Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible: a 1-year multicenter randomized controlled trial

Endosseous titanium implants, from various implant systems, have presented high long-term survival and success rates. The use of short implants could fulfill various indications where there is insufficient bone volume and avoidance of bone augmentation or intraradicular sinus procedures are preferred. The survival rates of implants shorter than 10 mm seem to be comparable to the longer implants (Anitua & Gorka 2010; Annibali et al. 2012; Brocard et al. 1997; Buser et al. 1997; Fugazzotto et al. 2004; Pommer et al. 2011; Renouard & Nisand 2005; Tellemann et al. 2011). The possibility to restore the dentition without the need for significant presurgical augmentation should give widened treatment options and simplify implant rehabilitation. This may increase patient acceptance, make it available to more persons, and contribute to a better oral function and general health (Gerritsen et al. 2010). The restrictions of the use of longer endosseous oral implants are more common in the posterior regions of the maxilla and the mandible because of the lack of sufficient bone volume. In these situations, surgical modification by bone grafting techniques, inferior alveolar nerve transposition, or alveolar distraction can allow the placement of longer and wider implants. The adaptation of the implant to the existing anatomy through the use of shorter implants should now be considered as an alternative procedure, because of a reduction in the number of treatment procedures, treatment time, and morbidity. Although the survival rate of implants with a
length of 6 mm has been evaluated as comparable with that of longer implants in case series or cohort studies (Ten Bruggenkate et al. 1998; Rossi et al. 2010), a randomized controlled clinical trial has not been conducted yet. The present study was designed to compare treatment using 6 and 11 mm length implants (OsseoSpeedTM 4.0 S; Astra Tech AB, Malmö, Sweden) in the posterior maxilla and none of the exclusion criteria were opposite jaw.

The distribution of contacts with the teeth in the levers supported by two or three implants. The primary objective of this study was to compare marginal bone level alteration, by radiological assessments, after 1 year. The secondary objectives of the study were to evaluate implant survival, condition of peri-implant mucosa, pocket depth, adverse events, and adverse device effects within the first year.

Material and methods

The design was a randomized controlled multicenter trial. The primary outcome (the mean marginal bone level alteration per subject) was used to estimate the number of subjects needed to be randomized to test and control groups. The difference in bone level worth detecting between the two groups was considered to be 0.5 mm (Gröndahl et al. 1998). If the assumed standard deviation was 0.8 mm, then 41 fully evaluable subjects in each group were needed to achieve 80% power to detect a statistically significant difference (P < 0.05). Compensating for a withdrawal rate of about 20% requires 100 patients in total. Six study centers included patients up to a maximum of 33 participants per study site. At each center, only one clinician performed the surgery and clinical observations.

Randomization was performed using a block randomization sequence to provide equal distribution of subjects treated with 6 mm or 11 mm implants at each center. The randomization was performed at the time of surgery after flaps were raised by opening a sealed envelope containing the allocated treatment.

Subjects missing teeth in the posterior part of the maxilla or the mandible (premolar and molar region) were considered for treatment in the study. They were each provided with one fixed partial denture (FPD) without cantilevers supported by two or three implants.

The planned FPD should have an even distribution of contacts with the teeth in the opposite jaw.

Subjects fulfilling all of the inclusion criteria and none of the exclusion criteria were informed orally and in writing about the study and signed the informed consent form. All study centers had been approved individually by the medical ethics committee of their jurisdiction.

The screening procedure included a clinical and radiographic examination (dental panoramic tomogram, intraoral radiographs, or CBCT/CT imaging as required). An intraoral nonfixed guided device was used for the radiographs as a simple solution with reliable results (Gröndahl et al. 1998; Sundén et al. 1995).

Inclusion criteria

For inclusion in the study, subjects fulfilled all of the following criteria: 1. Provision of informed consent. 2. Aged 20–70 years at enrollment. 3. History of edentulism in the study area of at least 4 months. 4. Neighboring tooth/teeth to the planned bridge must have natural root(s). 5. Presence of natural teeth, partial prosthesis, and/or implants in the opposite jaw in contact with the planned bridge. 6. Deemed by the investigator to have a bone height of at least 11 mm and a bone width of minimum 6 mm. Bone height and width assessments included CT and CBCT scans when required. 7. Deemed by the investigator as likely to present an initially stable implant situation.

Exclusion criteria

Any of the following was regarded as a criterion for exclusion from the study: 1. Unlikely to be able to comply with study procedures, as judged by the investigator. 2. Earlier graft procedures in the study area. 3. Uncontrolled pathologic processes in the oral cavity. 4. Known or suspected current malignancy. 5. History of radiation therapy in the head and neck region. 6. History of chemotherapy within 5 years prior to surgery. 7. Systemic or local disease or condition that could compromise postoperative healing and/or osseointegration. 8. Uncontrolled diabetes mellitus. 9. Corticosteroids or any other medication that could influence postoperative healing and/or osseointegration. 10. Smoking more than 10 cigarettes/day. 11. Present alcohol and/or drug abuse.

Surgical procedures

Implant surgery was performed using the standard Astra Tech protocol to a final drill diameter depending on the bone quality and modified to a one-stage procedure. Preoperatively, an antibiotic treatment, 2 g amoxicillin or, if allergic to penicillin, 600 mg clindamycin, was given. Postoperative treatment included a chlorhexidine rinse twice daily for 10 days, but no further antimicrobial therapies were used.

The surgical procedure was performed under local anesthesia. After a crestal incision and reflection of buccal and lingual/palatal flaps, a randomization envelope was opened to allocate the subject to either the 6 mm or the 11 mm group. Two or three implants of the same length were placed in each patient.

To improve the situation with reduced bone support in the spongy bone area, a modified drilling protocol was performed by reducing the diameter of the final drill in the standard sequence. The final drill size was recorded. In cases of a small dehiscence, autologous bone particles, harvested in the bone area close to the implant site, could be used (four subjects in each group, respectively). No other graft material was allowed.

Maximum torque used during implant installation was set according to Astra Tech’s surgical manual, and primary implant stability was assessed clinically through torque insertion measurements at placement and at later time points by manual mobility testing, that is, using 2 hand instruments to confirm absence of mobility. Screw-retained abutments (20 degree UniAbutments 0.5–2 mm height [Astra Tech AB]) were attached to the implants and protected with healing caps [Astra Tech AB]. Flaps were sutured, and intraoral radiographs and clinical photographs were obtained [Fig. 3 and 6]. During the 6-week healing period, the implants were left in a transmucosal position. In cases where little or no primary implant stability was achieved, a conventional two-stage approach with an extended healing period was applied [two subjects: 2 implants of 6 mm and 2 implants of 11 mm]. Except for the prescribed chlorhexidine rinse, no oral hygiene measures of the implant sites were allowed before the sutures were removed after 7–10 days. To avoid excessive loading of the implants during the initial healing period, the subjects were advised to use a soft diet from implant placement [IP] to delivery of the provisional prosthetic restoration at 6 weeks.

Prosthetic procedures

One week after IP, a follow-up visit was scheduled for suture removal and review of
the healing process. Adverse events and adverse device effects were recorded throughout all the visits. Five weeks after IP, implant stability was manually examined. Impressions at the abutment level were made for fabrication of the screw-retained provisional acrylic prosthesis delivered 6 weeks following IP (Fig. 4). An oral examination evaluating the presence of plaque and the condition of the peri-implant mucosa was performed at 6 and 10 weeks and 6 and 12 months after IP. Plaque was recorded as present or absent by visual inspection on four surfaces at each implant site. If presence of plaque was noted, the subject was re-instructed in oral hygiene. Intraoral radiographs and clinical photographs were taken at 6 weeks and 6 and 12 months after IP. An oral examination was performed 4 weeks after delivery of the provisional prosthesis. The screw-retained permanent restoration made of porcelain fused to metal was delivered 6 months after loading with the provisional prosthesis (Fig. 5 and 7). This was made using the same casts used to fabricate the provisional prosthesis or by recording a new impression and cast. Implant stability was assessed manually, and the oral examination and recordings were made. Subjects returned for follow-up visit 12 months after loading for the 1-year evaluation.

Clinical analysis
The time points for any lost implants were recorded. The presence of plaque was scored by running a probe across the smooth marginal surface of the crown or abutment. Probing depths and bleeding on probing were scored at four sites for each implant (mesial, distal, buccal, lingual/palatal).

Radiographic evaluation
Peri-apical radiographs were taken with a paralleling technique using film holders. They were the basis for the radiographic evaluation. No attempt was made to further standardize the radiographs, for example, use of customized bite blocks. The radiographs were examined and bone levels measured by an experienced radiologist at the Department of Radiology at the University of Gothenburg, Sweden. The evaluation was performed independent from investigators or sponsor. All radiographs were displayed in software [Illustrator CS; Adobe Systems Inc, San Jose, CA, USA] on a 24-inch LCD screen [iMac-Apple Inc, Cupertino, CA, USA]. The screen resolution was 1920 × 1200 pixels. The measuring tool of the software was used to make the measurement, taking the magnification into account. The brightness, contrast, and zoom of the images were adjusted to achieve optimal measuring conditions. Crestal bone loss was determined by measuring, both mesially and distally, the distance from the implant reference point [the junction between the machined bevel and the microthreads] to the level of bone to implant contact. In cases where the implant reference point was below the margin of the crestal bone, that is, subcrestal, the value was considered as zero. Bone loss was presented as the mean values for distal and mesial changes from baseline for each implant/subject and each time point. The anatomical crown height [Blanes et al. 2007] from the highest occlusal point to the implant/abutment junction was also measured radiographically.

Statistical method
The statistical software used was StatXact (Cytel, Cambridge, MA, USA) and descriptive statistics by means of Excel (Microsoft, Redman, WA, USA). The patient was used as the unit of analysis in all tests. For continuous data, a mean value was calculated per patient. Thus, probing depths were presented as the mean of all measurements on four sides of the implant (mesial, distal, buccal, and lingual). For categorical data, such as bleeding, a patient was considered as “bleeding” if at least one observation was “bleeding”, otherwise the patient was considered as “nonbleeding”. A nonparametric approach was taken because of the nature of the data. A Wilcoxon rank sum test was used for continuous data and Fisher’s exact test for categorical data. A P-value below 0.05 was considered as statistically significant.

Results
A total of 95 subjects (48 men and 47 women, mean age 54 years, range 26–70 years) were included after a clinical and radiographic examination verified that they fulfilled all inclusion criteria and none of the exclusion criteria (Table 1).

Forty-nine subjects were allocated to the 6 mm implant and 46 subjects allocated to the 11 mm implant treatment (Table 2). In total, 208 implants were placed (107 implants with a length of 6 mm and 101 implants with a length of 11 mm). The first patient was enrolled in November 2007 and the last patient in June 2010, thereby taking nearly 3 years to recruit 95 patients of whom 93 patients fulfilled all the criteria and have been evaluated with at least a full year follow-up. One of the 95 patients declined to

| Table 1. Baseline characteristics of the subjects in the 6 and 11 mm groups |
|-------------------------------------------------|-------|-------|
| Gender  | 6 mm  | 11 mm  |
| Male    | 21    | 27    | 48    |
| Female  | 28    | 19    | 47    |
| Age     |       |       |       |
| Mean    | 54.8  | 54.1  | 54.5  |
| Min     | 26    | 34    |       |
| Max     | 69    | 70    |       |
| Smoking |       |       |       |
| Non smoker | 29 | 33    |       |
| Ex smoker | 17 | 8     |       |
| Smoker  | 3     | 5     |       |
| Periodontitis | 12 | 7     |       |
| Bruxism | 3     | 3     |       |

| Table 2. Subjects per study center divided into group and number of implants in upper and lower jaw |
|---------------------------------|--------|--------|--------|--------|
|                                | 2-Lead | 3-Lead | 2-Lead | 3-Lead |
| Apeldoorn                       |       |       |       |       |
| upper 6 mm                      | 1      | 7     | 2      | 3      |
| lower 6 mm                      | 2      | 6     | 3      | 3      |
| Gothenburg                       |       |       |       |       |
| upper 3 mm                      | 2      | 5     | 2      | 4      |
| lower 3 mm                      | 2      | 2     | 4      | 1      |
| Melbourne                       |       |       |       |       |
| upper 5 mm                      | 2      | 2     | 4      | 1      |
| lower 5 mm                      | 2      | 2     | 4      | 1      |
| Iowa                            |       |       |       |       |
| upper 3 mm                      |        |       | 2      | 4      |
| lower 3 mm                      |        |       | 2      | 4      |
| California                      |       |       |       |       |
| upper 2 mm                      | 1      | 3     | 2      | 2      |
| lower 2 mm                      | 4      | 3     | 5      | 2      |
| London                          |       |       |       |       |
| upper 2 mm                      | 2      | 2     | 2      | 2      |
| lower 2 mm                      | 1      | 3     | 1      | 1      |
| Total                           | 39     | 10    | 37     | 9      |
enter the study for having previous debts to one of the clinics and the other did not fulfill the criteria by excessive smoking (Fig. 1).

