An In Vitro Evaluation of Titanium, Zirconia, and Alumina Procera Abutments with Hexagonal Connection

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***Purpose**: The purpose of this study was to assess the precision at the implant interface of titanium, zirconia, and alumina Procera abutments with a hexagonal connection for single-tooth restorations.* ***Materials and Methods**: Twenty Procera abutments were produced with commercially pure titanium, 20 with zirconia, and 20 with alumina using computer-assisted design and manufacture (CAD/CAM). The rotational freedom of the abutments was assessed to detect the precision of fit of each abutment on the top of the implant hexagon.* ***Results**: Significant differences relative to rotational freedom were found between groups: the titanium group and the zirconia group did not differ significantly, but both demonstrated significantly smaller mean rotational freedoms than the alumina group (P < .05). Rotational freedom was less than 3 degrees for all abutments.* ***Conclusions**: The hexagonal misfit of the Procera abutment on the implant hexagon may be implicated in screw joint loosening. In the present study, all types of CAD/CAM Procera abutments consistently showed less than 3 degrees of rotational freedom in a situation where the abutment was connected to an implant by a hexagonal external connection.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:575–580

Key words: *abutments, hexagonal connections, single-implant restorations*

Single-tooth replacement with implant-supported crowns has become a routine matter at many clinics. Various studies have reported on the predictability of single implant restorations.[1–7] Prosthodontic restoration with cement-retained, implant-supported, single-tooth crowns may involve abutments made from several materials and directly connected to endosseous titanium dental implants. In single-tooth restorations, the UCLA abutment is widely used.[8–10] This abutment is designed to engage the implant directly and it is usually cast in gold alloys.[11] In 1990, Nobel Biocare (Göteborg, Sweden) developed the Procera system based on computer-assisted design and manufacture (CAD/CAM) technology.[12–14] Implant abutments created with the Procera system were introduced in 1998. Since Procera abutments can be made of commercially pure titanium, concerns about dissimilar metals and about interfaces between machined and cast components are eliminated.[15] Lang and colleagues[16] stated that the Procera titanium abutment and the Procera titanium abutment screw can be universally applied to different implant systems with external hexes of similar dimensions.

Restorations in the anterior esthetic zone present challenges in both the surgical and prosthetic phases of implant dentistry.[17–19] Full ceramic crowns may be the ideal choice to replace natural teeth in esthetic areas. The use of ceramics for both the abutment and crown would provide better translucency for the implant restoration than is obtainable with metal abutments and ceramometal crowns. Ceramic abutments would also be preferable to metal components because of the gray color that can be transmit-

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ted through the peri-implant tissues with metal components.[20] In 1994, the first esthetic ceramic abutment of dense aluminum oxide (Al_2O_3) was introduced (Cer-Adapt; Nobel Biocare). The problems presented by this abutment included its radiolucency and low fracture resistance.[21–23] Some in vivo studies have tested the clinical characteristics of these esthetic abutments.[24–26] The tested abutments were satisfactory, although the fractured CerAdapt abutments indicated that ceramic abutments were more sensitive to handling procedures than titanium abutments. One recently presented solution is the ZiReal abutment (3i/Implant Innovations, Palm Beach Gardens, FL),[19] which is composed primarily of high-strength zirconia ceramic (zirconium oxide [ZrO_2]), a radiopaque material with well-documented biocompatibility. The ZiReal abutment is designed to engage the implant directly with its machined titanium base. A recent study showed a high level of precision for this abutment.[27] The introduction of sintered Al_2O_3 or ZrO_2 Procera abutments based on CAD/CAM technology has provided new opportunities for single-tooth esthetic restorations.

