A 10-year prospective study of ITI dental implants placed in the posterior region. II: Influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss

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Key words: cantilever, cemented, crestal bone loss, crown-to-implant ratio, implant biomechanics, implant–tooth connection, ITI dental implants, longitudinal study, non-submerged implants, partial edentulism, screw-retained

Abstract

Objective: To evaluate the influence of the crown-to-implant ratio (C/I) ratio and different implant prosthetic treatment modalities on crestal bone loss around dental implants placed in the posterior region.

Material and methods: A total of 192 ITI dental implants were consecutively placed in premolars and molars of 83 partially edentulous patients. All implants were restored by means of ceramic-to-metal fused fixed partial dentures or a single crown. Patients were followed as part of a prospective longitudinal study focusing on implant success. Surgical, radiographic and clinical variables were collected at the 1-year recall after implant placement and at the most recent clinical evaluation. Radiographic parameters were evaluated on periapical radiographs taken with a standardized long-cone paralleling technique. Implant restorations were divided into three groups according to their respective clinical C/I ratios: (a) 0–0.99, (b) 1–1.99 and (c) ≥ 2.

Results: The mean clinical C/I ratio was 1.77 ± 0.56 mm. A total of 51 implants (26.5%) showed a clinical C/I ratio equal to or greater than 2. In this group, three implants failed, giving a cumulative survival rate of 94.1%. Crestal bone loss was −0.34 ± 0.27 mm in group a, −0.03 ± 0.15 mm in group b and −0.02 ± 0.26 mm in group c. Differences among groups were statistically significant (P = 0.009). Mode of retention, splinting or presence of cantilever extensions did not have an effect on crestal bone loss around ITI dental implants.

Conclusions: Implant restorations with C/I ratios between 2 and 3 may be successfully used in the posterior areas of the jaw.

Implant-borne rehabilitations are a well-accepted treatment modality for the partially edentulous patient. Several studies have demonstrated the validity of dental implants for the rehabilitation of missing teeth in the posterior region [Buser et al. 1997; Eckert & Wollan 1998; Nedir et al. 2004; Glauser et al. 2005]. However, despite excellent implant survival rates, long-term studies show that a small group of implants – 20% – show annual crestal bone loss rates greater than 0.2 mm [Brägger et al. 1998; Carlsson et al. 2000; Hultin et al. 2000; Karoussis et al. 2004].

The relationship between crestal bone loss and non-axial loading has been observed in theoretical mathematical models [Weinberg & Kruger 1996], in vitro studies [Sertoz & Guvener 1996; Tashkandi et al. 1996; Yokoyama et al. 2004], animal stu-
The current study had two objectives: (1) to evaluate the influence of the C/I ratio on the long-term fixture survival rate and crestal bone loss around ITI dental implants placed in the posterior jaw, and (2) to evaluate the influence of different prosthetic treatment modalities [cemented vs. screw retention, cantilevered vs. non-cantilevered prostheses, splinted vs. single implants restorations and tooth–implant connections] on crestal bone loss around ITI dental implants.

Material and methods

Patient enrollment

A detailed description of the study design is available elsewhere (Blanes et al. 2007). In brief, between October 1989 and January 1996, 192 ITI dental implants were placed in the posterior jaws of 83 partially edentulous patients treated at the University of Geneva. All implants were part of a prospective clinical study on non-submerged ITI implants [Institute Straumann AG, Waldenburg, Switzerland]. For the purpose of this study, patients were selected according to the following inclusion criteria:

1. implants placed in the from October 1989 to January 1994;
2. partially edentulous patients;

![Fig. 1. Types of crown-to-implant ratio (C/I) ratios: anatomical C/I ratio and clinical C/I ratio.](Image)

![Fig. 2. Mechanism of action of anatomical crown-to-implant ratio (C/I) ratio-induced crestal bone loss: the occlusal activating force induces a bending moment, in which the anatomical crown length acts as a lever arm, causing crestal bone stress, which could eventually lead to crestal bone loss.](Image)
implants placed in the maxillary and mandibular premolar and molar regions;

implant designs: standard hollow-cylinder, standard hollow-screw, standard solid screw and narrow solid screw; and

implants restored by means of a fixed partial denture or single crown.

