

Geometric comparison of five interchangeable implant prosthetic retaining screws

Merle J. Jaarda, DDS, MS,^a Michael E. Razzoog, DDS, MS, MPH,^b
and David G. Gratton, DDS^c

School of Dentistry, University of Michigan, Ann Arbor, Mich.

Eight geometric parameters of five interchangeable prosthetic retaining screws (#1-3i Implant Innovation-gold, #2-Impla-Med-gold, #3-Nobelpharma-gold, #4-3i Implant Innovation-titanium, and #5-Implant Support Systems-titanium) were recorded with an Amray 1000-B scanning electron microscope at $\times 20$ to $\times 200$ magnification. Five screws of each type were measured and eight parameters were evaluated: (A) diameter of head, (B) screw length, (C) thread pitch, (D) major diameter, (E) neck diameter (F) length of neck, (G) crest width, and (H) root width. The Nobelpharma-gold prosthetic retaining screws served as controls. The results revealed significant differences between the control and test screws in all parameters except parameters C and G (ANOVA, $p < 0.05$) and Duncan's multiple range test (significance level 0.05). On the basis of these differences, it was concluded that interchanging prosthetic retaining screws can introduce unknown variables in treating patients. (J PROSTHET DENT 1995;74:373-9.)

The introduction of Brånemark implants¹ and predictable osseointegration success to North America has led to an unprecedented growth of the dental implant industry. Just as predictable has been the development of "interchangeable components" for the Brånemark implant system marketed to the profession at reduced costs. The question of scientific proof regarding the safety of interchangeable implant components was raised recently in two scientific journals. A panel of experts in *The International Journal of Oral and Maxillofacial Implants* came to the consensus that there is no scientific proof.² The lack of information about intersystem interchangeability of dental implants and clinical consequences was reemphasized in *The Journal of Dental Research*.³ This article and its findings brought to the profession's attention that scientific evidence must be demanded when commodity development replaces science. If the safety of interchanging components cannot be confirmed, the accepted percentages of long-term implant success, which are widely quoted, may not be valid as the combinations of look-alike components rise.

Understanding the total implant complex and influence on the implant-to-bone interface requires consideration of

the implant hardware as a dynamic complex that consists of multiple components. A typical implant complex consists of five components united to form six interfaces and function as an integrated unit (Fig. 1). These six interfaces serve as stress transmittal points, much as synaptic junctions within the nervous system, and have the potential to control, direct, or distribute these forces.

The potential interaction of these components was explained in detail by Burguete et al.⁴ The contacting surfaces of these interfaces play a major part in the torque-preload relationship and ultimately in the fatigue life of the screws. Applied torque and preload are only indirectly proportional because of the frictional forces that act on the interfaces. Frictional forces depend on the geometry and material properties of the components that make up the screw interfaces. Size and surface area of the contacting flanks (threads), the pitch, the screw radius, and the diameter of the head of a screw play a major role in the relationship between applied torque and preload. The length of the screw also influences the area of the contacting flanks, because a longer screw will have more thread surface engaged. On the basis of established engineering principles regarding the influence of geometry on the torque-preload relationship, every screw design has its own unique torque-preload relationship.

Screw design within implant systems was a major focus of the recent Osseointegration Ten Years in Private Practice conference.⁵ Screw loosening was cited as an ongoing complication in dental implant treatment. Inadequate screw length, diameter, thread, and neck design were given as potential causes of the complications. In section V, "The Role of Screws in Implant Systems," the expert panel

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^aAssistant Professor, Department of Prosthodontics.

^bAssociate Professor, Department of Prosthodontics.

^cAssistant Professor, Department of Prosthodontics, College of Dentistry, University of Iowa, Iowa City, Ia.

