Effect of implant connection and restoration design (screwed vs. cemented) in reliability and failure modes of anterior crowns


The mechanical performance of cemented or screw-retained implant-supported crowns with an internal or external configuration is yet to be understood. This in vitro study evaluated the effect of screw-retained and cement-retained prostheses on internal and external implant–abutment connections. Thereby, the reliability and failure modes of crowns were investigated. Eighty-four implants (Emfils; Colosso Evolution system) were divided into four groups (n = 21 each): screw-retained and internal connection (Si), screw-retained and external connection (Se), cement-retained and internal connection (Ci), and cement-retained and external connection (Ce). Ti-6Al-4V abutments were torqued (30 Ncm) to the implants, and maxillary central incisor metal crowns were torqued (30 Ncm) or cemented (Rely X Unicem; 3M-ESPE) and subjected to accelerated life-testing in water. Use-level probability Weibull curves and reliability for 50,000 cycles at 150 N were calculated. The β values for Si (1.72), Se (1.50), Ci (1.34), and Ce (1.77) groups indicated that fatigue/damage accumulation accelerated their failure. The Ci group presented the highest reliability, the Se group presented the lowest reliability, and Si and Ce groups presented intermediate reliability. Screw-retained restorations presented mainly abutment fracture. Cement-retained restorations resulted in failures of the screw in the Ce group, but implant/ screw fracture in the Ci group.

Single-tooth replacements in the anterior region using osseointegrated implants has become increasingly common in clinical practice, and the choice of the restorative components and the connection system between the implants and the restorations must be considered a paramount factor for long-term clinical success (1). In order to provide more predictable results regarding biological, mechanical, and aesthetic aspects, several connection designs (internal and external connections, for either screwed or cemented restorations) have been developed over the years.

However, the literature is still controversial concerning the choice of connection and/or crown-retaining system. The advantages of using cement-retained restorations, as given by several authors, were primarily aesthetics, passive fit of the crown, and the potentially improved load distribution during function (2–4). On the other hand, previous studies (5, 6) also highlighted the advantages of screw-retained restorations, such as their retrievability, making the evaluation of oral hygiene and peri-implant probing easier.

With respect to the implant–abutment connection configurations, different possibilities are also available, including the external and internal connections that are either screwed or interference-fit, or retained by a combination of both designs (7). Relative to external connections, the internal implant–abutment connections have been shown to present higher stability and improved force distribution as a result not only of their ability to dissipate lateral loads deeply within the implant, better shielding the abutment screw from stress, but also because of the longer internal wall engagement that creates a stiff, unified body to resist joint opening (micromovement) (8–11).

In vitro studies have shown improved mechanical behaviour for internal connections after cyclic loading relative to external connections (12–14). While mechanical strength is gained when internal connections are used vs. external connections, the thinner lateral fixture wall at the connecting part of internal connections may lead to a higher absolute strain value at the cervical area (13). Such stress shift has raised concerns regarding an increased risk of marginal bone resorption or fixture fracture (13).

Although different implant–abutment connections and restoration-retaining mechanisms have been used...
extensively in clinical practice, failures of implant–abutment connection present a relatively common clinical problem (15). The success rate for the implant-supported restorations was estimated to be 84.9% at 36 months of loading. The success rate was 88.6% for fixed dental prostheses and 86.4% for single crowns. The most common technical problems included screw loosening, screw fractures, and veneering material failures. Because mechanical complications comprised mainly screw loosening and screw fractures, it was suggested that the connection between the implant and the superstructure should be improved (16). In a systematic review that evaluated the 5-yr survival rates of implant-supported single crowns, it was observed, from the 26 clinical studies included, that the cumulative incidence of abutment screw or abutment loosening was 12.7% after 5 yr of clinical service in both external and internal connections (15).

The main challenge in the development of implant–abutment connection designs relies on reducing the incidence of mechanical failures while improving the soft/hard tissue and the prosthetic interface (12, 17, 18). Thus, evaluation of the reliability (the probability of an item functioning for a given amount of time without failure) (19–21) and the failure modes of currently used implant–abutment connections may provide insight into the mechanical behaviour of the different systems when used as single-unit anterior crowns. Therefore, the present study sought to evaluate the reliability and the failure modes of anatomically designed maxillary central incisor crowns by varying the configuration of the retention system (screw-retained or cement-retained restoration) and the type of implant–abutment connection (internal or external). The tested hypothesis was that different reliability and failure modes would be found for different implant–abutment connection designs used as anterior single-unit crowns when subjected to step-stress accelerated life testing (SSALT) (22, 23).

