Narrow-diameter implants can be used in narrow alveolar ridges, in incisor tooth sites, between convergent tooth roots, or in restricted interdental spaces. Recent systematic reviews have reported comparable survival rates for narrow-diameter implants to those of standard diameter implants.

One common complication with single-unit implant crowns is screw loosening, which can lead to crown loosening and wear at the implant abutment connection. When an abutment is fixed to an implant by means of a screw, the resulting unit is referred to as a screw joint. By applying a torque to the screw, the screw elongates and produces a tension in the shank and threads of the screw. Preload is defined as the load on the screw when a torque is applied. Intraorally, the screw joint is under separating forces that attempt to separate the components.

The design of the connection may be one of the causative factors promoting screw displacement. Intraorally, as the load on the screw when tightening may also occur during functional loading, creating unsettling forces that may cause loss of preload. A recent conical-hexagon connection with double friction fit (conical-hexagon connection) could prevent this axial displacement.

**ABSTRACT**

**Statement of problem.** Displacement of abutments into conical connection implants during screw tightening may also occur during functional loading, creating unsettling forces that may cause loss of preload. A recent conical-hexagon connection with double friction fit (conical-hexagon connection) could prevent this axial displacement.

**Purpose.** The purpose of this in vitro study was to measure the 3D axial displacement of abutments with a conical-hexagon connection or conical connection in narrow-diameter implants. Removal torque values (RTVs), preload efficiency, and survival after cyclic loading were also compared.

**Material and methods.** Narrow-diameter implants with a conical connection (Osseospeed EV, 3.0×13 mm-AST) and narrow-diameter implants with a conical-hexagon connection (Eztetic, 3.1×13 mm) were embedded in resin rods (G10) (n=6). Six titanium abutments per system were used, and their spatial relationship to the implant platforms after hand tightening was determined by using 3D digital image correlation. The abutments were tightened to the manufacturers’ specified values, and the abutments’ relative position was recorded again. The displacement of the abutment after tightening was calculated. The implants were subjected to cyclic loading (5×10⁶ cycles at 2 Hz) under 200-N loads at a 30-degree angle. After cyclic loading, the RTVs of screws were measured and compared with those specified by the manufacturers to calculate preload efficiency. ANOVA was used to compare the differences in displacements after tightening and to compare differences in RTVs after cyclic loading across the groups (α=.05).

**Results.** The mean displacement in the U direction (X-axis) for the AST was −0.7 μm and −4.7 μm for ZIM, with no statistical difference (P=.73). The mean displacement in the V direction (Y-axis) for AST was −37.0 μm, and −150.0 μm for ZIM, with significant statistical difference (P<.001). The mean displacement in the W direction (Z-axis) for AST was −0.9 μm, and −23.0 μm for ZIM, with no statistical difference (P=.35). The survival of groups was similar (P=.058). During cyclic loading, 3 AST specimens fractured. After cyclic loading, mean RTV for AST was −8.77 Ncm, and −14.24 Ncm for ZIM, and these values were significantly different (P=.04). Preload efficiency was 28.1% for AST and 41.5% for ZIM.

**Conclusions.** Greater abutment displacements were observed with the conical-hexagon connection, which required a higher torque, as specified by its manufacturer. The abutments displaced more in the V-axis in both implants. Only the conical connection implant (Ti Grade 4, commercially pure) had failures during cyclic loading, but the survival of the implants was similar. After cyclic loading, the abutment screws in both systems lost some of their torque value. The abutment screws of the conical-hexagon connection implant maintained preload more efficiently during cyclic loading than those of the conical connection implant (J Prosthet Dent 2022;127:100-6).
torque reduction and vertical settling with single crowns. Conical connections exhibit some degree of angular deformation and vertical displacement. Studies report microgap changes, screw loosening, and potential bone loss with conical connections, which may be reciprocal to implant diameter, with the greatest stress at diameters below 3.5 mm. The decreased side wall thickness of narrow-diameter implants makes them vulnerable to damage under masticatory forces.

The cumulative incidence of screw loosening has been reported to be 12.7% after 5 years. Studies report microgap changes, screw loosening, and potential bone loss with conical connections, which may be reciprocal to implant diameter, with the greatest stress at diameters below 3.5 mm. The decreased side wall thickness of narrow-diameter implants makes them vulnerable to damage under masticatory forces. The presence of a horizontal or oblique bevel within the implant platform (neck) of a conical connection has been subjected to dynamic loading and was reported to prevent bacterial leakage at the implant-abutment interface. A recently introduced narrow-diameter implant (Eztetic 3.1 mmD Implant System; Zimmer Biomet) by the same manufacturer features an innovative connection with a double friction fit conical-and-hexagon feature (conical-hexagon connection), but whether it provides a stable screw joint is unclear.

