INTRODUCTION

Implant therapy has advanced to the stage where it can greatly increase QOL, but prosthetic complications have been reported, including looseness or fracture of the abutment screw, fracture of the abutment or superstructure, and fracture of the implant body. There have been clinical studies, as well as numerous basic research studies on abutment screw looseness, and reasons for looseness that have been put forward include insufficient fastening torque of the screw, unfitted components, inappropriate direction or position of implant placement, and poor occlusal status. Looseess of the abutment screw causes poor fit of the superstructure, and can lead to fracture of the abutment screw and superstructure damage or detachment, as well as fracture of the implant or resorption of the peri-implant bone. A study using finite elements analysis reports that an implant system with external connection showed the highest stress values on the abutment screw and the implant-abutment connection during loading. Various stresses arise in the mouth during physiological and non-physiological function. These include stresses such as bending, tension, and torsion. Of these, there have been few studies of torsion in dental fields. This is probably because torsion combines bending and shear, and also because replication and assessment are difficult.

In the present study, different types of implant abutment systems were connected and fixed, and were then subjected to repeated torsional load in vitro, in order to investigate the effects of different systems on loosening of the abutment screw.

MATERIALS AND METHODS

Six types of implant abutment system currently in clinical use were evaluated. Those with internal connections were the Standard plus (SP; Straumann, Basel, Switzerland), the Osseo Speed (OS; Dentsply IH, Mölndal, Sweden), the Camlog K Series Promoteplus (KP; Altatec, Wimsheim, Germany), and the Replace Select Tapered (NR; Nobel Biocare, Karlskoga, Sweden); those with external connections were the Brånemark MkIII (BR; Nobel Biocare) and the SETiO (SE; GC, Tokyo, Japan) (Fig. 1, Table 1).

Measurement of removal torque before loading

The implant body was carefully mounted in a vise, the abutment was fitted, and the abutment screw was fastened to the torque value specified by the manufacturer using a digital torque meter (HDM-5, HIOS, Chiba, Japan) (Fig. 2). The implant system was left in this state for 5 min, and then the value of the removal torque in the opposite direction was measured.
Fig. 1 Tested implant systems.

**Table 1** Test specimens for six implant systems

<table>
<thead>
<tr>
<th>Connection</th>
<th>Implant body</th>
<th>Diameter (mm)</th>
<th>Abutment</th>
<th>Manufacturer</th>
<th>Code</th>
<th>Specified torque (Ncm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal/ 8° Taper</td>
<td>Standard Plus®</td>
<td>4.1</td>
<td>Cementation®</td>
<td>Straumann</td>
<td>SP</td>
<td>35</td>
</tr>
<tr>
<td>Internal/ 11° Taper</td>
<td>Osseo Speed®</td>
<td>4.0</td>
<td>Tight Design®</td>
<td>Dentsply IH</td>
<td>OS</td>
<td>20</td>
</tr>
<tr>
<td>Internal/ “Tube in tube” with cam-slot</td>
<td>Camlog K series Promoteplus®</td>
<td>4.3</td>
<td>Universal®</td>
<td>Altatec</td>
<td>KP</td>
<td>20</td>
</tr>
<tr>
<td>Internal/ “Tube in tube” with cam-slot</td>
<td>Replace Select Tapered®</td>
<td>4.3</td>
<td>Snappy®</td>
<td>Nobel Biocare</td>
<td>NR</td>
<td>35</td>
</tr>
<tr>
<td>External/ Hex</td>
<td>Bränemark MkIII®</td>
<td>3.75</td>
<td>Snappy®</td>
<td>Nobel Biocare</td>
<td>BR</td>
<td>35</td>
</tr>
<tr>
<td>External/ Hex</td>
<td>SETiO®</td>
<td>3.8</td>
<td>UCLA®</td>
<td>GC</td>
<td>SE</td>
<td>30</td>
</tr>
</tbody>
</table>

The removal torque value was measured twice in the same way; the first value was rejected and the second measured value was taken as the removal torque before loading.