Material and methods

Sample preparation

Eighty-four CP Ti (grade II) dental implants (4 mm in diameter × 10 mm in length; internal and external connections) (Fig. 1A) (Emфils; Colosso Evolution System, Itu, SP, Brazil) were used. The type of retention system, the configuration of implant connection, and the dimensions are presented in Table 1 and Fig. 1B. For screw-retained restorations the abutment and screw were not detachable from each other. All implants were vertically embedded in acrylic resin (Orthoresin; Degudent, Mainz, Germany) poured in a 25-mm-diameter plastic tube, leaving the prosthetic platform at the same level as the potting resin surface. In the screw-retained and internal connection (Si) and screw-retained and external connection (Se) groups, a maxillary central incisor crown was waxed in an attempt to produce the best internal fit to the customized abutments. Following connection of the corresponding abutments (Ti-6Al-4V) and crowns (in the screw-retained groups) were torqued [30 Newton cm (Ncm)] to the prefabricated abutments. The Ti-6Al-4V abutment screw was tightened using a torque gauge (Nobel Biocare, Göteborg, Sweden), according to the manufacturer’s instructions (30 Ncm). Abutments (Ti-6Al-4V) and crowns were torqued only once before mechanical testing.

The crown morphology and dimensions designed for Si and Se groups were reproduced in the cement-retained and internal connection (Ci) and cement-retained and external connection (Ce) groups by customizing the abutments using a metallic matrix. A metallic matrix that fitted all abutments in both cement-retained groups was fabricated in order to standardize the shaping of the remaining abutment groups. The cement-retained crowns were waxed and cast in an attempt to produce the best internal fit to the customized abutments. Following connection of the corresponding abutment to implants (30 Ncm torque, as per the manufacturer’s instructions), the cementation surface of the crowns was blasted with aluminum oxide (particle size ≤ 40 μm, using 276 KPa compressed air pressure), cleaned with ethanol, dried with air free of water and oil, and then cemented (Rely X Unicem; 3M ESPE, St Paul, MN, USA). The final dimensions for both screw-retained and cement-retained implant-supported restorations were similar for all groups (Fig. 1B, bottom).

Mechanical testing and reliability analysis

For mechanical testing, the specimens were subjected to 30° off-axis loading (Fig. 1C). Three specimens of each group underwent single load-to-fracture (SLF) and 18 specimens by the technician as a guide during waxing of the remaining crowns. The crowns presented with a thickness of 1.4 mm, and their final dimension was 11 mm from cervical to incisal, 7.4 mm proximally, and 6.7 mm bucco-lingually. Crowns were then torqued [30 Newton cm (Ncm)] to the prefabricated abutments. The Ti-6Al-4V abutment screw was tightened using a torque gauge (Nobel Biocare, Göteborg, Sweden), according to the manufacturer’s instructions (30 Ncm). Abutments (Ti-6Al-4V) and crowns (in the screw-retained groups) were torqued only once before mechanical testing.

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Mechanical testing and reliability analysis

