Change in Crown-to-Implant Ratio of Implants Placed in Grafted and Nongrafted Posterior Maxillary Sites: A 5-year Prospective Randomized Study

Rabah Nedir, DMD1/Nathalie Nurdin, PhD2/Guy Huynh-Ba, DDS, MS3/Mark Bischof, DMD4

Purpose: The aim of this study was to evaluate the performance of implants placed for 5 years in grafted vs nongrafted sinuses in relation to crown-to-implant ratio. The measurements of crown and implant lengths took into account changes in both endo-sinus and crestal bone levels over 5 years. Materials and Methods: Enrolled patients required one or two implants in at least one sinus and presented a residual bone height of posterior maxilla ≤ 4 mm. Individual sinuses were randomly allocated either to be grafted or not before surgery. Implants of 8 mm in length were placed using osteotome sinus floor elevation (OSFE). After 10 weeks of healing, they were loaded functionally using definitive single crowns. Radiographic measurements were made on periapical radiographs taken at surgery, prosthetic steps, and 5 years. The implant length was measured between the most apical and coronal contact of bone and implant, and the crown length was measured between the most occlusal point of the crown and the crestal bone. Data were analyzed using mixed linear models. Results: Twenty implants were placed in grafted sinuses and 17 in native bone (12 patients). One of the 35 restored implants failed. Immediately after surgery, the mean lengths of the implants placed in grafted and nongrafted sites were 2.4 ± 0.8 and 2.7 ± 0.9 mm, respectively (P = .351). At loading, the mean crown-to-implant ratios were 3.8 ± 0.8 and 4.6 ± 2.0 (P = .033), respectively, whereas at 5 years, they were 2.0 ± 0.8 and 2.1 ± 0.4, respectively (P = .341). Conclusion: The use of grafting material is not necessary to restore posterior maxilla ≤ 4 mm with OSFE and simultaneous implant placement. Over 5 years, all restored implants but one were functional. Despite unfavorable conditions in terms of initial bone anchorage and height of single crown restoration, a high initial crown-to-implant ratio did not compromise the long-term survival of implants placed in grafted or nongrafted sinuses. Int J Oral Maxillofac Implants 2019;34:1231–1236. doi: 10.11607/jomi.6766

Keywords: atrophic posterior maxilla, crown-to-implant ratio, dental implants, grafting material, osteotome sinus floor elevation, proximal bone-to-implant contact

The crown-to-root ratio is defined as the length of the crown from the most incisal or occlusal position to the crestal bone, divided by the length of the root in the bone. Where the height of the alveolar bone decreases, the harmful lateral forces acting on the coronal part of the tooth are greater. Although Ante postulated that "the total periodontal surface of the abutment teeth must equal or exceed that of the teeth to be replaced," the optimal ratio for a tooth used as an abutment for a fixed partial denture is 1:2. More frequently, it is approximately 2:3, with the minimal acceptable ratio being 1:1. From these principles, it has been deduced that the crown-to-implant ratio should not be greater than the crown-to-root ratio.

Implants ≤ 10 mm in length are frequently associated with lower levels of predictability than longer ones, particularly in posterior regions showing a low bone quality and height. Consequently, it is recommended that the bone should be augmented sufficiently for the placement of an implant ≥ 10 mm in length. However, the evolution of the design of the implants and surfaces has meant that limitations in length have been
overcome in augmented posterior maxillae.\textsuperscript{5} The use of an implant with a tapered shape and a reduced thread pitch can improve its primary stability and maintain the bone crest at the level of the machined-threaded junction of the implant, particularly in view of the limited bone support of the posterior maxillary regions.\textsuperscript{6}

One way of increasing bone height is via the osteotome sinus floor elevation technique (OSFE), which involves a crestal approach for elevating the sinus membrane and possibly filling using a grafting material. Implants can then be placed simultaneously.\textsuperscript{7–9} At the time of placement, the implants would then protrude into the sinus, especially when grafting material is not inserted.

