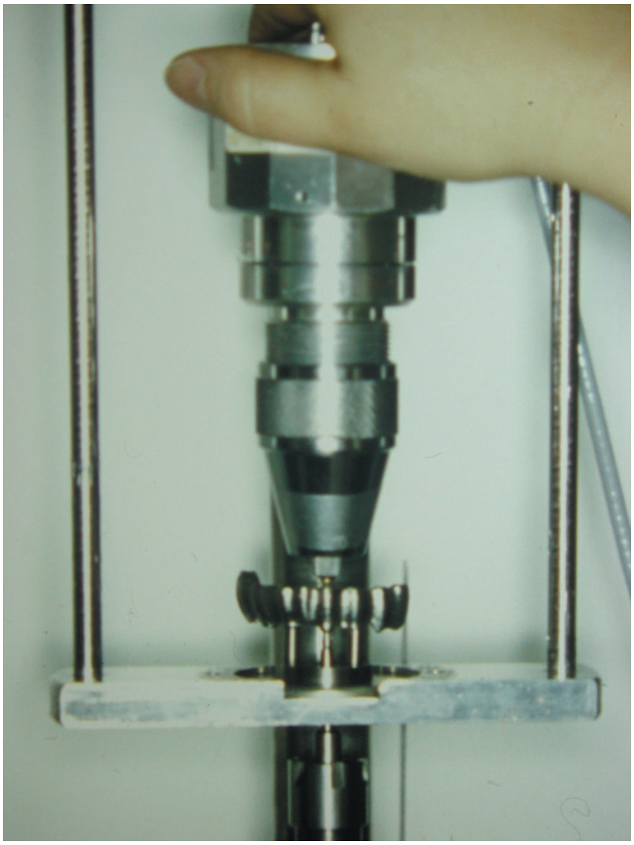

Figure 1 Measuring device with a CNC-milled titanium framework connected to a special holder.

For measurements at sites 2 and 3, the frameworks were secured to the holder by two prosthetic screws (DCA 074-0) that had been torqued to 5 Ncm. At site 4, no securing screws were necessary (because cylinders 3 to 5 were nearly in a straight line).

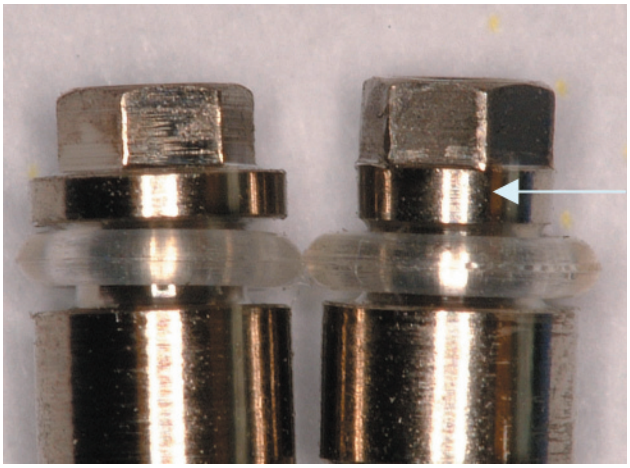

Figure 2 The heel above the O-ring on the abutment screw (*arrow*) was turned away to make measurements of the preload possible.

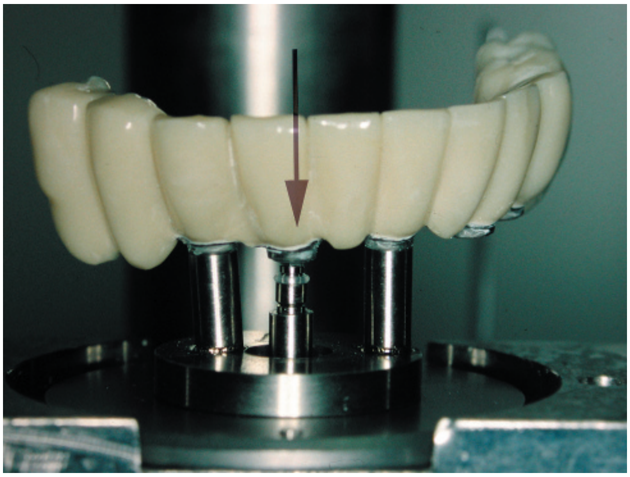

Figure 3 A veneered CNC-milled titanium framework connected to the special holder for preload measurements at site 4 (*arrow*).

