https://doi.org/10.4047/jap.2021.13.6.343

Rotational tolerances of a titanium abutment in the as-received condition and after screw tightening in a conical implant connection

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PURPOSE. The success of an implant-prosthetic rehabilitation is influenced by good implant health and an excellent implant-prosthetic coupling. The stability of implant-prosthetic connection is influenced by the rotational tolerance between anti-rotational features on the implant and those on the prosthetic component. The aim of this study is to investigate the rotational tolerance of a conical connection implant system and its titanium abutment counterpart, in various conditions. **MATERIAL AND METHODS.** 10 preparable titanium abutments, having zero-degree angulation (MegaGen, Daegu, Korea) with an internal 5-degree conical connection, and 10 implants (MegaGen, Daegu, Korea) were used. Rotational tolerance between the connection of implant and titanium abutments was measured through the use of a tridimensional optics measuring system (Quick Scope QS250Z, Mitutoyo, Kawasaki, Japan) in the as-received condition (Time 0), after securing with a titanium screw tightening at 35 Ncm (Time 1), after tightening 4 times at 35 Ncm (Time 2), after tightening one more time at 45 Ncm (Time 3), and after tightening another 4 times at 45 Ncm (Time 4). **RESULTS.** The group "Time 0" had the lowest values of rotational freedom (0.22 ± 0.76 degrees), followed by the group Time 1 (0.46 ± 0.83 degrees), the group Time 2 (1.01 ± 0.20 degrees), the group Time 3 (1.30 ± 0.85 degrees), and the group Time 4 (1.49 ± 0.17 degrees). **CONCLUSION.** The rotational tolerance of a conical connection is low in the "as received" condition but increases with repetitive tightening and with application of a torque greater than 35 Ncm. [J Adv Prosthodont 2021;13:343-50]

KEYWORDS
Rotational tolerance; Conical connection; Rotational freedom; Implant prosthesis

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Received September 10, 2021 /
Last Revision November 13, 2021 /
Accepted Novermber 23, 2021

INTRODUCTION

Replacement of teeth with dental implants has become a common option in clinical practice.[1] Implant-supported prostheses for totally and partially edentulous patients have been reported to have a high percentage of success.[2,3]

Whereas the osseointegration process has been highly investigated in the past, providing a good scientific knowledge,[4,5] recent research moved to the analysis of implant-retained prosthesis and its complications.[6,7] Prosthetic complications seem to be highly correlated with the type of implant-abutment connection.[8,9] Such connections are generally categorized as internal and external, depending on the site where the secondary component fits with the primary one.[10] The original implant-abutment connection design, consisting in a butt joint mediated by an external hexagon, was projected to be applied in full-arch rehabilitation.[11,12] External connection was very successful until some mechanical problems arose especially with single-tooth restorations. The most frequent drawbacks were related to the stability of the screwed joint, the screw loosening and fracture.[13,14] The potential for screw loosening and screw fracture can be influenced by the geometry and the material properties of the screws, the contact between the screw head and abutment, the contact between the screw threads and the threads within the implant, the design of the connection, the friction between the various implant components, the use of calibrated torquing devices rather than hand held screw drivers, and the fit tolerances between the antirotational features on the implant and those on the prosthetic component, also known as rotational tolerance or freedom.[15,16]

Several authors described the importance of rotational tolerance on the stability of abutment/implant screw joints.[17-19] It has been reported that in the external hex connection type abutment, a rotation of less than 2 degrees resists a mean of 6.7 million loading cycles before loosening, while rotation of up to 5 degrees will result in a 63% reduction in the cycles required to cause screw-joint loosening.[6,20] In order to overcome these issues, many efforts have been made to improve the precision of antirotational elements and the manufacturing tolerances, considering that the latter has been shown to be responsible for the distribution of the stress on all implant components.[21,22] The Morse taper connection, an internal connection also known as conical connection, was introduced and patented by Stephen Morse in 1864 for industrial milling machine and applied as a connection in implantology in the early 1990s.[23] Original Morse angle inclination defined by Stephen Morse for tools was a relatively small angle of 2° 50'. Today, Morse taper is used in orthopedics for arthroplasties generally falling in a range of 5 - 18°.[24] It is nowadays widely used as implant-abutment connection. The dimensions of tapers are not standardized; they vary from company to company ranging from 1 to 12 degrees. Generally, an acceptable interference happens for taper angles smaller than 5.8°.[25] Mechanical properties of the Morse taper conical connection provide a friction-locking mechanism between the mating parts of the joint, drastically reducing the movement between them.[24,26-29]

Conical connections improved mechanical properties and reduced the leakage. A better sealing has been demonstrated at the implant abutment interface, leading to less bacterial infiltration in conical connections compared to the others.[30,31]

While several studies were conducted on the evaluation of the interface stability and rotational tolerances of external- and internal-hexagonal connections,[20,32-35] little was published about the rotational misfit of the abutments in internal conical implant-abutment connections.[36-38]

The aim of this study was to investigate the rotational tolerance of an internal conical connection implant system and its titanium abutment counterpart, both in the as-received condition and after tightening several times at different torques. Hypothesis was that torque strength and the number of tightening could influence the structural integrity of the connection, increasing the rotational tolerance between the two parts and therefore incrementing the risk of screw loosening or fracture.