Radiographic peri-implant bone loss analysis

Radiographic variables were identified in standardized periapical radiographs taken by an experienced radiologist 1 year after implant placement and every 2 years, thereafter, using the long-cone technique and the Rynn system (XCP Instruments, Rinn Corporation Elgin, IL, USA). No further attempts were made for standardization. Radiographs were mounted on slides and projected on the screen with a magnification factor of $\times 13$. From the series of periapical radiographs taken during the longitudinal evaluation, the first year and the most recent radiographs were selected. The landmarks were taken twice, 1 week apart, by two examiners reaching consensus (Brägger et al. 1998). Linear distances between landmarks were measured in millimeters. The following linear measurements between landmarks were taken [Fig. 4]: (1) anatomical crown length (ACL; perpendicular distance from the implant shoulder to the most coronal aspect of the crown); (2) anatomical implant length (AIL; perpendicular distance from the implant shoulder to the most apical aspect of the implant); and (3) crestal bone level (CBLE; perpendicular distance from the implant shoulder to the first visible apical bone-to-implant contact in the mesial and distal aspects of the implant). Real measurements were calculated with the rule of three by using the real implant length or the distance between threads as the reference values. The following radiographic variables were calculated [Fig. 4]: (1) ACB/LE: average mesio-distal CBLE; (2) TCBL: total crestal bone loss [initial ACB/LE final ACB/LE]; (3) ABL: annual crestal bone loss [TCB/LE/months of follow-up $\times 12$]; (4) AC/I ratio: anatomical C/I ratio [ACL/AIL]; and (5) CC/I ratio: clinical C/I ratio [CCL [clinical crown length: the sum of the anatomical crown length plus the mean initial crestal bone loss]]/CIL [clinical implant length: the AIL minus the mean initial crestal bone loss)]. The precision of the radiographic measurements was calculated by comparing the values of the first and second radiographic readings. A total of 384 readings were performed when measuring the anatomical crown length. All paired measurements were within $\pm 0.25$ mm. The correlation between the first and the second measurements was $r = 1$ [Pearson’s correlation test].

Prosthetic procedures and modalities

A 3–6-month healing period was allowed before prosthetic loading. Rehabilitation of the posterior region consisted of 156 implants (81.2%) restored with implant-supported fixed partial dentures, 26 (13.5%) restored with single-tooth restorations and 10 (5.2%) with implant–tooth-supported fixed partial dentures. A total of 139 implants (72.3%) were restored without a cantilever extension. Twenty-two (11.4%) of the implants presented a half-tooth distal cantilever extension, while only 14 (7.2%) presented a one-tooth distal extension. Mesial extensions were present in 17 implants (6.9%). Cemented prostheses were utilized in 138 implants restorations (71.9%), while a screw-retained approach was used in 54 (28.1%).

Statistical analysis

Descriptive analysis – consisted of mean and standard deviation for all variables and each group. Comparative analysis – annual crestal bone loss was analyzed for different groups, classified by splinted/non-splinted implants, cantilevered/non-cantilevered implants and different C/I ratios. When the means of two groups were compared, a parametric unpaired $t$-test was utilized. However, if three or more groups were compared, the one-way parametric analysis of variance (ANOVA) test was applied. The non-parametric Wilcoxon’s test was used for two-group comparisons and the Krus-
Table 1. Annual crestal bone loss (ABL) with regard to the anatomical C/I ratio

<table>
<thead>
<tr>
<th>Anatomical C/I ratio</th>
<th>Number of implants</th>
<th>ABL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group a: &lt; 0.49</td>
<td>14</td>
<td>-0.21 ± 0.38*, †, ‡</td>
</tr>
<tr>
<td>Group b: 0.5–0.99</td>
<td>143</td>
<td>-0.02 ± 0.18</td>
</tr>
<tr>
<td>Group c: ≥ 1</td>
<td>35</td>
<td>-0.04 ± 0.17</td>
</tr>
</tbody>
</table>

*Kruskal–Wallis test for overall comparison P = 0.013.
†Crestal bone loss in group a > group b. Tukey's test; P = 0.002.
‡Crestal bone loss in group a > group c. Tukey's test; P = 0.015.
Groups were divided according to different C/I ratios.
C/I, crown-to-implant ratio.