Clinical Implications

Even though the 2 tested narrow-diameter implants had similar survival rates, clinicians may select the narrow-diameter implant with a conical-hexagon double friction fit connection for a more stable long-term screw joint.

MATERIAL AND METHODS

Six narrow-diameter implants (3.0×13 mm) with a conical connection (Osseospeed EV; Dentsply Sirona) (AST) and 6 narrow-diameter implants (2.9×13 mm) with a conical-hexagon connection (Eztetic; Zimmer Biomet) (ZIM) were selected. Six prefabricated titanium (Ti) abutments with conical connections (TiDesign EV 3.0 mm; Dentsply Sirona) and 6 with conical-hexagon connections (Contour Abutment, Eztetic NP 2.9 mmD; Zimmer Biomet) were used, and 1 abutment from each group was scanned by using a laboratory scanner (E3; 3Shape A/S) generating a standard tessellation language (STL) file that was used for computer-aided design (CAD) with a software program (MeshMixer; Autodesk Inc) of the hemispherical loading cap in accordance with the International Organization for Standardization (ISO) standard 14801:2007 (Fig. 1). The cap was designed to be the combination of a screwable and cementable option which offered the advantages of fixation to the abutment while maintaining access to the abutment screw. The caps were printed from a castable resin (Form 2; FormLabs) and cast in a base metal alloy (Argeloy NP; Argen Corp). The fit of the cap on the abutments was assessed by using a vinyl polyether silicone material (Fit Checker Advanced; GC America Inc), and adjustments were made to ensure the seating before luting. The caps were luted to the abutments by using an autopolymerizing resin cement (SpeedCEM; Ivoclar Vivadent AG).

Twelve 10×15-mm reinforced epoxy resin rods (G10; McMaster-CARR) were fabricated, and each implant was embedded in a rod. Osteotomy preparations corresponding to the respected implant diameters were made in the center of each rod to a depth of 10 mm, and a vent hole was placed at the apex. All implants were embedded in the rod to a depth of 10 mm, leaving the coronal most 3 mm of each implant exposed in accordance with ISO standard 14801:2007. Implants were fixed in the osteotomy preparations by using a dual-polymerizing resin...
(Rock Core, Core Build-up Composite Kit; Danville Materials) with a modulus of elasticity similar to that of bone to simulate osseointegration by filling in the spaces between the prepared sites and the implant surface.18,19 The spatial relationship of the abutment-cap complex to the implant platforms was measured by using 3D digital image correlation. This optical measurement technique relies on calibrated digital images made with two 1624×1224-pixel resolution cameras (GRAS-20S4 M) equipped with 35-mm lenses (Schneider-Kreuznach; Jos. Schneider Optische Werke). The digital cameras were mounted on a custom fixation device on a tripod and focused on the abutment and the cap (Fig. 2), providing a synchronized stereo view of the test specimens. Initial calibration of each camera was performed independently by making images of the same 1-inch glass calibration grid to establish a common world coordinate system, which was used to relate the image positions in both cameras to a common 3D location.20 A high-contrast, random dot pattern was applied to the surfaces of the abutment-cap complex and G10 resin rod to create measuring points for the image correlation software program (Vic-3D, Digital Image Correlation v2009.1.0, build RC 2009.448; Correlated Solutions Inc). By measuring the spatial relationship after hand tightening and specified torque application, the relative displacement between the 2 states could be derived.

TLDs from the implant manufacturers were used to deliver the torque during testing. The average hand tightening value has been reported to be 15 Ncm,21-23 which served as the baseline hand-tightened state and was delivered by using the calibrated TLDs. After initial tightening, the first set of digital images was made for 3D digital image correlation measurements. Each abutment was tightened to the manufacturer's specified torque value (25 Ncm for AST and 30 Ncm for ZIM) before capturing another set of digital images.