In the present study, 8-mm-long tapered implants were placed using OSFE in extremely resorbed posterior maxillae in grafted or nongrafted sinuses.\textsuperscript{8} The initial maxillary residual bone height was ≤ 4 mm. Therefore, at least 4 mm of the implants placed were initially not encased in bone. The study investigated the changes in crown-to-implant ratio with increasing endo-sinus bone gain over time. The performance of the implants and their prosthetic restoration was assessed, from their loading to 5 years after treatment. It was hypothesized that an unfavorable initial crown-to-implant ratio and an absence of grafting material do not compromise long-term survival of implants in atrophic posterior maxillae.

\section*{MATERIALS AND METHODS}

\subsection*{Patient Entry}

The Ethics Committees of the Geneva and Lausanne University Hospitals (Switzerland) approved the study protocol (references 06-089 and 245/06). Criteria for patient inclusion were as follows:

\begin{itemize}
  \item Patients required 1 or 2 implants per sinus.
  \item Tooth extractions at the sites of concern were performed ≥ 4 months before surgery.
  \item Measurement of the initial maxillary bone height by panoramic radiograph was ≤ 4 mm.
  \item The sinuses were augmented using OSFE and grafted, or not, according to a randomized process.
  \item Tapered and hydrophilic-surfaced implants of 8 mm in length were placed.
  \item Wearing a removable partial denture during the healing period was not allowed.
  
  Exclusion criteria were active periodontal disease, metabolic bone disease, diabetes, or a history of acute or chronic sinusitis.\textsuperscript{8}

  If only one sinus could be treated, it was randomized by allocation of a sealed, independently prepared envelope attributing the procedure. If both maxillary sides were treatable, the randomization attributed one procedure to the right side, whereas the other procedure was applied to the left side.

\subsection*{Implant Placement and Prosthetic Restoration}

The procedures for implant placement and prosthetic restoration were described previously.\textsuperscript{8} Surgery was performed under antibiotic prophylaxis. Full mucoperiosteal flaps were elevated following midcrestal incision without vertical or periosteal releasing incisions. Access to the sinus floor was obtained by marking the cortical bone with round burs of 1.4 to 3.1 mm in diameter, as well as using an initial osteotome 2.8 mm in diameter (Straumann). The sinus membrane was elevated by tapping the osteotome lightly. An osteotome of 3.5 mm in diameter allowed enlargement of the osteotomy site. If the sinus was randomized to be grafted, it was filled with Bio-Oss (Geistlich Pharma). One or two implants (TE SLActive; length: 8 mm; smooth neck length: 1.8 mm; Straumann) were seated in the grafted or nongrafted site, up to the mesial and distal limits of the rough surface. Hence, the implant neck protruded above the bone crest. The implants were left to heal transmucosally and prosthesis-free for 8 weeks. An impression was then made, and single porcelain-fused-to-metal, screw-retained crowns were fabricated.

\subsection*{Clinical and Radiographic Controls}

Examinations took place after implant placement at 1 week (suture removal), 8 weeks (making of impression), 10 weeks (loading step), and at 1, 3, and 5 years. Implants were considered to have survived if they were still in the mouth and functional. Prosthetic complications were recorded including loosening of the crown or abutment, loosening of the screw, and fracture of the abutment and porcelain veneer.

Standardized periapical radiographs were taken without prosthesis immediately after surgery, at the prosthetic steps, and at 5 years.\textsuperscript{8} Three interthread distances were measured for internal calibration on each radiograph prior to analysis (2.4 mm). The implant length was defined as the part of the implant in contact with bone. It reflected the anchorage of bone and integrated changes in the endo-sinus and crestal bone levels (Fig 1).