Table 2. Annual crestal bone loss (ABL) with regard to the clinical C/I ratio

<table>
<thead>
<tr>
<th>Clinical C/I ratio</th>
<th>Number of implants</th>
<th>ABL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group a: &lt;0.99</td>
<td>8</td>
<td>-0.34 ± 0.27*, †, ‡</td>
</tr>
<tr>
<td>Group b: 1–2</td>
<td>133</td>
<td>-0.03 ± 0.15</td>
</tr>
<tr>
<td>Group c: ≥ 2</td>
<td>51</td>
<td>-0.02 ± 0.26</td>
</tr>
</tbody>
</table>

*Kruskal–Wallis test for overall comparison P = 0.001.
†Crestal bone loss group a > group b. Tukey’s test; P < 0.001.
‡Crestal bone loss Group a > group c. Tukey’s test; P ≤ 0.001.
Groups were divided according to different C/I ratios.
C/I, crown-to-implant ratio.

Table 3. Logistic regression analysis of annual crestal bone loss (ABL) with regard to clinical and anatomical C/I ratios

<table>
<thead>
<tr>
<th>Groups</th>
<th>Odds ratio</th>
<th>95% confidence bounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical C/I ratios</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low C/I ratio*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Medium C/I ratios</td>
<td>0.1695</td>
<td>0.1981E – 01</td>
</tr>
<tr>
<td>High C/I ratio</td>
<td>0.1334</td>
<td>0.1449E – 01</td>
</tr>
<tr>
<td>Anatomical ratios</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–0.49*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>0.5–0.99</td>
<td>0.6</td>
<td>0.15</td>
</tr>
<tr>
<td>≥ 1</td>
<td>0.82</td>
<td>0.17</td>
</tr>
</tbody>
</table>

*Group of reference.

Results

Implant survival

Fifty-one implant restorations (26.5%) displayed high clinical C/I ratios (CC/I ratio ≥ 2 mm). In this group, three implants failed after a period of 10 years, giving a cumulative survival rate of 94.1%. All failures were hollow-cylinder implants.

C/I ratio

Anatomical C/I ratio

The average anatomical crown length was 9.57 ± 2.6 mm, while the average anatomical implant length was 12.01 ± 1.17 mm. The majority of the implant restorations (74%) displayed an anatomical ratio ranging from 0.5 to 0.99.

Clinical C/I ratio

The mean clinical crown and implant lengths were 13.57 ± 2.73 and 8.01 ± 1.45 mm, respectively. The overall clinical C/I ratio at the first-year evaluation was 1.77 ± 0.56 mm. Fifty-one implants (26.5%) showed a C/I ratio equal to or greater than 2.

Correlation between crestal bone loss and C/I ratio

Anatomical C/I ratio

Implants with lower C/I ratios showed a statistically significant greater ABL (–0.21 ± 0.38 mm) than implants with higher C/I ratios (–0.04 ± 0.17 mm, Kruskal–Wallis test; P = 0.013, Table 1). Pearson’s correlation analysis revealed a statistically significant inverse relationship between anatomical C/I ratio and ABL (r = 0.2, P = 0.002).

Clinical C/I ratio

Comparisons among groups a (–0.34 ± 0.27 mm), b (–0.03 ± 0.15 mm) and c (–0.02 ± 0.26 mm) yielded statistically significant greater ABL in low than in high C/I ratios [Kruskal–Wallis test; P = 0.001, Table 2, Fig. 5]. Correlation analysis also showed a significant inverse relationship between the two variables [Pearson’s correlation test; r = 0.3, P = 0.001]. Logistic regression analysis showed that higher clinical C/I ratios demonstrated seven to eight times less risk for ABL than lower ratios; however, this risk was not statistically significant [Table 3].
Correlation between bone loss and different prosthetic treatment modalities (Table 4)