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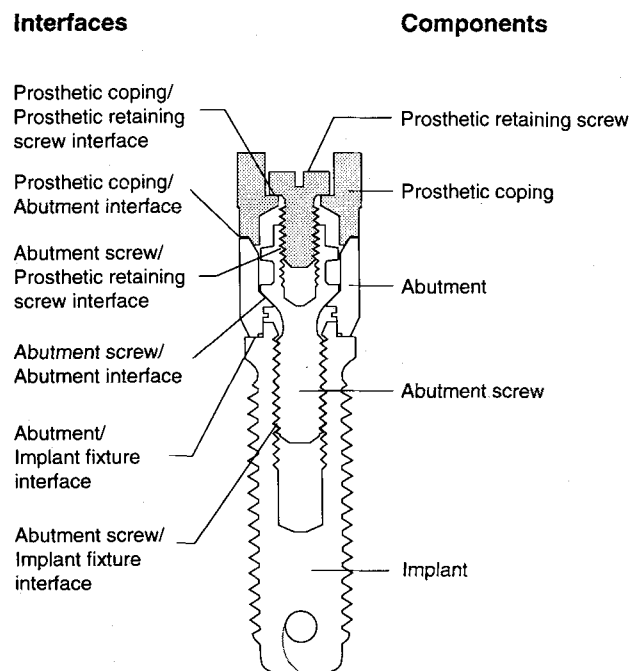


Fig. 1. Dental implant complex consists of five components that are united and form six interfaces.

agreed that even a minor change in thread design could change the screw fracture resistance under applied torque preload over 60% (18 Ncm to 29.5 newtons/centimeter). It was also stated that the geometry of the neck of a screw will greatly influence stress concentrations and that manufacturing tolerances and postmanufacturing processes such as casting are contributing factors of screw loosening.

Knowledge of torque and preload is paramount to understanding the significance of screw design and the torque/preload relationship. The purpose of a screw is to clamp two objects together, such as a prosthetic retaining screw, which clamps the gold cylinder and the abutment cylinder together. As the retaining screw is tightened, it stretches, which creates tension within the screw itself. Preload exists within the connection regardless of whether an external masticatory load is exerted. The preload tension within the screw produces compression in the parts being clamped.⁶ It is critical to have the greatest preload to maximize the fatigue life of the screw.⁴ The full screw strength must be used in developing the preload to attain maximum joint strength.⁶

To examine the role of preload in the fatigue life of a screw, it is helpful to examine a hypothetical tensile stress/strain diagram (Fig. 2). As a tensile load is applied, the screw begins to deform elastically until point E is reached. At this time plastic deformation begins. Below point E, the deformation is elastic, which means that if the load is removed, the screw will return to its original form. This tensile load may be in the form of a preload within the

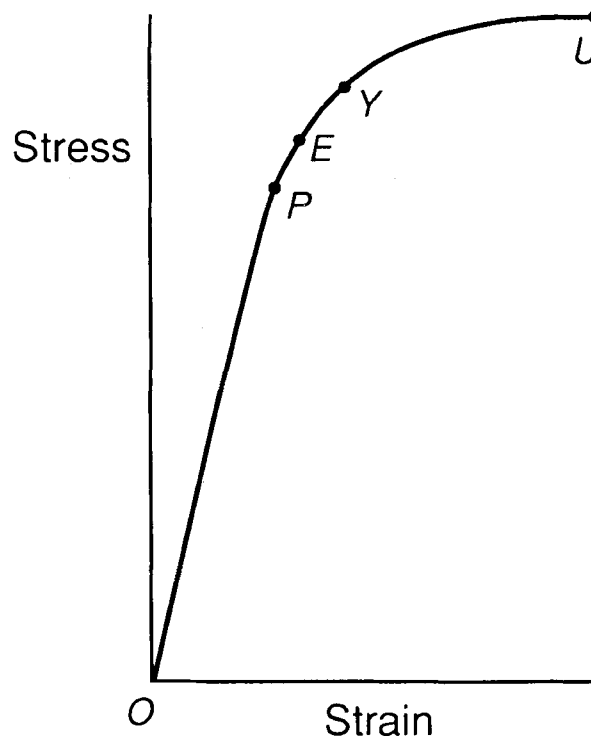


Fig. 2. Typical tensile stress/strain diagram of screw placed under tensile load. P, Proportional limit; E, elastic limit; T, yield point; U, ultimate strength.

