An In Vitro Load Evaluation of a Conical Implant System with 2 Abutment Designs and 3 Different Retaining-Screw Alloys

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Purpose: *The aim of this in vitro study was to evaluate the load resistance in a conical implant system by comparing combinations of 2 different abutment head angles and 3 different retaining screw materials.* ***Materials and Methods:*** *The retaining screw materials (titanium alloy, gold alloy, and commercially pure titanium) were tested with abutment-head angles of 20 degrees and 45 degrees. Six groups of 10 specimens each were prepared. An oblique (30-degree) compression test was performed in a Lloyd LRX universal testing machine with the abutment attached to a superstructure with a retaining screw. All specimens were loaded until fracture or permanent deformation occurred. The results were evaluated statistically with Wilcoxon signed rank test for variance distribution (*P *< .05 considered significant).* ***Results:*** *There were statistically significant differences in load resistance between 20-degree and 45-degree abutments. The titanium screws (titanium alloy and commercially pure) in the 45-degree abutment group had almost equal mean values, while the gold alloy had a significantly lower value. In the 20-degree abutment group, significantly higher values were found with commercially pure titanium compared to titanium alloy and gold alloy, but the difference between the values for the gold and titanium alloys was not significant.* ***Discussion:*** *The angulation of the abutment head played the most significant role in determining the amount of load withstood, but the material used for the screw was also relevant.* ***Conclusion:*** *A 45-degree abutment can be combined with a retaining screw of any of these materials to create a functional implant system. The test also substantiated that, irrespective of the retaining-screw material, a 20-degree abutment could resist loading forces of at least 900 N.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:733–737

Key words: *dental implant failures, dental implants, implant abutments, implant loading*

Mechanical failures of oral implants are most often related to undiagnosed unfavorable masticatory forces and/or incorrect choice of implant components and dimensions.[1–5] Metals still remain the predominant material used for oral implants, primarily because they allow biocompatibility, slender design with adequate strength, and intraoperative adjustment of shape.[5–8] This last feature is often seen as an advantage in loading situations for which no standard design can be adopted; for example, in patients developing abnormally high bite forces.[1] However, choosing an implant (ie, deciding on the material, components, and design) can be difficult when no "treatment planning tools" are available.[6] The matter is further complicated because the load and stress distribution in both the bone and the implant components must be considered.[9] Similarly, the connection between the superstructure and abutment requires consideration.[10,11]

Biological integrity is still, however, the predominant research topic in implant dentistry and the principal explanation for high survival rates. However, mechanical problems may also exist, primarily concerning the design principles used to produce an implant, the interaction between the different parts of the implant, and the connection between the implant and the superstructure.[2,3,5,7,12–18] In practice,

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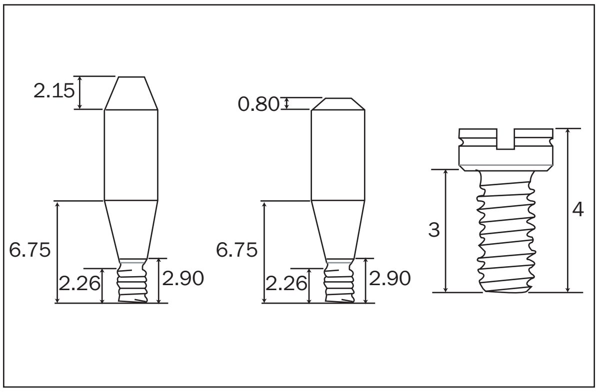

Fig 1 The shape of the abutments tested. The shape of the retaining screw, exaggerated, is also shown.

this means that the prosthesis should be given maximum support in both vertical and horizontal direction to ensure rigidity. At the same time it is preferable to have a mechanism that protects the implant from overload.[19] These opposing requirements can be difficult to balance using an inflexible Astra implant system with absolute rigidity on the conical abutment heads. Several retaining-screw material alternatives must therefore be available to compensate for the abutment head angle and provide resilience under stress.[17] This involves, among other things, theoretical understanding of the component performance.[20] To facilitate the choice among these options, more knowledge of the mechanical and functional behavior of these components, including design, dimension, and material composition would be desirable. The aim of this study was therefore to evaluate the load resistance in a conical implant system with 2 different abutment designs and three different retaining screw materials.

MATERIALS AND METHODS

The 20-degree and 45-degree Uni Abutments (Astra Tech, Mölndal, Sweden) were tested together with 3 retaining screw materials (Fig 1). A hemispherical superstructure in a high precious gold alloy M3 conforming to ISO 1562 (KAR/Sjödings Kista, Sweden) was manually tightened to the abutment with the screw to 10 Ncm with a torque wrench. The 3 screw materials were solid commercially pure titanium (cpTi; grade 2), an experimental nonoxidation (no-ox) gold clasp alloy, and a titanium alloy (Ti-6Al-4V). The hemispherical superstructure design was described in a draft standard ISO/CD 14801 with a diameter of 8 mm and height of 6 mm. Sixty-one bulb-shaped specimens were produced with gold cylinders (semi-burnout) incorporated in the center of the plane surface with a centric thread for the screw through the body. The lost wax technique was used together with a centrifugal casting procedure using a Degussa apparatus (Hanau, Germany). After casting, the bulb-shaped specimens were sandblasted with 110 μm Al_2O_3, except for the gold cylinder surface. Superstructure processing and assembly of the implant sections were undertaken at a dental laboratory. The other standard components were supplied from Astra Tech routine stock, except for the gold-alloy retaining screws, which were produced by KAR/Sjödings.

