Effects of Implant Diameter and Prosthesis Retention System on the Reliability of Single Crowns

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Purpose: The probability of survival of implant-supported prostheses may be affected by the interplay between different implant diameters supporting screwed or cemented crowns. The purpose of this study was to investigate the effect of implant diameter and prosthesis retention system on the reliability and failure modes of single crowns. Materials and Methods: Internal-hexagon implants were divided into six groups (n = 21 each) according to implant diameter (3.3, 4.0, or 5.0 mm) and crown retention system (screwed or cemented). Abutments were torqued to the implants, and crowns were then fixed and subjected to step-stress accelerated life testing in water. Two-level probability Weibull curves and reliability for missions of 50,000 cycles at 100, 150, and 200 N were calculated. Failure analysis was performed. Results: Cemented systems presented higher reliability than screwed ones, except between 3.3-mm-diameter cemented and screwed systems at a load of 100 or 150 N. Failure modes were restricted to the abutment screw and varied with implant diameter only in the cement-retained groups. Conclusion: Higher reliability was observed for cement-retained crowns and implants of larger diameter compared to screw-retained and smaller diameter. Failure modes differed between groups. Int J Oral Maxillofac Implants 2015;30:95–101. doi: 10.11607/jomi.3545

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Clinical studies involving retrospective or prospective follow-up evaluations of dental implant rehabilitations have focused extensively on implant survival, especially on parameters including bone stability and peri-implant soft tissue health. The performance of different prosthesis systems and especially the mechanical complications related to the connection components (e.g., screw loosening or fracture) and veneering materials have been less explored. Recent systematic reviews of full-arch prostheses and single crowns reported that abutment screw loosening is the most common prostodontic complication. The calculated cumulative complication rate was 20.8% for full-arch prostheses, and the cumulative incidence of screw or abutment loosening was 12.7% after 5 years for single crowns.

Along with the plethora of implant-abutment connection designs available in the market, such as external hexagon, octagonal, internal cone, and Morse taper, the fixation modes of the implant-supported restoration can be either screwed, cemented, or a combination of both. Although these crown retention systems have been widely employed, there has been controversy regarding which design may provide not only a particular set of clinical advantages, but more important, improved mechanical and biologic performance.

The rationale for screw retention of restorations relies mainly on retrievability, which prevents the need to undertake complex procedures during prosthesis removal should maintenance, hygiene, repairs, or abutment screw tightening be required. On the other hand, cement-retained prostheses have been claimed to overcome the esthetic shortcomings of visible occlusal screw access holes and to improve...
occlusal contacts. In some situations, such as poorly aligned implants or limited occlusal space, cementation may be the only treatment option. Also claimed as an advantage is the more conventional manufacturing process that does not demand an opening on the porcelain and the substructure to enable abutment screw access. Disadvantages are that excess cement could lead to peri-implant soft tissue inflammation if not properly removed and that retrieval of cement-retained restorations may necessitate destruction of a restoration.

Previous research has shown that fatigue reliability is significantly improved by crown cementation, even with external-hexagon implant-abutment connections, where most of the stresses are borne by the abutment screw. Because an internal-hexagon connection is expected to result in improved reliability given that loading stresses are also dissipated within the implant walls, the additional variable of implant diameter—and consequently implant wall thickness—may also play a role in the reliability and failure mode of implant-supported crowns. As the implant diameter decreases, the integrity of the implant's internal walls may be challenged by fatigue, potentially resulting in fractures at the cervical area as the chief failure mode, especially when crowns are cemented. In addition to the failure modes of implants with different diameters when subjected to step-stress accelerated life testing (SSALT), the role of crown fixation mode (i.e., screw or cement retained) remains unclear when such interplay is considered. Therefore, this study was conducted to assess the reliability and failure modes of screw- and cement-retained implant-supported single crowns connected to implants with three different diameters when subjected to SSALT. The research hypotheses tested were: (1) crown fixation mode (screw or cement retained) will not result in different reliability within the same implant diameter; and (2) failure mode will not differ between screw- and cement-retained crowns, regardless of implant diameter.