implant complex or an external masticatory load. If there is no preload, the retaining screw will experience substantial fluctuations in cyclic tensile loading, which could cause early failure of the joint. For example, during mastication, a cyclic load is applied to the screw in the OP range of the stress/strain diagram, resulting in deformation. However, the screw will return to its original form each time the teeth move out of contact, as long as the load does not exceed the elastic limit or point E. The negative feature of this cyclic loading is that it will lead to work hardening and an eventual decrease in the fatigue life of the screw. However, if a tensile preload less than or equal to the proportional limit P is applied during the tightening process, the screw will not "feel" the full functional load. A large portion of the functional load is absorbed by the joint and results in a small impact on the screw.⁷

Theoretically, preload causes tension in the screw and compression of the parts that are clamped. Application of an external load will increase tension in the screw only in as much as some of the compressive deformation of the clamped parts is relieved. In the case of the gold prosthetic retaining screw, increasing or decreasing preload torque has demonstrated no effect on the ultimate tensile strength of a gold prosthetic retaining screw.⁸ Preload protects the screw from the cyclic nature of functional loading and the potential for work hardening and thereby increases the fa-

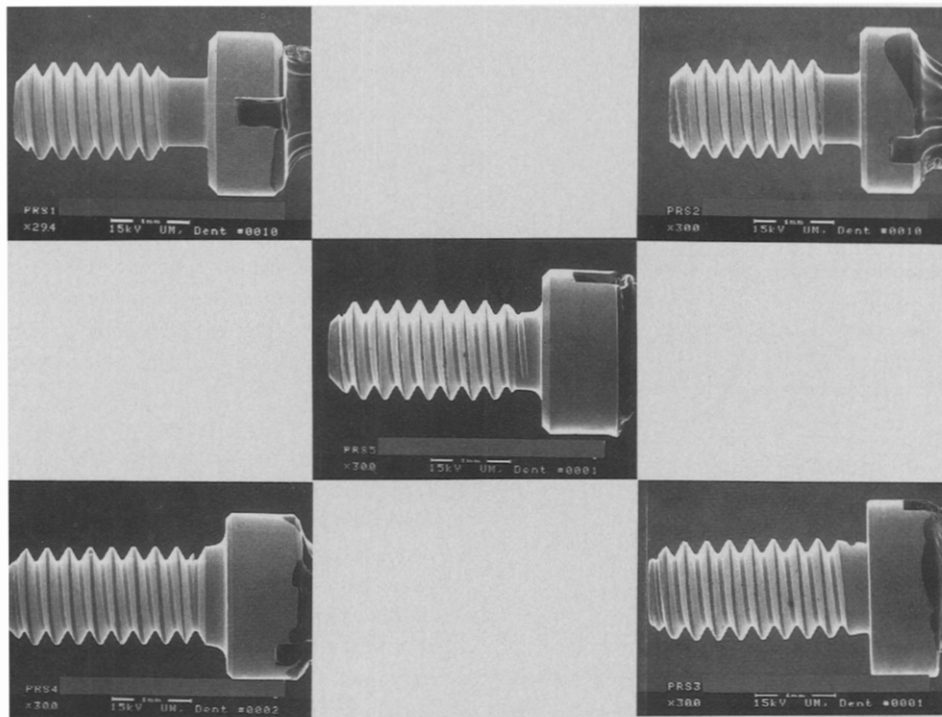


Fig. 3. Composite SEM of five screws examined: *PRS1*, 3i Implant Innovations gold; *PRS2*, 3i Implant Innovations titanium; *PRS3*, Implant Support Systems titanium; *PRS4*, Impla-Med gold; *PRS5*, Nobelpharma gold.