The specimens were subjected to an oblique compressive test in which a linearly increasing compressive force was applied from a flat surface at an angle of 30 degrees to the long axis of the implant. The abutments were gripped around their major cylindric diameters in a horizontally split metal clamping block (Fig 2). The test was performed in a water tank to simulate a frictional oral environment. The crosshead of the Lloyds machine (Lloyd Instruments, Fareham, England; Fig 3) advanced at a speed of 0.5 mm/min until failure occurred. Failure was defined as *(1)* a 3-mm deflection downward from the abutment's long axis, *(2)* achievement of the maximum load value (2,000 N), or *(3)* component breakdown. All 3 were detected by a load dip sensor in the test machine. The load geometry imposed a bending moment M (N), given by the formula $M = F \times L$, where L was the lever arm length (in cm) perpendicular to the force F measured by the load cell. Altogether 5 groups of 10 specimens each (and 1 group with 11 specimens) (Table 1) were prepared and compared crosswise, in combinations of the 2 conical designs and 3 different screw materials. The results were evaluated statistically using the Wilcoxon signed rank test for variance distribution ($P < .05$).

RESULTS

The commercially pure titanium and titanium-alloy retaining screws in the 45-degree abutment group had almost identical mean values; both withstood significantly higher loads than the gold-alloy retaining screws ($P < .033$ and $P < .008$). For the 20-degree abutment, the 2 types of titanium screws showed significantly different failure loads ($P < .037$). In the 20-degree group the commercially pure titanium retaining-screw assemblies also withstood significantly greater loads than the gold alloy assemblies ($P < .002$), but no significant difference was found between the gold alloy and the titanium-alloy retaining screws ($P < .045$). The highest group average (1570 N) and individual value (1821 N [SD 257]) were found in assemblies with a commercially pure tita-

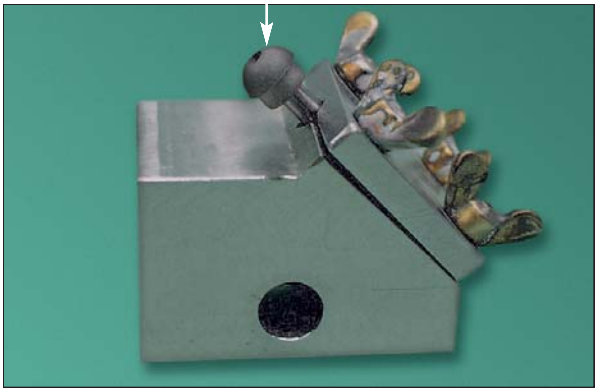

Fig 2 The test appparatus with the test specimen at a 30-degree angle. The arrow indicates the load direction.

Fig 3 Crosshead design with a rounded edge of 1 mm in diameter.

nium screw on a 20-degree conical head. The 45-degree abutment assemblies with gold screws demonstrated the lowest mean value (456 N [SD 48]) and the lowest individual value (366 N). A visual examination concluded that failure of all the 45-degree assemblies had occurred by complete transverse fracture of the threaded shank of the abutment screws between the abutment top and the gold cylinder (Fig 4), while the 20-degree group generally had deformed abutments, superstructures, and retaining screws (Fig 5), with just 3 fractures.

Table 1 Mean Maximum Load Values for All Groups

	Mean (N)	SD	SE
20-degree angulation			
Titanium alloy	1327	150	47
Gold alloy	1280	115	35
Commercially pure titanium	1570	257	81
45-degree angulation			
Titanium alloy	528	58	18
Gold alloy	456	48	15
Commercially pure titanium	529	51	16

DISCUSSION

The 3 groups with a 20-degree top angle could withstand much larger loads (ie, 2 to 3 times greater) than the assemblies with 45-degree abutments. The difference was substantiated by the visual examination of the failure mode. The permanent deformation of a 20-degree abutment may complicate the replacement of prosthetic and/or abutment components, while a fractured 45-degree abutment is more easily retrieved and replaced with a new one. This deformation is a consequence of the exposure of the protective 20-degree abutment head to the 30-degree force.[14] The present study indicated that the head angle of the conical abutment plays an important role in load resistance. This in vitro test represented a theoretical worst-case scenario, simulating a clinical situation with an unfavorable load to the abutment. Therefore, a critical limit for maximum bite-forces was estimated and set to 680 N in accordance with earlier studies.[21–27] The highest individual and group mean values were found among the commercially pure titanium screws and 20-degree abutments. The lowest mean values were seen with gold alloy screws and the 45-degree abutments; the lowest individual value was also recorded for this combination.