For mechanical testing, the specimens were subjected to 30° off-axis loading (Fig. 1C). Three specimens of each group underwent single load-to-fracture (SLF) and 18 specimens
were subjected to fatigue testing. Single load-to-fracture was performed at a cross-head speed of 1 mm min\(^{-1}\) in a universal testing machine (INSTRON 5666; Instron, Canton, MA, USA) with a flat tungsten-carbide indenter applying the load at the incisal edge of the crown. Based upon the mean load to failure from SLF, three SSALT profiles were determined for the remaining 18 specimens (Fig. 2) of each group, which were assigned to mild (n = 9), moderate (n = 6), and aggressive (n = 3) fatigue profiles (at a ratio of 3:2:1, respectively) (23–25). These profiles are named based on the stepwise load increase that the specimen will be fatigued throughout the cycles until a certain level of load is reached. It means that specimens assigned to a mild profile will be cycled for longer to reach the same load level of a specimen assigned to the moderate or aggressive profiles. The prescribed fatigue method was SSALT under water at 2 Hz using a servo-all-electric system (TestResources 800L; TestResources, Shakopee, MN, USA) where the indenter contacted the incisal edge, applied the prescribed load within the step profile, and lifted-off the incisal edge. Fatigue testing was performed until failure (bending or fracture of the abutment or crown screw, and/or bending, partial fracture or total fracture of the abutment) or survival (no failure occurred at the end of step-stress profiles, where maximum loads were up to 1250 N) (23, 25). Bending was determined when plastic deformation occurred in the abutment screw to an extent determined as failure. This failure was defined when the compressive displacement of the indenter surpassed the lower limit of the sample being tested (standardized in \(1 \text{ mm}\)), where the machine automatically halted testing.

Table 1

Description of the groups tested in the present study

<table>
<thead>
<tr>
<th>Groups</th>
<th>Si (n=21)</th>
<th>Se (n=21)</th>
<th>Ci (n=21)</th>
<th>Ce (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of implant–abutment connection</td>
<td>Screwed/internal (lot no. 1005153) Ø 4.0 mm per height = 4 mm, thickness = 1 mm Emfils, Colosso PTC body, Ti-6Al-4V (lot no. 081092)</td>
<td>Screwed/external (lot no. 100593) Ø 4.1 mm per height = 4 mm, thickness = 1 mm Emfils, Colosso body of Ti-6Al-4V transmucous pillar (lot no. 100127)</td>
<td>Cemented/internal (lot no. 1005153) Ø 4.0 mm per height = 8 mm, thickness = 1 mm Emfils, Colosso long body of adaptable standard pillar, Ti-6Al-4V (lot no. 1003232)</td>
<td>Cemented/external (lot no. 100468) Ø 4.1 mm per height = 8 mm, thickness = 1 mm Emfils, Colosso long body of adaptable standard pillar, Ti-6Al-4V (lot no. 100127)</td>
</tr>
<tr>
<td>Screw</td>
<td>Colosso Ti-6Al-4V fixation screw (lot no. 0907122)</td>
<td>Colosso Ti-6Al-4V fixation screw (lot no. 0907122)</td>
<td>Colosso Ti-6Al-4V fixation screw (lot no. 1005143)</td>
<td>Colosso Ti-6Al-4V fixation screw (lot no. 1005143)</td>
</tr>
</tbody>
</table>

Ce, cement-retained and external connection; Ci, cement-retained and internal connection; Se, screw-retained and external connection; Si, screw-retained and internal connection.

Statistical analysis

Use-level probability Weibull curves (probability of failure vs. cycles) with a power law relationship for damage accumulation were calculated (Alta Pro 7; Reliasoft, Tucson, AZ, USA) (26). Reliability (95% two-sided confidence bounds) for completion of 50,000 cycles at a 150 N (27) load was determined for group comparisons.

Failure analysis

Images of failed samples were taken using a macro lens attached to a digital camera (Nikon D-70s; Nikon, Tokyo, Japan) and utilized for failure mode classification and comparisons between groups. In order to identify fractographic markings and to characterize failure origin and propagation direction, the most representative failed samples of each group were inspected first under a polarized-light microscope (MZ-APO stereomicroscope; Carl Zeiss MicroImaging, Thornwood, NY, USA) and then by scanning electron microscopy (Model S-3500N; Hitachi, Osaka, Japan) (28).

Results

SLF and reliability

The mean ± SD SLF was 430.17 ± 50.22 N for the Si group, 526.9 ± 120.71 N for the Se group, 486.8 ± 51.78 N for the Ci group, and 468.8 ± 25.15 N for the Ce group.
lated reliability with 95% CIs for 50,000 cycles at 150 N of reliability at a given load level (Table 2). The calculations related to damage accumulation (23, 29, 30). The failure rate increases over time, associated with failures; \( \beta < 1 \): the failure rate decreases over time, commonly associated with ‘early failures’ or failures that occur as a result of egregious flaws; \( \beta \sim 1 \): the failure rate does not vary over time, associated with failures of a random nature; and \( \beta > 1 \): the failure rate increases over time, associated with failures related to damage accumulation (23, 29, 30).