tigue life of the screw. A good quality screw should withstand preloading into the plastic portion of the stress/strain diagram without fracture. As a general principle, a properly designed and preloaded screw will either fracture during tightening or not fracture at all.⁶

Torque, on the other hand, is a means used to apply a preload and is one of the methods used to measure preload. Torque "is the twisting or movement exerted by a force acting at a distance on a body equal to the force multiplied by the perpendicular distance between the line of action of the force and the center of rotation at which it is exerted."⁹

A torque wrench is the most common means used to apply and measure the amount of preload; however, it is not the best measurement instrument. Preload can best be measured by determination of the amount of elongation caused when a specific torque is applied to the screw, and elongation should be used whenever possible.⁶ However, in the case of implant-retaining screws, elongation cannot be measured because the screw threads into a blind hole and prevents visualization of any elongation. Thus the torque recorded in tightening the screw must be used as an estimate of the preload.⁶

To obtain scientific data on the interchangeability of implant components, a research project was initiated to investigate one aspect of the abutment screw/prosthetic retaining screw interface, that of the prosthetic retaining screw side of the interface. On the basis of the study by

Burguete et al.⁴ and the Osseointegration Ten Years in Private Practice conference,⁵ this study examined screw length, screw diameter, thread and neck design, and head diameter as the geometric parameters with the greatest impact on the torque-preload relationship. Five "interchangeable" prosthetic retaining screws from three manufacturers were examined dimensionally with scanning electron microscopy (SEM) to determine differences, if any, in their geometry. The null hypothesis that interchangeable prosthetic retaining screws are geometrically similar to the Nobelpharma gold implant prosthesis retaining screws in eight important geometric parameters was tested.

MATERIAL AND METHODS

Slotted test prosthetic retaining screws of two alloy types were selected from three manufacturers on the basis of claims of interchangeability with the Nobelpharma gold implant prosthetic retaining screws (Table I and Fig. 3). Brånemark slotted gold implant prosthesis retaining screws (Nobelpharma USA, Inc.) were the control with which the test retaining screws were compared.

Sample size was determined by use of the power calculation formula:

$$n/\text{group} = 2 [(Z_{\alpha} + Z_{\beta}) s/D]^2 \quad [1]$$

If the intersystem variability was no greater than the intrasystem variability, the screws were considered inter-

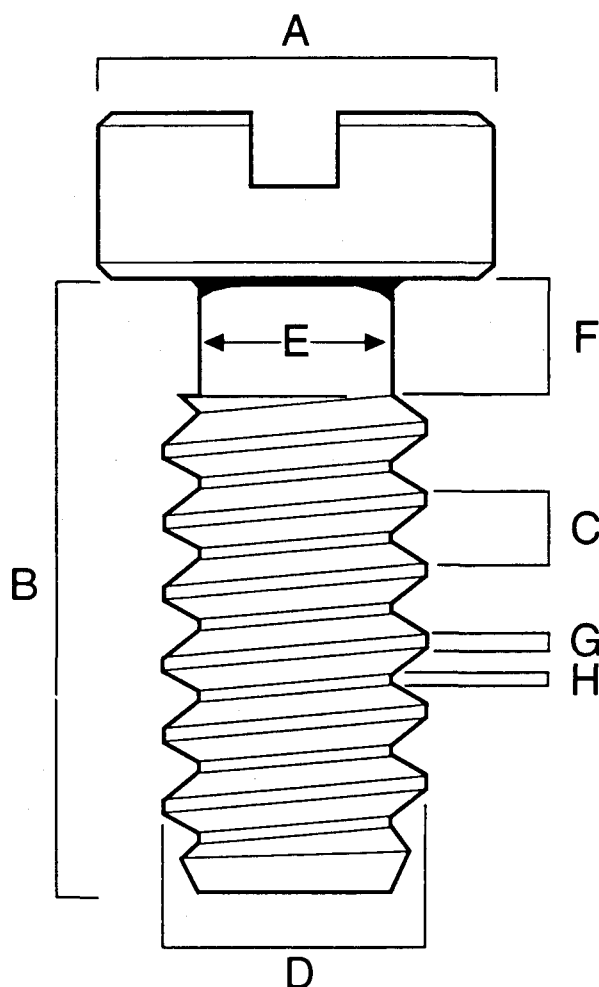


Fig. 4. Eight geometric parameters measured: A, diameter of screw head; B, screw length; C, thread pitch; D, major diameter; E, neck diameter; F, length of neck; G, crest width; H, root width.

