Axial Displacement in Cement-Retained Prostheses with Different Implant-Abutment Connections

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Purpose: The purpose of this study was to evaluate axial displacement in cement-retained prostheses using computer-aided design/computer-aided manufacturing (CAD/CAM) abutments with three different types of implant-abutment connections. Materials and Methods: CAD/CAM abutments made with two types of titanium blocks (made by the same manufacturer as the implant manufacturer and by a manufacturer with a patent for CAD/CAM abutment fabrication) were connected with three types of implant connections: external, internal butt, and internal conical connection. Titanium custom abutments and zirconia prostheses were fabricated using the CAD/CAM system for each specimen. The geometries and surface morphologies of CAD/CAM abutments and ready-made abutments were comparatively evaluated using scanning electron microscopy. Cemented prostheses on abutments were mounted on a universal testing machine and subjected to 250-N sine wave cyclic loads. Cumulative axial displacement was measured at 3, 10, 100, and 10⁶ loading cycles and analyzed by repeated measures analysis of variance (ANOVA). Results: Surface geometries and morphologies of CAD/CAM abutments varied by the implant-abutment connections and manufacturers of the titanium block. The internal conical connection exhibited the greatest axial displacement, while the external connection showed the lowest axial displacement. The CAD/CAM abutment made with a compatible titanium block exhibited a greater axial displacement than that exhibited by the abutment fabricated using a titanium block made by the implant manufacturer. Conclusion: In implant connections with a vertical stop, axial displacement occurred primarily in the early loading period and was self-limited. However, long-term axial displacement can occur with internal conical connection implants. Therefore, in internal conical connection implants, axial displacement should be managed more carefully using a provisional restoration, with consideration of the abutment fabrication method. Int J Oral Maxillofac Implants 2019;34:1098–1104. doi: 10.11607/jomi.7387

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Axial displacement is a unique biomechanical feature of internal conical connection (ICC) implants. ICC abutments lacking structures for a vertical stop might sink axially into the inner surface of the implant. Axial displacement is caused by three factors: machining tolerance, settling, and wedge effects.1,2 Machining tolerance and the settling effect are inevitable phenomena in all implants. However, the wedge effect, which induces concentrated axial compressive force in the direction of abutment sinking, is observed only in ICC implants.3,4 Axial displacement of abutments causes several mechanical problems in the implant-abutment complex. Ricciardi Coppedê et al5 insisted that axial displacement caused a decrease in the reverse torque of the screw after cyclic loading in spite of the relatively high joint stability of ICC implants. It was suggested that screws in ICC implants should be retightened after functional
loading in order to prevent loosening of screws in the implant-supported prosthesis. Negative occlusion may also be caused by axial displacement. Abutment displacement leads to prosthesis displacement and, consequently, negative occlusion.

Prosthetic restoration for nonparallel implants using a screw-retained prosthesis is challenging. The use of a cement-retained implant prosthesis is becoming increasingly common in clinical procedures. Several studies have reported no significant differences between cement- and screw-retained restorations with regard to complications or implant survival.

Custom abutment fabrication using computer-aided design/computer-aided manufacturing (CAD/CAM) technology is an efficient method that can be used to overcome tilted implant placement or esthetic complications. With CAD/CAM abutments, a natural emergence profile and ideal retention form can be made easily. Moreover, titanium CAD/CAM abutments are highly biocompatible with soft tissue.

CAD/CAM abutments can be fabricated using different methods, one of which involves milling of a titanium block from the top to the implant-abutment connection. Another method involves milling of the upper part of a titanium block with a ready-made connection for improvement of fit. CAD/CAM abutments might have greater machining tolerance compared with ready-made abutments. Moreover, they possess less-controlled surface roughness. Kim et al found that compared with ready-made abutments, CAD/CAM abutments had an unfavorable fit and low screw-joint stability. Furthermore, Mattheos et al reported that an abutment made by an implant manufacturer fit more precisely than did two types of compatible abutments made by other manufacturers. Hence, differences in the fit of implant-abutment connection are expected to result in differences in axial displacement.

