

Displacement of Implant Abutments Following Initial and Repeated Torqueing

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Purpose: To measure and compare the three-dimensional (3D) position of nine different abutments manufactured by different manufacturers after repeated torqueing on an internal-hexagon implant.

Materials and Methods: Nine tapered implants were placed into an acrylic resin block. Five specimens each of nine different abutments ($n = 45$) were placed into one of nine implants. The abutments were hand-tightened and then torqued to the manufacturer-recommended torque of 30 Ncm. After 10 minutes, 30 Ncm of torque was reapplied. Another 10 minutes elapsed before testing was completed. Images were recorded in 12-second intervals. The spatial relationship of the abutments to the resin block was determined using 3D digital image correlation. Commercial image correlation software was used to analyze the displacements. Mean displacements for the abutments were calculated in three dimensions and overall for both torque applications. Statistical comparisons were done with a *t* test and a step-down Bonferroni correction.

Results: The overall 3D displacement of the Atlantis Titanium abutment after the second applied torque was significantly greater than that of two of the eight other abutments. Displacement in all three dimensions for the Atlantis Titanium abutment changed direction between the first and second torque applications. All abutments moved further in the same direction except for the Atlantis Titanium abutment, which moved back toward its original hand-tightened position horizontally after the second torque application.

Conclusion: Re-torqueing of abutments after a 10-minute interval leads to minor displacement of varying degrees between the abutment and a tapered implant. A potential effect of embedment relaxation and/or manufacturing errors should be taken into consideration when selecting an abutment for a cement-retained crown on a tapered implant. Accordingly, clinicians may benefit from adjusting cement-retained implant crowns after re-torqueing the abutments to prevent potential occlusal and interproximal contact problems. INT J ORAL MAXILLOFAC IMPLANTS 2015;30:1011–1018. doi: 10.11607/jomi.3694

Key words: abutment, cement, dental implant, displacement, embedment relaxation, retention

Loosening and fracture of the prosthetic retaining screw are major problems with implant-supported restorations.^{1–4} Screw loosening is especially detrimental for abutments with cement-retained crowns

because the prosthesis may need to be sectioned and destroyed to gain access to the retaining screw. Ultimately, screw loosening can lead to screw fracture, which could render the implant nonrestorable.

An understanding of screw mechanics is necessary to comprehend why retaining screws become loose. When the implant and abutment are tightened together by a screw, the resulting unit is referred to as a *screw joint*.⁵ When torque is applied to the screw, the screw elongates and produces tension in the shank and threads of the screw. The clamping force is a result of elastic recovery, which pulls the two parts together.⁶ Preload refers to the initial load on the screw when a torque is applied and is equal in magnitude to the clamping force.⁵ Forces outside of the screw joint that attempt to separate the components are called *joint-separating forces*.⁵ Screw loosening occurs when the joint-separating forces are greater than the clamping force.⁵ Therefore, maximizing the clamping force and minimizing the joint-separating forces will prevent screw loosening.

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Table 1 The Nine Tested Implant Abutments

Abutment name (abbreviation)	Manufacturer	Material	Stock/custom	Connection to implant
Atlantis Titanium (A-T)	Dentsply Implants	Titanium	Custom	Titanium
Atlantis Zirconia (A-Z)	Dentsply Implants	Zirconia	Custom	Zirconia
Inclusive Custom Implant Abutment Titanium (G-T)	Glidewell Laboratories	Titanium	Custom	Titanium
Inclusive Custom Implant Abutment All-Zirconia (G-Z)	Glidewell Laboratories	Zirconia	Custom	Zirconia
Legacy Straight Contoured Abutment (ID-T)	Implant Direct	Titanium	Stock	Titanium
Legacy Zirconia Straight Contoured Abutment (ID-Z)	Implant Direct	Zirconia	Stock	Titanium insert
Hex-Lock Contour Abutment (Z-C)	Zimmer Dental	Titanium	Stock	Friction-fit titanium
Zimmer Contour Zirconia Abutment (Z-Z)	Zimmer Dental	Zirconia	Stock	Zirconia with internal-hex protecting titanium ring
Zimmer Patient Specific Abutment in Titanium (Z-PSA)	Zimmer Dental	Titanium	Custom	Friction-fit titanium