Preload measurements of the CNC frameworks were made at screw sites 2 and 4 before the veneers were applied and at sites 3 and 4 after veneering. Preload measurements of the gold alloy frameworks were made at sites 2 and 4.

The preload was first recorded after the prosthetic screw was torqued to 10 Ncm and then after the fifth tightening sequence of the same screw. A torque meter was used to apply a torque of 10 Ncm in each sequence (Tohnichi, Tokyo, Japan). All tests were performed in vitro in a dry area without lubricant and at room temperature.

Surface Topographic Analyses

After preload measurements, the 10 CNC frameworks were stabilized in plaster (Silky-Rock, Whip Mix, Louisville, KY, USA) on five standard abutment replicas (DCB 175-0, Brånemark System) and milled down to a horizontal level approximately 1.5 to 2 mm above the horizontal surface inside the cylinder to be measured. To protect the inside of the cylinders, minimal torque was used to place the laboratory screws (DCA 1003-0, Brånemark System).

Topographic three-dimensional analyses[15] were made with an interferometer, MicroXam™ (PhaseShift, Tucson, AZ, USA). A maximum vertical range of 5 mm and a vertical resolution of 0.1 nm can be attained with this equipment. The horizontal resolution is about 0.3 μm. All measurements were made at ×10 magnification objective and a zoom factor of 2. The size of each measured area was 206 × 156 μm, and the spatial sampling was 0.28 × 0.33 μm.

All five sites on the 10 CNC titanium frameworks were measured in four different areas on the internal horizontal shelf of the cylinder at each site (buccal, distal, lingual, and mesial; Figure 4A). Two hundred measurements were made. Sites 2, 3, and 4 were loaded sites. For control purposes, unloaded sites 1 and 5 were also measured.

No surface measurements were made for the gold frames.

The bearing areas of the gold screws at sites 2, 3, and 4 were measured (Figure 4B). Four areas on each screw were measured. In addition, the lower part of the three first threads of the screws (see Figure 4B) was measured. Two hundred ten measurements were made of the gold screws. For control purposes, another three new (unused) screws, received directly from the manufacturer, were measured using the same protocol as described above (21 measurements).

Surface Evaluation

For numeric characterization, 13 parameters describing the surface texture concerning height and spatial variation were calculated[15]; 3 of them are reported here. A gaussian digital filter, 50 × 50 μm, was used to separate roughness from errors of form and waviness[16]:

S_a = the arithmetic mean deviation of the surface, measured in micrometers, a parameter used to describe height

S_{ds} = the density of the summits on the surface, number/μm^2, a parameter used to describe spatial variation

S_{dr} = developed surface area, the ratio between the measured surface and an imaginary total flat area, measured in percent. This is a hybrid parameter; it takes both height and spatial variation into account.

Statistical Analyses

Data from preload before and after veneering of the CNC frameworks were analyzed with the Wilcoxon signed rank test.[17] This test was also used to analyze preload and different torque sequences. The Mann-Whitney test[17] was used to calculate *p* values for the preload of CNC frameworks before veneering and of gold frameworks. The same test was used to analyze the surface of loaded and unloaded screw sites in CNC frameworks and unloaded and loaded gold screws. Spearman's rank correlation test[17] was used to assess the relationship between the preload and surface roughness (pairwise) at the screw sites on the CNC frameworks and for the relationship of surface between screw and screw sites. Statistical significance was set at 5%.

RESULTS

Preload Measurements

The range of preload was large for all sites on all occasions (Tables 1 and 2). In the group veneered with porcelain, the range was slightly lower (see Table 2).

