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Effect of microthread presence and restoration design (screw versus cemented) in dental implant reliability and failure modes

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Abstract

Objectives: This study evaluated the reliability and failure modes of implants with a microthreaded or smooth design at the crestal region, restored with screwed or cemented crowns. The postulated null hypothesis was that the presence of microthreads in the implant cervical region would not result in different reliability and strength to failure than smooth design, regardless of fixation method, when subjected to step-stress accelerated life-testing (SSALT) in water.

Materials and methods: Eighty-four dental implants (3.3 × 10 mm) were divided into four groups (n = 21) according to implant macrogeometric design at the cervical region and crown fixation method: Microthreads Screwed (MS); Smooth Screwed (SS); Microthreads Cemented (MC), and Smooth Cemented (SC). The abutments were torqued to the implants and standardized maxillary central incisor metallic crowns were cemented (MC, SC) or screwed (MS, SS) and subjected to SSALT in water. The probability of failure versus cycles (90% two-sided confidence intervals) was calculated and plotted using a power law relationship for damage accumulation. Reliability for a mission of 50,000 cycles at 150 N (90% 2-sided confidence intervals) was calculated. Differences between final failure loads during fatigue for each group were assessed by Kruskal–Wallis along with Benferroni's post hoc tests. Polarized-light and scanning electron microscopes were used for failure analyses.

Results: The Beta (β) value (confidence interval range) derived from use level probability Weibull calculation of 1.30 (0.76–2.22), 1.17 (0.70–1.96), 1.12 (0.71–1.76), and 0.52 (0.30–0.89) for groups MC, SC, MS, and SS respectively, indicated that fatigue was an accelerating factor for all groups, except for SS. The calculated reliability was higher for SC (99%) compared to MC (87%). No difference was observed between screwed restorations (MS – 29%, SS – 43%). Failure involved abutment screw fracture for all groups. The cemented groups (MC, SC) presented more abutment and implant fractures. Significantly higher load to fracture values were observed for SC and MC relative to MS and SS (P < 0.001).

Conclusion: Since reliability and strength to failure was higher for SC than for MC, our postulated null hypothesis was rejected.

Dental implant success may be evaluated from both esthetic and mechanical perspectives. Considering that both are affected by the achievement and maintenance of osseointegration, (Abuhussein et al. 2010) macro and microstructure engineering parameters of the implant, such as shape, type of implant-abutment connection, presence of microthreads, thread design, and surface treatment have been described to influence interfacial interactions between implant and bone and hence the long-term success of osseointegration. (Shin et al. 2006; Piao et al. 2009)

The use of microthreads in the crestal portion of the implant has been proposed as a bone-retention element to stabilize the peri-implant marginal bone. (Hansson 1999; Abuhussein et al. 2010) Animal experiments have demonstrated increased amount of mineralized bone in contact with the implant surface and well maintained marginal bone level around microthreaded implants compared to non-microthreaded implants. (Rasmussen et al. 2001; Abrahamsson & Berglundh 2006) Also, a 3-year prospective study revealed that the microthreaded implants might have an
effect in maintaining the marginal bone loss against loading in comparison to implants without microthreads. (Lee et al. 2007)

From a mechanical perspective, the effect of implant microthread has raised concerns regarding the system robustness (as wall thicknesses and other design parameters are altered relative to non-microthreaded designs) as well as stress distribution in bone and is yet to be characterized. Two-dimensional finite element analysis (2D-FEA) work has shown that microthreaded implant models presented greater stress at the crestal bone in comparison to the smoother design implant macrogeometry. (Schrotenboer et al. 2008) Recently, it has been shown that although peak principal stress values were higher around a microthreaded implant, peri-implant bone volume exhibited smaller strain level compared to a smooth implant. (Hudieb et al. 2011)