**MATERIALS AND METHODS**

**Sample Preparation**

One hundred twenty-six titanium-aluminum-vanadium (Ti-6Al-4V) dental implants with an internal-hexagon configuration (Colosso ECI Evolution, Emflis Sistema de Implantte Iti, SP, Brazil) were divided into three groups (n = 42 each) according to implant diameter (3.3, 4.0, and 5.0 mm). Each group was then subdivided into another two groups (n = 21 each) according to crown fixation system as follows: group S3, 3.3 mm implant diameter (ECI 3310) and screwed crown; group C3, 3.3 mm implant diameter (ECI 3310) with cemented crown; group S4, 4.0 mm implant diameter (ECI 4010) with screwed crown; group C4, 4.0 mm implant diameter (ECI 4010) with cemented crown; group S5, 5.0 mm implant diameter (ECI 5010) with screwed crown; and group C5, 5.0 mm implant diameter (ECI 5010) with cemented crown. All implants were embedded vertically in acrylic resin (Orthoresin,Degudent), which was poured into a 25-mm-diameter plastic tube, with the implant platform left at the level of the resin surface.

Maxillary central incisor crowns were waxed up and cast in a cobalt-chrome metal alloy (Wirobond 280, BEGO). Impressions were taken of the waxed crowns to standardize the anatomy of both screwed and cemented crowns (n = 21 for each group) throughout the study. The internal surfaces of the crowns were designed to fit the screwed or cemented abutments. The proprietary prefabricated abutments were torqued to the respective implants with a torque gauge according to the manufacturer's instructions (30 N.cm). Subsequently, the internal surface of each cement-retained crown was sandblasted with 50-μm aluminum oxide (Al₂O₃) particles, cleaned with 100% ethanol, and dried with oil-free steam. They were then cemented with a self-adhesive dual-curing resin cement (Relinc X Uncem, 3M, ESPE) to their respective prefabricated abutments (CPPL 3314, 4014, 5014 Adjustable Standard Abutments, Emflis Sistema de Implantte). For the screw-retained crown groups (S3, S4, and S5), the abutments (CPTC 3304, 4004, 5004 Titanium Transmucosal Abutments, Emflis Sistema de Implantte) were tightened to their respective implants with a torque gauge (30 N.cm). Then a 10-N.cm torque was applied to tighten the crowns to their respective abutments.

**Mechanical Testing**

Three specimens of each group underwent single load to fracture (SLF) testing in a 30-degree off-axis loading orientation in a universal testing machine (Model 5666, Instron) equipped with a 10-kN load cell at a crosshead speed of 1 mm/min. The load was applied to the specimens at their incisal edge through a flat tungsten carbide indenter. The SLF test is conducted so that step-stress fatigue loading profiles can be designed. Based on the mean load to failure from the SLF results, three profiles for SSALT were established for the remaining crowns (n = 18 each group), which were randomly distributed as follows: mild (n = 9), moderate (n = 6), and aggressive (n = 3). The SSALT was carried out on a servo-all-electric system (TestResources 800L) underwater at 9 Hz. All samples were subjected to fatigue until failure (bending or fracture of the fixation screw and/or of the abutment or implant) or survival (no fracture at the end of step-stress profiles, where maximum loads were 500
The load was applied at the incisal edge of the crowns with a flat tungsten carbide indenter.

Use-level probability Weibull curves (probability of failure versus number of cycles) using a cumulative damage and power law relationship were calculated (Alta Pro 7, Reliasoft). The reliability (the probability of an item functioning for a given amount of time without failure) for completion of a mission of 50,000 cycles (using 90% two-sided confidence intervals) was determined for group comparisons. The reliability for the C3 and S3 groups was determined based on loads of 100 N and 150 N. For the remaining groups, loads of 100 N and 200 N were used to estimate the reliability. This difference in reliability calculations for only the greater loads (150 N and 200 N) was made on the basis of indications for small-diameter implants, ie, for areas where forces are of lower magnitude. If the use-level probability Weibull calculated beta (β) values were lower than 1 for any group, then a probability Weibull contour plot (Weibull modulus [m] vs characteristic strength [η]) was calculated using final load to failure or survival of groups (95% confidence intervals). Alternatively, Kruskal-Wallis along with Duncan’s multiple-comparison post hoc test at a 95% level of significance was carried out based on the load to failure of all samples tested, also under SSALT.

Failure Analyses
All specimens were first inspected under a polarized light microscope (M2-APO Stereomicroscope, Carl Zeiss Microimaging) to analyze and classify the modes of failure. Most representative failed samples were also imaged under a scanning electron microscope (SEM) (Model S-3500N, Hitachi) for qualitative fractography.

RESULTS
SLF and Reliability
The SLF mean values (± standard deviations) were 318.99 ± 139.67 N for C3, 489.41 ± 37 N for S3, 642.93 ± 188.88 N for C4, 569.47 ± 26.25 N for S4, 975.13 ± 190.77 N for C5, and 873.97 ± 159.26 N for S5. Abutment screw fracture was the only observed failure mode for all groups after SLF.