**Measurement of removal torque after loading**

The cyclic torsional loading test device planned and trial manufactured in this program (AG-XR, Shimadzu, Kyoto, Japan) was used in the cyclic torsional loading test (Fig. 3). This device’s measurement accuracy of this device was ±0.3% of the measurable maximum torque.

Test implants were once again fastened with a digital torque meter to the torque value specified by the respective manufacturers. The torsional loading test device was set up with the test implant gripped by two three-jaw scroll chucks, positioned at 5 mm on either side of the implant-abutment interface, such that the implant was the fixed side and the abutment the moveable side. The cyclic torsional loading test was then carried out. The test load was a torque control of 10% of the abutment screw fastening torque specified by the
manufacturer, the test velocity was 10º/min, and the test comprised 100,000 cycles. Following loading, the implant system was again mounted in a vise, and the removal torque was measured. The measured value was taken as the removal torque after loading. Measurements were carried out on six samples of each implant system, and the mean value for each system was calculated.

**Statistical analysis**

Removal torque values before and after loading were compared using a paired *t*-test. The difference in removal torque before and after loading was converted to a percentage (reduction rate) for each system, and the values for each system were compared using one-way ANOVA and Tukey’s multiple comparison test. Statistical analysis was conducted using Excel Statistics 2010 (SSRI, Tokyo, Japan).

**Observation by scanning electron microscope**

Each implant system was examined using a scanning electron microscope (S-800, Hitachi, Tokyo, Japan) to compare the components when unused, after fastening once to the specified torque, and after the cyclic torsional loading test.

### RESULTS

**Removal torque before loading**

Removal torque before cyclic torsional loading, expressed as the reduction rate relative to the manufacturer’s specified torque, was in the order (highest to lowest) BR, OS, SE, NR, KP and SP (Table 2). Of these, the removal torque of SP was greater than the specified fastening torque. For all other implant systems, the removal torque was less than the specified fastening torque.

**Removal torque after loading**

The values for removal torque after cyclic torsional loading indicated that with all the systems, the abutment screw was looser after cyclic torsional loading test than before (Fig. 4). A paired *t*-test of the removal torque values before and after loading showed a significant difference for SE (*p*<0.05) and a highly significant difference for SP, OS, KP, and NR (*p*<0.01).

### Table 2  Average removal torque for each implant system

<table>
<thead>
<tr>
<th></th>
<th>Specified torque (Ncm)</th>
<th>Removal torque before cyclic torsional loading (Ncm)</th>
<th>Removal torque after cyclic torsional loading (Ncm)</th>
<th>Reduction in removal torque (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>35</td>
<td>38.6 [−10.2]</td>
<td>34.8 [0.6]</td>
<td>9.9</td>
</tr>
<tr>
<td>KP</td>
<td>20</td>
<td>19.0 [5.0]</td>
<td>17.2 [14.0]</td>
<td>9.5</td>
</tr>
<tr>
<td>NR</td>
<td>35</td>
<td>30.8 [12.0]</td>
<td>29.3 [16.3]</td>
<td>4.7</td>
</tr>
<tr>
<td>BR</td>
<td>35</td>
<td>28.7 [18.0]</td>
<td>28.0 [20.0]</td>
<td>2.4</td>
</tr>
<tr>
<td>SE</td>
<td>30</td>
<td>26.3 [12.3]</td>
<td>25.1 [16.3]</td>
<td>4.6</td>
</tr>
</tbody>
</table>

[ ]=Reduction from specified torque (%)
The removal torque reduction rate was in the order (highest to lowest) OS, SP, KP, NR, SE and BR. Tukey’s multiple comparison test showed significant differences between SP and BR, and KP and BR (p<0.05), and highly significant differences between OS and NR, OS and BR, and OS and SE (p<0.01) (Fig. 5).