MATERIALS AND METHODS

Before performing the experiments, sample size calculation revealed that 10 implants were necessary for each group to confer a power of 80% of detecting a significant difference in rotational freedom, with an alpha error set to 0.05, based on results from study of Semper *et al*.[36] Power analysis was performed considering a mean rotational tolerance of 0.72 degrees with a standard deviation of 0.447 degrees in the group with internal octagon and 8-degree cone connection. Considering four groups of our study, between-group variance was set at 0.10 and error group variance was set at 0.30.

Ten preparable titanium abutments designed for cemented restorations with an internal 5-degree conical connection EZ Post Abutment, 4.0 mm diameter, 2 mm cuff height, 5.5 mm post length, and zero-degree angulation (AANEPH4025L; MegaGen, Daegu, Korea) and 10 implants (AnyRidge 4.5 mm diameter and 10 mm length FANIHR4510C MegaGen, Daegu, Korea) were selected (Fig. 1). Rotational tolerance between the conical connection of the implants (AnyRidge 4.5 mm diameter and 10 mm length FANIHR4510C; MegaGen, Daegu, Korea) and titanium abutments was assessed through the use of a tridimensional optics measuring system (Quick Scope QS250Z; Mitutoyo, Kawasaki, Japan). Both abutments and implants had a hexagonal antirotational feature. The former was a male hex of 1.2 mm length while the latter was a female one. (Fig. 2A, B) A measuring system (Quick Scope QS250Z; Mitutoyo, Kawasaki, Japan) evaluated the profile of the hexed antirotational feature of the abutment and of the hexed antirotational feature in the implant with an accuracy of 2.5 µm, and then, using these geometric figures, determined the rotational tolerance of the two parts (Fig. 2C). The system measured the profile of the two connecting parts at 45× magnification, one at a time, determining the value of rotational tolerances between the parts, expressed in degrees. The measurement error of the instrumentation used (Quick Scope QS250Z; Mitutoyo, Kawasaki, Japan) was evaluated to be around 2.5 µm,

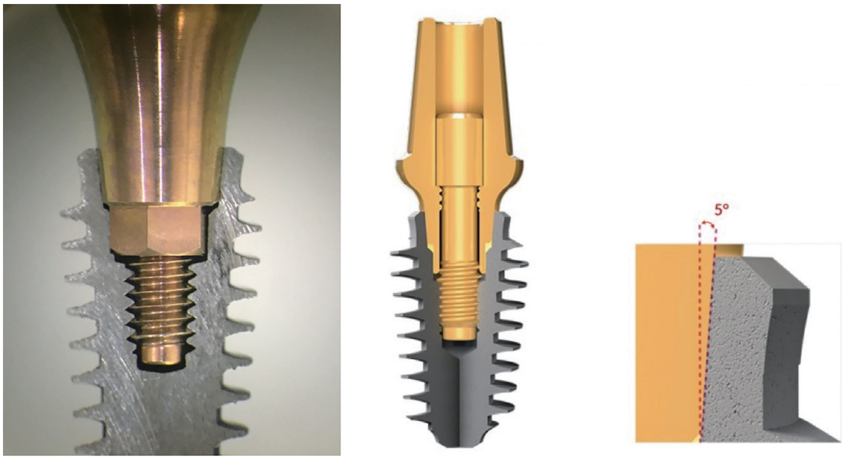

Fig. 1. Internal hexagon 5-degrees conical connection.

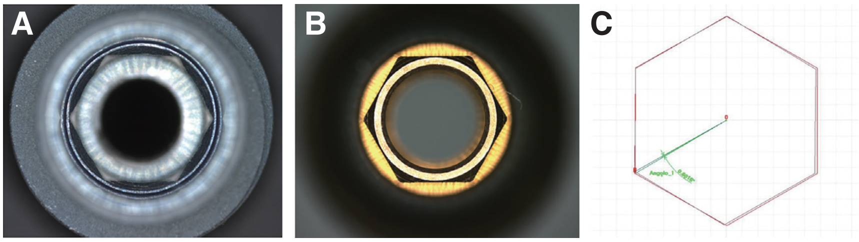

Fig. 2. (A) Implant female hex antirotational feature, (B) Abutment male hex antirotational feature, (C) Hexagonal rotational tolerance measurement.