To analyze the data collected from the digital images, a digital image correlation software program (Vic-3D, 2009 Digital Image Correlation v2009.1.0, build RC 2009.448; Correlated Solutions) was used. The software program used a preset data set that was defined on both the abutment-loading cap complex and the G10 resin rod based on the random dot pattern generated. Then, 2 points were selected, one approximately in the middle of

![Figure 1](image1.png)

**Figure 1.** Abutments tested with different internal connection designs and their screws A, Osseospeed EV 3.0×13 mm (AST). B, Eztetic, 3.1×13 mm (ZIM).

![Figure 2](image2.png)

**Figure 2.** Three-dimensional digital image correlation test apparatus. Specimen embedded in G10 resin and high-contrast, nonrepetitive, random dot pattern used during 3D digital image correlation measurements.
the abutment data set and the other on the G10 resin rod data set, approximately 11 mm directly below the first point. The 3D coordinates of these 2 points were extracted from the data after hand tightening to 15 Ncm and again when the abutment was tightened to the manufacturer’s specified values; 25 Ncm for AST and 30 Ncm for ZIM. Relative displacement was calculated by subtracting the abutment and cap point coordinates from the G10 resin rod point coordinates to account for possible movement between the camera arrangement and the table fixing the resin block during the test. The displacements were analyzed and symbolized as U, V, and W, which were the displacements of the X, Y, and Z coordinates, respectively. The U direction represented a horizontal displacement along the X-axis or the abutment and cap displacing side-to-side, the V direction represented a vertical displacement along the Y-axis or the abutment and cap displacing up and down, and the W direction represented displacement along the Z-axis or the abutment and cap displacing closer or farther from the cameras.

After 3D digital image correlation measurements, specimens were retrieved and mounted in 30-degree angled steel holders (ISO 14801:2007) for cyclic loading. Cyclic loading was carried out at 2 Hz for 5 million cycles under 200-N loads simulating 5 years of functional loading (Fig. 3). After cyclic loading, a digital torque gauge (Model DFS II R ND; Chatillon) was used to measure the peak RTV that loosened the screw. This RTV was compared with the manufacturer specified torque values that were applied during the 3D digital image correlation testing to calculate the preload efficiency. Only pairwise comparisons in each direction were considered relevant. The RTVs after cyclic loading were analyzed for least square means by using the restricted maximum likelihood estimation. The LIFETEST Procedure was used to analyze the survival probability of the groups (SAS 9.4; SAS Institute Inc).

**RESULTS**

The mean displacement in the U direction (X-axis) for the AST was −0.7 µm, and −4.7 µm for ZIM, with no statistical difference (P=.73). The mean displacement in the V direction (Y-axis) for AST was −37.0 µm, and −150.0 µm for ZIM, with statistical difference (P<.001). The mean displacement in the W direction (Z-axis) for AST was −0.9 µm, and −23.0 µm for ZIM, with no statistical difference (P=.35). Mean displacement values and confidence intervals for displacements in 3 directions are presented in Figure 4.

During cyclic loading, 3 of the AST specimens sustained fractures (Fig. 5). Specimen 4 was the first to fracture at approximately 256 260 cycles, followed by specimen 3 at approximately 278 600 cycles and specimen 5 at approximately 788 650 cycles. Only the internal connection part of the abutment fractured in specimen 4, whereas the implants of specimens 3 and 5 fractured. All ZIM specimens survived the cyclic loading of the study as shown in the survival curves (Fig. 6). No significant
difference was found between the survival of AST and ZIM ($P=0.058$).

The mean RTV for AST was $−8.77$ Ncm after cyclic loading and significantly smaller than the mean RTV for ZIM, which was $−14.24$ Ncm ($P=0.04$). AST preload efficiency was 28.18%, and ZIM preload efficiency was 41.5%.

**DISCUSSION**

The null hypothesis that no significant difference would be found in the axial displacement of abutments between different narrow-diameter implants was rejected, based on a significant interaction between the effects of the system (AST and ZIM) and the direction (U, V, and W) of the displacement. Further analysis on the effect of the system in each of the 3 directions also found a significant difference between the systems in the V direction.

Previous studies evaluated the displacement of implant superstructures into conical connection implants by using varying torque values, abutment materials, and splinted versus nonsplinted designs and reported varying results with different connection designs.15–20 25 26 One of these studies reported a mean vertical displacement of 43 μm between the hand-tightened and tightened states in a conical connection system.8 A displacement of this magnitude could result in esthetic and functional deficits.9 The displacement of internal hexagon friction fit abutments from the manufacturer of ZIM implants after initial and repeated tightening was also evaluated.27 No differences were reported for vertical displacement between the abutments tested, with the largest vertical displacement of 5 μm and the smallest vertical displacement of 3 μm being reported.