Within the 45-degree abutment groups, all 3 screw metals fractured at approximately 500 N under oblique compression load (Table 1 and Fig 6). This was below the critical load limit for hazardous masticatory forces and in accordance with the fail-safe philosophy.[28] This is also in accordance with the Brånemark System, where a gold alloy screw is the main factor in the fail-safe mechanism.[29,30] The low-angle (45-degree) conical abutment uses the same principle: a weak link, in this case the retaining-screw material, is included in a passive-fit system, where rigidity combined with bruxism might cause breakdown of the surrounding bone and damage to the components.[2,11,31–33]

All retaining screws in the 20-degree abutment group withstood 680 N of force, and not until 940 N was reached did a critical deformation occur in 1 of the test specimens. This high load value makes the 20-degree abutment less suitable for clinical applications in which the retaining screw must be capable of fracturing like the 45-degree abutment, which did not deform elastically. As stated earlier, the high values withstood can mainly be explained by the angle of the abutment.[17] Another difference between the 20-degree and 45-degree abutments was that in the

Fig 4 Typical failed specimen from the 45-degree abutment group.

Fig 5 Typical failed specimen from the 20-degree abutment group.

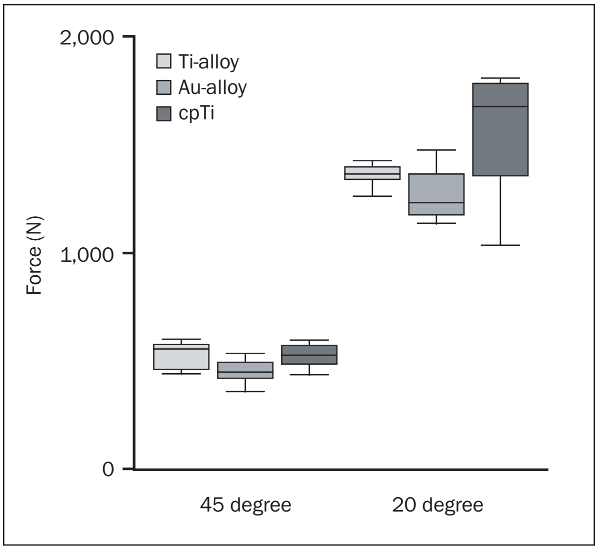

Fig 6 Distribution plot of maximum force by groups (outliers and extreme values excluded).

20-degree group, the assemblies with pure titanium screws were significantly stronger than those with the other 2 screw metals. Whether this high value is of clinical relevance is difficult to say, but the present study demonstrated that screw material has a greater effect when the conical taper is steeper.[34] This suggests that the properties of the screws influence the system mechanics more in this protected load situation than in an unprotected situation with a more flat abutment head design and that the properties (specifically, the elasticity modulus) of the material used are crucial. Yet the main difference between the 2 abutment systems was the mean force withstood (450 to 530 N for 45-degree abutments compared with 1280 to 1570 N for the 20-degree assemblies). In vivo, such heavy masticatory loads would break the 45-degree abutment and related components, while the 20-degree assemblage might resist much greater load and protect the screw from fracture but at the same time expose the bone tissue to potential damage. The large difference in mean force withstood shows the different mechanics of the 2 designs. The 45-degree taper transmits bending forces onto the retaining screw, inducing fracture under excessive loading. The 20-degree taper withstands bending forces with the surface of the taper, protects the retaining screw from fracture, and transmits the load to the implant and surrounding bone tissue.

The present study uses a simplified model. However, the results indicate that the Astra system may be too strong under specific circumstances, and that the implant could fracture under heavy masticatory forces if the dimension, table width, height, and depth of the joint were unfavorable.[14,18,35] Although implant fracture is rather rare, it is occasionally reported[4,5,8,35–37] together with excessive occlusal forces in the molar region.[38] These circumstances, combined with a rigid coupling (20 degrees), most likely increase the risk of exceeding the physical limit for the implant and causing a fracture.

More research, both experimental and clinical, is necessary to evaluate an optimal top angle under varying conditions. The UniAbutment system generally uses more than 1 implant element that might lead to deviating stress distribution and conduction of the forces into other loading areas; the number of options available makes load evaluation complex.[39,40] Therefore, the current in vitro results and observations are to be regarded as complementary to clinical experience, and further investigations are needed.

CONCLUSION

1. A steep-angle taper connection (20 degrees) withstood nonaxial forces to a greater extent than a 45-degree taper, regardless of retaining-screw material.

2. Differences in retaining-screw material are more obvious in a 20-degree taper abutment constructions but not insignificant in a 45-degree situation.
3. The 45-degree taper construction failed under oblique loads between 450 and 530 N, which might be suitable for overload protection of implants.
4. Finally, abutment taper angles are more important than retaining-screw material in determining assembly strength.

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