also defined as a max permitted error (MPE). Before starting the tests, the instrument was calibrated and certified. Initially, rotational tolerance between the 10 abutments and the 10 implants without the screw in the "as received" condition (Time 0) was measured. Then, the abutments were mounted on the implants and secured with anodized titanium screws (AS20; MegaGen, Daegu, Korea), which were pretorqued at 35 Ncm and tightened again after 10 minutes at 35 Ncm, as suggested by the manufacturer, through the use of an electronic torque driver limiting device (W&H Group, Lengerich, Germany). This pretorquing procedures were repeated at each experimental time. The torque force was applied to the abutment by the driver to the bolt head as it was tightened. The implant-abutment complex was kept locked and held during the application of torque using a bench vise. Previously, the bench vise's ability to withstand that torque force was tested on another implant-abutment complex. The abutments were then removed from the implants and rotational tolerance between the abutments and the implants was measured again (Time 1). The same 10 abutments on the same implants were then subjected to screw tightening 4 more times at 35 Ncm (Time 2), disassembled and measured for rotational tolerance over again. After that, the 10 abutments were tightened just once more at 45 Ncm (Time 3) on the same implants and rotational tolerance was measured. Lastly, 45 Ncm torque was applied 4 more times to each abutment, disassembled, and measured (Time 4). The 5 different assessing times were: the as-received condition (Time 0), one 35 Ncm screw tightening (Time 1), 35 Ncm screw tightening 4 more times (Time 2), 45 Ncm one time screw tightening (Time 3) and 45 Ncm screw tightening 4 more times (Time 4). For each assessing time, a new screw was used. Company information tells that internal hex deformation starts after 50 Ncm torque. Neither joint nor bolt bottomed out during torquing procedures from Time 1 to Time 4.

The evaluation of a normal distribution was performed using the Kolmogorov-Smirnoff test. Hence, data were statistically analyzed by Kruskal-Wallis test. In addition, comparison among single groups was performed using Tukey multiple comparison test. The threshold of statistical significance level was set at *P* value < .05.

RESULTS

Results of the measuring system showed that the group "As received" had the lowest values of rotational tolerance (0.22 ± 0.76 degrees), followed by the group "Time 1" screwed once at 35 Ncm (0.46 ± 0.83 degrees), the group "Time 2" screwed four more times at 35 Ncm (1.01 ± 0.20 degrees), the group "Time 3" screwed once at 45 Ncm (1.30 ± 0.85 degrees), and the group "Time 4" screwed four more times at 45 Ncm (1.49 ± 0.17 degrees)(Fig. 3). The test of multiple comparison revealed the presence of significant statistical differences (*P* < .05) among all the groups analyzed (Table 1).

DISCUSSION

The primary aim of tightening any screw joint is to create an adequate clamping force to maintain the components joined, resisting to the cyclic load. Among the factors that influence the stability of abutment/implant joint, rotational tolerance between the implant and the prosthetic components seems to play a fundamental role.[18-20]

Various studies investigated the rotational tolerance in flat to flat external hexagonal implant-abut-

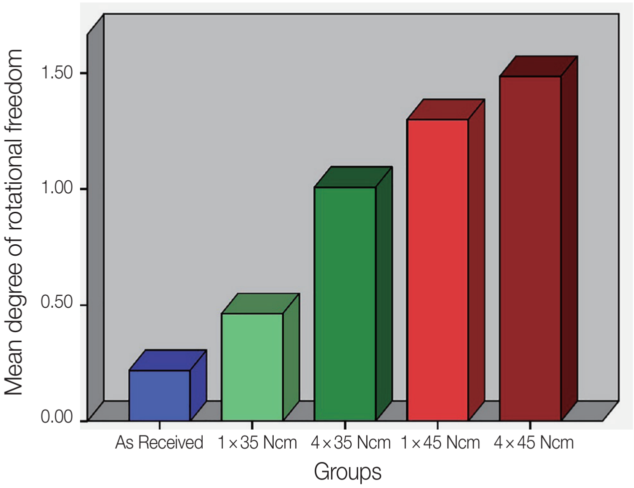

Fig. 3. Mean degrees of rotational freedom in tested groups.