The results revealed no significant differences in preload between CNC frameworks before veneering and cast gold alloy frameworks ($p > .05$), indicating a similar mean preload for the two groups (see Table 1).

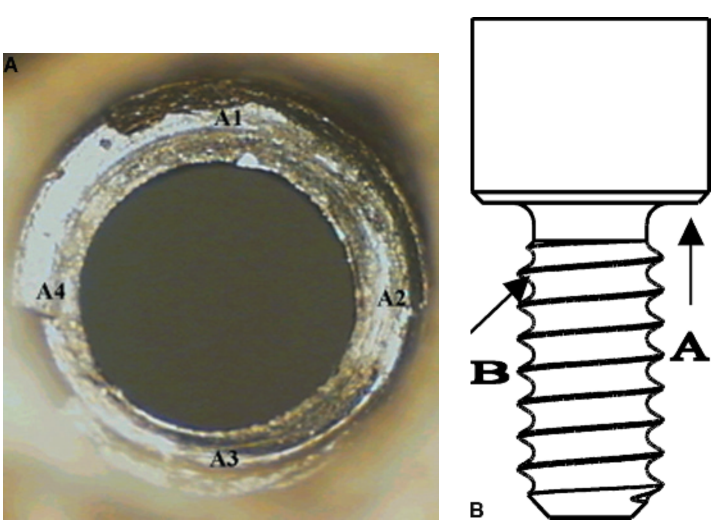

Figure 4 *A* and *B*, Surfaces measured at the screw sites in the CNC framework (A1–A4) and surfaces measured on the gold screw (A, under the surface of the screw head; B, three upper threads).

A significantly lower preload was measured for the fifth torque than for the first for both CNC ($p < .05$) and gold alloy frameworks ($p < .01$; see Table 1). The same difference between the first and fifth torques was seen with the CNC frameworks after veneering ($p < .01$; see Table 2).

There were no significant differences in preload before and after the CNC frameworks were veneered ($p > .05$). Data from this study indicate that the mean preload for CNC frameworks veneered with porcelain is lower than for CNC frameworks veneered with acrylic or before the veneering process (see Table 2). However, this trend was nonsignificant ($p > .05$).

Surface Evaluation

Ten of the 431 surface measurements were impossible to evaluate owing to manufacturing defects in the surface that exceeded the measuring range.

There was an obvious variation in surface roughness (S_a, S_{dr}) between the different measuring areas of the CNC titanium frameworks, independent of load and veneering material (see Figure 5 and Table 2). Loaded titanium screw sites had lower mean S_a values than unloaded sites ($p < .001$; Table 3).

Higher mean S_a values were observed for the bearing surfaces of the loaded gold screws ($p < .001$) and for the surfaces of the upper threads ($p < .05$) of the gold screws compared with the control gold screws (Table 4). No significant correlation between the preloads and the surface characteristics of the sites was found in analyses of the surfaces of the screw sites in CNC titanium frameworks and the surfaces of the gold screws ($p > .05$).

TABLE 1 Preload after First and Fifth Torque (10 Ncm)

Times Torqued Framework	First Torque	Fifth Torque	First Torque	Fifth Torque
	Preload (*n*)			
	Site 2*	Site 2	Site 4	Site 4
CNC before veneering (*n* = 10)				
Mean (SD)	186 (49)	190 (75)	213 (47)	179 (41)
Median	172	166	213	184
Range	157	201	136	131
Maximum	296	319	288	255
Minimum	139	118	152	124
Gold alloy (*n* = 5)				
Mean (SD)	176 (45)	144 (38)	214 (65)	184 (54)
Median	185	156	208	207
Range	98	102	174	121
Maximum	215	189	306	237
Minimum	117	87	132	116

One gold screw was used for each site.
*One measurement in the gold alloy group failed.