A significant mechanism that results in screw loosening is the settling effect, also known as *embedment relaxation*.⁷ Embedment relaxation occurs because no surface is completely smooth.⁷ When viewed microscopically, every machined surface is slightly rough. Because of this micro-roughness, no two surfaces are ever completely in contact. After the initial torqueing of the screw, the rough areas collapse, leading to a loss of preload. One study reported a reduction of 2% to 10% in preload within the first few seconds or minutes after tightening as a result of embedment relaxation.⁸ This loss of preload makes the screw joint less stable and more susceptible to joint-separating forces, which can lead to slippage between the screw threads and the implant threads, resulting in a further loss of preload.⁹ The accumulated loss of clamping force leads to screw loosening and possible fracture of the retention screw. To account for the reduced torque caused by embedment relaxation, Siamos et al⁶ recommended re-torqueing abutment screws 10 minutes after the initial torque application for implants with external-hexagon connections. Another study¹⁰ recommended re-torqueing the screw at least twice during a 10-minute interval in all laboratory and clinical procedures for implants with conical internal connections. Dailey et al¹¹ reported consistent axial displacements of 7 to 12 μm with each increasing 5 Ncm of torque application of abutments in implants with a conical internal connection.

The Tapered Screw Vent (TSV) implant (Zimmer Dental) features an internal-hexagon connection platform.¹² Numerous implant manufacturers feature similar internal-hex designs. Several companies other than Zimmer Dental offer after-market abutments for cement-retained restorations for the TSV implant, including Implant Direct, Dentsply (Atlantis), and Glidewell Laboratories.

The Zimmer Hex-lock Contour and Zimmer PSA abutments (Zimmer Dental) have a 1-degree taper from the base of the abutment body to the bottom of the hex. Because these abutments are seated into the TSV implant under applied torque, the abutment hex frictionally engages the walls of the implant's internal hex. Zimmer claims that this friction fit reduces rotational misfit when components are fully seated to the manufacturer-recommended torque of 30 Ncm.¹³ The Zimmer Contour Zirconia (Zimmer Dental) abutment has a solid zirconia body with a titanium alloy seating ring at the implant-abutment interface. Zimmer claims that the titanium alloy seating ring provides greater resistance to abutment micro-movements and tilting during functional loading and reduces the possibility of screw loosening, wear, and abutment fracture.¹⁴ The Legacy Straight Contoured abutments (Implant Direct), manufactured in titanium and zirconia versions, are stock abutments with titanium connections. The Atlantis Titanium (Dentsply) and the Inclusive Titanium Custom (Glidewell Laboratories) abutments are both created through computer-aided design/computer-assisted manufacture (CAD/CAM) and milled from titanium blanks. The Atlantis Zirconia (Dentsply) and the Inclusive Zirconia Custom (Glidewell Laboratories) abutments are also created with CAD/CAM and milled from zirconia blanks; both feature all-zirconia connections. All of the abutments use a titanium alloy retention screw.

The aim of this study was to evaluate, using three-dimensional digital image correlation (3D DIC), the 3D displacement of nine different abutments for cement-retained crowns after re-torqueing on a TSV implant.¹⁵ The null hypothesis was that the 3D displacements of all nine abutments tested would not be significantly different from one another after a second 30-Ncm torque was applied.



Fig 1 (above) The 12 × 2 × 8-mm resin block with nine pilot holes drilled 1 inch apart.

Fig 2 (right) Preparation of implant sites with surgical implant handpiece.

Fig 3 (below) Resin block with the implants in place.



MATERIALS AND METHODS

Nine different implant abutments for cement-retained crowns were selected for testing, based on the available options for restoring TSV implants. The selected abutments varied by manufacturer, material, type of connection to the implant, and whether they were customized or stock. Table 1 provides details on the nine abutments tested. The four types of stock abutments were prefabricated by their respective manufacturers. The five types of custom abutments were created digitally using CAD/CAM software and then milled to the design specification five times by their respective manufacturer.