The importance of absence of rotation at the implant-abutment interface has been highlighted by several studies.[28–30] The fit between the implant and the implant-supported prosthesis has been advocated as a significant factor in stress transfer, biologic response of the peri-implant host tissues, and mechanical complications in the prosthetic restoration. It has been suggested that the fit between the external hexagon of the implant and the internal hexagon of the abutment should permit less than 5 degrees of rotational movement to sustain a stable screw joint.[29,30] Vertical and horizontal misfit applies loads to various restorative components, the implant, and the bone.[31] It can result in loosening of the prosthesis-retaining screws, locking or fracture of the abutment-retaining screws, bone microfracture, zones of partial ischemia, crestal bone loss, and loss of osseointegration.[32] Despite various improvements in impression methods, transference, indexing to the master cast, and framework and definitive prosthesis fabrication, the prosthodontist is frequently faced with unstable screw joints, especially in partially edentulous and single-tooth applications.[33–35] Lack of precision may lead to micromovement, which can strip the implant hex. The amount of freedom between the implant hexagonal extension and the UCLA abutment counterpart has been evaluated in recent studies,[28–30] and a direct correlation has been established between the hexagonal misfit of UCLA abutments and screw joint loosening. In 1 study[11] it was shown that premachined 3i UCLA abutments subjected to casting with a high-fusing gold-palladium alloy and subsequently to porcelain baking did not demonstrate any significant alteration of the original measurements or rotational freedom of the interface surface of the abutment. In a recent study, 4 Brånemark System abutment designs (Nobel Biocare) were examined for fit between the internal hexagon of the abutment and the external hexagon of the implant.[36] The CeraOne, EsthetiCone, Procera titanium custom abutment, and AurAdapt all demonstrated a maximum amount of rotation of the abutment around the implant hexagon of less than 3.5 degrees, thereby satisfying the tolerance requirement suggested.[29,30] Little or no data have been published concerning Procera abutments with a hexagonal connection made from zirconia or alumina.

The following study was undertaken to assess the rotational freedom between the hexagonal extension of the implant and hexagonal counterpart of the abutment for Procera abutments made with different types of material (titanium, zirconia, and alumina).

MATERIALS AND METHODS

Abutment Preparation Procedures

Sixty standard external-hexagon analogs (Nobel Biocare) were embedded in sample cups with Sampl-kwick resin (Buehler, Lake Bluff, IL) and allowed to polymerize overnight. Subsequently, a machined base cylinder (Nobel Biocare) was fixed to the implant analog and wax was applied to build the abutment to full contour. The abutments were waxed to achieve a shape comparable to that corresponding to an average-sized central incisor aligned with the long axis of the implant (Fig 1). A silicone mold was fabricated and used to standardize the shape of all abutments during waxup. The patterns were then positioned in the Procera scanner (Nobel Biocare) to obtain digitally-scanned images of the waxed abutments. The resulting wire mesh digital design was reviewed on a monitor and sent electronically to the production facility (Nobel Biocare). Twenty Procera abutments were produced with commercially pure titanium, 20 were produced with zirconia, and 20 were produced with alumina.

Rotational freedom between the implant hexagonal extension and the abutment counterpart was measured using a custom-made apparatus similar to that described by Binon[28] (Fig 2). This apparatus has been used in previous investigations.[11,27] To summarize, a standard threaded 3.75 × 10-mm implant (Mk III, regular platform, 3.75 mm diameter, TiUnite; Nobel Biocare) was secured in the table base of the apparatus with a set screw, and the abutment was seated

Fig 1 Procera abutments in *(a)* titanium, *(b)* zirconia, and *(c)* alumina were prepared to achieve a shape comparable to that of an average-sized central incisor aligned with the long axis of the implant.

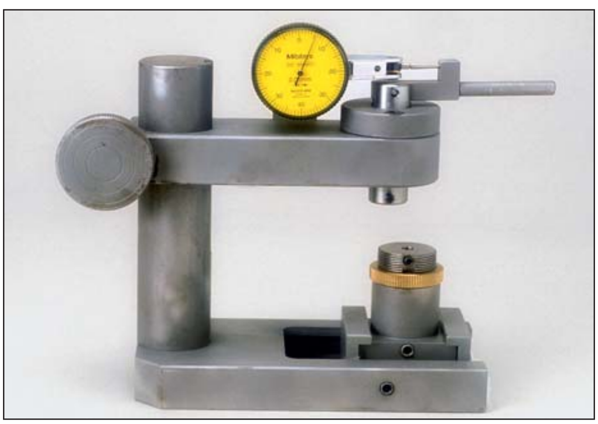

Fig 2 Custom-made apparatus used to assess rotational freedom at the implant-abutment interface. The needle pointer, with its clockwise and counterclockwise rotation, allowed rotational freedom to be recorded.