TABLE 2 Preload after First Torque and Fifth Torque (10 Ncm) after Veneering

Times Torqued Framework	First Torque	Fifth Torque	First Torque	Fifth Torque
	Preload (*n*)			
	Site 3	Site 3	Site 4	Site 4
CNC, acrylic (*n* = 5)				
Mean (SD)	187 (14)	170 (32)	205 (40)	200 (81)
Median	188	162	188	173
Range	38	78	82	201
Maximum	202	224	250	341
Minimum	164	146	168	140
CNC, porcelain (*n* = 5)				
Mean (SD)	153 (13)	128 (24)	123 (17)	101 (12)
Median	145	116	122	94
Range	30	57	37	26
Maximum	173	169	143	117
Minimum	143	112	106	91

One gold screw was used for each site.

DISCUSSION

The differences in preload between the gold alloy frameworks and the CNC frameworks were nonsignificant (see Table 1), which should indicate that similar preloads for titanium and for conventional cast gold alloy frameworks could be anticipated in clinical practice. The present preload measurements were similar to those reported by Carr and colleagues[11]; however, the preloads did not reach 300 N, which has been reported by others[9,18] and was recommended theoretically by Brunski and Skalak.[8] A preload of 300 N arises in ideal conditions with gold screw or gold cylinder surfaces that have not been damaged.[8] Such preloads are difficult to achieve in more "clinical" situations regardless of whether titanium or gold is used.

Higher preload levels have been reported by Smedberg and colleagues[9] and Jemt and colleagues.[19] This difference could be because they used a different technique to indirectly calculate the preload on the

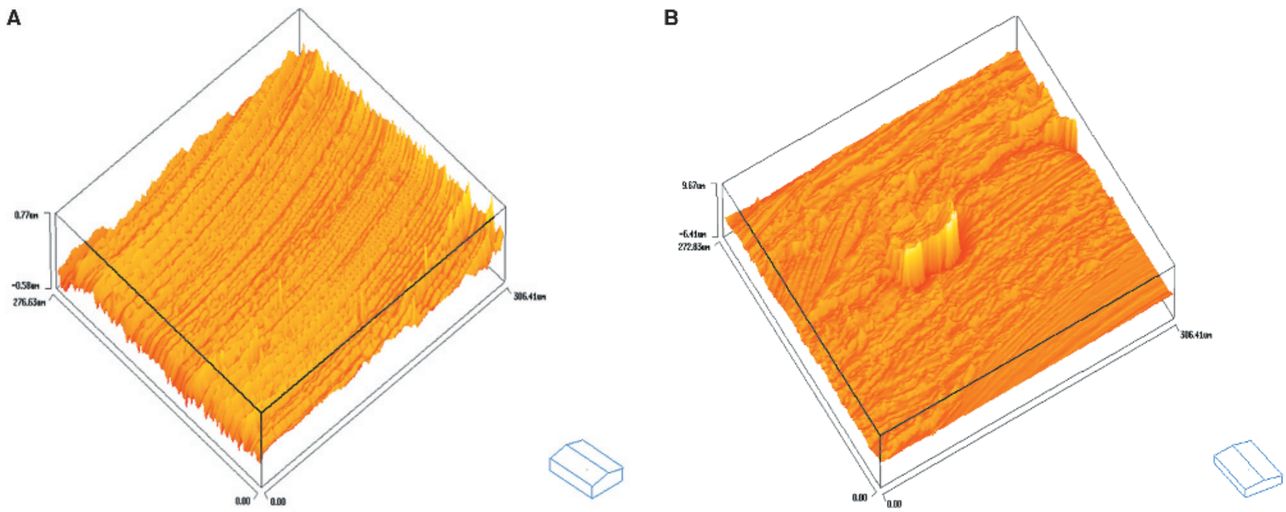

Figure 5 Two images of topographic measurements made with an interferometer. Production marks are clearly visible. *A*, A typical anisotropic topography. *B*, Scratches and pores.

screw joint. Saliva has probably also acted as a lubricant in these clinical tests and caused higher preload values. The role of saliva could be exemplified by Burguete and colleagues, who noted an increase in the preload of well-lubricated metal components over the preload of a dry test area.[20] Accordingly, it can be anticipated that preload will be higher in the clinic because saliva most likely acts to reduce friction in the screw joint. Long-term clinical studies on gold alloy and titanium frameworks have found that few or no gold screws loosen when torques of 10 Ncm are used to tighten the screws.[21–23] Accordingly, it is reasonable to assume that the preload measured in this study is clinically acceptable.