**Implant survival**

Two 6-mm implants failed to integrate (early loss), one 6 mm was lost before the 1-year evaluation, and one 11-mm implant was lost 4 weeks after loading. The early loss of the 6-mm implants occurred within the same patient in bone quality 4 (Lekholm et al. 1985). The other two implants were lost because of progressive bone loss. This indicated a survival rate of 97% (3/107) for the 6-mm implants and 99% (1/101) for the 11-mm implants.

**Radiographic bone levels**

Bone level changes were analyzed by radiographs taken at IP, at 6 weeks when the provisional prosthesis was placed (T = 0), at
6 months ($T = 6$), and at 1 year ($T = 12$). The evaluation was patient based, and all the intended subjects to treat were analyzed.

For the 6-mm implants, the mean bone level change from IP to 6 months was 0.24 mm (SD 0.21) bone loss and 0.2 mm (SD 0.22) bone loss between IP and 12 months. For the 11-mm implants, the corresponding bone level change was 0.45 mm (SD 0.43) bone loss and 0.41 mm (SD 0.46) bone loss.

From the loading baseline ($T = 0$) to the 12 months' ($T = 12$) follow-up, a mean marginal bone gain of 0.06 mm (SD 0.27) in the 6 mm group and 0.02 mm bone gain (SD 0.6) in the 11 mm group was found ($P = 0.48$). The differences were not statistically significant between groups (Table 3).

The frequency of implants experiencing bone loss more than 1.0 mm (Albrektsson et al. 1997; Albrektsson & Zarb 1993, Roos et al. 1997) from $T = 0$ to $T = 12$ was 3.2% (3/92) for the 11 mm group and 2.3% (2/86) for the 6 mm group. No bone loss (even bone gain) was found in 52.2% (48/92) for the 11 mm group and 53.4% (46/86) for the 6 mm group (Fig. 2).

### Table 3. Marginal bone levels and changes from the loading ($T_0$)

<table>
<thead>
<tr>
<th>Implant placement</th>
<th>$T_0$</th>
<th>$T_6$</th>
<th>$T_{12}$</th>
<th>$T_0-T_6$</th>
<th>$T_0-T_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 mm</td>
<td>Mean</td>
<td>0.04</td>
<td>0.28</td>
<td>0.20</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.60</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>0.28</td>
<td>0.90</td>
<td>0.88</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.08</td>
<td>0.27</td>
<td>0.22</td>
<td>0.24</td>
</tr>
<tr>
<td>11 mm</td>
<td>Mean</td>
<td>0.31</td>
<td>0.46</td>
<td>0.41</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-1.38</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>3.98</td>
<td>2.68</td>
<td>1.75</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.72</td>
<td>0.64</td>
<td>0.43</td>
<td>0.54</td>
</tr>
<tr>
<td>6 mm vs. 11 mm</td>
<td>$P$-value</td>
<td>0.098</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values correspond to the distance of the reference point of the implant above bone level. Reference point below bone level has been considered as value zero.

Radiographic crown height

For the 6 mm group ($n = 78$), the mean anatomical crown height was 11.0 mm (SD 2.15, range 6.8–16.8). For the 11 mm group ($n = 75$), the mean crown height was 10.2 mm (SD 1.81, range 6.6–15.3). The differences were statistically significant between groups ($P = 0.018$).

Bleeding and plaque

Presence of bleeding on probing was 21% for the 6-mm implant and 29% for the 11-mm implant at the time of loading and 53% for the 6 mm and 56% for the 11 mm implant after 1 year. There was no significant difference between groups ($P$-value, respectively, 0.46 and 1.0, Fisher's exact test). Plaque scores after 6 months were, respectively, 22% and 24% for the 6 mm and 11 mm group ($P = 0.72$) corresponding to the last time the temporary restoration was in function. After 1 year, 50% plaque score in both of the 6 and 11 mm group was found ($P$-value 1.0 Fischer’s exact test, two-sided).

Probing depths

Probing depth was measured at time of loading ($T_0$), 1 month, 6 months, and 1 year later. The mean value of the probing depths of the four sites of all the implants was calculated, taking the subject as a unit. There were no statistically significant differences in mean probing depth between groups at any time point ($P$-values were, respectively, 0.55, 0.54, 0.86, and 0.91 using the Wilcoxon rank sum test two-sided) (Table 4).

### Table 4. Probing depths (subject as unit) at provisional prosthesis loading ($T_0$), 1 month ($T_1$), 6 months ($T_6$), and 12 months ($T_{12}$)

<table>
<thead>
<tr>
<th></th>
<th>$T_0$</th>
<th>$T_1$</th>
<th>$T_6$</th>
<th>$T_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 mm</td>
<td>Mean</td>
<td>1.9</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.8</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>11 mm</td>
<td>Mean</td>
<td>1.9</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.8</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>$P$-value</td>
<td>0.55</td>
<td>0.54</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Adverse events

Adverse events and adverse device effects were monitored:

- Abutment screws loosened in six cases in the first year, equally divided between the 6 and 11 mm implants.
- Healing caps loosened in four of the cases (3 × 6 mm and 1 × 11 mm).
- The provisional prosthesis fractured in two cases, one in each group.
- The definite FPD loosened in three cases in the group with 11 mm implants and none in the 6 mm group.

![Fig. 2. Cumulative plot of the average bone level change per implant from provisional prosthesis to 12 months ($T_{12}$) comparing 6 mm with 11 mm.](image-url)
Discussion

Comparison with other studies

The implant survival was comparable with the findings of the meta-analyses ofTell-
eman et al. (2011) and Pommer et al. (2011), who confirmed the high survival rate of
implants shorter than 10 mm. Although within the boundaries of overall implant sur-
vival rates, the upper jaw seemed to be more vulnerable for short implant failures, possibly
because of surgical challenges in the region. Renouard & Nisand (2005) mentioned the
handling of short implants in the upper jaw as "a surgical learning curve". Therefore, a
two-stage procedure might be recommended using short implants in situations with mini-
cortical bone is present.

After the osseointegration period, no differ-
ences in performance between the 6 and
11 mm implants were observed. Mean mar-
ginal bone gain around the 6 mm implants
was 0.06 mm [SD 0.27] and 0.02 mm [SD
0.47] for the implants with 11 mm length
after 1 year of function.

In both groups, there was an initial bone
loss between placement and loading 6 weeks
later, with a mean loss of 0.23 mm for the
6 mm implants and 0.11 mm for the 11 mm
implants (P = 0.036). The maturation of bone
after IP and adaptation of bone to func-
tional forces have been described by Adell
et al. [1981]. In the present study, the differ-
ence in bone level between the 6 and 11 mm
implants might have been caused by a
slightly deeper placement of the 6 mm
implants and subsequently more bone
remodeling. This change is, however, well
within the limits proposed by Albrektsson
et al. [1986].

The results of the present study are compa-
rable with the results of a prospective 2-year
follow-up cohort study of 6 mm implants of
Rossi et al. 2010. Their study reported a sur-
vival rate of 95% [because of early implant
loss] and a mean marginal bone loss of
0.23 mm 1 year after loading. The recorded
differences with the present study might be
because of the single (non-splinted) loading of
implants and the reduced volume of bone in
the study of Rossi, which are not directly
comparable with the present study.

As the present study was designed as a ran-
donized study in subjects with at least
11 mm of bone height, no differences of ana-
tomical crown lengths between test and con-
trol was expected. The average crown length
of the 6 mm group was 0.8 mm greater than
the 11 mm group. Although a small but sig-
nificant difference, the explanation might
also be because of a slightly deeper place-
ment of the 6 mm implants. In clinical prac-
tice, it is likely that 6 mm implants will be
indicated in regions with greater jaw resorp-
tion and associated increased crown height.
The crown implant height ratio in this study
was 1.8 for the 6 mm group and 0.9 for the
11 mm group. According to Blanes (2009),
peri-implant crestal bone loss seemed not to
be influenced by the C/I ratio of the implant
rehabilitation. Technical complications of
implant components and superstructure
related to different C/I ratios were not found
in the present study and also confirm the
findings in the review of Blanes (2009). A
longer follow-up study of patients with
severe resorption may give clinically signifi-
cant differences in crown heights to implant
length and could possibly lead to different
conclusions.

All FPDs in this study had splinted restora-
tions. In Guichet et al. (2002) recommended
the splinting of restorations to distribute
forces between implants and to provide a pre-
dictable long-term prosthesis for the patient.
In a recent study of Vigolo & Zaccaria (2010),
comparing splinted and nonsplinted restora-
tions, no significant difference in the mar-
ginal bone level change between the two
groups was found. One proposed advantage of
nonsplinting restorations is to provide a bet-
ter approach to oral hygiene, although this
has not been adequately evaluated.

Probing depths measured at one, 6, and
12 months, provided a measure of soft tissue
behavior, with no significant differences
between the 6 and 11 mm implants. This is

Key findings

This study revealed that the performance of
two or three implants of 6 mm length with a
splinted fixed dental prosthesis in the poster-
ior area of the jaws was comparable with the
same treatment using 11 mm implants. The
1-year survival rate was 97% for the 6 mm
implants and 99% for the 11 mm implants.
The mean marginal bone level did not change
between loading and the 1-year evaluation
with even a small mean bone gain reported
in both groups. Moreover, soft tissue behav-
ior was comparable between the groups.
most probably due to the fact that there were no differences in plaque and bleeding on probing between the two groups, rather than any effect of implant length. The bleeding score after 1 year in function was approximately 55%. Taking the patient as the unit, any bleeding at any implant gave a positive score that resulted in a higher score than taking the implant as a unit (35% for the 6 mm and 40% for the 11 mm implant after 1 year).

In one case of bruxism, mechanical complications occurred. In this particular case, there was no evidence of biological overload, that is, more marginal bone loss, even though the maxillary prosthesis was supported by 6 mm implants. Despite some proposals that longer implants could improve the biomechanical prognosis of a restoration, Pierrisnard et al. (2003) suggested that the use of short implants may even be beneficial for the long-term biomechanical prognosis.

**Clinical implications**

The results of this study support the use of short implants and suggest further investigation in cases of severely resorbed jaws, as short implants may offer greater simplicity and safety compared with bone augmentation procedures.

**Conclusion**

One-year data indicate that treatment with, 4.0 mm in diameter, 6 mm-long implants is as reliable as treatment with 4.0 mm in diameter, 11-mm-long implants when used to support FPD’s in the posterior maxilla or mandible in areas with adequate bone height and a favorable crown/implant length ratio. Whether or not short implants provide a predictable treatment alternative to bone augmentation procedures remains in areas with limited bone height of the residual alveolar ridge remains to be investigated in future randomized controlled clinical trials.