The step-stress derived probability Weibull plots and summary statistics at a 150 N load are presented in Fig. 3 and Table 2, respectively. The \( \beta \) values and associated upper and lower bounds derived from use-level probability Weibull calculations (probability of failure vs. number of cycles) of 1.34 (0.80–2.10) and 1.77 (1.20–2.62) for screw-retained restorations (Si and Se groups, respectively), and \( \beta \) values of 1.72 (1.14–2.58) and 1.50 (0.96–2.35) for cement-retained restorations (Ci and Ce groups, respectively) indicated that fatigue was an accelerating factor for all groups. The \( \beta \) value describes failure rate changes over time (\( \beta < 1 \): the failure rate decreases over time, commonly associated with ‘early failures’ or failures that occur as a result of egregious flaws; \( \beta \sim 1 \): the failure rate does not vary over time, associated with failures of a random nature; and \( \beta > 1 \): the failure rate increases over time, associated with failures related to damage accumulation) (23, 29, 30).

The step-stress accelerated fatigue permits estimates of reliability at a given load level (Table 2). The calculated reliability with 95% CIs for 50,000 cycles at 150 N showed that the cumulative damage from loads reaching 150 N would lead to implant-supported restoration survival in 96% of cemented restorations over implants with an internal connection (group C), whereas only 6% would survive in group B (screwed restorations over implants with an external connection) when considering the given mission (50,000 cycles at 150 N). These values depict a statistically significant difference between Ci and Se groups. On the other hand, the overlap between the upper and the lower limits of reliability values in Si and Ce groups indicates no statistically significant difference. For the same mission (50,000 cycles at 150 N), survival rates of 64% of the specimens in the Si group and 76% of the specimens in the Ce group were observed (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Output (50,000 cycles @ 150 N)</th>
<th>Groups</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Si</td>
</tr>
<tr>
<td>Upper</td>
<td>0.80</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.64**</td>
</tr>
<tr>
<td>Lower</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Ce, cement-retained and external connection; Ci, cement-retained and internal connection; Se, screw-retained and external connection; Si, screw-retained and internal connection. The number of asterisks depicts statistically homogeneous groups.

Discussion

A slightly lower reliability was found for the Si group (0.64) than for the Ce group (0.76), although the results were not significantly different. However, the calculated reliability scores for the Si and Ce groups were significantly lower than for the Ci group (0.96) and significantly higher than for the Se group (0.06). It is possible that the improved stabilization of the implant/abutment/crown system provided by the increased internal surface area in the Si configuration was hampered by the presence of the second screw for crown retention and the reduced abutment height. When this fixation mode was
evaluated on an external hexagon, where the stabilization of the system is mainly held by the abutment and crown screws (Se) (14), the system resulted in the lowest reliability. Fixation of the crown with cement in the external hexagon configuration (Ce) significantly increased the reliability relative to Se, and two explanations may be given to account for this finding: (i) by eliminating the crown screw, only the longer, and probably more resistant, abutment screw was challenged by the fatigue-loading scenario; and (ii) the increased dimension of the abutment on the cemented crowns may have provided better support for load distribution (although the final system dimension and lever arm acting on the whole structure was the same for all groups). Such an assumption warrants future investigation. The extra screw component that adds to the number of parts requiring adequate fit/tolerance increases the likelihood and amplitude of the overall system motion between parts. In addition, the increased dimension of the abutment on the cemented crowns, and its intimate interaction with the crown as a result of cementation (minimizing or eliminating misfit and motion between parts), probably decreased the system’s susceptibility to cyclic loading.

For screw-retained restorations (Se and Si), the chief failure mode was the abutment screw fracture at the first abutment-screw thread region. Such failure probably occurred because bending was accentuated more in the region of the abutment screw threads than in the crown’s retention screw. However, because the abutment-screw threads that connect the abutment to the implant are one piece, it was considered an abutment fracture.