A 12 × 2 × 8-mm block of resin (ABS transparent resin, DSM Somos) was produced by Accidental Inc. The resin's elastic modulus was 2,000 MPa, which approaches the published estimate for cancellous bone of 1,507 MPa.¹⁶ Nine pilot holes about 5 mm deep were drilled 1 inch apart from each other on the resin block; a drill press was used to ensure parallelism (Fig 1). An experienced periodontist prepared nine implant sites, using a 3.8-mm tap drill with a surgical implant handpiece (Surgical Motor System, Zimmer Dental) set to 900 rpm, to a depth of 12 mm (Fig 2). The threads of nine 4.1 × 11.5-mm TSV implants were coated with cyanoacrylate adhesive (Permabond 910, Permabond LLC). The implants were driven into the resin block using the same surgical implant handpiece set to 35 Ncm and then made flush with the resin surface manually with a torque wrench (Fig 3). The cyanoacrylate adhesive simulated osseointegration by filling the void between the prepared site and the TSV implant surface.

Each of the nine types of abutments was assigned to only one of the nine implants. Five samples of each type of abutment were used for testing (n = 45). All five samples of each abutment type were tested on the same designated implant.



Fig 4 Experimental setup.

The 3D DIC technique was used to measure the displacements of each abutment relative to the resin block after hand-tightening, an initial torque application, and a second torque application. Commercial DIC software (Vic-3D, 2009 Digital Image Correlation Version 2009.1.0, build RC 2009.448, Correlated Solutions) was utilized to analyze data from digital images collected by two cameras (GRAS-20S4M-C, Point Grey Research). Both of the cameras had a 1,624 × 1,224-pixel resolution and were equipped with Schneider-Kreuznach 35-mm lenses (Jos. Schneider Optische Werke). The digital cameras were mounted on a custom fixation device on a tripod directed at the abutment specimens on the resin block, which was fixed to a table (Fig 4). The two high-resolution cameras provided a synchronized stereo view of the abutments during testing. Initially, each camera was calibrated independently with images of the same 1-inch glass calibration grid taken from different views. For each calibration image captured, a system of equations relating the sensor position of the calibration grid points to the camera parameters was developed. The solutions to these equations provided the cameras with parameters to convert camera sensor coordinates to a common world coordinate system.

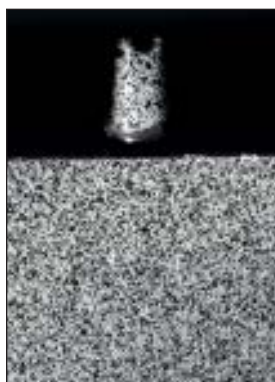


Fig 5 Appearance of the nonrepetitive, high-contrast dot pattern on the abutment and the acrylic resin block.

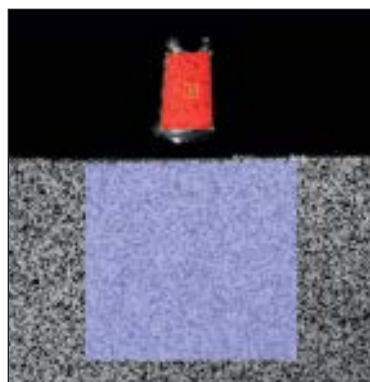


Fig 6 Defined data sets on both the abutment and the resin block.

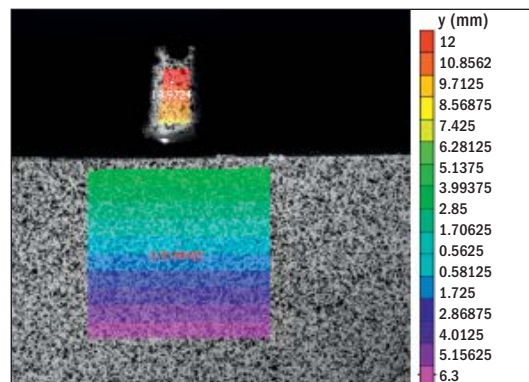


Fig 7 Two points were selected: one point approximately in the middle of the dot pattern of the abutment and the other on the resin block approximately 11 mm below the first point.