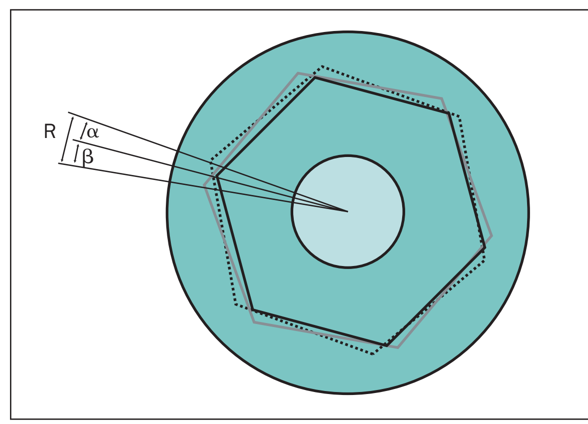

Fig 3 Diagram illustrating rotational freedom (R) between the hexagonal extension of the implant and Procera abutment counterpart. R represents difference between clockwise (α) and counterclockwise (β) rotation of the needle pointer attached to the Procera abutment collar.

on the implant and secured with the abutment screw in a manner that still permitted the rotation of the abutment. The clockwise and counterclockwise rotation of the needle pointer attached to the abutment collar was measured in minutes, and the difference between the 2 values was recorded as the degree of rotational freedom (Fig 3).

Statistical Analysis

Measurements of rotational freedom were compared between groups. Mean, minimum, maximum, and standard deviation were calculated for rotational freedom for each group. The Bartlett test was used to test the homogeneity of variances between groups, and the Kolmogorov-Smirnov test was used to test for normality.

Quantitative differences between the groups were assessed using analysis of variance (ANOVA), while pairwise comparisons between groups used Tukey's honestly significant difference method. *P* values less than .05 were considered significant.

RESULTS

Table 1 shows mean, minimum, maximum, and standard deviation relative to rotational freedom for each group. Means and standard deviations are also plotted in Fig 4. The Bartlett test was performed, and the homogeneity of variance was accepted for rotational freedom between each group, with $P > .5$. The distribution of rotational freedom for each material is shown in Fig 5.

The Kolmogorov-Smirnov test revealed that the normality of rotational freedom was accepted for all groups ($P > .3$ for the zirconia group, $P > .05$ for the titanium group, and $P > .4$ for the alumina group). Thus, 1-way ANOVA revealed quantitative differences of rotational freedom between the means of the 3 groups ($P < .001$). Tukey's honestly significant difference method was used for the pairwise comparison of groups. The zirconia group and titanium group were not significantly different; however, the mean rotational freedoms for both of these groups were significantly smaller than that of the alumina group.

Table 1 Rotational Freedom (min) for Each Material

Procera abutments	Mean	SD	Minimum	Maximum
Titanium	120.7	1.45	117	122
Zirconia	121.5	1.32	119	124
Alumina	123.8	1.70	121	127

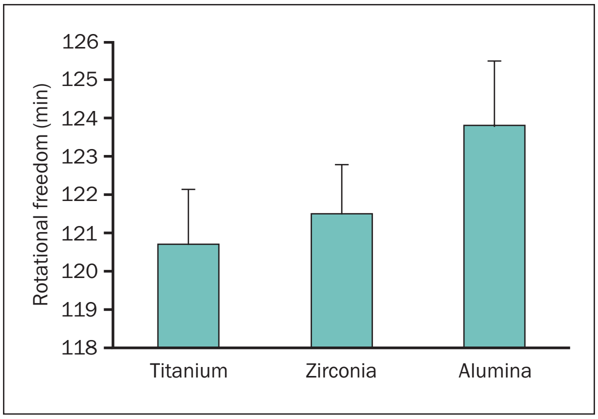

Fig 4 Mean rotational freedom in minutes for each material. Line extending from top of bar indicates standard deviation.

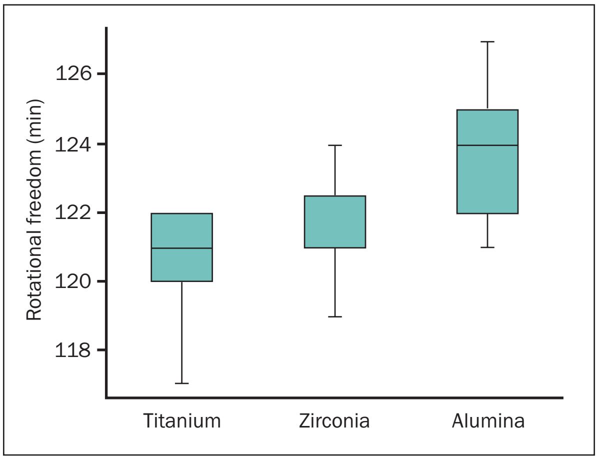

Fig 5 Box-whisker plot comparing rotational freedom in minutes for each material. Top and bottom of boxes show 75th and 25th percentiles. Top and bottom of whiskers depict maximum and minimum values. The horizontal line inside the boxes is the median value.