Three typical implant-abutment connections—external-butt (EXT), internal-butt (INT-Butt), and internal-conical connections (ICC)—have been known to provide satisfactory results in clinical practice. Differences in implant-abutment connection type have been known to result in variations in axial displacement. Although axial displacement in a screw-type prosthesis has been reported previously, information regarding axial displacement in a CAD/CAM custom abutment with cement-retained prostheses is scarce. Furthermore, the axial displacement of cement-retained prostheses is expected to exhibit a complex pattern because the axial displacement can fluctuate depending on various conditions, such as cement type, abutment fabrication methods, and implant types. The purpose of this study was to quantitatively evaluate axial displacement in cement-retained prostheses with three different implant-abutment connections using CAD/CAM abutments made by two different manufacturers.

**MATERIALS AND METHODS**

**Specimen Preparation for Cyclic Loading**

Three implant-abutment connection systems were tested: EXT (Sola, Shinhung), INT-Butt (Stella, Shinhung), and ICC (Luna, Shinhung). In each group, two implant replicas were positioned 6 mm apart in a 15-degree convergent relationship within a type IV dental stone (GC Fujirock EP, GC Europe). The upper 3 mm of the implant-abutment connection was exposed (Fig 1).

All CAD/CAM abutments were fabricated with a titanium alloy (Ti-6Al-4V ELI, Dynamet) that exhibited hardness (Vickers: 341) and modulus of elasticity (113.8 GPa). The CAD/CAM abutment was made with two different titanium blocks that exhibited the same physical properties with a ready-made connection. One titanium block (SI, Shinhung) was made by an implant manufacturer, while another titanium block (DI, E-pros) was made by a manufacturer with a patent for CAD/CAM abutment fabrication. DI is a titanium block that has been approved by the ISO 13485 and is widely used. Because the SI block for INT-Butt was not made by an implant manufacturer, the SI block was only evaluated for EXT and ICC implants, while the DI block was assessed for all the connections.

Cement-retained prostheses were fabricated using zirconia (Zirkonzahn prettau, Zirkonzahn). All prostheses were fabricated using a CAD/CAM system (MS, Zirkonzahn) to conform to the following dimensions: 14-mm width, 25-mm length, and 13-mm height. Zirconia prostheses were sintered in the Zirconofen v600 furnace (Zirkonzahn) after CAD/CAM milling. The CAD/CAM data for CAD/CAM abutments and prostheses were duplicated for fabrication of 10 specimens in five groups (EXT with DI, EXT with SI, INT-Butt with DI, ICC with DI, and ICC with SI). For each group, 10 prostheses were prepared. Abutments and implant replicas were connected using a hand screwdriver; then, a 30-Ncm torque was applied using a digital torque gauge (SERIES TT03, Mark-10). For minimizing the chances of discrepancy in the assembly, all CAD/CAM abutments were luted using a provisional luting agent (Temp bond NE, 3M) before they were embedded in a type IV dental stone (GC Fujirock EP).

**Cyclic Loading**

Prostheses embedded in the master cast were mounted on a mechanical loading machine (ElectroPlus E 3000,
A testing device delivered dynamic loading forces between 20 and 250 N at 3 Hz for $10^6$ cycles. As an average of occlusal force for a fixed prosthesis supported by implants, 250 N axial loading was applied. After cyclic loading, axial displacement of the implant replica–abutment–prosthesis assemblies was measured using an electronic digital micrometer (No. 293-561-30, Mitutoyo). To enhance the reproducibility of measurement, the same measurement point was used as a standard.

**Evaluation of CAD/CAM Abutment Geometry and Surface Morphology**

The precisions of connections in implant replica–abutment assemblies for three types of implants were evaluated. Three types of abutments (ready-made abutment, DI, and SI) were connected to implant replicas. The geometry and surface morphology of the contact area between the implant and abutment were observed using scanning electron microscopy (SEM; VEGA, TESCAN).

**Statistical Analysis**

All statistical evaluations were performed using the SPSS software (SPSS 23.0, SPSS). Cumulative axial displacement into the implant replica was measured repeatedly at each step; an analysis was performed using repeated measures ANOVA. Scheffé’s multiple range test was used for post hoc comparison of selected pairs. Values of $\alpha < .05$ were considered statistically significant for all analyses.
RESULTS

The geometry (Fig 2) and surface milling patterns (Fig 3) of abutment connection varied by the types of abutments. CAD/CAM abutments have a geometry and milling pattern different from those of ready-made abutments. The precision of abutment connection varied with screw tightening and loading cycles. In ready-made abutments, screw tightening was sufficient for a precise implant-abutment assembly, while CAD/CAM abutments exhibited a precise assembly only after cyclic loading.