Non-standardized periapical radiographs with prostheses in place were also obtained both at the prosthetic step and at 5 years (Fig 2). Internal calibration was performed on each radiograph by setting the total implant length to 9.8 mm. The crown length was the distance measured from the most occlusal point to the crestal first contact of bone and implant. The crown-to-implant ratio was obtained by the division of the crown length by the implant length.
Statistical Analysis
Radiographic measurements were presented with descriptive statistics and analyzed using mixed linear models. These models included a random effect for each patient and a fixed effect for the treatment group and year. The $P$ values took into account the random effects factor. The statistically significant threshold was set at $P < .05$.

RESULTS
Among nine women and three men (mean age $57.6 \pm 4.7$ years), the inclusion criteria were met at 32 molars and five premolars with residual bone height $\leq 4$ mm. Seven patients were treated in both sinuses (one sinus grafted and the other nongrafted) and a single sinus was involved in five patients. Twenty implants were placed in grafted and 17 in nongrafted sinuses. Antagonists in contact with the planned crowns were natural teeth or restored implants, and the indication for all patients except one was free-end edentulism. The patients did not wear night guards because none suffered from parafunction or muscular hypertrophy at the initial preoperative clinical examination.

Two implants that were placed in fused cortices showed mobility before the loading step and failed (patient 2, maxillary right first molar implant in grafted site; patient 12, maxillary left second molar implant in grafted site). Consequently, restorations were performed on 35 implants with single crowns. The mean healing time of the implants was $2.6 \pm 0.9$ months. One prosthetic complication, a ceramic fracture, occurred 2.5 years after loading (patient 7, maxillary right first molar implant in nongrafted site). In addition, the failure of that same implant occurred at 2.7 years because of the recurrence of periodontal disease that had been treated before implant placement. After 5 years, 34 of 35 restored implants survived without prosthetic complications.

Table 1 shows implant length, crestal bone level, crown length, and crown-to-implant ratio for each patient. Immediately after surgery, the mean lengths of implants placed in grafted and nongrafted sites were $2.4 \pm 0.8$ and $2.7 \pm 0.9$ mm, respectively. There was no significant difference between the grafted and nongrafted sites ($P = .351$). At loading, implant lengths were $3.7 \pm 0.8$ and $3.5 \pm 1.3$ mm in grafted and nongrafted sites, respectively ($P = .405$), while at 5 years, they were $7.0 \pm 1.1$ and $6.4 \pm 0.9$ mm, respectively ($P = .002$). The mean implant length increased significantly between

Fig 1. Measurements of crestal bone level and implant length on standardized periapical radiographs. Crestal bone level: Distance A, parallel to the implant axis and between the most coronal bone-to-implant contact and the most apical thread of the implant, was measured on both sides of each implant and averaged. A decrease in these mean values measured at loading and after 5 years was indicative of crestal bone loss (negative value). Conversely, an increase indicated crestal bone gain (positive value). Implant length: Distance I, between the most coronal and apical contact of bone and implant, was measured on both sides of each implant and averaged.

Fig 2. Patient 3. Radiographic evolution of crown length (C) and implant length (I) on nonstandardized periapical radiographs taken at (a) loading and (b) after 5 years.
At 5 years, 11 implants that were grafted and 4 implants that were not grafted showed at least one side that was embedded completely in newly formed bone.

The mean change in crestal bone level showed no significant difference between the implant groups ($P = .134$ at loading; $P = .527$ at 5 years). Furthermore, it did not change significantly between the time of loading and 5 years ($P = .696$).

The mean overall crown length was $13.4 \pm 1.3$ mm at loading and $13.5 \pm 1.4$ mm at 5 years ($P = .319$) without significant difference between grafted and nongrafted sites ($P = .686$ at loading and $P = .445$ at 5 years).