**Conflict of interest**

This international multicentre study has been fully sponsored by Astra Tech AB. However, none of the researchers have economical interest in the product related in this study or in the company.

**References**


Efficacy and Predictability of Short Dental Implants (< 8 mm): A Critical Appraisal of the Recent Literature

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**Purpose:** This review of literature was conducted to evaluate the predictability of treatment outcomes with short dental implants (SDI), ie, implants shorter than 8 mm. **Materials and Methods:** The review included studies, published between January 1990 and July 2011, that (1) involved SDI (< 8 mm) placed in human jaws, (2) had a minimum of 20 SDI in their analysis, (3) provided data on survival rates, and (4) reported a minimum observation period of at least 3 months after placement. **Results:** Forty-one studies fulfilled the above criteria; only 17 of these studies reported outcomes with microrough surface SDI. Six different lengths (4, 5, 6, 6.5, 7 and 7.5 mm) of microrough surface SDI with varying diameters (3.5 to 6 mm) were identified in the studies. A total of 1,828 microrough surface SDI were inserted and 45 failures were reported. Observation periods ranged from 3 months to 9 years. The reported survival rates for SDI ranged from 92.2% to 100%. From a total of 1,123 SDI inserted in specified jaw locations, failures were observed more often in the maxilla (n = 297, failed = 13) than in the mandible (n = 826, failed = 19). The review did not identify any correlation between implant diameter and survival for the microrough SDI. **Conclusions:** Microrough surface short implants (6 to 7.5 mm) appear to provide favorable survival rates and, therefore, can be predictably employed for simplification of implant therapy in situations of reduced alveolar heights in the posterior jaw segments. Int J Oral Maxillofac Implants 2012;27:1429–1437

**Key words:** dental implant, implant length (< 8 mm), literature review, short dental implants, treatment outcomes

Short dental implants were introduced for simplified placement in compromised alveolar situations to avoid interference with vital anatomical structures, minimize surgical trauma and associated risks, and consequently reduce the morbidity of advanced surgical procedures. Early descriptions in literature considered standard length implants as implants with intrabony lengths of 10 mm or more, and short dental implants (SDI) as implants with less than 10 mm intrabony length. The currently accepted definition for short dental implants is “a device with ≤ 8 mm intrabony length.”

It has often been hypothesized that shorter implants have lower success rates than standard length fixtures. However, no distinct linear relationship between implant length and survival has been scientifically established. Standard length implants (≥ 10 mm) are quoted to represent a minimum length for predictable success because, hypothetically, a better distribution of functional forces throughout the entire length of the implant was assumed. However, these forces are demonstrated to be concentrated at the peri-implant crestal bone. There is evidence that implant length has minimal influence on the bone stress location, the intrabony implant displacement, and the implant component stress. It has also been suggested that longer implants are more prone to mechanical
complications because of their rigidity, while SDI allow flexure within the bone inducing a stress breaking effect.\(^1\)\(^9\) Hence, it would appear that using SDI represents an overall prosthetic advantage in terms of long-term success in implant supported restorations.\(^5\) However, this hypothesis needs to be challenged by randomized controlled trials. Bone quality, or bone density, in the region of installation has also been reported to play a role in SDI survival, and the posterior maxilla has been cited as a region for frequent failures.\(^11\)\(^-\)\(^15\) Studies, however, do exist that demonstrate favorable success rates in this region.\(^2\)\(^,\)\(^16\)\(^,\)\(^17\)

Current literature classifies implants of 8-mm length as short implants. These have been associated with favorable success rates and high predictability, with reported survival rates of 96% to 100% (over a 3- to 7-year observation period).\(^2\)\(^,\)\(^18\)\(^-\)\(^20\) It is therefore natural to consider the use of 8-mm lengths as a routine treatment option and shift focus to lengths < 8 mm as “short implants.” Few systematic reviews assessing the performance of SDI and their survival have been published to date.\(^21\)\(^-\)\(^24\) These have, however, included implants up to an intrabony length of 10 mm.\(^21\)\(^,\)\(^23\)\(^,\)\(^24\) Thus, the inclusion of longer implants in a short implant review may not effectively deliver a precise conclusion on predictability.

Therefore, the purpose of this review was to focus on evaluating the predictability of treatment outcomes with commercialized short implants of lengths < 8 mm by reviewing the available relevant publications. By excluding 8-mm implants from this analysis, the authors hypothesized to get a better insight on the clinically relevant predictability of SDI. Based on this assumption, a critical appraisal of the published data on such short implants (< 8 mm) placed in various edentulous segments of the jaws was undertaken to propose a well-defined rationale for the decision-making process when considering the installation of short implants in both compromised conditions or even routine situations.

**MATERIALS AND METHODS**

An electronic database search of the dental literature using PubMed was undertaken to identify all papers published in English between January 1990 and July 2011, using the following search terms individually and in different combinations: “short dental implants,” “length,” “studies on,” “clinical studies,” “prospective,” “retrospective,” “randomized,” “survival and success rates,” “dental implants,” “treatment outcomes,” “systematic review,” “literature review,” and “meta-analysis.”

**Selection of Studies**

For inclusion in this review, the studies were required to (1) involve SDI (< 8 mm) placed in human arches, (2) have a minimum number of 20 implants of the specified lengths in their analysis, (3) provide data on survival rates, and (4) report a minimum observation period of at least 3 months after placement.

Studies were excluded, if (1) implant length was not specified, or (2) complex surgical interventions and bone augmentation procedures were performed prior to implant placement.

Since the available research on this topic is limited, it was decided to include, besides randomized clinical trials (RCTs) and systematic reviews of RCTs, case series studies, cohort studies, and case control studies. Publications were excluded if there was more than one study by the same researcher(s) conveying the same data. In such an instance, only the most recent study was included.

The database search strategy was devised and performed by the first author (MS). The abstracts of the searched articles were screened thoroughly by two reviewers (MS and PR). Full-text analyses were performed only on the short-listed articles based on the initial screening and on mutual agreement between the two reviewers. The data were extracted jointly by the two reviewers, and were subsequently rechecked and verified by a third reviewer (LV); any disagreement was solved by means of a consensus discussion presided over by a senior reviewer (UCB). The information was extracted from the selected publications, including name of author(s), journal, study type, implant length, surface characteristics, diameter of the implants, number of implants placed and failed, survival rates, and region of placement (if mentioned). A meta-analysis was planned for the extracted data.

**RESULTS**

The PubMed search yielded a total of 842 articles for the various combinations of the search terms mentioned in the methods section. The procedural aspects of the literature search and selection process are presented in Fig 1. From the screened titles and abstracts (n = 842), full-text analysis (n = 58), and reference crosschecks (n = 3), 41 publications qualified to be included in this study.\(^1\)\(^,\)\(^17\)\(^,\)\(^19\)\(^-\)\(^25\)\(^-\)\(^61\) However, studies reporting on machined surface implants were excluded from this review,\(^1\)\(^,\)\(^17\)\(^,\)\(^19\)\(^-\)\(^25\)\(^-\)\(^50\)\(^,\)\(^52\)\(^,\)\(^62\) and, finally, 17 quality studies reporting on microrough surface SDI were included for data extraction and interpretation (Table 1). Six lengths of implants < 8 mm (4, 5, 6, 6.5, 7, and 7.5 mm) were identified in this review. Different implant brands (eg, 3i, Astra-Tech, Bicon, BTI, Endopore, Nobel, RBM, Straumann) with varying diameters (3.5 to 6 mm) and surface characteristics (coated, porous, and microrough) were used in the selected studies.
Most articles reported only a cumulative or an overall survival rate for the different lengths of implants investigated, while others did the same for different diameters. Some studies did not specify the region of installation of the implants (maxilla or mandible). The exact number of dropouts or the exact time of failure(s), specific to length, site, and observation time was not mentioned in many articles. Furthermore, the selected articles differed from each other in the following parameters: implant number, implant length, implant diameter, study design, statistical analysis, and observation time. Due to the heterogeneity amongst the studies, the originally planned meta-analysis was not possible and a comprehensively structured descriptive analysis was performed in this review.

### Observed Time Period

The observed time periods, ranging from 3 months to 9 years, reported in the studies have been converted into years for convenience and uniformity.

### Survival Rates with Respect to Implant Lengths

Survival rates reported for microrough surface SDI (placed = 1,828, failed = 45) ranged from 92.2% to 100% for an observation period of up to 9 years (Table 2). Three studies on 7-mm SDI and one study on 6.5- and 7.5-mm SDI, reported 100% survival rates.

#### 4-mm and 5-mm Lengths

A single study presented data on 4-mm-long SDI, that was a recent prospective multicenter study. The study, based on 100 implants, reported an implant survival rate of 92.3% over a 2-year period. A pilot study of a RCT on 5-mm SDI reported a 98.3% survival rate after 1 year. This study reported on 60 SDI (5 mm × Ø 6 mm) that were placed in atrophic posterior maxillae and mandibles, with one failure in the maxilla before loading. Two other studies on 5-mm SDI reported 100% survival rates in a 1 to 9 year follow-up, but these were excluded from the review because of their small sample sizes.

#### 6-mm Length

From all studies reviewed, a total of 639 microrough surface implants were inserted and from these only 18 failed, with overall survival rates of 92.2% to 98.5% (observed period of 1 to 8 years). The majority of the 6-mm SDI used were Straumann dental implants, comprising a total of 594 implants placed with only 15 failures (SLA = 302 placed, failed = 7; TPS = 292 placed, failed = 8).

#### 7-mm Length

A total number of 758 microrough surface SDI of 7 mm length were placed in both arches and 19 implants failed. The survival rates reported in a total of nine studies ranged from 96.2% to 100% for an observed time of up to 9 years.

#### 6.5-mm and 7.5-mm Lengths

Only one study supplied data in this category and reported a 100% survival rate over an observation period of 1 to 8 years.

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**Fig 1** Procedural flow of the literature search and selection process. SDI = short dental implants.
Implant Diameter
Three of the 17 reviewed studies compared the impact of implant diameters and survival. In a study by Davarpanah et al., an increase in failures rates corresponded to increasing implant diameters, irrespective of implant length. The study reported the highest failure rates (25%) for 6-mm-diameter implants. Fugazzotto reported survival rates of 99.2% for wide neck configurations. Finally, Sohn et al. reported survival rates of 100% for both 5-mm and 4.1-mm diameters.

Location
Twelve studies specified the location of implant placement, reporting a total number of 1,123 SDI placed in different segments of the maxilla.
and mandible. From this total, 297 implants were placed in the maxilla (13 failures) and 826 were inserted in the mandible, revealing 19 failures (Table 3). Most studies reported a higher number of implant failures in the maxilla,\textsuperscript{38,54,59,61} while Fugazzotto\textsuperscript{19} demonstrated higher failures in the mandible.

### DISCUSSION

This comprehensive structured review scrutinized the clinical studies published from January 1990 through July 2011, while corresponding to strict inclusion and exclusion criteria. It primarily drew focus to implants of lengths less than 8 mm. The data obtained in this review are exclusively from peer-reviewed scientific journals.
in English. The studies exhibited a broad diversity in terms of observation time, implant length, implant diameter, implant surface, location of installation, study design, and surgical protocol. Furthermore, the studies showed variations related to the cited text and tables, unspecified dropouts, specific time of failure with respect to specific length, method of statistical analysis, and reporting. These factors deemed it impossible to systematically compare the reviewed publications with one another; which was a similar finding in an earlier published review.42 Hence, the initially planned meta-analysis for the extracted data was not possible, and a descriptive, but nevertheless structured and methodologically sound, analysis was carried out in this review.