The results of axial displacement are presented in Tables 1 and 2. Different implant-abutment connection types exhibited significantly different axial displacement ($P < .05$). The EXT group (DI: $-5.7 \pm 1.8 \text{ µm}$, SI: $-4.5 \pm 1.5 \text{ µm}$) exhibited the least axial displacement after $10^6$ loading cycles ($P < .05$). Although the EXT group exhibited some axial displacement in the early phase of loading, the displacement gradually decreased with the increase in the loading cycle. In the INT-Butt group (DI: $-12.5 \pm 4.3 \text{ µm}$), most of the axial displacement occurred at the beginning of the loading cycle, and little difference was observed after 10 loading cycles. In comparison with the other two groups, the ICC group (DI: $-24.1 \pm 5.5 \text{ µm}$, SI: $-12.4 \pm 2.6 \text{ µm}$) demonstrated greater axial displacement after $10^6$ loading cycles ($P < .05$). Upon cyclic loading, the ICC group exhibited continuous axial displacement, which gradually declined with the increase in the loading cycle.

The type of CAD/CAM titanium block has a significant effect on the axial displacement ($P < .05$). In the EXT and ICC implant connections, the DI group exhibited a greater axial displacement compared with the SI group after $10^6$ loading cycles. Implant connection type exhibited a significant interaction with the abutment ($P < .05$). The difference in the axial displacement between the DI and SI groups was the greatest in ICC implants ($11.7 \text{ µm}$); this was the greatest difference among all test conditions.

There were significant differences in axial displacement among the loading periods (all $P < .05$). The ICC implant group with DI abutment (12 µm) exhibited the greatest axial displacement in cycles 0 to 3. The INT-Butt implant group with the DI abutment (9 µm) also exhibited greater axial displacement. However, after 10 cycles, axial displacement in the EXT and INT-Butt implants was nearly negligible, regardless of abutment type (Fig 4).

DISCUSSION

This study aimed to evaluate axial displacement in cement-retained prostheses with three different implant-abutment connections (EXT, INT-Butt, and ICC) using CAD/CAM abutments made by two different manufacturers. The results revealed that the ICC and EXT groups exhibited the greatest and least degrees of axial displacement, respectively.

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Several recent studies have reported that a considerable amount of axial displacement in ICC implants was caused by a conical connection without a vertical stop.\textsuperscript{1,2} The INT-Butt system used in this study has a coronal bevel structure on the top of the implant, which can vertically support the abutment. Although the connection structure of the INT-Butt system has a vertical stop similar to that in the EXT connection system, the INT-Butt group exhibited a significantly greater axial displacement compared with the EXT group. This result cannot be explained by the wedge effect within the implant-abutment connection. Differences in machining tolerance and microgap originating from the structure of the INT-Butt system may contribute to this result. Mettheos et al\textsuperscript{15} reported that an abutment made by an implant manufacturer has a more precise fit compared with other abutments made by different manufacturers with an INT-Butt connection. The connection structure of the INT-Butt group is more complicated than that of the EXT group, which has an outer bevel and an inner tapered part, along with an octagonal connecting structure. The complexity of the connecting structures might lead to an increase in the machining tolerance and microgap between components, which could lead to further axial displacement. Considering that the EXT group with a vertical stop presented the smallest axial displacement, it is expected that the axial displacement of the INT-Butt group can be improved if machining tolerance and surface roughness are carefully controlled.

The CAD/CAM abutments used in this study were fabricated from titanium blocks with ready-made connections. However, the precision of the connection in the assembly of the CAD/CAM abutments appeared to vary by the manufacturer of the titanium block. Geometry and surface morphology also differed by the manufacturer. These differences in precision and microgap can significantly affect the degree of axial displacement. CAD/CAM abutments fabricated by using the titanium block made by the implant manufacturer generally showed slight axial displacement compared with the compatible block. This phenomenon is not observed in screw-retained prostheses fabricated using the ready-made connection.\textsuperscript{1} A certain range of discrepancy in the assembly can be compensated by the axial displacement during screw tightening and functional loading. This phenomenon was also observed by evaluation via optical microscopy. However, considerably uncontrolled abutment fabrication may cause mechanical problems in clinical situations. The DI abutment is more likely to cause mechanical complications because the axial displacement of the DI abutment group was 1.5 to 2 times greater than that of the SI group. Even without mechanical complications, it needs more retightening procedures and a longer period of provisional restoration to acquire implant-abutment joint stability.