On the other hand, for cement-retained restorations (Ce and Ci), fracture at the first thread region of the abutment screw was the chief failure mode. A potential reason for the dominating abutment screw failure mode is the lever created during loading in the connecting region of the implant/abutment, creating stresses around the first abutment-screw thread region. Moreover, abutment screw fracture was associated with implant fracture in the Ci group, but not in the Ce group. Such a fracture was only observed for the Ci group, presumably because the cement-retained restoration associated with internal implant connection represented the strongest interlock between components among groups, as evi-

<table>
<thead>
<tr>
<th>Mechanical test procedure</th>
<th>Groups</th>
<th>Si</th>
<th>Se</th>
<th>Ci</th>
<th>Ce</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF (n = 3)</td>
<td>Screw 3 intact</td>
<td>Screw 3 intact</td>
<td>Screw 1 bending</td>
<td>Screw 3 bending</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abutment 1 bending</td>
<td>Abutment 3 fracture</td>
<td>Abutment 3 intact</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 fracture (1st thread)</td>
<td>3 fracture (1st thread)</td>
<td>3 intact</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Implant 18 intact</td>
<td>Implant 18 intact</td>
<td>Implant 18 intact</td>
<td>Implant 18 intact</td>
<td></td>
</tr>
<tr>
<td>SSALT (n = 18)</td>
<td>Screw 16 intact</td>
<td>Screw 17 intact</td>
<td>Screw 15 fracture</td>
<td>Screw 17 fracture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 fracture (1st thread)</td>
<td>1 fracture (1st thread)</td>
<td>2 fracture (head)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Abutment 16 fracture</td>
<td>Abutment 17 fracture</td>
<td>Abutment 18 intact</td>
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<td></td>
<td>(1st thread)</td>
<td>(1st thread)</td>
<td>(1st thread)</td>
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<td></td>
<td>2 intact</td>
<td>1 intact</td>
<td>1 intact</td>
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<td></td>
<td>Implant 18 intact</td>
<td>Implant 18 intact</td>
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<td></td>
<td>18 intact</td>
<td>18 intact</td>
<td>18 intact</td>
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</table>

Ce, cement-retained and external connection; Ci, cement-retained and internal connection; Se, screw-retained and external connection; Si, screw-retained and internal connection; SLF, single load-to-fracture; SSALT, step-stress accelerated life testing.

Fig. 4. Macro picture (A) and scanning electron microscopy micrograph (B) (30x magnification) of a fractured implant from the cement-retained and internal connection (CI) group. In all specimens, the fracture occurred at the buccal side.

Table 3
Failure modes after mechanical testing according to the failure criteria used
Fig. 5. Representative failure modes of screw-retained restorations observed in abutments after step-stress accelerated life testing (SSALT). (A) A fracture occurring at the first thread region viewed from the abutment's long axis. (B) Scanning electron microscopy micrograph (50× magnification) of the fractured surface of the sample shown in panel A. The white dotted arrows show a compression curl that provides evidence for the fracture origin at the opposing tensile side (large white arrow). Such a feature is representative of flexure failures and results from a travelling crack changing direction as it enters a compression field. The beach marks (yellow arrows) are semi-elliptical lines running perpendicular to the overall direction of fatigue crack propagation and marking successive positions of the advancing crack front, also indicating the direction of crack propagation (dcp) (black arrow). In a reverse-angle view (C) (45°) of the abutment it is possible to note some marks on the lateral surface (lingual side), indicating that the crack propagated from the lingual direction to the buccal direction. Similar fractographic markings, representative of the same travelling crack history, can be observed on the fractured surface of abutments from the screw-retained and external connection (Se) group (D,E,F) (50×). Si, screw-retained and internal connection.