Table 1. Multiple comparisons between experimental groups

Comparison	Mean difference	95% Confidence interval		*P* value
		Lower limit	Upper limit	
Time 0 vs Time 1	-0.24	-0.41	0.76	1
Time 0 vs Time 2	-0.79	-0.96	-0.62	< .001
Time 0 vs Time 3	- 1.08	-1.25	-0.91	< .001
Time 0 vs Time 4	-1.27	-1.43	-1.01	< .001
Time 1 vs Time 2	-0.54	-0.71	-0.37	< .001
Time 1 vs Time 3	-0.84	-1.01	-0.67	< .001
Time 1 vs Time 4	-1.02	-1.19	-0.85	< .001
Time 3 vs Time 2	0.29	0.12	0.46	< .001
Time 3 vs Time 4	-0.19	-0.36	-0.17	.025
Time 2 vs Time 4	-0.48	-0.65	-0.31	< .001

Ncm: newton centimeter

ment connections, showing a variation between 2.9 and 5 degrees.[20,39,40] For such connections, an optimal joint stability was identified in a rotational tolerance less or equal to 2° degrees.[20] Not so many data are available in the literature regarding the ideal rotational tolerance in conical implant-abutment connections. Binon *et al*. investigated friction fit in an internal hexagonal system (ScrewVent), showing the amount of rotational tolerance to be of 1.4° in the "as received" condition.[41] In the paper published by Semper *et al*., the authors showed that in 4 conical connection implant systems, the median rotational tolerance at "as received" condition ranged from 0.25° to 1.19°.[37] In the present study, the rotational tolerance between the 5-degree implant conical connection and the corresponding titanium abutments was evaluated, showing statistically different results for the evaluated groups depending on the number and the strength of tightening, confirming the hypothesis of the study. These results are likely due to some essential material wear and massive plastic deformation because of an increase of the settling effect and decrease of coefficient of friction that might occur at the implant-abutment interface, as supposed in several studies evaluating the effects of fatigue loading.[42,43] No group at any level of tightening presented a rotational misfit greater than 1.5 degrees. Factory information related to the "as received" AnyRidge implant-abutment rotational tolerance reports a value of 0.5°. Such measurement was higher than the value emerged from our experiments, the latter being 0.2°. Surprisingly, once the screw was tightened down at 35 Ncm (Time 1) through the use of an electronic torque driver limiting device, as requested from the manufacturer, the rotational tolerance increased to 0.46°. Problem arose when the operation was repeated 4 more times (Time 2), bringing the rotational tolerance value to 1.01°. This test was programmed to simulate the typical clinical situation, in which an abutment is screwed onto the implant several times during clinical steps such as a metal try-in, two porcelain try-ins, and final prosthesis delivery. Tightening torque was established based on the manufacturer's recommendations (35 Ncm) and increased to 45 Ncm, getting as close as possible to the torque of 50 Ncm, indicated by the manufacturer as limit for internal hexagon deformation. No experiments with lower or higher torque values were programmed in order to avoid the risk of an axial displacement of abutments into implants, as suggested to occur by Dailey and co-authors.[44] Semper *et al*. evaluated rotational torques of 4 conical systems, screw hand tightened. In such study, the worst value found in "as received conditions" was 1.19°,[37] which is higher than the value of 1.01° obtained in our results after 5 times of tightening (Time 1 plus Time 2). Additionally, rotational tolerance was measured after tightening the abutments one more time at 45 Ncm and four more times at 45 Ncm, which is a torque value far beyond clinical situation in order to evaluate how the stress potentially act on the connection and on rotational tolerance. Both of the procedures (Time 3 and Time 4) were performed by the same person with implantology skills through the use of an electronic torque driver limiting device. The values of rotational tolerance appeared to increase, but barely matching Binon's result of 1.4° for a friction fit internal hexagonal system and far from the value of 2° reported for a flat to flat external hexagonal implant-abutment connections.[41] The limit of the study is given by the lack of clear data concerning the rotational tolerance of the conical connections below which the prosthetic junction would be affected. Morse taper connection is ensured by angle inclination from 1.49° (as a specification) to almost 2.50°, but we also know that a certain kind of friction fit is possible for taper angles smaller than 5.8°. However, it is not possible to determine whether the cone taper interferes with the hexagonal antirotational feature or if the hexagon ensures, with its precision, resistance to the applied stress.

The findings of this study may have important clinical implications. Even after multiple tightening, the tolerance remained below the value of 1.5°, which is well below the values that put the connection and the screw at risk of breaking. Nevertheless, the clinicians should know that multiple tightening of the screw increases the rotational tolerance and this phenomenon may increase the risk of prosthetic complications and attention should be placed on the torque recommendations of the manufacturer.

CONCLUSION

Multiple screw tightening and increased torques applied to the screw produce an increase of rotational tolerance of implant-abutment connection. Such tolerance, however, resulted to be very low, remaining below 2° even after several tightening at 35 Ncm, as well as in over stressed conditions. Further studies are needed in order to translate such findings into more clinical implications.

ACKNOWLEDGEMENTS

We would like to cite the memory of our colleauge Dr. Paolo Vigolo, with acknowledgments for his intellectual heritage in field of prosthetic dentistry. We gratefully acknowledge MegaGen, Daegu, Korea for providing titanium abutments and implants for experiments.

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