Repeatedly tightening the screws significantly reduced the screw preload in both the titanium and the gold alloy frameworks (see Tables 1 and 2). This must be interpreted as increased friction in the screw joint, which is not in accordance with the findings of Haack et al.[6] They found friction to be higher for the first tightening and loosening of an abutment screw and lower after subsequent tightening and loosening cycles of the screws. According to their results, preload increases and then levels out, which contradicts the present results. However, they apparently used the same implant or abutment for all of their screws.[6]

In the present study, surfaces on the titanium framework became significantly smoother ($p < .001$) after repeated tightening (see Table 3; S_a), whereas surfaces on the gold screws became significantly ($p < .05$–$.001$) rougher (see Table 4; S_a). These values, however, had different initial levels of roughness, and the roughness became more similar after tightening. Both smoother surfaces, which increase the contact area in the screw joint, and rougher surfaces could be factors that increase friction in the screw joint. Differences in the methods used to measure and calculate preload might explain the difference in results between the present study and the study of Haack and colleagues.[6]

Preload had a wide range in this study, which agrees with other reports.[6,11] Burguete and colleagues are of the opinion that the amount of torque required

TABLE 3 Three-Dimensional Surface Roughness Parameters for Loaded Screw Sites Measured on Four Locations in 10 Titanium Frameworks after Veneering and for Unloaded Screw Sites (Controls)

CNC Framework	S_a (μm)	S_{ds} (/μm^2)	S_{dr} (%)
Sites (loaded) 2, 3, 4 (n = 117*)			
Mean (SD)	0.54 (0.35)	0.03 (0.01)	23.53 (26.74)
Median	0.44	0.03	12.88
Maximum	2.47	0.05	155.20
Minimum	0.12	0.02	2.32
Sites (unloaded) 1, 5 (n = 77*)			
Mean (SD)	0.68 (0.41)	0.03 (0.01)	35.67 (48.66)
Median	0.54	0.03	19.17
Maximum	2.47	0.50	314.36
Minimum	0.30	0.02	4.52
p value, loaded-unloaded sites	***	NS	**

NS = not significant.
*Three measurements failed.
**$p < .01$; ***$p < .001$.

TABLE 4 Three-Dimensional Surface Roughness Parameters Characterizing Surface Structure for Four Measurements on Bearing Area on Gold Screws and on Areas for Three Upper Threads for Sites 2, 3, 4 for 10 CNC Frameworks and Three Control Screws on Four Bearing Areas and Three Upper Threads

Surface Roughness	S_a (μm)	S_{ds}(/μm^2)	S_{dr} (%)
		Bearing Area	
Loaded gold screws			
Mean (SD) (n = 120)	0.16 (0.10)	0.02 (0.01)	1.31 (1.06)
Median	0.13	0.02	1.07
Maximum	0.83	0.04	8.72
Minimum	0.07	0.01	0.23
Control gold screws			
Mean (SD) (n = 11)†	0.06 (0.01)	0.01 (0.01)	0.20 (0.04)
Median	0.06	0.01	0.20
Maximum	0.07	0.02	0.29
Minimum	0.05	0.00	0.13
p value, loaded-unloaded screws	***	***	***
		Upper Thread	
Loaded gold screws			
Mean (SD) (n = 87)‡	0.66 (0.37)	0.05 (0.01)	24.57 (24.33)
Median	0.58	0.05	19.13
Maximum	2.23	0.07	166.52
Minimum	0.22	0.03	4.04
Control gold screws			
Mean (SD) (n = 9)	0.42 (0.16)	0.05 (0.01)	15.68 (5.44)
Median	0.36	0.05	14.66
Maximum	0.80	0.06	22.32
Minimum	0.28	0.04	8.69
p value, loaded-unloaded screws	*	NS	NS