Table I. Test prosthetic retaining screws by manufacturer and alloy type as stated by the manufacturer

Manufacturer	Alloy	Abbreviation code
3i Implant Innovations, Inc., West Palm Beach, Fla.	Gold	3i Au
Impla-Med, Inc., Sunrise, Fla.	Gold	ImMd Au
Nobelpharma USA, Inc., Chicago, Ill.	Gold	Nobel Au
3i Implant Innovations, Inc., West Palm Beach, Fla.	Titanium	3i Ti
Implant Support Systems Inc., Irvine, Calif.	Titanium	ISS Ti

changeable. The value of Zb was set at 1.28 to establish a 90% certainty to detect a difference if a true difference of 2 (standard deviation) exists. A two-tailed test was planned and α was fixed at the conventional level of 0.05, with α 0.025 in each tail. From this, number/group was calculated:

$$2[(1.96 + 1.28) SD/2SD]^2 = 5.24 = 5 \text{ screws per group} \quad [2]$$

Five screws of each type and eight geometric parameters (Fig. 4) were measured: (A) diameter of screw head; (B) screw length; (C) thread pitch; (D) major diameter; (E) neck diameter; (F) length of neck; (G) crest width; and (H) root width.

Each screw was measured with the particle measurement system on the Amray 1000-B SEM (Amray Inc., Bedford, Mass.). This system is calibrated semiannually against a National Bureau of Standards calibration standard and is accurate to within 0.01%. The particle measurement system uses a horizontal scale marker that can be directly superimposed on the feature of interest. The true distance is corrected for working distance, kilovolts, and zoom.

Because it was not within the realm of this project to hypothesize whether changes in these parameters might be interrelated, it was decided to perform a one-way ANOVA and Duncan's new multiple range test to determine significant differences.

RESULTS

Tables II and III provide the data to test the null hypothesis. The ANOVA ($p < 0.05$) and the Duncan new multiple range test (significance level 0.05) revealed significant differences between the five types in all parameters except parameters C and G.

Significant differences are noted and presented in Tables IV through XI. For parameter A, the diameter of the head, 3i Implant Innovations gold and the Implant Support Systems titanium screws were significantly larger than the Nobelpharma gold screws (Table IV).

For parameter B, the screw length, 3i Implant Innovations gold and titanium screws were shorter than the Nobelpharma gold screws, whereas the Impla-Med gold and Implant Support Systems titanium screws were longer (Table V). For parameter C, the thread pitch, there were no significant differences in comparing the look-alike screws with the Nobelpharma gold screws (Table VI).

For parameter D, the major diameter, the Impla-Med gold screws had a significantly smaller diameter than the Nobelpharma gold screws (Table VII). For parameter E, the neck diameter, the Impla-Med gold and Implant Support Systems titanium screws were significantly larger whereas the 3i Implant Innovations gold and titanium screws were significantly smaller than the Nobelpharma gold screws (Table VIII).