This world coordinate system was the basis for relating the image positions in both cameras to a common 3D location.¹⁷

A random, high-contrast dot pattern was applied to external surface of the resin block and the coronal portion of each abutment specimen above the margin (Fig 5). Initially, a white spray paint was applied as a base coat and allowed to dry. Next, a contrasting black spray paint was lightly spattered on the white base coat and allowed to dry. During the testing, the cameras recorded changes in the random dot pattern as the torques on the abutments were applied.

An adjustable restorative torque wrench (part #TWR, Zimmer Dental) was used to apply the torque for testing. This mechanical wrench has adjustable torque settings between 10 and 35 Ncm, with 5-Ncm demarcations. Kanawati et al¹⁸ found that the average torque generated by 50 subjects with a finger driver was 24 Ncm. For the current study, it was decided to round this figure down to the nearest 5-Ncm demarcation (ie, 20 Ncm) to represent hand tightening with a laboratory finger driver. Data collection using the 3D DIC system began immediately after the initial 20-Ncm torque was applied to the abutment in the implant. Images were captured in 12-second intervals for the remainder of the test. After a few images were collected in the initial hand-tightened position, the abutment screw was torqued to the recommended 30 Ncm with the torque wrench. Ten minutes elapsed to allow for embedment relaxation; then, the abutment was again torqued to 30 Ncm with the torque wrench. Images were collected for another 10-minute period. This torquing protocol was repeated for all five of the same type of abutment on their respective implant until all 45 abutments had been tested.

The Vic-3D DIC software was used to collect and process all of the data obtained from the captured images.

First, a data set on both the abutment and the resin block was defined in the software (Fig 6). Second, two points were selected, one approximately in the middle of the abutment data set and another approximately 11 mm directly below the first point in the resin block data set (Fig 7). Next, the 3D coordinates of the two points over all the 12-second intervals were extracted from the data. Relative displacement was calculated by subtracting the abutment point coordinates from the resin block point coordinates to account for any possible movement between the camera setup and the table to which the resin block was fixed during the testing. The displacements that occurred 10 minutes after the first and second applied torques were evaluated for each of the 45 specimens.

Statistical analysis of the displacements was carried out with SAS software (SAS Institute Inc). The mean relative displacements for all five specimens for each abutment were determined. A *t* test with a step-down Bonferroni correction was used for pairwise comparison of the mean displacements of each abutment to determine statistical differences ($\alpha = .05$) for both torque applications.

RESULTS

The mean displacements of the 3D coordinates for the five samples for each of the nine abutments were determined for both 30-Ncm torque applications. Plots of the mean displacements and their associated confidence intervals for all nine abutments are presented in the horizontal dimension (x-axis, mesiodistal) in Fig 8, in the vertical dimension (y-axis, incisocervical) in Fig 9, and in the normal dimension (z-axis, buccolingual) in Fig 10. The 3D coordinates were then used to calculate an overall 3D distance traveled by the point

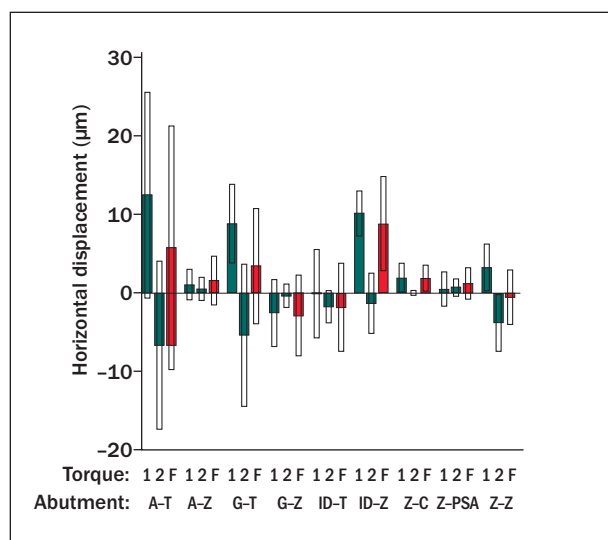


Fig 8 Plot of the mean horizontal (mesiodistal) displacements and confidence intervals for the nine abutments after the first and second torque applications and relative displacement (F). Refer to Table 1 for definitions of abutment abbreviations.