Fig. 6. Representative failure modes of cement-retained restorations observed in retention screws after step-stress accelerated life testing (SSALT). (A) A fracture occurring at the first thread region. (B) A scanning electron microscopy micrograph (50× magnification) of the fractured surface of the sample shown in panel A. The yellow arrows (in panel A) show beach marks and the white dotted arrows show the compression curl. The large white arrow (fracture origin) at the opposing tensile side indicates the fracture origin and the direction of crack propagation (dcp) (black arrow) from the lingual direction to the buccal direction. The micrograph in panel C represents a higher magnification (500×) of the boxed area in panel B in a reverse-angle view. The dotted circle shows fine parallel marks indicating that two parts rubbed together during fatigue testing. The micrograph in panel D is a higher magnification (500×) of the fracture origin shown in panel B. (E) A representative image illustrating a fracture occurring between the sixth and seventh threads in a sample from the cement-retained and external connection (Ce) group. (F,G) Scanning electron microscopy micrographs of the fractured surface of the sample shown in panel E, illustrating the fracture origin (the larger white arrow), the compression curl (the white dotted arrows), and the direction of crack propagation (the black arrow) from the lingual direction to the buccal direction. The micrograph in panel H is a higher magnification (500×) of the boxed area in panel F, showing the fracture origin. Ci, cement-retained and internal connection.
denced by the significantly higher reliability. Thus, the implants from the Ci group were subjected to loads of higher magnitude and did not support the stress concentration at the implant’s neck area (13, 31). From a clinical perspective, the resulting failure mode involving implant fracture presents the only scenario where prosthetic replacement is no longer an option under the same support.

Considering that the reported maximal bite force in the incisor area may vary from 108 N (32) to 190 N (33, 34), the load used for reliability calculation fell within the physiologic range.

Our results showed higher fatigue endurance for cement-retained restorations, regardless of the configuration of implant connection, and are in contrast to those found by Zarone et al. (2007), who compared screw restorations and cement-retained restorations using implants restored with porcelain-fused-to-metal crowns. It should be pointed out that in their work all the samples failed by cohesive fractures of the porcelain veneer and not by implant component failure. In order to address the question of mechanical performance of cemented vs. screwed restorations in both external and internal connections, we utilized a metallic crown, which eliminated failure of the restorative crown material and permitted us to analyze the mechanical performance of the different groups.

Concerning the configuration of implant connection (internal vs. external), higher reliability was observed in samples with internal connection only when the screw was retained. It has been shown that deep joints favoured structural strength of implant systems (12, 14). The increased stability, and thereby improved stress distribution associated with lower micro-movements, were identified as the main reasons for the better mechanical behaviour of internally connected systems (13). It should be noted, however, that because of engineering design constraints, such as minimal wall thickness for proper mechanical performance, differences in both external and internal features of the implant, abutment, and screw designs existed. While from a research standpoint it is highly desirable that only the connection is changed (with the connecting screw and the implant remaining the same), such interplay is unfeasible when one is attempting to make clinically relevant comparisons (implants presenting the same diameter, length, and crown size) between external and internal connections in most commercially available systems. The reason is that alterations in the external shape of the implant are usually performed by manufacturers in order to maintain tolerances for appropriate fit and wall thickness to ensure internal connection robustness.

Based on fractographic features of failed specimens observed in polarized-light and scanning electron microscopy, all fractures were characterized by material tearing and exhibited gross plastic deformation, suggesting ductile fractures (35, 36). In a higher magnification of the fractured surface, fine parallel marks could be observed, indicating the smearing of the titanium alloy surface as a result of two parts rubbing together during fatigue testing (37). The ductile fractures caused by stresses exceeding the material yield strength left marks indicating crack propagation from the lingual to the buccal direction, where forces naturally occur.

The most common fracture-origin sites observed in fatigue are stress raisers, including porosity and voids, thread roots, sharp radii of curvature, through holes, and surface discontinuities (38). As per our imaging analysis, the threaded area of crown and abutment screws appeared to be more prone to fracture as a result of the presence of thread roots and surface discontinuities. Moreover, analyses of the sample’s fractured surface at higher magnifications showed a concentration of voids in the area of fracture origin. In an attempt to simulate the oral environment, the present study comprised fatigue in water, which has been suggested as an important service-related cause of failure in metals (38).

As the restoration of single-unit edentulous spaces in the anterior region with implant-supported crowns is a challenging scenario in terms of long-term success and aesthetics (39), it is crucial to acknowledge the functional and mechanical limitations of the implant-abutment connections (4). Therefore, further evaluations of the implant–abutment stability, combined with fatigue testing, are warranted. The postulated hypothesis, that different implant-abutment connection designs used as anterior single-unit crowns would result in different reliability and failure modes, was confirmed. Cement-retained implant-supported restorations with an internal implant connection showed the highest reliability between investigated groups after SSALT, while screw-retained restorations associated with an external connection resulted in the lowest reliability.

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