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Implant site</th>
<th>Implant length (mm)</th>
<th>Crestal bone level (mm)</th>
<th>Crown length (mm)</th>
<th>Crown-to-implant ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>After surgery</td>
<td>Loading</td>
<td>5 y</td>
<td>Loading</td>
</tr>
<tr>
<td>1</td>
<td>Grafted</td>
<td>5.1 3.1 3.3 2.6</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>14.8 14.9 15.1 15.1</td>
<td>4.5 5.0 5.0 5.0</td>
</tr>
<tr>
<td>2</td>
<td>Grafted</td>
<td>5.1 4.0 4.0 3.6</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>12.7 12.7 16.9 16.9</td>
<td>3.2 3.2 3.2 3.2</td>
</tr>
<tr>
<td>3</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>11.3 11.3 12.5 12.5</td>
<td>2.5 2.5 2.5 2.5</td>
</tr>
<tr>
<td>4</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>12.1 12.1 11.5 11.5</td>
<td>3.1 3.1 3.1 3.1</td>
</tr>
<tr>
<td>5</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>14.1 14.1 14.1 14.1</td>
<td>4.2 4.2 4.2 4.2</td>
</tr>
<tr>
<td>6</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.2 13.2 12.6 12.6</td>
<td>3.9 3.9 3.9 3.9</td>
</tr>
<tr>
<td>7</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>12.8 12.8 14.2 14.2</td>
<td>2.0 2.0 2.0 2.0</td>
</tr>
<tr>
<td>8</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.0 13.0 12.4 12.4</td>
<td>3.8 3.8 3.8 3.8</td>
</tr>
<tr>
<td>9</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.7 13.7 14.2 14.2</td>
<td>4.5 4.5 4.5 4.5</td>
</tr>
<tr>
<td>10</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.1 13.1 13.5 13.5</td>
<td>3.0 3.0 3.0 3.0</td>
</tr>
<tr>
<td>11</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.7 13.7 13.6 13.6</td>
<td>3.4 3.4 3.4 3.4</td>
</tr>
<tr>
<td>12</td>
<td>Grafted</td>
<td>5.1 2.4 2.1 2.1</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>14.5 14.5 14.5 14.5</td>
<td>2.9 2.9 2.9 2.9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>5.1 3.1 3.1 2.6</td>
<td>−0.1 −0.6 −0.9 −0.6</td>
<td>13.4 13.4 13.5 13.5</td>
<td>4.2 4.2 4.2 4.2</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>0.9 0.9 0.9 0.9</td>
<td>0.9 0.9 0.9 0.9</td>
<td>1.3 1.3 1.3 1.3</td>
<td>1.5 1.5 1.5 1.5</td>
</tr>
</tbody>
</table>

The mean overall crown length was $13.4 \pm 1.3$ mm at loading and $13.5 \pm 1.4$ mm at 5 years ($P = .319$) without significant difference between grafted and nongrafted sites ($P = .686$ at loading and $P = .445$ at 5 years).

Hence, at loading, the mean crown-to-implant ratios

*FDI implant numbering system. SD = standard deviation.
for implants placed in grafted and nongrafted sites were 3.8 ± 0.8 and 4.6 ± 2.0, respectively, with a range of 2.0 to 9.3 \((P = .033)\). At 5 years, they were 2.0 ± 0.8 and 2.1 ± 0.4, respectively, with a range of 1.4 to 4.8 \((P = .341)\). There was a significant difference in mean crown-to-implant ratio measured at loading and 5 years after placement \((P = .002)\). The mean decrease in crown-to-implant ratio was 1.7 for the grafted sites and 2.6 for the nongrafted sites. Seven implants placed in grafted sites and 10 in nongrafted sites presented a 5-year crown-to-implant ratio ≥ 2. Only two implants (patient 2, maxillary right second premolar implant in grafted site; patient 7, maxillary right second molar implant in nongrafted site) showed a large increase in crown-to-implant ratio between the prosthetic period and the 5-year control. These two patients showed a worsening of their periodontal condition, although they had been successfully treated prior to implant placement. The mean 5-year crestal bone loss around these implants was high: −4.3 mm for patient 2 and −1.8 mm for patient 7.