Among the prosthetic complications reported for implant-supported restorations, abutment screw loosening is the most common and presents a cumulative incidence of 12.7% after 5 years in both internal and external connections (Jung et al. 2008). In addition, the fixation mode (cemented or screwed) has shown to affect the mechanical performance of implant-supported restorations, where cemented crowns have shown improved reliability over screwed ones (Freitas et al. 2011). As to implant fracture rates, the 5-year cumulative incidence has been reported to be of 0.14% (Jung et al. 2008). Whereas the vast majority of clinical studies comprise evaluations up to 10 years (Zarb & Schmitt 1990; Naert et al. 1992; Pylant et al. 1992; Gunne et al. 1994; Henry et al. 1996; Leckholm et al. 1999), concerns toward the increase in implant fracture rates have been raised as a follow-up evaluation of 15 years, for instance, has shown an implant fracture incidence of 3.5% (Adell et al. 1981) in external hexagon connections. Therefore, fatigue seems to play a role in the long-term survival of the implanted device and potential changes in the macrogeometry aimed at improving the implant/bone interface should be carefully evaluated from a mechanical perspective. Thus, fatigue loading may be used to describe the reliability and failure modes of microthreaded implant designs relative to their non-microthreaded, smoother design counterparts. In addition, considering the fixation mode choices of screwing or cementing an implant-supported crown, evaluation of both scenarios on different implant macrogeometries is warranted.

This study aimed to evaluate the reliability and failure modes of implants with a microthreaded or smooth design at the crestal region, restored with screwed or cemented crowns. The postulated null hypothesis was that the presence of microthreads in the implant cervical region would not result in different reliability than smooth design, regardless of fixation method, when subjected to step-stress accelerated life-testing (SSALT) in water.

Materials and methods

Sample preparation

Eighty four grade 2 Ti dental implants (3.3 x 10 mm, Emfils, Colosso® Evolution system, Itu, SP, Brazil) with internal hexagon were divided into two groups (n = 42 each) according to the implant macrogeometry at the crestal region and subdivided in another two (n = 21 each) according to the crown fixation method: Microthreads Screwed (MS); Microthreads Cemented (MC) (CPTC-3304 - screwed) [Fig. 1a and b]; Smooth Screwed (SS) and Smooth Cemented (SC) [CPPL-3314 cemented] Fig. 1c and d). The description of the groups is provided in Table 1. All implants were vertically embedded in acrylic resin (Orthoresin, Degudent, Mainz, Germany), poured in a 25-mm-diameter plastic tube, leaving the top platform in the same level of the potting surface.

A maxillary central incisor crown was waxed to its close anatomical shape and cast in CoCr metal alloy (Cobalt-chrome partial denture alloy, BEGO, Bremen, Germany). To reproduce the anatomy of the crowns, an impression was taken from the first waxed pattern and used by the technician as a guide during waxing of the remaining crowns. The proprietary prefabricated abutments (Ti-6Al-4V) (Emfils, Colosso® Evolution system) were tightened with a torque gauge according to the manufacturer’s instructions (30 Ncm) using the respective Ti-6Al-4V abutment screws. Following connection of the corresponding abutment to implants, the cementation surface of the crowns was blasted with aluminum oxide [particle size ≤ 40μm, 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 screwed groups (MS, SS) had their crowns torqued to their abutments according to the manufacturer’s instructions (30 Ncm).

Mechanical testing and reliability analysis

For mechanical testing, the specimens were subjected to 30° off-axis loading. Three specimens of each group underwent single-load-to-failure (SLF) testing at a cross-head speed of 1 mm/min in a universal testing machine (INSTRON 5666, Instron Worldwide Headquarters, Canton, MA, USA) with a flat tungsten carbide indenter applying the load at the incisal edge of the crown. Based on the mean load to failure from SLF, three step-stress accelerated life-testing profiles were determined for the remaining 18 specimens of each group which were assigned to mild (n = 9), moderate (n = 6), and aggressive (n = 3) fatigue profiles [ratio 3 : 2 : 1, respectively]. (Hellsing 1980; Manda et al. 2009; Reliasoft 2011) These profiles are named based on the step-wise load increase that the specimen will be fatigued throughout the cycles until a certain level of load, meaning that specimens assigned to a mild profile will be cycled longer to reach the same load level of a specimen assigned to the aggressive profile (Abernethy 2006).