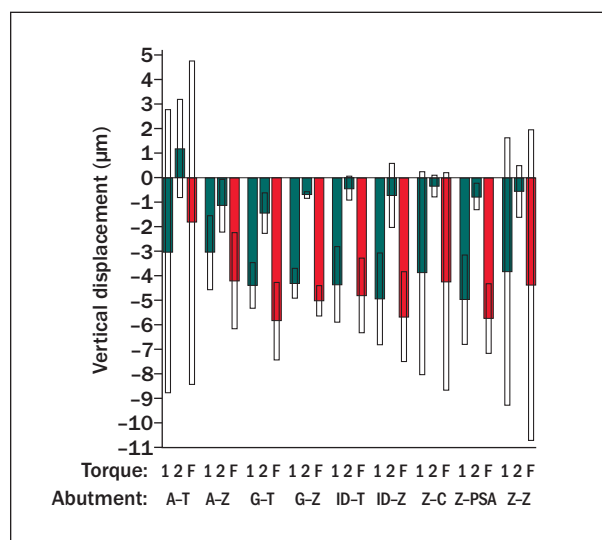


Fig 9 Plot of the mean vertical (incisocervical) displacement and confidence intervals for the nine abutments after the first and second torque applications and relative displacement (F). Refer to Table 1 for definitions of abutment abbreviations.

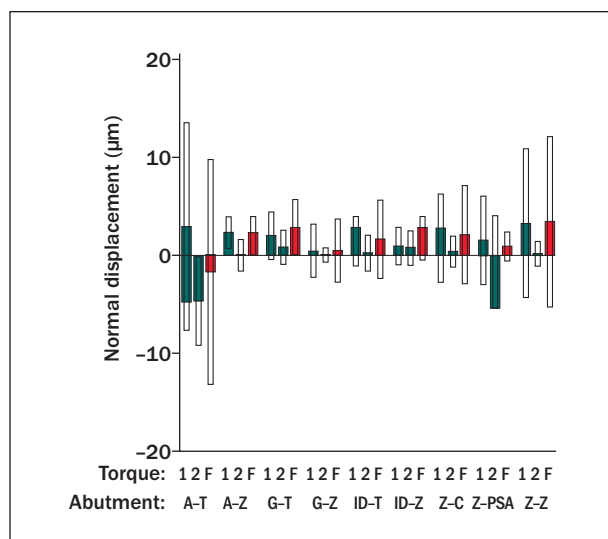


Fig 10 Plot of the mean normal (buccolingual) displacement and confidence intervals for the nine abutments after the first and second torque applications and relative displacement (F). Refer to Table 1 for definitions of abutment abbreviations.

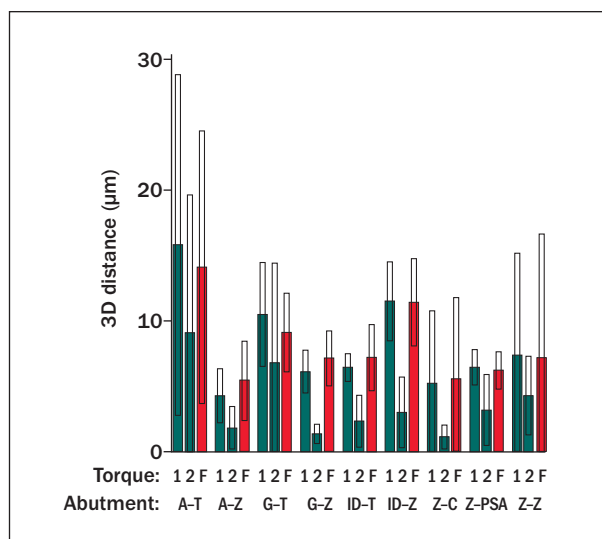


Fig 11 Plot for the mean total 3D displacement and confidence intervals for the nine abutments after the first and second torque applications and relative displacement (F). Refer to Table 1 for definitions of abutment abbreviations.

selected on each abutment; these distances are shown in Fig 11. The first torque value in the plots in Figs 8 to 11 represents the displacement from the initial hand-tightened position to 10 minutes after the first 30-Ncm torque application. The second torque value in the plots is the displacement from the first 30-Ncm torque to 10 minutes after the second 30-Ncm torque was applied. The red bar indicates the relative displacement from the initial hand-tightened position to 10 minutes after the second torque application.