<table>
<thead>
<tr>
<th>Table 4. Annual crestal bone loss (ABL) with regard to different implant prosthetic treatment modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of implants</strong></td>
</tr>
<tr>
<td>Single-splinted restorations</td>
</tr>
<tr>
<td>Splinted-implant restorations</td>
</tr>
<tr>
<td>Single-implant restorations</td>
</tr>
<tr>
<td>Splinted tooth-implant restorations</td>
</tr>
<tr>
<td>Absence of cantilever</td>
</tr>
<tr>
<td>Small distal cantilever</td>
</tr>
<tr>
<td>Large distal cantilever</td>
</tr>
<tr>
<td>Mesial cantilever</td>
</tr>
<tr>
<td>Mode of prosthesis retention</td>
</tr>
</tbody>
</table>

Discussion

Our results indicate that both anatomical and clinical C/I ratios appear to have an inverse relationship with annual crestal bone loss. Specifically, implant restorations with high C/I ratios showed significantly less crestal bone loss than implant restorations with low C/I ratios. This finding seems to disagree with mathematical models indicating higher bending moments and greater possibility of bone loss around dental implants with long lever arms, as those present in high C/I ratio restorations (Rangert et al. 1997; Glantz & Nilner 2000).

The ITI dental implant system was designed to provide a more favorable C/I ratio than other submerged dental implant systems. Because the implant shoulder is placed 2.8 mm above the bone crest, the resulting clinical restoration displays a shorter crown and a longer implant than an implant restoration in which the implant shoulder is placed at the bone crest. If the implant shoulder is placed coronal to the bone crest, the lever arm of the bending moment (height of the crown) is then decreased, and the resulting crestal bone stress is diminished.

In our study, two different C/I ratios were established. In the anatomical C/I ratio, the fulcrum for the bending moment is located at the implant shoulder, while in the clinical C/I ratio, this fulcrum is placed at the most coronal bone-to-implant contact. As a result, the anatomical C/I ratio shows a lower lever arm, and theoretically, a more favorable biomechanical situation than the clinical C/I. However, and contrary to this hypothesis, the results of our study indicate that implant restorations with high C/I ratios (anatomical and/or clinical) display less crestal bone loss than implant restorations with short C/I ratios. These results contradict the concept that long crowns should be contraindicated in the posterior areas of the mouth (Rangert et al. 1997).

Our findings were tested with various statistical approaches, with consistency in all tests – comparative, correlative and logistic regression analysis – proving that the relationship established in this study between crestal bone loss and C/I ratio is reliable.

Our observations are in agreement with the findings of other animal (Celletti et al. 1995; Barbier & Schepers 1997) and human long-term implant studies (Lindquist et al. 1996; Wennstrom et al. 2004). In these reports, implants subjected to biomechanically unfavorable non-axial loading forces, similar to the forces observed in high C/I ratios, did not experience an increase in crestal bone loss. In fact, those implant restorations with higher C/I ratios showed a statistically significant lower crestal bone loss over time. This observation confirms the results reported in a previous longitudinal study, in which implants with C/I ratios between 1 and 3 did not affect crestal bone levels (Rokni et al. 2005). This finding may be explained by the stimulatory nature of bone stress. It seems that the stress concentration at the bone crest induced by the masticatory forces may stimulate bone formation around some fixtures, while in others it may induce bone loss. The threshold above which bone stress causes bone loss has not yet been clarified (Brunski 1999). However, some authors have suggested that this threshold may be genetically related (Rubin & McLeod 1990).

Although our study found an inverse relationship between C/I ratio and crestal bone loss, final conclusions should be made with reservations. Our sample included a wide variety of implant restorations, but it lacked extreme biomechanically unfavorable clinical situations. First, the number of cases with clinical C/I ratios greater than 3 was very low (4.2%). Second, most of the implant restorations were splinted (81.3%). It has been proposed that splinting of the implant restorations could provide a better distribution of the occlusal forces among the implants (Rangert et al. 1997). Consequently, most of the theoretically negative effect of the C/I ratio could have been diminished by the protective scenario provided by splinting the implants. As a result, further long-term clinical and radiographical research should be performed in order to understand fully the effects of the C/I ratio on the performance of dental implant restorations.