The prescribed fatigue method was step-stress accelerated life-testing (SSALT) under water at 9 Hz with a servo-all-electric system [TestResources 800L; TestResources Inc. Corporate Headquarters, Shakopee, MN, USA]. Fatigue testing was performed until failure [bending or fracture of the fixation 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 600 N]. [Nelson 2004; Coelho et al. 2009; Silva et al. 2009]
Table 1. Description of the groups tested in the present study

<table>
<thead>
<tr>
<th>Groups</th>
<th>MS (n = 21)</th>
<th>SS (n = 21)</th>
<th>MC (n = 21)</th>
<th>SC (n = 21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of implant</td>
<td>Microthreads/screw</td>
<td>Smooth/screw</td>
<td>Microthreads/cemented</td>
<td>Smooth/cemented</td>
</tr>
<tr>
<td>Abutment</td>
<td>Coloso body of titanium</td>
<td>Coloso body of titanium</td>
<td>Coloso long body of adaptable</td>
<td>Coloso long body of adaptable</td>
</tr>
<tr>
<td>Screw</td>
<td>transmucous</td>
<td>transmucous</td>
<td>standard pillar</td>
<td>standard pillar</td>
</tr>
<tr>
<td></td>
<td>Coloso fixation screw</td>
<td>Coloso fixation screw</td>
<td>Coloso fixation screw</td>
<td>Coloso fixation screw</td>
</tr>
</tbody>
</table>

Results

SLF and reliability

The SLF mean ± standard deviation values were 544 N ± 14 N for MS, 675 N ± 158 for SS, 356 N ± 164 for MC and 375 ± 43 for SC.

The step-stress derived use level probability Weibull plot and summary statistics at a 150 N load are presented in Fig. 2 and Table 2, respectively. The Beta [β] values mean [confidence interval range] and associated upper and lower bounds derived from use level probability Weibull calculation (probability of failure versus number of cycles) of 1.30 (0.76–2.22), 1.17 (0.70–1.96), 1.12 (0.71–1.76), and 0.52 (0.30–0.89) for groups MC, SC, MS, and SS, respectively, indicated that fatigue was an accelerating factor for all groups, except for group SS (Table 2). The resulting Beta [β] for group SS indicated that load alone dictated the failure mechanism for this group, and that fatigue damage did not appear to accumulate.

Load-at-failure data of the groups were then used to calculate a probability Weibull distribution. The probability Weibull distribution showed a mean of 12.3 for the group MS, m = 11.8 for the group SC, m = 10.5 for the group SS and m = 6.9 for the group MC. The characteristic strength was higher for SC (η = 246.2N) and MC (η = 238.6N) compared to SS (η = 174.9N) and MS (η = 174.9N). An instructive graphical method to determine whether these data sets are from different populations (based upon non-overlap of confidence bounds) is the utilization of a Weibull parameter contour plot (Weibull modulus (m) versus Characteristic Strength (η = Eta) as presented in Fig. 3. Kruskal-Wallis along with Benferroni post hoc test showed the same trend in load to failure analysis per group, where significantly higher load to fracture values were observed for SC and MC relative to MS and SS [P < 0.001]. No differences were detected between SC and MC, and MS and SS groups.

The step-stress accelerated fatigue permit estimates of reliability at a given load level (Table 2). The calculated reliability with 90% confidence intervals for a mission of 50,000 cycles at 150 N showed that the cumulative damage from loads reaching 150 N would lead to 99% implant-supported restoration survival in group SC, 87% in the MC group, 43% in SS, and 29% in the MS group.