**DISCUSSION**

The present study provides an evaluation of the crown-to-implant ratio over 5 years after implant placement in grafted and nongrafted sites of the atrophic posterior maxilla. All patients were recruited using wide inclusion criteria, reflecting the usual current practice encountered in private dental offices. The protocol was tailored to serve the study, particularly by restoring implants with single crowns and by avoiding the placement of provisional restorations. An especially low range of residual bone height was set at ≤ 4 mm. No minimal height was considered. The purpose of this inclusion criterion was to evaluate the feasibility of OSFE in extreme cases. Although tapered implants were used to improve initial stability, two implants were mobile 1 to 2 months after placement and failed. These failures were attributed to the implant sites, composed of fused cortices, regardless of the presence of filling material.

The low residual bone height conferred an unfavorable initial crown-to-implant ratio (mean value: 4.2 ± 1.5). However, OSFE allowed the formation of bone within the sinus even where the site was not grafted. The mean gain in endo-sinus bone was 4.8 ± 1.2 mm in grafted sites after 5 years.10

Hence, the mean osseointegrated implant length was 2.0 ± 0.4 (range: 0.9 to 3.2) and 1.82 ± 0.42 (range: 1.04 to 3.31), respectively, for implants ≤ 8.5 mm long. The mean crown-to-implant ratio reported by Malchiiodi et al18 was 2.08 ± 0.80 (range: 0.95 to 4.80). It should be noted that no value was as high as that obtained in the present study at the time of loading. At 5 years, the values of crown-to-implant ratio were consistent with those found in the literature and could be considered promising for maintaining appropriate biomechanical conditions and implant function.

The posterior maxilla region may be at higher risk for implant complications because of increased occlusal forces. For this reason, implants ≤ 10 mm long have

---

**The International Journal of Oral & Maxillofacial Implants** 1235

© 2019 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY.
NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
been recommended only when two or more implants were placed and rigidly splinted by the restoration.19 However, implants with an internal conical interface were reported to improve marginal tissue response and resistance to micromovement under bending moments. With such a design and a rough surface, these implants could be suited to unsplinted restorations in posterior regions.20 The present study used implant-supported single crown restorations. In this case, stress was exerted individually on each implant without redistribution to adjacent implants, unlike with splinted restorations. The main reason for single-crown restorations was to measure the crown-to-implant ratio vs bone levels around each implant without any influence on adjacent implants. In the present study, no implant had preexisting adjacent dentition bilaterally, which may influence the distribution of the force and may be beneficial for the implant.21 All were multiple single implants. The regenerated bone within the sinus, grafted or not, was able to withstand masticatory strains exerted on the implant/single crown system. Among the 35 restored implants, only one prosthetic complication occurred in the present study. The relationships between the crown-to-implant ratio and complications of restorations have not yet been clarified.22,23

The main limitation of the present study was the low number of studied implants. Furthermore, study specifics were tailored to serve data analysis and to validate the objectives. They could serve as a model, to be used in conjunction with the technique of sinus elevation with osteotomes, but caution must be exercised before such a protocol can be brought into general use.

CONCLUSIONS

This study resulted in a high 5-year survival rate for restored implants placed in grafted and nongrafted maxillary sites with ≤ 4 mm residual bone height. Within the limitations of the study and despite the low initial bone-to-implant contact height, location (posterior maxilla), and use of nonsplinted restorations, no influence of the crown-to-implant ratio was observed. The mean initial crown-to-implant ratio was high, 4.2 ± 1.5 at the prosthetic step. After 5 years, it changed to 2.1 ± 0.6. The use of grafting material does not seem to be necessary to rehabilitate a severely atrophic posterior maxilla with OSFE and simultaneous implant placement.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the International Team for Implantology (ITI) Foundation for its financial support (grant no 428/2005). They have no conflicts of interest to declare.

REFERENCES