NS = not significant.
†One measurement failed.
‡Three measurements failed.
*$p < .05$; **$p < .01$; ***$p < .001$.

to achieve optimum preload is difficult to specify because it will vary from one screw to another, even though the screws and their joints might be nominally the same.[20] The authors concluded that it was important to consider each joint separately,[20] which agrees with the clear variation in preload found between the different sites in the present study. There could be several reasons for the range of preload in this study. McGlumphy and colleagues suggested that factors such as screw alloy, screw head design, abutment alloy, abutment surface, and lubricant may contribute to variations in preload.[24] Accordingly, the preload in a screw joint is a function of the dimensions, the torque applied, and the friction between surfaces in the screw joint. The variations in macrodimensions and applied torque are minimal in this study, but, owing to the shape of the framework, different sites have somewhat different orientations in relation to each other. This study, however, was designed to reproduce the clinical situation, as others have also done.[9,18,19] Still, when the sites are considered separately, as recommended by others,[20] significant changes in preload were observed after repeated tightening.

A large number of measurements were made to understand surface roughness in this material. Although 13 parameters were evaluated, only the values of the three most representative parameters were presented. One height, one spatial, and one hybrid parameter were included for topographic evaluation of implant surfaces, as recommended by Wennerberg and Albrektsson.[16]

All measured surfaces were anisotropic, that is, they displayed a clearly oriented pattern that had been created during the manufacturing process (see Figure 5). Surface roughness varied greatly between the measuring areas, indicating that the surfaces were inhomogeneous (see Figure 5). Such inhomogeneity may have camouflaged minor differences in roughness that are characteristic of the type of metal or amount of preload. The surface roughness at the titanium sites did not change as much as at the gold screws. This may be due to the different properties of the materials.

No correlation between surface roughness and preload was found in this study, but CNC frameworks veneered with porcelain tended to have lower preloads than frameworks veneered with acrylic. This has not previously been reported in the literature, but one hypothesis could be that oxidation caused by the firing process altered the hardness of the material. The protection screws used during acrylic veneering may also have protected the framework surfaces.

Friction is one variable that is difficult to control, and, according to Carr and colleagues, friction between fastening components is a major factor influencing preload.[11] Furthermore, Carr and colleagues stated that increased torque in a high-friction environment does not predictably produce higher preloads.[11] It could be supposed that veneering would alter friction in the screw joint, but the present measurements did not show any significant changes (see Tables 1 and 2). Thus, preloads have wide ranges (this study), lubricated components increase preloads,[20] and repeated tightening can increase[6] or decrease (this study) preload. Although the hardness of the gold alloy in the gold screws is higher than the hardness of titanium grade 2, the gold screws become rougher and the titanium surfaces become smoother in repeated tightening sequences, further exemplifying the complex character and problem of controlling friction.

CONCLUSIONS

Given the limitations of the sample size, this study found that

1. Gold screws tightened to CNC titanium frameworks have preloads similar to those of gold alloy frameworks ($p > .05$).
2. Preload decreases from the first to the fifth torque for both gold alloy and CNC titanium frameworks ($p < .05$–$.01$).
3. Preloads measured before and after CNC titanium frameworks were veneered were similar ($p > .05$).
4. Unloaded CNC screw sites have rougher surfaces (S_a, S_{dr}) than loaded sites ($p < .01$–$.001$).
5. The bearing area of loaded gold screws showed rougher surfaces (S_a, S_{dr}, S_{ds}) than unloaded screws ($p < .001$).
6. No correlations were observed between preload measurements and surface measurements on CNC titanium frameworks and gold screws ($p > .05$).

ACKNOWLEDGMENT

We gratefully acknowledge math statistician Camilla Billström, MSc, and biostatistician Emma Jaensson for their statistical assistance and guidance. The study was supported by grants from Nobel Biocare AB, the Swedish Medical Research Council, the Hjalmar Svensson Research Foundation, and the Wilhelm and Martina Lundgren Research Foundation.