The authors observed that, although the studies were conducted with the focus of evaluating short length implants, the definition of “short length” varied in each study and ranged within a broad spectrum (4 to 11 mm). Although 8-mm length is considered short by the standards of current literature, its evaluation in this review was eliminated because the current-day survival rates for the 8-mm-length short implants are predictably high and comparable to those of standard implants.18–20 Hence, the present review focused on lengths shorter than 8 mm and the authors suggest redefining the term “short dental implant” as a dental implant with an intrabony length between 6 and 7.5 mm; and define “ultra-short dental implant” as an implant with an intrabony length of less than 6 mm.

This review identified considerable heterogeneity in the observation periods and in the sample sizes of the reviewed studies. A significant number of quality studies1,5,8,17,18,42,43,47,63–72 were excluded from this review because they had a sample size of less than 20 implants. An estimation of a proportion on small samples is unreliable and the chance of detecting a low or a high proportion is weak.23 Hence, pooling studies with small sample sizes may underestimate the proportion of failures. It would also not be correct to pool all the studies analyzing implants with the same length and different surfaces because this may also further underestimate the failure rates. Therefore, studies with machined surface SDI were later decided to be excluded from this review, although they fulfilled the inclusion criteria and had adequate sample sizes.1,17,25–36,39–44,47,48,52,62 Furthermore, machined surface implants are obsolete in modern day implant practice, hence, including them in the analysis would not have provided a clinically relevant comparison.

A total of 17 studies on SDI with structured micro-rough surfaces were reviewed and revealed survival rates of 92.2% to 100%.19,37,38,45,46,49–51,53–61 The most recent study examined in this review was a 2-year prospective study on 4-mm long implants that reported a survival rate of 92.3% over a 2-year period in severely atrophied posterior mandibles.60 The study, however, strongly hypothesized on the need for extreme care during the surgery and meticulous planning of the prosthetic superstructure in terms of occlusion, so as to prevent implant overload and eventual implant loss. The results were said to be comparable with other short implant lengths (6 to 8.5 mm), and the success was predominantly attributed to the excellent implant stability at placement.

The occurrence of peri-implantitis in 16% of patients treated with machined-surface implants 9 to 14 years after loading has been documented.74 A systematic review reported that the incidence of peri-implantitis is likely to be higher in implants with roughened surfaces at 3 years of loading when compared with machined-surface implants (risk ratio = 0.80; 95% CI: 0.67 to 0.96).75 Implants with turned surfaces had a 20% reduction in risk of being affected by peri-implantitis. This may in fact be critical for survival in microrough SDI, especially with very short lengths (4 mm and 5 mm). It has been documented that untreated peri-implant mucositis, which may lead to progressive destruction of the peri-implant tissues and subsequently to peri-implantitis, ultimately may lead to implant failure.76 With longer implants, this situation may still be manageable as the increased implant length provides better chances of survival. Hence, extreme care should be emphasized in maintaining the peri-implant bone levels while employing SDI of lengths < 6 mm. Clinical common sense and concerns relative to dimensional manufacturing limitations, peri-implantitis, technical complications related to implant components, and, importantly, a lack of sufficient research restrict the use of such SDI (< 6 mm) to extreme clinical situations only.

The majority of studies included in this review have used SDI of 6-mm and 7-mm lengths. These dimensions seem to be the preferred choice of clinicians. Interestingly, the most commonly used 6 mm SDI was that of the Straumann Dental Implant System (Straumann AG).22 Studies on SLA surface 6-mm implants have been consistent with reported overall high survival rates between 94.2% and 100% for an observed period of 1 to 8 years.19,37,38,50,53,57,60,61 Former studies suggest that the implant diameter is of more significance to the survival outcome than its length.77,78 Frequent failures were experienced with 5-mm diameter machined surface implants in comparison to the smaller diameters of 3.75 mm or 4.0 mm.40 This increased failure rate may be attributed to the implant design, the bone quality at the site of placement, and the operator’s learning curve. This review, however, did not identify such a correlation between implant diameters and implant survival in the microrough implants examined. In fact, this review identified...
only three studies that had performed a comparison between implant diameters and failure rates.\textsuperscript{19,46,58} Davarpanah et al\textsuperscript{46} reported higher failure rates for large diameter implants, while Fugazzotto\textsuperscript{19} reported better survival rates for wide neck configurations. Sohn et al\textsuperscript{58} reported high survival rates for both standard (4.1 mm) and wide (5 mm) diameters of SDI. It should be underlined that data extracted from the studies on this topic were limited and inconclusive.

Bone quality and region of placement appear to play an important role in implant survival. In this review, the studies reported a marginally higher number of failures associated to SDI placed in the posterior maxilla.\textsuperscript{38,54,59,61} In comparison, the number of failures in the mandible was less. This could be explained by the fact that the shape of the jaw and bone density are governing factors that play an important role in the survival of implants.\textsuperscript{26} Traditionally, the emphasis has been primarily placed on bone morphology or bone density as important factors in predicting implant success and survival, and comparisons between short and standard length implants have been made in this light.\textsuperscript{79} However, it is important to note that this is not an appropriate assessment of the outcomes associated with the use of SDI, since in most studies SDI were usually placed under compromised situations. Unless studies have evaluated outcomes of SDI under normal alveolar conditions, superficial comparisons should not be made with standard length and/or longer implants.

Finally, very few RCTs relevant to the current topic were identified by this review. Thus, prospective clinical trials with standardized protocols and well-defined study parameters are needed to further assess treatment outcomes and predictability of SDI, especially with regard to shorter implants (< 6 mm).

**CONCLUSIONS**

The survival rates and treatment outcomes associated with short implants are dependent on multifactorial parameters, and cannot be determined by mere comparisons between the existing studies, which differ from one another. This structured review, however, provides sufficient evidence of the predictability of treatment outcomes with microrough surface SDI (< 8-mm lengths) in the treatment of partially and fully edentulous arches. Microrough surface implants with lengths in the range of 6 to 7.5 mm appear to provide favorable survival rates, and this fact may significantly contribute to the simplification of implant therapy, namely in posterior segments of the arches.

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Endosseous dental implants have become a highly predictable treatment option for completely and partially edentulous patients. After tooth loss, severe atrophy of the alveolar ridges is quite common in patients with a history of periodontitis or in patients whose edentulism is of long duration. Especially in the posterior region, the applicability of dental implants may be limited because of insufficient alveolar ridge height caused by bone resorption. This results in a closer proximity to adjacent anatomical structures (eg, the inferior alveolar nerve, the sinus floor). In these cases, advanced surgical procedures, such as vertical bone grafting, are often performed to allow the placement of longer implants.1–3 Other alternatives, such as alveolar nerve transpositions, are accompanied by high rates of complications.2 On the other hand, the use of shorter implants can reduce the need for augmentative procedures and thus diminish morbidity and treatment time for patients.

A review by Esposito et al4 compared the results of vertical ridge augmentation procedures to those of the insertion of short dental implants. The vertically augmented group experienced a higher implant failure rate and statistically significantly more complications. Therefore, the authors concluded that short implants appear to be a superior alternative to vertical bone grafting.4 Other authors, however, often associate the resulting poor crown-to-implant ratio of short implants with higher implant failure rates and higher marginal bone loss. Winkler et al documented a survival rate of 74.4% for 7-mm implants over 3 years.5 Herrmann et al presented similar results, with a survival rate of 78.2%.6

Purpose: The use of short implants can reduce the need for augmentative procedures prior to implant placement and, thus, morbidity and treatment time for patients with severely atrophied alveolar ridges. However, the inevitably less favorable crown-to-implant ratio is often associated with higher implant failure rates and greater marginal bone loss. The aim of this study was to evaluate the long-term survival and success rates of short implants in severely atrophic alveolar ridges retaining restorations on these short implants only.

Materials and Methods: In this study, 8-mm and 9-mm implants were inserted in atrophic alveolar ridges according to the manufacturer’s protocol for the respective bone quality and loaded after 3 months of healing. Prosthetic restorations were supported only by short implants (not in combination with longer implants). After a mean observation period of 10.1 years (± 1.9 years), all patients were re-examined clinically and radiographically. Results: In this study, fifty-two 8-mm and 9-mm implants were placed in 14 patients. After 10.1 years, no implants and suprastructures had been lost. A mean marginal bone loss of 0.3 mm (± 0.4 mm) was recorded. According to the Albrektsson criteria, all implants were successful; with respect to the more rigorous Karoussis et al criteria, four implants failed. Conclusions: The results of this long-term study suggest that the use of short implants results in marginal bone resorption and failure rates similar to those for longer implants. The higher crown-to-implant ratio did not seem to have any negative influence on implant success in this study. Int J Oral Maxillofac Implants 2012;27:1501–1508

Key words: bone atrophy, dental implants, implant success, implant survival

Use of 8-mm and 9-mm Implants in Atrophic Alveolar Ridges: 10-Year Results

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Many other studies demonstrated higher failure rates. In contrast, other studies showed similar survival rates for short and longer implants.\textsuperscript{7,8} A further group of studies reported that implant length did not influence survival rates.\textsuperscript{9–11} In addition, other factors seem to influence implant survival. With respect to implant surface topography, machined implants show significantly higher rates of implant failure than those with rough surfaces. Furthermore, adapted surgical protocols can have positive effects on implant survival.\textsuperscript{12,13}

The aim of this retrospective study was to evaluate long-term survival rates and bone level alterations around short implants that acted as sole support for prostheses. Furthermore, parameters determining implant prognosis, such as peri-implant bleeding on probing, probing depth, and radiographic marginal bone levels, were assessed over a period of 10 years.

**MATERIALS AND METHODS**

**Patients**

All included patients had been referred to the Department of Oral and Maxillofacial Surgery, University Hospital Heidelberg, for implant treatment between 1998 and 1999. The study was conducted in accordance with the principles of the Declaration of Helsinki. In addition, the Ethics Committee for clinical studies of the Medical Faculty of the Heidelberg University had reviewed and approved the study protocol, and informed consent was obtained from each patient.

All patients had to fulfill the following inclusion criteria:

- Atrophic edentulous or partially edentulous ridges (Class III and IV according to Cawood and Howell\textsuperscript{14}) with at least 8 mm of residual bone height prior to implant placement
- Sufficient denture in the opposing arch providing for good occlusion
- Suprastructures retained exclusively by short implants

Exclusion criteria were:

- Untreated periodontal diseases
- Caries
- Insufficient oral hygiene
- Previous radiation therapy and systemic disorders potentially affecting the outcome of the implant therapy (eg, uncontrolled diabetes mellitus, current chemotherapy, pregnancy)

Patients with treated periodontal diseases, smoking habits, or clenching/parafunctional habits were not excluded.

Implants were defined as short if they were 9 mm or shorter.\textsuperscript{15–17} Short implants were not splinted together with longer implants. Single crowns, splinted crowns, and partial and complete dentures were included if they were supported solely by short implants. The implants under examination were used for all indications.

**Implant Treatment**

After clinical and radiographic examinations, the patients were scheduled for implant placement. Implant surgery was performed by one experienced surgeon under local anesthesia using a two-stage surgical approach. The implants had a moderately rough titanium-blasted surface (TiOblast, Astra Tech) and were screw-shaped and parallel-walled. The implants differed in diameter (3.5/4.0/4.5 mm) and in effective length (8 and 9 mm), depending on the bone dimension at each site. The drilling protocol was performed according to the manufacturer's specifications and was adapted to bone quality. The insertion depth of the implants was determined by the surrounding bone; the implant neck was placed flush with the alveolar ridge.

After surgery, patients were advised not to wear any removable dentures for 1 week. A chlorhexidine mouth rinse was prescribed for use two times per day. No antibiotics were prescribed before or after implant placement. Sutures were removed after 7 days. When the patients began to use their dentures again, any pressure from the denture base on the implant region was relieved. The healing period was 3 months for both maxillary and mandibular implants.

All prosthetic rehabilitations were performed by the same prosthodontist and were constructed to enable patients to maintain optimal oral hygiene. Therefore, reconstructions in the molar and premolar regions were mainly screw retained. Hygiene instructions, including the use of interdental brushes and flossing technique, were given to each patient.