Internal gaps in the prosthesis can affect the degree of axial displacement. In this study, a provisional luting agent was used. A provisional luting agent has poor physical properties compared with other luting agent materials.\textsuperscript{19} If a provisional luting agent is used, it is expected to affect the axial displacement. However, the cement-retained prosthesis with EXT (DI group: \(-5.7\) µm, SI group: \(-4.5\) µm) exhibited an axial displacement similar to that of the screw-retained prosthesis \((2.7\) µm),\textsuperscript{1} which indicates that the internal gap in cement-retained prostheses was somewhat compensated by the luting agent.

The vertical vector of loading is related to the occlusal force. Maximum occlusal forces at the molars and premolars are known to be within the ranges of 300 to 500 N and 200 to 300 N, respectively.\textsuperscript{20,21} In this study, the prosthesis was subjected to a vertical load of 250 N, which has been reported to be the average occlusal force for fixed prostheses supported by implants.\textsuperscript{17,18} However, clinical overload due to gender-based differences and individual factors leads to greater axial displacements in some clinical situations.\textsuperscript{22–24} Considering the significant axial displacement of ICC regardless of abutment type, clinicians need to regularly examine occlusal contacts in patients with appropriate provisional prostheses. Additionally, retightening of the abutment screw and ensuring proper occlusion prior to placement of the definitive prosthesis are recommended.

Loading cycle is another influencing factor for the magnitude of vertical loading. A comparative study on the clinical situation during cyclic loading did not arrive at any conclusions in this regard. The functional loading cycle per year in the oral cavity has been reported to vary greatly, from 50,000 cycles to 800,000–1,000,000 cycles.\textsuperscript{25,26} In this study, the loading period of \(10^6\) cycles was selected to represent functional loading for approximately 10 months in the oral cavity, in order to allow comparison of the present and previous findings.\textsuperscript{1,2} However, most of the axial displacement occurred in the early stages of loading, which indicates that the abutments had mostly displaced into the implants in the early loading period. These results are similar to the results observed with screw-retained prostheses.\textsuperscript{1,2}

The axial displacement in the early loading stage compensated for the microgap and machining tolerance of the CAD/CAM abutments, which seemed to be a favorable effect. However, axial displacement of the ICC implants ceased much later in comparison with that in the other implant systems. Therefore, clinicians should use provisional restorations, especially in case of a cement-retained prosthesis for ICC implant placement. Nevertheless, the possibility of mechanical problems due to uncontrolled machining tolerance and
surface roughness of CAD/CAM abutments cannot be excluded. Because of their uncontrolled milled shape and surface differences at the implant-abutment connection, the INT-Butt prostheses exhibited some axial displacement despite their vertical stop structure in this study. If these factors are not controlled carefully, mechanical wear of the implant inner surface and elastic deformation of the coronal wall of the implant may be induced. Moreover, mechanical complications in the implant-abutment assembly can result in stress transfer to the surrounding bone.

CAD/CAM abutments for cement-retained prostheses in this study exhibited a greater axial displacement than did screw-retained prostheses in a previous study. The differences in the geometry and surface of CAD/CAM abutments, elastic deformation of prostheses, and insufficient splint effect provided by the cement-retained prostheses caused a greater axial displacement. However, axial displacement was self-limited owing to close surface contact with the settling effect, which compensated for the machining tolerance and stress resistance by the coronal wall of the implant after certain periods of cyclic loading. In clinical situations, axial displacement should be controlled by the use of provisional restorations with consideration for the type of implant connection and the fabrication method of the abutments.

Based on this result, EXT or INT-Butt implants are recommended for molar areas that are subjected to vertical force, because these implants exhibit a vertical stop and relatively minimal axial displacement. If the ICC is placed for surgical convenience and initial stability, an abutment with precise connection should be used. When using CAD/CAM abutments, it is especially important to use a titanium block produced by an implant manufacturer. Moreover, it is advisable to use a provisional prosthesis for a sufficient period of time and subsequently make a definitive prosthesis after axial displacement has become self-limited.

CONCLUSIONS

The morphology and surface geometry of the implant-abutment connection appear to vary by the CAD/CAM abutment manufacturing method. CAD/CAM abutments fabricated with a titanium block made by the implant manufacturer would be beneficial for achieving a stable connection. Axial displacement occurred mostly in the early cyclic loading periods. Axial displacement differed significantly by implant-abutment connection types. The ICC implant group exhibited the greatest axial displacement, while the EXT group exhibited the lowest.

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