DISCUSSION

In single-tooth restorations, the adaptation of various abutments to implants has been evaluated in a limited number of studies. Some investigators have assessed the horizontal adaptation of different abutments to selected implants by evaluating the rotational freedom of the abutment on the implant hexagon.[29,30] These studies demonstrated a direct correlation between hexagonal misfit and screw joint loosening and indicated that a rotational misfit under 2 degrees would result in the most stable and predictable screw joint. Similar conclusions were drawn by Jörnéus and coworkers,[37] who concluded that screw joints could be made more resistant to screw loosening if elimination of rotational misfit could be eliminated.

Two previous studies evaluated the rotational freedom of 2 abutments commonly used in single implant restorations. One study suggested that subjecting premachined UCLA abutments to casting with a high-fusing gold-palladium alloy and subsequently to porcelain baking did not significantly alter the performance of the abutments or the rotational freedom between the abutment and the interfacing surface.[11] The 3i ZiReal abutment is an esthetic abutment composed primarily of high-strength zirconia ceramic (ZrO_2) and is designed to engage the implant directly with its machined titanium base. A previous study demonstrated that the ZiReal abutment laboratory preparation does not result in significant abutment-implant interface alterations.[27]

The introduction of the Procera system, based on CAD/CAM technology,[12–14] allowed the production of abutments made of commercially pure titanium, eliminating concerns about the use of dissimilar metals and about interfaces between machined and cast components.[15] The Procera system also allowed the production of sintered alumina and zirconia abutments, which have provided new opportunities for single-tooth esthetic restorations. This study was undertaken to assess the rotational freedom between the hexagonal extension of an implant and the abutment hexagonal counterpart for Procera abutments made with different types of material (titanium, zirconia, and alumina). The greater rotational freedom was demonstrated for all 3 types of Procera abutments compared to premachined UCLA abutments[11]; the rotational freedom demonstrated for Procera abutments was similar to that previously demonstrated for ZiReal abutments.[27] In any case, the rotational freedom of all 3 types of Procera abutments was consistently demonstrated to be no greater than 3 degrees. This should allow for a stable screw joint and may reduce the risk of screw loosening. The mean degree of rotational freedom was significantly different for the alumina group than for the other 2 groups; however, the clinical significance of this difference has not been demonstrated.

The biologic implications of misfit have been investigated for the most part in multiple-implant restorations.[35,38–41] The data presented in these studies did not establish a significant correlation between vertical misfit and marginal bone resorption or loss of osseointegration. For single-tooth implant restorations, the biologic consequences of a less than optimal fit in the vertical and horizontal dimensions have not been investigated. However, at the level of peri-implant soft tissues, misfit in subgingival locations, as in the case of Procera abutments, may result in bacterial aggregation with subsequent peri-implant inflammation. Verification of the horizontal and vertical fit of a Procera abutment directly to the implant shoulder at the level of the osseous crest in a clinical setting is difficult, since it cannot be visually or manually inspected, adequately checked with an explorer, or even assessed with radiographs, because minor discrepancies would not be discernible.[9] The application of disclosing media and other materials[42] can be difficult in subgingival locations and unreliable for evaluation of rotational freedom. Although the rotational freedom of restorations using Procera abutments can be measured in a laboratory setting using devices such as that introduced by Binon,[28] the reproduction of these measurements in actual clinical conditions may be more difficult. In the absence of simple and specific clinical fit evaluation methods, the recommendation is to use implant/abutment combinations that have demonstrated a good original fit in research quantitative tests and to apply laboratory techniques which would not introduce additional significant discrepancies at the implant-abutment interface.[43]

CONCLUSIONS

Hexagonal misfit of the Procera abutment on the implant hexagon may be implicated in screw joint loosening. This study suggests that all types of CAD/CAM Procera abutments consistently showed less than 3 degrees of rotational freedom between the implant and abutment in case of hexagonal external connection.

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