**Clinical Examinations**

Patients were followed up yearly. Clinical parameters such as the Mombelli et al Modified Plaque Index and Sulcus Bleeding Index were determined.\textsuperscript{18} Peri-implant pocket depths were measured at four sides per implant (mesial, distal, vestibular, and oral). Furthermore, in cases of screw-retained suprastructures, the mobility of each individual implant was tested manually after the restorations were removed. Occlusion was monitored and hygiene instructions were given to the patients.

**Radiographic Examination**

At the time of placement of the definitive reconstruction, intraoral radiographs were obtained (baseline). Additional radiographs were acquired at the annual follow-up visits. To ensure standardization, all periapical
radiographs were taken with the long-cone technique and using a film holder (Figs 1 and 2). The distance between the implant shoulder and the first visible bone-to-implant contact was assessed at the mesial and distal aspects of the implant using the Friacom DentalOffice software program (Version 2.5, Friadent). The linear dimensions of the digitized images were calibrated to take into account anatomic magnification and distortions in the films. This was achieved by setting the scale in the image to the known distance between the implant threads. All radiographs were analyzed by the same independent radiologist, who had not previously been actively involved in this study. Any apparent bone gain was recorded as zero bone loss.

Success Criteria

The Albrektsson et al. radiographic success criteria were applied to determine the success or failure of an implant. That is, an implant was considered successful if the marginal bone loss was 1 mm or less during the first year after insertion of the prosthesis and no greater than 0.2 mm in every following year of function and if no signs of peri-implant radiolucency were apparent.

Furthermore, the more stringent success criteria of Karoussis et al. were applied, since these additionally include soft tissue parameters, such as probing depths and bleeding on probing. To be defined as successful, the following requirements had to be met:

1. Absence of mobility
2. Absence of persistent subjective complaints (pain, foreign-body sensation, and/or dysesthesia)
3. No probing pocket depth > 5 mm
4. No probing pocket depth = 5 mm with bleeding on probing
5. Absence of continuous radiolucency around the implant
6. Vertical bone loss not to exceed 0.2 mm annually after the first year of function

Data Analysis

Statistical analysis was performed using SPSS (version 18, IBM) and SAS (version 9, SAS Institute) software. Only exact statistical methods were applied (‘SPSS module’, ‘Exact Tests’). Arithmetic means, medians, percentiles, standard deviations (SDs), and cumulative frequencies were calculated for descriptive purposes. The main outcome parameter was implant survival; the secondary outcome variable was implant success according to the criteria of Albrektsson et al. and Karoussis et al.

Fig 1  Radiographic follow-up after 10 years (diameter 3.5 mm, length 9 mm).

Fig 2  Radiographic follow-up after 10 years (diameter 4.0 mm, lengths 9 and 8 mm).
**RESULTS**

**Patients**

Fifty-two dental implants were placed in 14 patients (11 women, 3 men). The mean age of patients at implant surgery was 57.9 years (SD 8.9 years; range, 37.3 to 71.5 years). Mean follow-up time was 10.1 years (SD 1.9 years; range, 9.5 to 12 years). Twelve of the 14 patients were observed for at least 9 years. One patient died during the study period (after 6 years and 9 months), and another did not appear for follow-up examinations after 6 years.

Thirty-six implants were placed in the mandible and 16 in the maxilla. Forty-two implants were placed in posterior regions (ie, premolar/molar areas) and 10 were placed in the anterior arches (Table 1). The distribution of implants with respect to jaw positions is depicted in Fig 3.

**Clinical Examination**

Measurement of the peri-implant Plaque Index showed good oral hygiene for 82.7% of the implants at the last follow-up visit (grades 0 and 1; Table 2). At 23.1% of the implants, peri-implant bleeding could be provoked but was predominantly weak. A maximum periodontal probing depth of less than 4 mm was recorded for 82.7% of all implants, and a maximum of 6 mm was found at only 1.9% of the implants. No implants were lost during the observation period, resulting in a survival rate of 100%.

**Bone Loss and Implant Success**

After a mean observation period of 10.1 years, an average marginal bone loss of 0.3 mm (SD 0.5 mm; range, 0 to 1.4 mm) was recorded. Bone loss on the mesial and distal surfaces did not differ significantly: 0.24 mm (SD 0.45 mm) and 0.36 mm (SD 0.52 mm), respectively. Almost half of all implants (48%) showed no marginal bone loss, and 12 implants (23%) showed a loss of less than 0.5 mm of marginal bone (Table 3). Marginal bone loss was greater in the mandible (0.37 mm; SD 0.54 mm) than in the maxilla (0.15 mm, SD 0.3 mm; Fig 4). Screw-retained reconstructions showed an average

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**Table 1  Implant Distribution**

<table>
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</tr>
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<tr>
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<td>Interconnected crowns</td>
<td>18</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Single crown</td>
<td>13</td>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2  Scores for Clinical Parameters (n = 52 Implants)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of implants</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Probing depth</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 mm</td>
<td>43</td>
<td>82.7</td>
</tr>
<tr>
<td>4 mm</td>
<td>5</td>
<td>9.6</td>
</tr>
<tr>
<td>5 mm</td>
<td>3</td>
<td>5.8</td>
</tr>
<tr>
<td>6 mm</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Plaque</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score 0</td>
<td>20</td>
<td>38.5</td>
</tr>
<tr>
<td>Score 1</td>
<td>23</td>
<td>44.2</td>
</tr>
<tr>
<td>Score 2</td>
<td>9</td>
<td>17.3</td>
</tr>
<tr>
<td>Score 3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Bleeding</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score 0</td>
<td>40</td>
<td>76.9</td>
</tr>
<tr>
<td>Score 1</td>
<td>12</td>
<td>23.1</td>
</tr>
<tr>
<td>Score 2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Score 3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*According to Mombelli et al. 18

---

**Fig 3** Distribution of placed implants according to position in the jaw.
marginal bone loss of 0.36 mm (SD 0.57 mm), whereas cemented reconstructions showed less bone loss (mean of 0.14 mm).

According to the Albrektsson et al criteria, all implants were successful. Under the more stringent success criteria of Karoussis et al, four implants failed.

Prosthetic Treatment and Success
After a healing period of 3 months, patients received their definitive rehabilitation from the same prosthodontist. All 52 implants supported fixed reconstructions. Twelve implants supported two screw-retained full-arch restorations in the mandible. Nine implants supported four screw-retained partial dentures in the mandible, whereas 13 implants were loaded with cemented single crowns and 18 implants supported splinted interconnected crowns (Table 1). In all, 36 implants had screw-retained suprastructures and 16 implants had cement-retained restorations.

No reconstructions had to be replaced. Thus, the survival rate of 100% and low marginal bone loss of 0.3 mm of short dental implants placed in various clinical situations in this long-term follow-up analysis are outcomes that are comparable to those reported for longer implants from the same manufacturer for the same observation period. Also, in a recent review that compared the survival of short and conventional implants, no significant differences between totally and partially edentulous patients could be demonstrated. Although there are some long-term studies on short implants, to the authors’ knowledge, there are no long-term studies over a period of 10 years of short implants as the sole support for prosthetic reconstructions. Therefore, the success and survival rates of those short implants were assessed in the present study.

The use of short implants is well documented from a biomechanical point of view. Multiple finite element analysis studies have proven that the highest stress concentrations in bone occur in the crestal region of an implant, whereas very little stress is transferred to implant surfaces, the success rates of short and longer implants have become similar. In addition, a high implant-to-crown ratio was assumed to have a negative biologic effect on crestal bone loss. Overloading as a result of higher bone stress was believed to lead to bone atrophy and greater marginal bone loss. However, a systemic review by Blanes found that implant-to-crown ratios did not influence marginal bone loss. One article even reported less marginal bone loss with higher crown-to-implant ratios.

The results of the presented data are in accordance with recent studies on short implants, whereas older studies often described higher implant failure rates and higher marginal bone loss for short versus longer implants. The high survival rate of 100% and low marginal bone loss of 0.3 mm of short dental implants placed in various clinical situations in this long-term follow-up analysis are outcomes that are comparable to those reported for longer implants from the same manufacturer for the same observation period. Also, in a recent review that compared the survival of short and conventional implants, no significant differences between totally and partially edentulous patients could be demonstrated. Although there are some long-term studies on short implants, to the authors’ knowledge, there are no long-term studies over a period of 10 years of short implants as the sole support for prosthetic reconstructions. Therefore, the success and survival rates of those short implants were assessed in the present study.

The use of short implants is well documented from a biomechanical point of view. Multiple finite element analysis studies have proven that the highest stress concentrations in bone occur in the crestal region of an implant, whereas very little stress is transferred to
the apical portion. Increased implant length can decrease the stress around the implant neck only in a very minor way. Perrinsard et al even stated that, independent of implant length, bone stress was virtually constant. However, implant stress increased significantly with implant length and bicortical anchorage. Ivanoff et al also observed that implants with bicortical anchorage failed almost four times more often than those with monocortical anchorage.

According to recent reviews, the success of short implants is dependent upon multiple factors. For example, the implant surface structure is important. Therefore, all included implants in this study had a moderately rough surface, which has been found to achieve higher bone-to-implant contact. Furthermore, an increase in diameter could also help minimize complications. While all implants in this study were short, their diameters varied. However, a short implant with a wide diameter provides an increased implant surface area, which then results in a higher bone-to-implant contact area. This could make a short implant comparable to a longer implant with a smaller diameter.

Another influencing factor is the individual bone quality; different site preparation is required depending on the specific bone quality to ensure primary stability. Therefore, the survival and success of short implants placed in severely resorbed jaws should not be compared with those of longer implants placed in adequate native bone but rather with the outcome of implants placed in grafted sites. This is because the treatment alternatives to short implants are complex bone grafting procedures, such as vertical ridge augmentation (eg, distraction osteogenesis, onlay grafts, sinus floor augmentation), or alveolar nerve transposition. These operations are often associated with higher morbidity for the patient and less favorable implant survival and success rates. Versus longer implants placed in augmented bone, short implants also have the advantage that they are retained by native bone only. This bone is more reliable than bone, eg, from the iliac crest. Depending upon the amount of residual bone still available, implants placed in grafted bone may be retained solely by the softer iliac crest bone graft. Such grafts are often associated with significantly higher implant failure and complication rates.

The very good outcome of the short implants in this study could be a result of splinting the implants. Most implants in this study were reconstructed with an interconnected suprastructure to provide additional stability. Bergkvist et al reported that stresses levels in the bone tissue surrounding splinted implants were markedly lower than stress levels surrounding uncoupled implants by a factor of nearly 9. Also, the number of implants placed and splinting of short implants to longer implants can influence implant survival. To eliminate the possible positive influence of longer implants in this study, however, only reconstructions with short implants exclusively were included.

The long study observation period of 10 years resulted in highly reliable data, despite the fact that the number of implants was limited. To increase the homogeneity and significance of the data, only patients with suprastructures solely retained by short implants were observed. Patients with suprastructures retained by short implants as well as longer implants (implants at least 10 mm long) were not included. Also, only implants with rough surfaces from the same manufacturer were inserted.

A comparison of the present evaluation of short implants inserted in atrophied bone with results of the placement of long implants in similar bone could have increased the value of the study. Thus, the inclusion of an adequate control group in this research would have been beneficial. The defined inclusion criteria, however, focused the evaluation of patients with a degree of atrophy, which—without prior bone augmentation—permitted the insertion of short implants only. Therefore the selected degree of bone atrophy did not allow the placement of longer implants under identical conditions.

Another debatable point of this study is the definition of the “short implant”; many studies have used different definitions. In this clinical study, a short implant was defined as an implant with a maximum length of 9 mm. At the time of placement of the present implants, implants shorter than 10 mm in length were considered to be short, and many authors still use these definitions. However, the definition of short implants has changed over the years. While a 9-mm implant was considered short at the time of placement in this study, nowadays it is considered to be a standard-length implant by several authors. In addition, the same implant company currently produces 6-mm-long implants; however, no long-term results (>5 years) on this implant length have yet been published.