One of the goals of the present study was to investigate the displacement of the newly introduced connection design to determine whether inclusion of double friction fit limits the amount of vertical displacement previously reported in studies evaluating conical connection implants. The mean displacements in the V direction (Y-axis) for the specimens tested was $−150$ μm for the conical-hexagon connection and $−37.0$ μm for the conical connection system. The minus sign indicates a displacement into the implant in the V direction. The displacement results for the conical connection implant corresponded well with those of a previous study evaluating this system.8 However, the mean vertical displacement of the conical-hexagon connection reported was greater than previously reported displacement values for implants from the manufacturer of conical-hexagon connection implants.27 An explanation for displacement differences could be the difference in the specified final torque values delivered to each system in the present study. The conical connection system required 25-Ncm torque, while conical-hexagon connection required 30 Ncm. Displacement as it relates to torque values has been previously reported, and a continuous vertical displacement of abutments into implants occurred as the torque value on the abutment screw increased.28 Conical connection systems that require higher torque to secure the abutment into the implant have been reported to demonstrate greater abutment displacement.29

Because of the multiple mating surfaces in close frictional contact with one another in the double friction fit connection of the conical-hexagon, it is possible that the hand-tightened state was not able to overcome this friction and seat the abutment vertically as much as a conical connection. This could have created a space for the abutment to displace axially when the manufacturer-specified torque value was applied. The second null hypothesis, that no significant difference would be found in the manufacturer-specified torque values obtained before
cyclic loading and the RTVs obtained after cyclic loading for either the conical connection or conical-hexagon connection narrow-diameter implant systems, was also rejected.

Paepoemsin et al\textsuperscript{24} tested different implant systems with different abutment screws and concluded that the preload efficiency in all groups decreased significantly. The results of the present study showed that the conical-hexagon connection system maintained its preload efficiently when compared with the conical connection. Preload efficiency was calculated to provide an accurate representation of the torque value delivered to the abutment screw during testing.

Different abutment screw designs were tested in the present study. Previous studies have evaluated the ability of tapered head and flat head screws to maintain preload,\textsuperscript{26,27} reporting that flat head screws were preferable for preload maintenance because of even force distribution within the screw and the head of the screw. It was also reported that longer stems provide favorable elongation during preload development.\textsuperscript{21} These 2 attributes are in the ZIM’s abutment screw but not ASTM’s. The newly designed double friction fit ZIM connection could also provide a more stable joint that is able to resist unsettling forces during cyclic loading. The implant fractures were only observed in the conical connection implant, which may be because it is made of grade 4 commercially pure Ti. The conical-hexagon connection implant is made of Ti grade 5 alloy. Additionally, the fractured implant (conical connection) is narrower than the conical-hexagon connection implant, and its narrower diameter might have contributed to the fracture. The fact that fractures were seen in only the conical connection group and that the $P$ value for survival difference was small ($P=.058$) warrant the need for further investigation of their survival in the long term.

The abutment-implant systems might have performed differently if the abutment screws had been retightened after an interval. The displacement of abutments after repeated tightening has been reported, especially when conical connections were used.\textsuperscript{26,27} These displacements were attributed to an embedment relaxation after the initial torque application.\textsuperscript{26,27} Accordingly, the 2-time tightening procedure could have affected the RTVs.

Limitations of the present study include its in vitro design and small sample size. Nevertheless, the sample size and study design enabled the detection of statistically significant differences ($P<.001$) for displacement values, and significance was found for RTVs. The results derived from the presented in vitro study should be corroborated with clinical evaluations to observe the effects of internal connection designs on the screw stability and survival of implant restorations.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Greater abutment displacements were observed with the implant, which required a higher torque value to secure the abutment into the implant.  
2. The abutment displaced significantly more in the $V$-axis in both implant systems.  
3. The conical internal connection (Ti grade 4, commercially pure) implant had failures during loading, but the implant with the conical-hexagon connection (Ti grade 5 alloy) had no failures. However, the survival of both implants was similar.  
4. After cyclic loading of conical connection and conical-hexagon connection implants, the abutment screws lost part of their original torque value.  
5. The abutment screws of the conical-hexagon connection implant maintained their preload more efficiently during cyclic loading than those of the conical connection implant.

REFERENCES


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