In the x-axis, after the first 30-Ncm torque, the Atlantis Titanium abutment had the greatest mean displacement ($\approx 12 \mu\text{m}$) and the largest confidence interval. In fact, the approximately $12\text{-}\mu\text{m}$ displacement was the largest mean displacement in all dimensions. The Legacy Zirconia Straight Contoured abutment had the next largest mean horizontal displacement ($\approx 10 \mu\text{m}$), followed by the Inclusive Titanium abutment ($\approx 9 \mu\text{m}$). After the second 30-Ncm torque, the Atlantis Titanium abutment again had the largest mean displacement

Table 2 Significant Differences Between Abutments in Overall 3D Displacement Relative to Initial Hand-Tightened Position

Comparison	Difference (μm)	P value
A-T vs G-Z	7.72	< .0144
A-T vs Z-C	7.93	< .0144

($\approx 6 \mu\text{m}$) as well as the largest confidence interval; however, the displacement was in the opposite direction of the first mean displacement. Moreover, six of the abutments showed a mean displacement in the opposite direction after the second torque application. This would indicate that these abutments were moving back toward the original hand-tightened position after the second torque application. The three remaining abutments showed a mean displacement in the same direction as the initial displacement and were all less than $1 \mu\text{m}$. No statistically significant differences were found between any of the abutments after the second torque.

In the y-axis, after the initial 30-Ncm torque was applied, the mean displacement values were all between 3 and $5 \mu\text{m}$. The Atlantis Titanium and the Zimmer Contour Zirconia abutments both had large confidence intervals. After the second torque was applied, all the abutments showed a vertical mean displacement less than $1.5 \mu\text{m}$. The Atlantis Titanium was the only abutment that showed a noticeable increase in vertical displacement ($\approx 1 \mu\text{m}$). No statistically significant differences were found between any of the abutments.

In the z-axis, after the initial torque, all of the mean displacement values were below $3 \mu\text{m}$. The Atlantis Titanium and Zimmer Contour Zirconia abutments had the largest mean displacements ($\approx 3 \mu\text{m}$ each) and the greatest confidence intervals. After the second torque was applied, the Atlantis Titanium abutment had the greatest mean displacement ($\approx 4.5 \mu\text{m}$), which was larger than the initial displacement and also in the opposite direction. Again, no statistically significant differences were found between any of the abutments.

In a comparison of the overall 3D distance traveled by the abutments at the designated points after the initial 30-Ncm torque, the Atlantis Titanium abutment showed both the greatest distance ($\approx 16 \mu\text{m}$) as well as the largest confidence interval. The only other abutments with movements of at least $10 \mu\text{m}$ are the Inclusive Custom Titanium abutment ($\approx 10 \mu\text{m}$) and the Legacy Zirconia Straight Contoured abutment ($\approx 11 \mu\text{m}$). The Atlantis Zirconia abutment had the smallest displacement ($\approx 4 \mu\text{m}$), followed by the Zimmer Hex-Lock Contour abutment ($\approx 5 \mu\text{m}$). The other four abutments were all in the 6- to $8 \mu\text{m}$ range. After

the second 30-Ncm torque, the Atlantis Titanium abutment again traveled the greatest distance ($\approx 9 \mu\text{m}$) and had the largest confidence interval. The Inclusive Titanium Custom abutment had the second largest distance ($\approx 6 \mu\text{m}$) and had a relatively large confidence interval. The Zimmer Hex-Lock Contour abutment traveled the smallest distance (about $1 \mu\text{m}$), and the values for the other six abutments were all below $4 \mu\text{m}$. The 3D distance traveled by the Atlantis Titanium after the second torque was statistically significantly greater than the Inclusive Zirconia Custom abutment and the Zimmer Hex-Lock Straight Contour abutment ($P < .0144$). Of all the comparisons performed for the second applied torque, these were the only two statistically significant differences found (Table 2).