With regard to the value of short implants, it must be kept in mind that not all degrees of bone atrophy and types of defects can be treated with short implants. While in the lateral region of the arch, the implant-to-crown ratio (with longer crowns resulting from the use of short implants) may not be an esthetic impairment for the patient, it will certainly compromise esthetics in the anterior maxilla. To achieve a functionally and esthetically satisfying result, the bone in this area must be reconstructed, eg, with autologous block grafts. In such cases, the higher morbidity related to bone grafting procedures must be accepted even if it would be possible to place a short implant. Also, in cases of severe atrophy (ie, Cawood and Howell classes V and VI), grafting will be required prior to implant placement. Otherwise, a satisfactory implant-retained solution is impossible.
CONCLUSION

This study followed and evaluated short implants (ie, < 10 mm) inserted for various indications over an average period of 10 years. The implant survival and success rates were 100%. The success of prosthetic restorations supported solely by these short implants was also 100%. Thus, the use of short implants can be a reliable, long-term stable treatment option, particularly in areas of insufficient or atrophied residual bone, and can help to reduce morbidity for patients. However, it must always be kept in mind that the use of short implants cannot be regarded to represent a general alternative to all bone grafting procedures. Nevertheless, it can be a good solution for various indications and a certain degree of atrophy.

ACKNOWLEDGMENTS

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REFERENCES


Biomechanical Comparison of a Single Short and Wide Implant with Monocortical or Bicortical Engagement in the Atrophic Posterior Maxilla and a Long Implant in the Augmented Sinus

Shih-Hao Chang, DDS, MS1/Chun-Li Lin, PhD2/Yang-Sung Lin, MS3/ Shue-Sang Hsue, PhD4/Shiang-Rung Huang, MS5

Purpose: The present study investigated the biomechanical interactions of a monocortically or bicortically engaged short and wide implant in the atrophic posterior maxilla and compared them to those of a long implant in the augmented sinus under different loading conditions via a nonlinear finite element (FE) approach.

Materials and Methods: Nonlinear FE models of a single implant in the posterior maxilla were constructed for the following conditions: (1) A monocortically engaged 5-mm-long, 7-mm-wide implant with an internal tripod-grip abutment connection (SIT-1), (2) a bicortically engaged 6-mm-long, 7-mm-wide implant with internal tripod-grip abutment connection (SIT-2), and (3) a 13-mm-long, 4.5-mm-wide implant with an internal-hexagon abutment connection in an augmented sinus. Simulated loads of 150 N were applied axially at the central fossa, off-axis at the buccal and palatal cusps, and toward the axis at the buccal and palatal cusps. Results: The simulated results showed that loading condition was the main factor influencing the mechanical responses. Oblique occlusal forces increased implant stress and stress/strain values for the surrounding bone. The use of a long implant decreased the implant stress but increased the bone stress/strain values relative to a short and wide implant. The SIT-1 and SIT-2 implants increased the implant stress on average by 2.94 and 2.67 fold, respectively. However, the SIT-2 implant reduced the average stress and strain in bone by 37%, and the SIT-1 implant reduced average stress by 33% and average strain by 32%. Conclusions: Placement of a short and wide implant in the atrophic posterior maxilla may be a possible alternative for reducing the strain/stress on the surrounding bone. Detrimental off-axis loads should always be minimized to prevent extraordinarily high bone strain and stress.

Key words: biomechanics, dental implants, finite element analysis, paranasal sinuses, short implants, sinus floor elevation, wide implants

The high success rate achieved by dental implants with respect to osseointegration has become an accepted clinical reality. Clinical studies have revealed high success rates for different kinds of implant-supported prosthetic rehabilitations, confirming the advantages of dental implant treatment. However, in patients with advanced alveolar bone resorption or adjacent vital structures, the provision of dental implants with standard dimensions often becomes an arduous task. This is particularly true in the atrophic posterior maxilla and mandible, where there are risks of penetrating the maxillary sinuses or damaging the inferior alveolar nerves. Thus, implant therapy in patients with reduced alveolar bone quantity may be compromised. Advanced surgical techniques for implant placement, such as horizontal and vertical osseous ridge augmentations and sinus elevation, are therefore utilized to increase the quantity of alveolar bone. Although there is considerable chance for success, these additional surgical interventions inevitably increase treatment duration and cost, as well as morbidity of both the donor and recipient sites. Esposito et al found, in a systematic review of horizontal and vertical bone augmentation techniques for dental
implants (5 to 8 mm) may be as effective as a prosthetic solution in more complex techniques. A short implant has also been defined as an implant with a specific maximum designed intrabony length. This alternative simplifies treatment and reduces the need for additional bone augmentation surgeries and the related costs and morbidity.

Several authors have provided an overview of the literature of short dental implants. In the past, short implants have been associated with lower survival rates. However, a number of publications advocated that the failure rates of short implants were not higher than those for implants 10 mm or longer. Hagi et al found that, when applying implants of 7 mm or less in length, machined-surface implants experienced greater failure rates than textured-surface implants. He concluded that dental implant surface geometry is a major determinant in how well these implants perform in short lengths, defined here as lengths of no more than 7 mm. In a systematic review and meta-analysis on the effect of implant length on the survival of rough-surface implants, Kotsovilis et al observed no statistically significant difference in the survival of short (≤ 8-mm or < 10-mm) and conventional (≥ 10-mm) rough-surfaced implants placed in totally or partially edentulous patients. They thus concluded that the placement of short rough-surfaced implants is less effective than the placement of longer rough-surfaced implants.

In addition to surface texture, several other factors have been assumed to be responsible for the lower survival rate of short implants. First, short implants are usually placed in the posterior arches, where the bone quality is relatively poor, especially in the maxilla. Second, compared to longer implants with comparable diameter, there is less bone-to-implant contact simply because of the smaller implant surface area. Third, alveolar bone resorption is often accompanied by an unfavorable jaw relationship and/or increased interarch space, which inevitably leads to an increased buccolingual cantilever and/or an increased crown height. Crown-to-implant ratios between 0.5 and 1.0 have been proposed to prevent excessive peri-implant bone stress, crestal bone loss, and eventual implant failure. But a recent systematic review concluded that this ratio does not influence peri-implant bone loss. However, occlusal overloading has been associated with the higher failure rate of short implants. The increased force magnitude, unfavorable force distribution, and high bending moments, together with poor bone quality, may produce biomechanical overloading and increased failure rates for implants in the posterior maxilla.

The failure of threaded dental implants is generally considered to be related to progressive crestal bone loss. A number of factors may account for crestal bone loss, such as the establishment of "biologic width," local trauma, interference with vascularity during implant placement, peri-implant infection, and other biomechanical influences. The higher bending moment at the implant site may lead to increased marginal bone loss or loss of osseointegration around the implant as a result of overload. Several experimental studies indicated that marginal bone loss around implants can be induced by excessive occlusal overloading. Engineering complications, such as abutment screw loosening (with screw-retain ed prostheses) or implant or prosthesis fractures, may also occur under long-term loading. Biomechanically, short dental implants would be more likely to suffer from detrimental effects. However, it is often very difficult or impossible to directly measure the stress and strain on implants and the surrounding bone in individual patients. Mathematical simulations, such as finite element (FE) analysis, can provide detailed mechanical responses and are complementary tools in dental biomechanical studies.

To the authors’ knowledge, in spite of a considerable number of studies on the clinical survival rates of short implants and general biomechanical evaluations of short implants, no biomechanical study with sophisticated FE models to determine the possible detrimental factors has yet been performed for short implants in the atrophic posterior maxilla and longer implants in the grafted sinus. Therefore, the present study sought to compare the biomechanical interactions of an implant with standard length and diameter placed in the grafted sinus and a short and wide (short-wide)
implant with monocortical or bicortical engagement placed in the atrophic posterior maxilla without sinus graft under different occlusal loading conditions and favorable or unfavorable jaw relationships.

MATERIALS AND METHODS

FE Models of the Implants and Grafted Sinus

To create a solid model of alveolar bone, computed tomographic (CT) images (i-CAT Cone Beam 3D Dental Imaging System, Imaging Sciences International) of a middle-aged Chinese woman with a 6-mm subantral bone height in the edentulous maxillary first molar area were selected from the authors’ CT database. A series of CT images at 1-mm intervals of the posterior edentulous maxilla from the selected patient was obtained from the second premolar to the second molar. All CT image cross sections were processed on a personal computer with commercially available image processing software (Amira, version 4.1, Visualization Sciences Group) that allowed identification of the cortical and cancellous bone contours. These contours were extracted and converted into mathematic entities. The coordinates of each point on the contours were entered into an FE program (ANSYS, version 11.0, ANSYS) to generate solid models. A sinus graft was constructed from the bottom of the sinus floor to a level that would allow placement of implants of standard length and width.

To compare the biomechanical effects of a short-wide implant without sinus grafting and a longer implant with sinus grafting in the posterior maxilla, three FE models of a single implant placed in the posterior maxilla were constructed:

1. A 5-mm-long implant, 7 mm in diameter, with internal tripod-grip abutment connection and monocortical engagement (SIT-1);
2. A 6-mm-long implant, 7 mm in diameter, with internal tripod-grip abutment connection and bicortical engagement (SIT-2); and
3. A 13-mm-long implant, 4.5 mm in diameter, with internal-hexagon abutment connection placed in augmented sinus (LIH-S) (Fig 1).

Solid models of the short-wide (Rescue Implant, Megagen Co) and long (Frialit, DENTSPLY Friadent) implant systems and corresponding cemented porcelain-fused-to-metal crowns were constructed using a 3D computer-aided design system (Creo Elements/Pro, Parametric Technology) and exported into ANSYS to place in the first molar position of the posterior maxilla to complete the models (Fig 2).

Three mesh models for SIT-1, SIT-2, and LIH-S implant/bone/prosthesis systems were generated with quadratic 10-node tetrahedral structural solid elements (Solid 92) after the mesh convergence test while controlling the strain energy and displacement variations of < 5% for models with different element sizes. Nonlinear frictional contact elements (defined as surface-to-surface) were used to simulate the adaptation between the abutments and implants within the implants. The simulation procedure for all models was divided into two loading steps. The first loading step applied 32 Ncm of torque moment (the manufacturer’s...
recommended tightening torque) to the abutment screw and assumed a friction coefficient of 0.2 to all contact surfaces to simulate the preload effect. The applied moment in the preload was transformed along the interface of the abutment screw thread surfaces and the implant bore threaded surfaces. The transformed force then induced the contact force in the interface between the abutment and implant surfaces that were being clamped together. The corresponding stress values in the implant system in the simulated preload for each model were output as the initial condition in the second step. Occlusal loading conditions were then applied in the second step to simulate an implant receiving occlusal forces.\textsuperscript{6,16}

### Loading Conditions

To simulate the buccolingual forces during normal occlusion and/or possible crossbite caused by resorption of the alveolar process in the maxilla, axial and 30-degree nonaxial loads at 150 N of magnitude were simulated as follows: (1) axial load at the central fossa (A-c), (2) off-axis load at the buccal cusp (OA-b), (3) off-axis load at the palatal cusp (OA-p), (4) toward-axis load at the buccal cusp (TA-b), and (5) toward-axis load at the palatal cusp (TA-p). The mesial and distal exterior nodes of the bony segment were fixed in all directions as boundary conditions. The authors assumed linearly elastic, homogenous, and isotropic material properties for the osseous tissue, prosthesis, and implant system in all simulations, as adopted from the relevant literature (Table 1).\textsuperscript{31,32} The maximum von Mises strain for alveolar bone was recorded and the maximum von Mises stresses for alveolar bone and implant systems were recorded for all FE analyses.