The plot and summary statistics for step-stress-derived use-level probability Weibull with use stress of 150 N are presented in Fig 1a and Table 1, respectively. The β value means (confidence interval bounds) derived from use-level probability Weibull calculations (probability of failure versus number of cycles) were 0.60 for C3, 3.29 for S3, 1.64 for C4, 0.59 for S4, 2.74 for C5, and 1.59 for S5. The resulting β values indicated that the fatigue was a strong accelerating factor for all groups, except for C3 and S4. The β value describes failure rate changes over time (β < 1: failure rate is decreasing over time, commonly associated with “early failures” or failures that occur because of egregious flaws; β > 1: failure rate is increasing over time, associated with failures related to damage accumulation; β = 1: failure rate does not vary over time, associated with failures of a random nature). Thus, the resulting β values for C3 and S4 indicated that, regardless of the step-stress level at which samples were fatigued, failures were associated with load (stress level) and that fatigue damage did not appear to accumulate.

As two groups showed β values lower than 1, the probability Weibull distribution was determined using fatigue load to failure data of the groups. The probability Weibull distribution presented values of 9.67 for C3, 10.24 for S3, 10.65 for C4, 5.5 for S4, 8.21 for C5, and 9.26 for S5. The highest η was 369.96 N, recorded for group C5. The Weibull parameter contour plot (Fig 1b) presents this information graphically and detects whether these data sets are from different populations (based upon nonoverlap of confidence bounds). The Kruskal-Wallis test showed that there were statistically significant differences between the evaluated groups (P < .0001). Overall, multiple comparisons between groups showed a statistically higher fatigue load to failure for the C5 group than for the other groups, and groups S3, C3, and C4 displayed statistically similar behavior (Fig 2).

The step-stress accelerated fatigue technique permits estimates of reliability at a given load level. The calculated reliability (Table 1) with 90% confidence intervals for missions of 50,000 cycles at 100-, 150-, and 200-N loads indicated that the cumulative damage for higher loads and smaller-diameter implant-abutment connections would lead to a lower survival, as well as for larger-diameter connections when screwed crowns were used. When pairwise comparisons between cemented and screwed crowns presenting the same diameter were performed, the cemented systems always presented higher reliability than screwed ones, except for the comparisons between C3 and S3 at a 100- or 150-N load (not statistically different). The calculated reliability was significantly higher for C4 than for S4 at the 100- and 200-N load levels and was also significantly higher for C5 than for S5 at 200 N (not different at 100 N). Conversely, C5 presented very close calculated reliability for load levels of 100 and 200 N.

Failure Modes
All specimens failed after SLF and SSALT tests. Failures comprised abutment screw fracture, regardless of crown fixation system. Failures of screw-retained crowns were mainly observed at the first or second thread, irrespective of implant diameter. The cemented crowns of groups C3 and C4 presented with abutment screw fractures located before the abutment screw...
Fig 1a Use-level probability Weibull showing probability of failure as a function of time.

Fig 1b Contour plot (Weibull modulus vs characteristic strength $\eta$ in N) for group comparisons. Note that there is no statistical difference where contour plots overlap.

### Table 1 Calculated Reliability for a Given Mission of 50,000 Cycles According to Load

<table>
<thead>
<tr>
<th>Result</th>
<th>C3 100 N</th>
<th>S3 150 N</th>
<th>C4 100 N</th>
<th>S4 150 N</th>
<th>C5 100 N</th>
<th>S5 200 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper bound</td>
<td>0.98</td>
<td>0.67</td>
<td>0.97</td>
<td>0.91</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.95</td>
<td>0.35</td>
<td>0.90</td>
<td>0.72</td>
<td>0.99</td>
<td>0.67</td>
</tr>
<tr>
<td>Lower bound</td>
<td>0.79</td>
<td>0.13</td>
<td>0.65</td>
<td>0.29</td>
<td>0.99</td>
<td>0.48</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.60</td>
<td>3.29</td>
<td>1.64</td>
<td>0.59</td>
<td>2.74</td>
<td>1.59</td>
</tr>
</tbody>
</table>

Fig 2 Mean load to failure values of each group. Different numbers of asterisks represent statistically significant differences in between group comparisons.

Fig 3 Polarized light micrographs showing the main failure modes for each group. Whereas screw-retained crowns presented similar fracture patterns, cemented crowns displayed failures at different loci of the abutment screw, especially in C5, where it chiefly occurred at the head of the abutment screw.

came into contact with the internal threads of the implant. Conversely, crowns in the C5 group depicted failures occurring at the head of the abutment screw (fracture), along with bending of both the screw and the antirotational mechanism of the abutment in some samples (Fig 3). No implants fractured during either SLF or SSALT.