The results of our study indicate that crestal bone-level changes were not affected by different prosthetic treatment modalities, such as the use of cantilever extensions, the screw-retained approach, the connection between implants and teeth or the use of single-tooth restorations. The use of cantilever extensions on dental implants has been proposed since the early 1980s. Several authors have reported an
increased load on the fixture nearest to the cantilevered end, which could elicit crestal bone stresses around the distal fixture. This cantilever-induced crestal bone stress has been shown at different in vitro scientific levels [White et al. 1994, Sertoz & Guven 1996, Tashkandi et al. 1996, Yoykoyama et al. 2004]. Nevertheless, long-term clinical studies have demonstrated that the results observed in vitro cannot be extrapolated to the clinical scenario [Carlsson et al. 2000, Romeo et al. 2004; Wennstrom et al. 2004]. Our results corroborate these clinical observations and suggest that the use of one-tooth cantilevered extensions, either in the distal or mesial aspects of the implant restorations, does not influence crestal bone loss around dental implants and may be an excellent alternative to other surgical options, such as lateral ridge augmentations and sinus lift elevation, which require longer and more uncomfortable healing periods [Zijderveld et al. 2005].

Splitting multiple dental implants has been recommended in the prosthetic rehabilitation of implants placed in the posterior jaw in order to reduce load risk factors, and thus, crestal bone loss and component and metal fatigue [Rangert et al. 1997, Vanden Bogaerde et al. 2004]. However, the use of single units offers a more comfortable prosthetic approach: elimination of additional laboratory steps, better emergence profiles, improved passive fit of the metal framework and better oral hygiene access [Solnit & Schneider 1998]. Our observations corroborate the findings of other authors who suggest that single implant restorations could be a viable option for the rehabilitation of the posterior jaw [Henry et al. 1996, Scheller et al. 1998, Mericske-Stern et al. 2001; Fugazzotto et al. 2004; Glauser et al. 2005; Renouard & Nisand 2005].

The connection between implant and tooth has been used as a prosthetic alternative for the treatment of partial edentulousness in cases where anatomical limitations are present. Despite the early skepticism surrounding this prosthetic modality [Rangert et al. 1989], several longitudinal clinical studies have demonstrated that mobility differences between implants and teeth do not prevent a long-term successful outcome of a tooth-implant-supported fixed partial denture [Gunne et al. 1999, Hosny et al. 2000]. Our results seem to agree with the crestal bone changes observed in these studies. In our study, mean crest bone loss was greater around free-standing fixed partial dentures than around tooth-implant-supported restorations. This finding has been attributed to the presence of tactile and proprioceptive sensors in the periodontal ligament, which may restrict the amount of load applied to these implant restorations, and hence to the bone crest [Gunne et al. 1999].

Although cemented restorations have been associated with a more passive fit and better occlusion schemes [Misch 1993, Hebel & Gajjar 1997, Assenza et al. 2005], hence clinical comparison of crestal bone loss around cemented and screw-retained restorations has shown no difference in either mode of prostheses retention [Vigolo et al. 2004]. Our results corroborate this report and suggest that the theoretical biomechanical advantage of the cemented approach does not provide a better crestal bone stability over time.

In summary, implant restorations with high C/I ratios (C/I ratio ≥ 2) showed a cumulative survival rate of 94.1%. Consequently, and within the limitations of this study, we conclude that implant restorations with high clinical or anatomical C/I ratios do not demonstrate lower survival or success rates as compared with implant restorations with low C/I ratios. As a result, the use of implant restorations with C/I ratios of 2–3 may be successful in the posterior region of the mouth. Additionally, our results suggest that, from the point of view of crestal bone stability, the use of one-tooth cantilevered extensions, tooth-implant-supported fixed partial dentures, different modes of prosthesis retention or single-tooth restorations will not result in a greater risk of implant failure or crestal bone loss.

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References


Blanes et al. Crown-to-implant ratio and crestal bone loss