Table 2. Calculated reliability for a mission of 50,000 cycles at 150 N load

<table>
<thead>
<tr>
<th>Output (50,000 cycles @ 150 N)</th>
<th>Microthreads screwed</th>
<th>Smooth screwed</th>
<th>Microthreads cemented</th>
<th>Smooth cemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>0.5011</td>
<td>0.6066</td>
<td>0.9452</td>
<td>0.9988</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.2949</td>
<td>0.4334</td>
<td>0.8738*</td>
<td>0.9929*</td>
</tr>
<tr>
<td>Lower</td>
<td>0.1155</td>
<td>0.2469</td>
<td>0.7240</td>
<td>0.9582</td>
</tr>
<tr>
<td>Beta (0.71–1.76)</td>
<td>1.12</td>
<td>0.52 (0.30–0.89)</td>
<td>1.30 (0.76–2.22)</td>
<td>1.17 (0.70–1.96)</td>
</tr>
</tbody>
</table>

*Represents statistically significant difference.
For the group MS and SS, failure predominantly involved abutment screw fracture whereas the abutments and implants remained intact after mechanical testing. For the MC and SC groups, the abutment, abutment screw and implant fractures were the main failure modes. The SC group had more abutment and implant fractures in comparison to the MC group (Figs 4–6 and Table 3).

Observation of the polarized-light and SEM micrographs of the fractured surface of the abutment screws allowed the consistent identification of fractographic markings, such as compression curl, and the identification of fracture origin, and the direction of crack propagation (Fig. 6).

Discussion

Considering the need to better understand the mechanical behavior of microthreaded implants relative to their non-microthreaded counterparts, the present study evaluated the reliability and failure modes of implant-supported anterior crowns screw or cement retained as a function of the presence of microthreads at the implant cervical region. The postulated null hypothesis that the presence of microthreads would not result in different reliability than smooth design, regardless of fixation method was rejected. Our results showed that only when crowns were screwed to their respective abutments the reliability was not affected by implant macrogeometry, being not statistically different for a mission of 50,000 cycles at 150 N between smooth and microthreaded implants. Conversely, the highest reliability values were observed for

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Microthreads screwed</th>
<th>Smooth screwed</th>
<th>Microthreads cemented</th>
<th>Screwed cemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF ($N = 3$)</td>
<td>Abutment screw: 3 bending</td>
<td>Abutment screw: 2 bending/1 fracture</td>
<td>Abutment screw: 1 bending/2 intact</td>
<td>Abutment screw: 1 bending/2 intact</td>
</tr>
<tr>
<td></td>
<td>Abutment: 3 intact</td>
<td>Abutment: 3 intact</td>
<td>Abutment: 3 intact</td>
<td>Abutment: 3 intact</td>
</tr>
<tr>
<td></td>
<td>Implant: 3 intact</td>
<td>Implant: 3 intact</td>
<td>Implant: 3 intact</td>
<td>Implant: 3 intact</td>
</tr>
<tr>
<td></td>
<td>Abutment screw: 18 fracture</td>
<td>Abutment screw: 18 fracture/1 bending</td>
<td>Abutment screw: 18 fracture</td>
<td>Abutment screw: 18 fracture</td>
</tr>
<tr>
<td></td>
<td>Abutment: 18 intact</td>
<td>Abutment: 18 intact</td>
<td>Abutment: 2 fracture/16 intact</td>
<td>Abutment: 8 fracture/10 intact</td>
</tr>
<tr>
<td></td>
<td>Implant: 18 intact</td>
<td>Implant: 1 fracture/17 intact</td>
<td>Implant: 2 fracture/16 intact</td>
<td>Implant: 4 fracture/14 intact</td>
</tr>
</tbody>
</table>

Table 3. Description of the failure modes of the groups tested
cemented crowns where the implant macrogeometry did affect the reliability of the system, being higher for the smooth design relative to the microthreaded. The present finding of higher reliability for cemented compared to screw retained crowns is in agreement with a previous study (Freitas et al. 2011) and potential reasons include: [1] when the crown screw is eliminated, only the longer and likely more robust abutment screw is challenged by fatigue loading, [2] the presence of the crown screw adds to the number of parts requiring appropriate fit and likely increases the amplitude of motion between connecting parts, [3] the presence of the cement between the crown and abutment increases the interaction due to the intimate contact created by the filling cementing media, which potentially reduces misfit and motion between parts. All these assumptions warrant additional investigation.