Scanning electron microscope observation
The bearing surface of the NR abutment screw and the thread of the KP abutment screw both showed abrasion on the metal over a wide area after cyclic torsional loading test in comparison with the unused state, and there was also a small amount of abrasion visible after tightening the screw once according to the manufacturer’s specifications (Figs. 6 and 7). The same tendency was observed in other systems. No large changes were observed in places other than the abutment screw.

DISCUSSION

Experimental apparatus and methods
On cyclic torsional loading test, an implant and abutment that are connected together are held at either end and subjected to a repeated forward-reverse rotational load. This is a typical fatigue test used in the industrial world. The cyclic torsional loading test indirectly

Fig. 5 Loosening ratio for abutment screw before and after cyclic torsional loading test in each implant system (one-way ANOVA and Tukey’s test).

Fig. 6 NR Abutment screw (bearing surface).

Fig. 7 KP Abutment screw (thread surface).
causes torsional stress on the abutment screw. The torsional stress exerted on the abutment screw probably varies according to differences in the type of connection, and the fit and shape of the different components. Experiments using positive-negative torque have more rigorous conditions than unidirectional torque experiments, as there is a greater amount of movement.

It is very difficult to estimate the load that will be applied to implants, including through non-physiological oral functions, in ordinary clinical practice. As safety needs to be fully taken into account, the safety coefficient was set at 10 and the experimental load was thus set at 10% of the specified tightening torque value. For this, reference was made to Article 562, Chapter 10 of the Ordinance on Industrial Safety and Health\(^\text{27}\), in which a safety coefficient of 10 is applicable to ensure safety. Even though the applied occlusal force of the implant was same in the mouth, each cyclic torsional torque decided to 10% of tightening torque of abutment screw in this study due to the specified tightening torque at abutment screw was different with each implant systems. In order to investigate differences in removal torque due to differences in testing load, a preliminary experiment was carried out with SP at 30% of the specified removal torque. However, no differences in removal torque were observed between a testing load of 30% and a testing load of 10% of the specified torque\(^\text{28}\). This may be an indicator of the minimum standard for cyclic torsional loading test when carrying out the test under strict loading conditions, as in the present study.

In addition, the number of loading cycles in the test was set at 100,000, in accordance with the estimates of Kim et al.\(^\text{16}\) regarding the number of cycles in one month following implant repair.

The systems tested were implant systems currently in clinical use with differing connection configurations — some with internal connections and some with external connections. It was not possible to use implants that all have the same diameter as there is no uniform standard implant diameter; systems with an implant diameter of around 4.0 mm were selected.

Removal torque before and after loading

1. Removal torque before loading

In the present study, the abutment screws were tightened to the specified torque recommended by each manufacturer, and left for 5 min before the torque was measured again. This was to take the so-called “settling effect” into account. Jorge et al.\(^\text{16}\) reported that when an unused abutment screw is tightened, the metals settle together over the space of a few minutes. Therefore, in our study, the implant system was left for 5 min after tightening.

The first measured value was rejected and the second measured value used as the standard value because it was assumed that in clinical use the abutment screw would be tightened for a try-in of the superstructure, and also because, according to Barbosa et al.\(^\text{12}\), the metals settle together at the first tightening, resulting in higher removal torque values than at the second and third tightening. Consequently, the second measurement was used as the standard value.

The SP system showed a removal torque value greater than that of the specified tightening torque. Uraguchi et al.\(^\text{29}\) measured the removal torque of systems with tapered connecting parts, and reported that because the tapered part becomes wedged in place when tightened, the removal torque is greater than the tightening torque. It is likely that SP gave the same result because this system uses a taper. The OS system also fits together with a taper, but the same result was not obtained; this was probably because of differences in the shape of the connecting part and in the specified tightening torque. SP has a taper in the screw thread, whereas OS does not, and so it is likely that this causes the components of SP to become more tightly wedged together, giving a stronger connection. In addition, the angle of taper of the implant-abutment connection part is 8° with SP and 11° with OS, and so it is likely that the smaller taper angle of SP allows greater elastic deformation of the metal, and the components are wedged together more strongly. The specified torque values are 35 Ncm for SP and 20 Ncm for OS; thus, SP has the greater specified torque. OS and SP may not have shown the same results because the wedging effect was less with OS than with SP as a result of these factors.