DISCUSSION

When a second torque was applied after a 10-minute interval, all tested abutments showed some displacement. In most cases, these displacements were much smaller in magnitude than the initial torque displacements. The largest mean 3D movement was approximately $9 \mu\text{m}$ by the Atlantis Titanium abutment (in the opposite direction to the displacement observed after first torquing). These results are consistent with the values reported by Kim et al¹⁰ when an abutment was re-torqued at 30 Ncm after a 10-minute interval into an implant with an internal conical connection. Although these displacements are small in magnitude, they may indicate that embedment relaxation is occurring between the implant and abutment surfaces. The displacements found in these studies were slightly smaller than those found by Dailey et al,¹¹ who reported a constant axial displacement of 7 to $12 \mu\text{m}$ with each 5-Ncm increase in torque application. The increased displacements found in that study may be attributed to the increasing torque applied for each test.

The friction-fit connection on the Zimmer PSA abutment showed significantly less displacement than its competitors. The assumption is that friction fit is a very tight tolerance, and it is possible that this friction fit played a role in minimizing embedment relaxation. However, the Zimmer Hex-Lock Contour abutment, which also has friction fit, showed no significant difference versus the Legacy Straight Contoured Titanium abutment. Also, the Zimmer Contour Zirconia abutment with the titanium alloy seating ring showed no significant difference versus the Legacy Straight Contoured Zirconia with a titanium connection.

When all 3D displacements were put together into an actual 3D distance traveled by the abutments, only the Atlantis Titanium abutment had a significantly greater overall movement compared to some other

abutments. In fact, the overall distance traveled by the Atlantis Titanium abutment was significantly greater than six of the other eight abutments studied. It was a combination of translation and rotation; however, the movement was primarily translational. Furthermore, the Atlantis Titanium abutment also had the largest confidence interval, which may suggest issues with machining tolerance, consistency, quality control, and—potentially—embedment relaxation. It is interesting to note that the second torque actually moved the Atlantis Titanium abutment back toward its original hand-tightened position, which may again be related to machining tolerance, consistency, and quality control. To reduce the displacement caused by the initial torque, it may be necessary to torque Atlantis Titanium abutments a second time after seating in the mouth.

A study of Guichet et al¹⁹ evaluated the relationship between marginal gap and stress for cemented and screw-retained restorations. They reported higher marginal gap values and less strain with cemented restorations after luting, compared to low marginal discrepancy and higher stress induced for screw-retained restorations after the prosthesis screws were tightened. The existence of cement might have caused some seating issues, resulting in marginal gaps, according to the authors of this study. The increase in marginal opening seen with cementation was reported to be associated with less stress generation in the bone model with the cement-retained group.¹⁹

In present study, after torquing and re-torquing, abutments for cement-retained restorations showed displacement, although this was small in magnitude, which could result in marginal discrepancy of crowns and/or fixed partial dentures before, and particularly after, cementation. However, regarding stress, this situation may help decrease stress around the implant and surrounding tissues.

The larger displacements measured in this study may indicate potential instability in the implant-abutment connection. Other studies have shown a direct correlation between hexagonal misfit and screw joint loosening and indicated that a rotational misfit of less than 2 degrees would provide the most stable and predictable screw joint.^{20,21} Future studies are needed to determine the degree of joint misfit, including scanning electron microscope analysis of the implant/abutment connection, strain analysis with off-axis loading, and cyclic loading tests, and evaluate joint stability.

CONCLUSIONS

Re-torquing of nine different name-brand and after-market abutments after a 10-minute interval led to small amounts of displacement between the

abutments and a Tapered Screw-Vent implant. However, the Atlantis Titanium (an after-market abutment) displaced more than a name-brand abutment (Zimmer Hex-Lock Contour) and the Inclusive Custom Zirconia (another after-market abutment). In addition, re-torquing of the Atlantis Titanium abutment resulted in displacement in the opposite direction versus the initial torque displacement. The displacement values of the remaining after-market abutments were similar to those of the name-brand abutments after re-torquing. Therefore, clinicians should take into consideration the potential effect of embedment relaxation when selecting an abutment for a cement-retained crown on a Tapered Screw-Vent implant. Accordingly, clinicians may benefit from making interproximal and occlusal adjustments of cement-retained implant crowns after re-torquing the abutments to prevent potential occlusal and interproximal contact problems.

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