### Statistical Analyses

Multiple-factor analysis of variance was applied to determine the relative importance of the investigated factors and their interactions (Minitab, version 12.23, Minitab). The main effect of each level of factors (implant type, load condition) on mechanical response (stress and strain) was also computed. To determine the effects of length or surface area on the biomechanical interactions, the bone-to-implant contact areas were also calculated and evaluated.
RESULTS

Maximum von Mises stresses and strains in the implants and bone in the various loading situations and implant/bone models are shown in Table 2. The simulated results showed that the loading condition was the factor that most strongly influenced the magnitude of all mechanical responses; the percentage contributions were 65% for implant stress, 71% for bone stress, and 70% for bone strain (Table 3). Generally, oblique occlusal forces (OA-b, OA-p, TA-b, and TA-p) increased the implant stress and stress/strain values for the surrounding bone more than the axial loading condition (A-c) (Table 2, Fig 3). The main effect plot showed that off-axis loads (OA-b and OA-p) induced extraordinarily high stress/strain in comparison to toward-axis loads (TA-b and TA-p) in the implant and surrounding bone (Fig 3). The implant system was the second most important factor influencing the mechanical responses: the percentage contributions were 27%, 16%, and 17% for implant stress, bone stress, and bone strain, respectively (Table 3). The main effect plot showed that the long implant model (LIH-S) decreased the implant stress but increased the bone stress/strain values more than short implants (SIT-1 and SIT-2) (Fig 3). The bicortically engaged short implant (SIT-2) increased the implant stress by an average of 2.67 fold, and the monocortically engaged short implant (SIT-1) increased the implant stress by an average of 2.94 fold. However, compared to the LIH-S implant, SIT-1 and SIT-2 implants reduced the bone stress/strain; SIT-2 (bicortically engaged) reduced average stress and strain by 37%, and SIT-1 (monocortically engaged) reduced average stress by 33% and strain by 32%.

The highest bone strain values were found at the crestal cortex and implant-abutment junction in all investigated conditions (Fig 4). A comparison of the areas of maximum stress for implants revealed that the maximal stress was located at the tripod grip of the abutment in the SIT-1 and SIT-2 models (Fig 5). The maximal implant stress in the LIH-S group occurred at the butt joint of the abutment-implant junction (Fig 5).

DISCUSSIONS

Although outcomes following advanced osseous augmentation techniques vary,\textsuperscript{3,4,36,37} considering the increased treatment cost, duration, and morbidity involved in augmentation surgeries, the use of short dental implants is a rational alternative in situations where a limited amount of alveolar bone is available. This study revealed that loading conditions significantly influenced the magnitude of stress and strain. Generally, oblique occlusal forces increased the stress/strain in the surrounding bone more than axial forces. Off-axis loads, which might occur during the lateral excursion in group function or in posterior crossbite occlusions, induced extraordinarily high strain in the surrounding cortical bone. Compared to the long implants, short-wide implants reduced the bone stress/strain.

Table 2  Bone Stress, Bone Strain, and Implant Stress Under Various Loading Conditions and Implant/Bone Situations Obtained from FE Simulations

<table>
<thead>
<tr>
<th>Area of stress/strain</th>
<th>Loading conditions</th>
<th>Off-axis loads</th>
<th>Toward-axis loads</th>
<th>Axial load</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OA-b</td>
<td>OA-p</td>
<td>TA-b</td>
</tr>
<tr>
<td>Bone stress (MPa)</td>
<td>LIH-S</td>
<td>79</td>
<td>78</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>SIT-1</td>
<td>47</td>
<td>55</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>SIT-2</td>
<td>47</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Bone strain (μ)</td>
<td>LIH-S</td>
<td>5,378</td>
<td>5,365</td>
<td>2,393</td>
</tr>
<tr>
<td></td>
<td>SIT-1</td>
<td>3,190</td>
<td>2,554</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>SIT-2</td>
<td>3,171</td>
<td>3,782</td>
<td>1,473</td>
</tr>
<tr>
<td>Implant stress (MPa)</td>
<td>LIH-S</td>
<td>170</td>
<td>195</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>SIT-1</td>
<td>478</td>
<td>536</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>SIT-2</td>
<td>419</td>
<td>504</td>
<td>178</td>
</tr>
</tbody>
</table>

Table 3  Summary of Analysis of Variance of Maximum Stresses and Strains (%TSS) in Implants and Bone

<table>
<thead>
<tr>
<th>Source</th>
<th>Implant stress</th>
<th>Bone stress</th>
<th>Bone strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading condition</td>
<td>65</td>
<td>71</td>
<td>70</td>
</tr>
<tr>
<td>Implant type</td>
<td>27</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Loading condition × implant type</td>
<td>8</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
strain during nonaxial loads, and they were especially helpful in reducing peri-implant bone strain in off-axis load conditions. Regarding the patterns of bone strain distribution, the areas of bone that received the maximum strain were located around the neck of the implant on the buccopalatal and the mesial rim for the nonaxial and axial loading conditions, respectively. This location was identical for all examined implant lengths and diameters and is in agreement with previous publications.\textsuperscript{26,28}
The off-axis loads and related high bone strain values for the long implant in this study were 1.42- to 2.10-fold higher than those for the short-wide implants (Table 2). Short-wide implants may have the potential to reduce the risk of high concentrations of bone strain, which can lead to crestal bone loss. Failure of threaded dental implants is generally considered to be related to progressive crestal bone loss. Excessive forces are likely to develop, especially in bone regions that are in contact with implant compression surfaces.\textsuperscript{38,39}
Table 4  Contact Area Between Bone and Implants

<table>
<thead>
<tr>
<th>Implants</th>
<th>Implant dimensions (diameter × length)</th>
<th>Total bone contact area (cortical + cancellous)</th>
<th>Cortical bone contact area</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIT-1</td>
<td>7 × 5 mm</td>
<td>146.240 mm²</td>
<td>45.520 mm²</td>
</tr>
<tr>
<td>SIT-2</td>
<td>7 × 6 mm</td>
<td>174.321 mm²</td>
<td></td>
</tr>
<tr>
<td>LIH-S</td>
<td>4.5 × 13 mm</td>
<td>186.595 mm²</td>
<td></td>
</tr>
</tbody>
</table>

and may lead to bone microfractures and resorption on the compression surfaces. It is most likely that bone cells respond directly or indirectly to the local strain engendered in their vicinity by the loads from normal functional activity. Frost proposed a domestic mechanostat that is "off" under circumstances of normal physiologic strain and "on" in response to strain magnitudes outside normal physiologic thresholds. He stated that in vivo studies have shown that bone strain in or above the range of 1,500 to 3,000 microstrains causes bone modeling to increase cortical bone mass, while strain below the range of 100 to 300 microstrains releases basic multicellular unit–based remodeling to remove existing cortical/endosteal and trabecular bone. Carter et al hypothesized that bone strain above 3,000 microstrain may be troublesome for bone, leading to a hypertrophic response, and that bone strain above 4,000 microstrain may cause local overloading, followed by bone loss in the acting force locations. Thus, it is the nonphysiologic strain, rather than the stress on bone, that may induce osseous tissue resorption. Although the high bone strain values for the long implant under off-axis loads (Table 2) may be different under different load magnitudes and within different qualities of bone, the trend remains. The use of short-wide implants, on the other hand, may have the potential to reduce the risk of high concentrations of bone strain and any resulting crestal bone loss under nonaxial load conditions.

The mechanisms of reduced stress/strain in bone for the short-wide implants, compared to the long implant placed in the grafted sinus, may be caused by the increased primary stress-bearing area of the crestal cortex in implants with wider diameter (Table 4). Previous investigations reported that less stress was transmitted to the surrounding bone by wider or longer implants. It was also concluded that implant diameter was more important for improved stress distribution than implant length. Similar effects were observed for implants with diameters ranging from 3.8 mm to 6.5 mm. In the present study, the diameter in the LIH-S group was 4.5 mm, and the SIT implants were 7 mm wide. The total bone-to-implant contact areas in the SIT-1 and SIT-2 groups were 78.37% and 93.42%, respectively, when compared to that of the LIH-S group. However, the crestal cortical bone-to-implant contact areas in the SIT groups were twice that obtained in the LIH-S group. The increased primary stress-bearing crestal cortex area of the short-wide implant may have contributed to the reduced stress/strain bone values around it.

Traditionally, researchers believed that short dental implants would be more likely to suffer from detrimental effects as the compressive forces concentrated over a relatively small coronal area to the implant’s center of resistance, with a counteracting force acting apical to the center of resistance. It was believed that longer implants might result in greater stress-bearing area and thus reduce the local stresses acting on the supporting bone, reducing the probability of microfracture. However, recent clinical studies have reported that the failure rates of short dental implants were no greater than those for longer implants. The present investigation provides a biomechanical rationale for the use of short-wide implants in the posterior maxilla. Under the conditions investigated in this study, advanced osseous augmentation surgeries seem to be just one option for patients with insufficient subantral bone volume. Further investigations regarding the effects of the diameter and design (abutment and implant) of short implants in different bone quality should be conducted to help clinicians choose the optimal implant therapy and reduce the cost, time, and risk of additional surgeries for their patients.

To simulate reality, an implant system with an internal-hexagon abutment design, which is widely used in commercial implant systems, was chosen as the control group (the implant of standard length and diameter in the grafted sinus). Further comparison using implants with other abutment/implant interface designs or implant topographies may be needed. Although accurate 3D implant (long and short-wide)/bone/prosthesis FE models were constructed here to investigate the basic mechanical interactions under different loading conditions, this investigation was limited by theoretical assumptions, including the loading conditions (aforementioned), bone-implant interface assumptions, and material properties. These assumptions likely affected the accuracy of the results obtained regarding...
the mechanical responses and stress states. For the bone-implant interface assumption, several recent publications advocated that the higher failure rates of short implants were related to the smooth surface, external-hex interface, and screw-type design and could be reduced considerably by the use of short implants with microtextured surfaces.\(^\text{8,14,15,44}\) Compared to the smooth machined implant surface, the microtextured implant surface increases the implant's anchorage to the bone during osseointegration.\(^\text{10,45}\) With improved implant surface treatments, the anchorage between the implant and bone is considered optimal and thus the bone-to-implant bonding conditions in the present simulations were rationally modeled as perfect. Therefore, the FE model assumed that osseointegration of the bone-implant interface was 100%, which indicated that the bone was perfectly bonded to the implant surface. The effects of the implants' properties and coating material on the surface were not discussed in this study. Also, linearly elastic (homogeneous and isotropic) properties were adopted for all materials because of numeric convergence considerations and the large variance in physical properties in the literature, especially those involving characterization of the periodontal ligament.\(^\text{38,39}\) Therefore, the present FE modeling results provide only general insight into the biomechanical aspects of the implant (long and short-wide)/bone/prosthesis system under average conditions.

**CONCLUSIONS**

Based on extensive three-dimensional nonlinear numeric analyses, the following may be concluded.

1. Compared to a long implant placed in a grafted sinus, the placement of a short and wide implant may reduce the transmitted stress and resultant strain in the surrounding bone in the posterior maxilla.
2. The loading conditions significantly influenced the magnitude of the stress and strain values. Off-axis loads were found to be detrimental and should always be reduced by using occlusal equilibration, a smaller occlusal table, and smaller cusp inclinations. Modification of the interarch relationship, either by horizontal osseous augmentation procedures or orthodontic tooth movement, might be considered to reduce off-axis loads in patients with posterior crossbite occlusion.