For parameter F, the length of the neck, the 3i Implant

Table II. Means (in microns) of parameters for five test screws

	A	B	C	D	E	F	G	H
3i	2140	2612	239	1258	908	514	47.6	25.2
Au	(31.6)	(36.3)	(7.8)	(14.8)	(11.0)	(35.8)	(5.2)	(1.1)
ImMd	2092	2894	227	1214	1272	276	52.4	54.4
Au	(38.9)	(8.9)	(6.8)	(24.0)	(17.9)	(8.9)	(7.9)	(1.7)
Nobel	2100	2720	233	1246	1000	340	51.8	59.4
Au	(31.6)	(28.2)	(8.8)	(27.0)	(14.1)	(10.5)	(1.1)	(0.9)
3i	2104	2526	238	1244	892	474	46.0	28.0
Ti	(8.9)	(24.0)	(6.0)	(15.2)	(17.9)	(29.7)	(4.9)	(3.5)
ISS	2236	2792	244	1268	1156	122	43.6	57.6
Ti	(8.9)	(33.4)	(11.0)	(19.2)	(21.9)	(22.8)	(13.5)	(4.6)

Standard deviation in parentheses. Brand name abbreviations in Table I. Parameters A through H defined in Abstract.

Table III. One-way ANOVA *p*-values on eight dimensions

Parameter	<i>p</i> -Value
A	0.0001
B	0.0001
C	0.0350
D	0.0067
E	0.0001
F	0.0001
G	0.3439
H	0.0001

Table IV. Duncan new multiple range test for parameter A, diameter of head

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	8.000	35.791	
	3i Ti	4.000	35.791	
	3i Au	40.000	37.611	S
	ISS Ti	136.000	35.582	S

Significance levels 0.05; S, significantly different at this level. Abbreviation code in Table I.

Innovations gold and titanium screws had significantly longer necks, and the Impla-Med gold and Implant Support Systems titanium screws were shorter than the Nobelpharma gold screws (Table IX).

For parameter G, the crest width, there were no significant differences (Table X). For parameter H, the root width, the 3i Implant Innovations gold and titanium screws and the Impla-Med gold screws were significantly smaller than the Nobelpharma gold screws (Table XI).

DISCUSSION

The significance of these findings can be understood if one examines each of the parameters in light of what is known about the mechanics of screw design. The feasibility

Table V. Duncan new multiple range test for parameter B, screw length

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	174.000	38.710	S
	3i Ti	194.000	38.719	S
	3i Au	108.000	36.845	S
	ISS Ti	72.00	36.845	S

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

Table VI. Duncan new multiple range test for parameter C, thread pitch

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	6.400	10.895	
	3i Ti	4.400	10.895	
	3i Au	5.800	11.449	
	ISS Ti	11.200	11.744	

Significance level 0.05; S, significant different at this level. Abbreviation code in Table I.

Table VII. Duncan new multiple range test for parameter D, major diameter

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	32.000	27.230	S
	3i Ti	2.000	27.230	
	3i Au	12.000	27.230	
	ISS Ti	22.000	28.614	

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

ity of the clinician to physically place a retaining screw is based on parameters C, D, and G. If the thread pitch, major diameter, or the crest widths were significantly different, the screws would not go into place. For parameters C

Table VIII. Duncan new multiple range test for parameter E, neck diameter

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	272.000	23.527	S
	3i Ti	108.000	23.527	S
	3i Au	92.000	22.389	S
	ISS Ti	272.000	23.527	S

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

Table IX. Duncan new multiple range test for parameter F, length of neck

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	63.600	31.612	S
	3i Ti	134.400	31.612	S
	3i Au	174.400	33.220	S
	ISS Ti	217.600	33.220	S

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

(the thread pitch) and G (the crest width), no significant differences were revealed. For parameter D, Impla-Med gold screws had a significantly smaller diameter than the Nobelpharma gold screws, which would not prevent insertion of the screw. Therefore in the sense that the screws will go to place, they can be considered interchangeable. This is exactly what is found clinically when these screws are interchanged; the retaining screw will thread into the Nobelpharma abutment screw and they will "fit." "Interchangeability," however, implies more than just "fit." "Interchangeability" as used in conjunction with implant components implies that components can be substituted without an adverse effect on the overall implant success rate. Particularly in regard to prosthetic screws, it has come to imply that all prosthetic retaining screws can be used with the Nobelpharma protocol of tightening to 10 Ncm torque. The clinician should question what is the proper preload torque to which these screws need to be tightened. As was pointed out by Burguete et al.,⁴ the torque/preload relationship depends on the specific design of the screw. All of the geometric parameters measured in this project are design characteristics that influence the torque/preload relationship. Even though the Impla-Med gold screw would fit, its smaller major diameter would affect the torque/preload relationship because the smaller diameter results in a decrease in the surface area of the contacting flanks and a decrease in frictional resistance to tightening. Therefore if the Nobelpharma gold screw and the Impla-Med gold screw were both tightened to 10 Ncm torque, the Impla-Med screw would have a lower tensile preload within the neck of the screw itself.