The abutment screw commonly failed during fatigue in most groups. However, the cemented groups [MC and SC] presented abutment and implant fractures not observed in the screwed groups, which indicate that a shift in biomechanical behavior and stress concentration may have occurred for these types of implant/restoration configuration. Because the load at failure was significantly higher \( P < 0.001 \) for the cemented groups, it is expected that more stresses are transferred to the implant, especially at the cervical region of internally connected abutments (Pessoa et al. 2010), potentially leading to failure. In contrast, when compared to an external hexagon connection, smaller amounts of shear stress are expected to occur at the cervical area of internal hexagon implants (Pessoa et al. 2010). From a mechanical standpoint, stabilization of either screw or cement-retained prostheses in external hexagon abutment connections is held by the crown screw and/or abutment screw, instead of between abutment screw, abutment, and internal walls of implant as in internal hexagon connections (Adell et al. 1981). Although implant fracture rates have been somewhat documented for external hexagon connections (Adell et al. 1981), information regarding internal connections effect on implant fracture is warranted in long-term clinical trials. As previously observed (Freitas et al. 2011), implant fractures are characterized by material tearing and gross plastic deformation (Parrington 2002) as a result of stresses exceeding the material yield strength. The fractographic marks commonly indicate crack propagation from lingual to buccal, where occlusal forces naturally occur.

Fatigue played little or no role in the failure of SS \( \beta < 1 \), as opposed to other groups where fatigue was an accelerating factor. Hence data replotted according to fatigue load at failure showed that the characteristic strength was higher for MC and SC compared to SS and MS \( \text{differences between groups supported by the Benferroni post hoc test} \). The Weibull modulus “m” is an indicator of strength reliability and/or the asymmetrical strength distribution as a result of flaws within the material (Ritter 1995). A higher “m” indicates smaller and/or fewer defects (greater structural reliability), and a lower “m” is evidence of greater variability of the strength, reflecting more flaws in the system, and a decrease in reliability (Ritter 1995). Therefore, although failing at lower loads during fatigue, the screwed systems seem to have failed in a consistent load range, which resulted in a higher m compared to the microthread cemented, for example.

Although the microthreaded design was considered as a retentive element reducing marginal bone resorption in clinical and animal studies (Palmer et al. 2000; Rasmusson et al. 2001; Zhao 2005; Hansson & Halldin 2009), from a mechanical standpoint, it presented lower reliability compared to the smooth implant when used in anterior cemented retained restorations according to the present study. Previous 2D-FEA demonstrated that the maximum von Misses stress was higher in the crestal bone around microthread implants. (Schrotenboer et al. 2008) Another study has shown lower compressive stress in the bone for microthread implants, but higher shear and tensile stress values in comparison to the smooth model. (Hudieb et al. 2011) However, it must be considered that the shape of the thread profile has an effect on the magnitude of the stress in the bone and that a bigger pitch seems to produce smaller peak bone stresses than the microthread [Hansson & Werke 2003]. Nevertheless, the latter simulation used only axial loading and the interface between bone and implant was also integrated. Therefore, future studies concerning the linear biomechanical analysis of the use of different microthread implants are warranted. Finally, to address the mechanical behavior of implants with and without microthreads either cemented or screwed, a full metal crown was chosen in an attempt to eliminate a confounding failure of the restorative crown material, i.e. the veneering porcelain.

Conclusion

Since the reliability and strength to failure was higher for Smooth Cemented than for Microthread Cemented group, our postulated null hypothesis was rejected.

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References