2. Removal torque after loading

Internal connections such as taper fittings have long connection areas, thus stabilizing each component via the wedge effect between the implant and abutment. In contrast, for external connections, the abutment screw bears most of the torque due to the lack of internal connections.

Systems with a taper fitting showed a greater reduction rate in the removal torque after loading, as compared with non-taper systems. Torsional torque applied to a unified test piece by taper fitting may decrease implant/abutment frictional forces and indirectly reduce the tightened torque of the abutment screw.

The external connection for BR showed the smallest reduction in removal torque after loading, possibly because it also showed the highest removal torque before cyclic torsional loading, as a result of the connection structure between the implant and abutment. Kitagawa\(^\text{17}\) used the finite elements method to conduct a dynamic response analysis during loading of an internal connection system with a tapered connection and an external connection with a hexagonal construction, and found that the hexagonal connection structure did not function to prevent rotation and that there was cyclic rotational movement of between implant and abutment. Moreover, he suggested that screw loosening or not loosening depended on rotational movement around the abutment screw axis. In this study, the cyclic torsional load focused on the abutment screw rather than the implant/abutment connection. Thus, the load might be permitted by its elasticity, thereby reducing subsequent loosening.

There is a need to conduct finite element analysis in
order to demonstrate how the different systems behave under cyclic torsional loading tests. Moreover, this study was supposed one month’s mastication as 100,000 cyclic torsional loading. It showed a tendency of abutment screw loosening.

**Differences in screw shape before and after testing**

Screws were examined by scanning electron microscope in their unused state, after being tightened once, and after cyclic torsional loading test. Scarano et al. examined unused abutment screws, and while they found no macroscopic deformation, they reported surface roughness and grooves. In the present study, the scanning electron micrographs of the unused screws showed fine surface roughness and grooves. Barbosa et al. reported that screws after tightening showed removal of surface irregularities. It therefore appears that the abrasion of the metal following tightening is produced by deformation of the roughness and grooves.

Abrasión of the metal was found across an even greater range after cyclic torsional loading test. However, it cannot be determined whether this abrasion occurred as a result of the cyclic torsional loading itself or as a result of the screw being tightened a total of three times before loading, and this needs to be verified in the future. Scarano et al. examined the abutment screws of patients from clinical practice who complained of loosening of the superstructure, and found microscopic cracks. Although observation revealed no cracks in the screws in the present study, it appears likely that loosening of abutment screws in clinical practice is caused by such cracks, which can lead to fracture.

**CONCLUSIONS**

In this study, six types of implant system, including types with internal and external connections, were used to investigate the effects on the abutment screw of a cyclic torsional load delivered by a torsional loading test device. The following conclusions were drawn:

1. Loosening of the abutment screw occurs as a result of cyclic torsional loading test.
2. The degree of looseness of the abutment screw resulting from the cyclic torsional loading test varies according to the implant system.

The above suggests that in clinical practice the abutment screw may become loose within the relatively short period of 1 month; thus, screw looseness should be measured and the screw should be tightened at the time of recall.

**ACKNOWLEDGMENTS**

Finally, the authors would like to express their gratitude to Dr. Yuichi OTSUKA and Dr. Yukio MIYASHITA of Nagaoka University of Technology and to everyone at the Department of Crown and Bridge Prosthodontics, The Nippon Dental University School of Life Dentistry at Niigata, for their cooperation and guidance in this research.

**REFERENCES**

18. Balik A, Karatas MO, Kesk H. Effects of different abutment