REFERENCES

1. Örtorp A, Jemt T. Clinical experiences of CNC-milled titanium frameworks supported by implants in the edentulous jaw: 1-year prospective study. Clin Implant Dent Relat Res 2000; 1:2–9.
2. Örtorp A, Jemt T. Clinical experiences of CNC-milled titanium frameworks supported by implants in the edentulous jaw: a 3-year interim report. Clin Implant Dent Relat Res 2002; 2:104–109.
3. Örtorp A, Jemt T. Développement des aramatures en titane pour la prothése implantaire. Implant 2001; 7:169–175.
4. Jemt T, Bäck T, Petersson A. Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. Int J Prosthodont 1999; 12:209–215.
5. Jemt T, Bäck T, Petersson A. Photogrammetry—an alternative to conventional impressions in implant dentistry? A clinical pilot study. Int J Prosthodont 1999; 12:363–368.
6. Haack JA, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. Int J Oral Maxillofac Implants 1995; 10:529–536.
7. Jörneus L. Screws and cylinders in the Nobelpharma implant system. A glimpse of miniature research and development. Nobelpharma News 1997; 1:7.
8. Brunski JB, Skalak R. Biomechanics of osseointegration and dental prostheses. In: Naert I, van Steenberghe D, Worthington P, eds. Osseointegration in oral rehabilitation:

an introductory textbook. Chicago: Quintessence, 1993: 133–156.

9. Smedberg JI, Nilner K, Rangert B, Svensson SA, Glantz P-O. On the influence of superstructure connection on implant preload: a methodological clinical study. Clin Oral Implants Res 1996; 7:55–63.
10. Örtorp A, Jemt T, Bäck T, Jälevik T. Comparisons of precision of fit between cast and CNC milled titanium implant frameworks for the edentulous mandible. Int J Prosthodont 2003; 16:194–200.
11. Carr AB, Brunski JB, Hurley E. Effects of fabrication, finishing, and polishing procedures on preload in prostheses using conventional ''gold'' and plastic cylinders. Int J Oral Maxillofac Implants 1996; 11:589–598.
12. Zarb GA, Janson T. Prosthodontic procedures. In: Brånemark P-I, Zarb GA, Albrektsson T, eds. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago: Quintessence, 1985:241–282.
13. Duceratin, Titankeramik, Arbeitsanweisung. Rosbach, Germany: Ducera Dental GmbH, 1999.
14. Mackert R. Dental ceramics. In: Anusavice KJ, ed. Phillipś science of dental materials, Vol 26. 10th Ed. Philadelphia: Saunders, 1996:583–618.
15. Wennerberg A. On surface roughness and implant incorporation. PhD thesis, 1996, Department of Biomaterials/Handicap Research, University of Göteborg, Göteborg, Sweden.
16. Wennerberg A, Albrektsson T. Suggested guidelines for the topographic evaluation of implant surfaces. Int J Oral Maxillofac Implants 2000; 15:331–344.
17. Colton T. Statistics in medicine. Boston: Little, Brown, 1974.
18. Jörneus 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.
19. Jemt T, Carlsson L, Boss A, Jörneus L. In vivo load measurements on osseointegrated implants supporting fixed or removable prostheses: a comparative pilot study. Int J Oral Maxillofac Implants 1991; 6:413–417.
20. Burguete RL, Johns BR, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. J Prosthet Dent 1994; 71:592–599.
21. Jemt T, Bergendal B, Arvidson K, et al. Implant-supported welded titanium frameworks in the edentulous maxilla: 5-year prospective multi-center study. Int J Prosthodont 2002; 15:544–548.
22. Örtorp A, Lindén B, Jemt T. Clinical experiences of laser-welded titanium frameworks supported by implants in the edentulous mandible: a 5-year follow up study. Int J Prosthodont 1999; 12:65–72.
23. Örtorp A, Jemt T. Clinical experiences of computer numeric controlled–milled titanium frameworks supported by implants in the edentulous jaw: a 5-year prospective study. Clin Implant Dent Relat Res 2004; 6:199–209.
24. McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. Dent Clin North Am 1998; 42:71–89.