SEM observation of the fractured abutment screws allowed for consistent identification of fractographic marks, including compression curl, beach and ratchet marks, which indicated the origins and nature (fatigue) of the fractures, as well as the direction of crack propagation (Figs 4 to 6).
DISCUSSION

The present study evaluated the reliability and failure modes of screwed and cemented implant-supported incisor crowns under SSALT of implants with different diameters. A general trend for better reliability of cement-retained prostheses on implants with larger diameter was observed. These findings reflected in a difference in failure modes: screw-retained prostheses, failing at lower loads during fatigue testing, presented with abutment screw fractures at the first or second thread, in contrast to cement-retained crowns, in which higher fatigue loads eventually led to failures at different loci, such as the head of the abutment screw. From a clinical standpoint, failure modes of either group could be considered repairable, since they did not affect the implant's integrity perse, as observed in previous fatigue studies. As a consequence, expected long-term maintenance of the investigated system would likely be limited to the prosthetic components.
Traditionally, the clinical decision to choose a screw- or cement-retained prostheses has been made on the basis of personal preference and clinical restraints, with negligible concern for the longevity of the restoration or its components. Typical advantages of screw-retained prostheses are retrievability and marginal integrity, with the disadvantages including the need for ideal implant placement and open screw-access holes that may interfere with occlusion, esthetics, and integrity of the porcelain veneer. Although some of these disadvantages may be overcome with cemented prostheses, cemented restorations also present some shortcomings that should not be overlooked, such as difficult retrievability and the need for extremely careful removal of excess cement. From a mechanical standpoint, the finding concerning higher reliability for cement-retained implant-supported prostheses compared to screw-retained prostheses has been previously reported in fatigue studies of the authors' group and was recently confirmed by a clinical study. In a split-mouth study, implant-supported screw-retained prostheses placed in the posterior arches and followed for up to 15 years showed remarkably higher complication rates than cemented prostheses in terms of fractures of the porcelain veneering material (38% vs 4%, respectively), abutment screw loosening (32% vs 9%, respectively), mean gingival index (0.48 vs 0.09, respectively), and mean marginal bone loss (1.4 mm vs 0.69 mm, respectively). Therefore, cement-retained prostheses are expected to present fewer complications, not only from a mechanical standpoint, but relevant biologic parameters also seem to be less strongly affected over the long term. In an extensive review, the survival of cement-retained single crowns was 93%, compared to 83% for implant-supported screwed crowns for follow-up periods commonly longer than 6 years.

In addition to fixation mode, different implant diameters influenced both the reliability and characteristic strength; this is shown clearly in the contour plot, in which the smallest implant (3.3-mm-diameter) was located in a significantly different position (nonoverlap between the contours) compared to the intermediate (4.0-mm-diameter) implants, regardless of retention system. Only the 5.0-mm-diameter screwed group overlapped both 4.0-mm-diameter groups as well as the 5.0-mm cemented group, meaning that survival is likely similar within the same populations, with no significant differences between them. On the other hand, unaltered (and the highest) reliability was observed for the 5.0-mm cemented group for simulations when loads were increased from 100 to 200 N, whereas a significant decrease in reliability was observed in the 5.0-mm screw-retained group for the same simulation. Such an observation may be a result of the increased internal wall thickness provided by the 5.0-mm-diameter implants, along with the reduced motion between the components, likely caused by the filling of the spaces between the crown and abutment in the cemented group.
Although it was not the aim of this study to perform quantitative fractography, a visually larger fast fracture zone was observed in the fractured abutment screws of the S3 group compared to the C3 group, according to the imaging results. Since the reliability and characteristic strength levels were not different between these groups, it is suggested that different fracture kinetics likely occurred for these systems. Another relevant fractographic mark consistently observed in the samples was the beach marks on the cyclically grown portion of the fracture; these are typical of failed metal surfaces subjected to varied load ranges, as occurring in chewing and simulated in SSALT fatigue blocks. Since the maximal bite force in the incisor area may vary from 108 to 190 N, the loads used for reliability calculation fell within the physiologic range, as did the resulting characteristic strength values for all groups.

CONCLUSION
The postulated hypothesis that crown fixation modes (screw or cement retention) would not result in different reliability within the same implant diameter was partially accepted. The second hypothesis was rejected, since failure modes differed between screw- and cement-retained crowns, irrespective of implant diameter.

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REFERENCES

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