Table X. Duncan new multiple range test for parameter G, crest width

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	.600	10.178	
	3i Ti	5.800	10.696	
	3i Au	4.200	10.178	
	ISS Ti	8.200	10.972	

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

Table XI. Duncan new multiple range test for parameter H, root width

Control	Vs	Difference	Critical difference	
Nobelpharma Au	ImMd Au	5.000	3.802	S
	3i Ti	31.400	3.900	S
	3i Au	34.200	3.986	S
	ISS Ti	1.800	3.618	

Significance level 0.05; S, significantly different at this level. Abbreviation code in Table I.

In the case of the diameter of the head, the 3i Implant Innovations gold and the Implant Support Systems titanium screws were significantly larger than the Nobelpharma gold screws. A larger screw head will result in a larger surface area at the prosthetic coping/prosthetic retaining screw interface. Given that all other conditions were equal, a similar tightening torque measured at the head of the screw would result in different preload and different damping power.

Similarly the shorter 3i Implant Innovations gold and titanium screws and the longer Impla-Med gold and Implant Support Systems titanium screws will affect the preload of the screw. The length of the screw will directly influence the amount of surface area of the contacting interface. The greater the surface area, the greater the frictional resistance to the tightening torque, and the less the resultant preload. Shorter screws, with the same tightening torque as a longer screw, will result in more elongation of the body of the screw because of the decreased surface area of the abutment screw/prosthetic retaining screw interface.

Published guides by which the entire profession is basing arguments for optimal tightening torque were established for a specific geometric configuration, namely the Nobelpharma gold screw. Deviations from the standard will directly influence the amount of friction generated during tightening and thereby require different amounts of tightening torque as measured at the head of the retaining screw.

In addition to the effect on preload, geometric variations will affect the mechanical properties of a fastener or, in this

case, the prosthetic retaining screws. Variations in neck length and major diameter have the potential to alter the ultimate tensile strength of these screws. This will influence load transference to the remainder of the implant complex and will again dictate a change in the recommended preload torque. The multiplicity of variations from the accepted norm in the test screws intimates that the potential for complications will increase exponentially. It is impossible to predict exactly what will happen, but it is safe to say that these screws are not interchangeable other than that they will fit.

Application of mechanical engineering principals regarding screws, fasteners, preload, coefficients of friction, lubricants, and fatigue has until recently been ignored in the dental literature. Implant components have been designed for convenience and implant suppliers have introduced interchangeable components on the basis of "the look-alike" principal. Specifications for implant components have been ignored and yet all theoretical discussions about biomechanics mandate that they are vital to the overall lifetime survival of any implant system. It is critical that the profession establish standardized specifications for implant fixtures and components.

CONCLUSIONS

Under the test conditions of this study, the following conclusions were drawn.

1. The null hypothesis was rejected because significant differences were found between the test screws and the control screws.
2. On the basis of the differences found it may be concluded that interchanging prosthetic retaining screws without substantively altering treatment techniques will introduce unknown variables in treatment of patients.

3. On the basis of accepted engineering principles regarding screw design and torque preload relationship it may be concluded that the recommendations of tightening torque for Nobelpharma gold screws cannot be accepted as correct for all screw designs.

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Reprint requests to:

DR. MERLE J. JAARDA
DEPARTMENT OF PROSTHODONTICS
SCHOOL OF DENTISTRY
UNIVERSITY OF MICHIGAN
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