**ACKNOWLEDGMENTS**

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**REFERENCES**


Survival of Short Dental Implants for Treatment of Posterior Partial Edentulism: A Systematic Review

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Purpose: Dental implant therapy for posterior partial edentulism may utilize short implants. The advantages of short implants include the ability to avoid the additional surgical procedures that would be required to place longer implants. The aim of this study was to systematically review studies concerning dental implants of ≤ 8.5 mm placed in the posterior maxilla and/or mandible to support fixed restorations. Materials and Methods: English-language articles published between 1992 and May 2011 were identified electronically and by hand search of the PubMed, Embase, and Cochrane libraries. Data were extracted and compared statistically. Forest plots were generated to compare outcomes of short versus long implants. Results: An initial screening of 1,354 studies led to direct evaluation of 401 articles. Of these, 33 met the research criteria: 5 randomized clinical studies; 16 prospective, nonrandomized, noncontrolled studies; 12 retrospective, nonrandomized studies; and 1 study with both prospective and retrospective data. These studies indicated that there is no significant difference in the reported survival of short versus long implants. Failure of 59 of 2,573 short implants at 1 year was recorded, with 71% of them failing before loading. Only 101 short implants were followed for 5 years. Conclusions: The initial survival rate for short implants for posterior partial edentulism is high and not related to implant surface, design, or width. Short implants may constitute a viable alternative to longer implants, which may often require additional augmentation procedures. Int J Oral Maxillofac Implants 2012;27:1323–1331

Key words: posterior partial edentulism, short dental implant, systematic review

Dental implant therapy is currently used for the replacement of missing teeth in diverse clinical situations. The use of osseointegrated dental implants has evolved from its initial application for mandibular edentulism to include all clinical scenarios for tooth replacement. Different scenarios are associated with unique challenges. When considering placement of implants in the posterior maxilla or mandible, the superoinferior dimension of available bone is defined by the extent of alveolar ridge resorption and the location of the maxillary sinus or the inferior alveolar nerve. These factors can limit or preclude dental implant placement.1,2 Additional factors that may add to the risk of osseointegration failure include the lower quality bone that is present in parts of the maxilla.3

Clinical solutions to these problems involve alveolar ridge augmentation procedures.4 Additional solutions include the movement of the inferior alveolar nerve (lateral nerve transposition)2 and sinus elevation, with or without grafting.4 Each of these surgical approaches to increasing the bone volume and vertical dimension of available bone for implant placement has been evaluated in terms of the possible subsequent implant survival rates, and each approach has attendant and specific complications and limitations.

An alternative approach for the treatment of posterior partial edentulism involves the use of short dental implants. The definition of what constitutes a short implant has not reached consensus; however, implants of 10 mm or shorter have generally been considered “short” by existing clinical standards.5–8 The use of short dental implants remains controversial, particularly in comparison to alternative approaches to the treatment of posterior partial edentulism. For example, sinus augmentation versus the use of short dental implants was recently considered,9 and there is limited evidence that short dental implants provide acceptable and comparable success.

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Irrespective of other approaches available, the use of short implants in the treatment of posterior partial edentulism offers some advantages (Fig 1). Included are the reduced surgical risks of paresthesia, contact with adjacent tooth roots, and overheating of bone; the reduced exposure to bone grafting and reduced time, discomfort, and cost; and improved surgical placement by expanding surgical access and reducing implant inventories. However, these advantages could be irrelevant if the survival of short implants is significantly lower than that of the facilitated use of longer implants.

Therefore, the aim of the present study was to determine whether there is a significant difference in the survival of short implants (≤ 8.5 mm) and longer implants for the treatment of posterior partial edentulism. The treatment of the maxilla and mandible using single implants and fixed partial dentures was evaluated by completing a systematic review of prospective, retrospective, and randomized clinical studies published in English up to May 2011.

**MATERIALS AND METHODS**

The search for articles included in this systematic review was divided into primary and secondary stages. The primary stage was initiated by searching the National Library of Medicine database (Medline) through its online site (PubMed). This investigation was followed by searches of the Cochrane Library and Embase databases.

Key words and search inquiries that were used during primary stage were as follows:

- Posterior dental implant
- (Posterior dental implant) AND (short OR ultra-short OR ultra-wide OR wide OR length OR width OR diameter OR 5 mm OR 6 mm OR 7 mm OR 8 mm OR 8.5 mm)
- Posterior dental implant AND (retrospective OR prospective OR clinical trial)
- Short implant survival

The choice of key words was intended to be broad to collect as much relevant data as possible without relying on electronic means alone to refine the search results. The titles of the articles retrieved were searched manually. After that, manual and electronic searches of the abstracts and full texts were performed to identify relevant articles. Additionally, the references of each article were thoroughly inspected for more possible candidates.

The resulting articles were then subjected to clear inclusion and exclusion criteria by two reviewers as follows.

- Were human prospective or retrospective follow-up studies and clinical trials, published in English
- Investigated implants ≤ 8.5 mm long
- Examined implants in posterior partially edentulous patients restored with fixed restorations
Followed short implants for at least 1 year after loading and reported clear data regarding follow-up intervals, dropouts, and failures

Could not be excluded before careful reading

The following articles were excluded:

- Studies that targeted dental implants in medically compromised patients
- Studies that did not separate the data of edentulous from partially edentulous and anterior from posterior implant cases
- Studies that did not attribute implant loss to specific implant length
- Case reports
- Studies that included unclear data, with authors who could not be contacted for any reason

From the included articles, data were collected and arranged in the following fields: implant system, design, and surface; implant length and diameter; implant location; type of surgical procedure used; healing time; type of restoration; number of short implants, number of failed short implants, and the time to failure; and survival criteria. Other factors that were planned to be included but were not obvious in most of the studies were: type of placement (immediate or late) and type of loading (immediate, early, or late).

Two tables were created initially with the data: one for short dental implants (≤ 8.5 mm) and the other for dental implants that were both short and wide (short-wide) (≤ 8.5 mm in length and ≥ 4.8 mm in diameter). The previous data were also used to construct different life table analyses.

RESULTS

The initial search, after duplicates were removed, resulted in 1,354 articles. After manual search of the article titles, manual and electronic searches of the abstracts and full text were done, resulting in 331 possibly relevant articles. Additionally, the reference section of each article was thoroughly inspected, resulting in 70 new articles. After the inclusion and exclusion criteria were applied to the 401 articles, 33 articles were included.

A total of 3,573 short dental implants was reported in the 33 studies that fulfilled the inclusion criteria. Of those implants, 38% were in the maxilla, 51% were in the mandible, and the location of the remaining implants was unclear. The majority of short dental implants (59%) were 8 mm long, and a majority (56%) of the implants with known diameters were wide (≥ 4.8 mm). The distribution of these implants according to length, diameter, and location is shown in Tables 1 to 3. Regarding the surfaces of the reported implants, only 4.6% of the reported implants had a machined surface. More than 64% of the reported short implants were represented by titanium plasma spray (TPS) surfaces or the SLA surface (sandblasted, large-grit, acid-etched; Straumann) (Table 4). Information about posterior partially edentulous restorations for Kennedy Class I, II, and III situations was extracted from the reviewed papers. The total number of restorations was distributed nearly equally between single crowns and fixed partial restorations (Table 5).

Implant Survival and Life Table Analyses

Only two studies were excluded from the life table analyses of short dental implants. Data from 16 of 21 studies were used in the life table analyses for the short-wide dental implants. The reported average follow-up period was 3.9 years (range, 1 to 7 years). Of the 3,573 implants studied, 67 failures were reported. The majority (71%) of failures occurred before loading. Based on the information available, it is apparent that many short implants were not followed for the duration of the investigation. To better understand the potential limitations in interpreting these data, life tables were constructed to include censored implants (implants that were not continuously reported, as well as dropouts recorded by the investigators). All of the included papers contained data that were censored; however, 16 studies provided information (including dropouts) concerning all implants for all time points (78% of the reported implants).
A 5-year cumulative survival rate of 98% was calculated for all short implants (Table 6). When short (≤ 8.5 mm) and longer (> 8.5 mm) implants were compared from the aggregate data set, comparable 5-year cumulative survival rates were observed (98.3% and 97.7%, respectively) (Table 7). An additional comparison of short implants (< 4.8 mm in diameter) versus short-wide implants (≥ 4.8 mm in diameter) is reported in Table 8 and revealed similar 5-year cumulative survival rates (98.9% and 98.6%, respectively).

**Forest Plots**

Six of the 33 examined studies included a comparison of short versus long implants as the objective of the study. Among these studies, the definition of short implants varied. Two of them defined ≤ 8.5-mm implants as “short,” another two studies reported ≤ 9-mm implants as “short,” one compared ≤ 10-mm implants as “short” versus other longer implants, and the last one compared 7-mm implants to ≥ 10-mm implants. A meta-analytic representation of these studies in the form of forest plots was performed; risk ratio was used as the effect size measure, and the tested outcome was implant survival risk ratio. The implant survival risk ratios were used instead of implant survival rates because the length of follow-up periods varied between studies and these studies included censored data. However, the total number of placed and failed implants was known (since it was an inclusion criterion for the selected studies). Calculations were adjusted to unify the criteria for “short implant” to ≤ 8.5 mm. The resultant forest plot is shown in Table 9.11–16 The result showed that the overall risk ratio was equal to 1, meaning that the survival rate of the surveyed implants was not related to length.

**Table 3** Implant Distribution According to Location

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>1,373</td>
</tr>
<tr>
<td>Mandible</td>
<td>1,820</td>
</tr>
<tr>
<td>Unknown</td>
<td>380</td>
</tr>
</tbody>
</table>

**Table 4** Implant Distribution According to Surface

<table>
<thead>
<tr>
<th>Surface</th>
<th>No. of implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAE</td>
<td>60</td>
</tr>
<tr>
<td>HA-coated</td>
<td>168</td>
</tr>
<tr>
<td>Machined</td>
<td>163</td>
</tr>
<tr>
<td>Roughened (HA-blasted)</td>
<td>30</td>
</tr>
<tr>
<td>SLA</td>
<td>405</td>
</tr>
<tr>
<td>SLActive</td>
<td>40</td>
</tr>
<tr>
<td>SPS</td>
<td>317</td>
</tr>
<tr>
<td>TiO₂ blasted</td>
<td>10</td>
</tr>
<tr>
<td>TiUnite</td>
<td>511</td>
</tr>
<tr>
<td>TPS</td>
<td>14</td>
</tr>
<tr>
<td>TPS or SLA</td>
<td>1,851</td>
</tr>
<tr>
<td>Unknown</td>
<td>4</td>
</tr>
</tbody>
</table>

DAE = dual acid-etched; HA = hydroxyapatite; SLActive = the SLA surface, conditioned with nitrogen and kept in isotonic solution (Straumann); SPS = sintered porous surface; TiUnite = porous anodized, highly crystalline, and phosphate-enriched titanium dioxide (Nobel Biocare); TPS = titanium plasma spray.

**Table 5** Implant Distribution According to Type of Restoration

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>No. of implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single tooth</td>
<td>1,952</td>
</tr>
<tr>
<td>Fixed partial</td>
<td>1,198</td>
</tr>
<tr>
<td>Cantilever</td>
<td>63</td>
</tr>
<tr>
<td>Unspecified fixed restoration</td>
<td>360</td>
</tr>
</tbody>
</table>

**Table 6** Life Table Analysis of Short Dental Implants, Combined from the Reviewed Papers

<table>
<thead>
<tr>
<th>Interval (y)</th>
<th>Implants at risk</th>
<th>Failed</th>
<th>Censored</th>
<th>ISR</th>
<th>CSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>3,457</td>
<td>53 (38)</td>
<td>35</td>
<td>98.5%</td>
<td>98.5%</td>
</tr>
<tr>
<td>1–2</td>
<td>2,288</td>
<td>7</td>
<td>1,116</td>
<td>99.7%</td>
<td>98.2%</td>
</tr>
<tr>
<td>2–3</td>
<td>1,297</td>
<td>3</td>
<td>984</td>
<td>99.8%</td>
<td>97.9%</td>
</tr>
<tr>
<td>3–4</td>
<td>786</td>
<td>0</td>
<td>508</td>
<td>100.0%</td>
<td>97.9%</td>
</tr>
<tr>
<td>4–5</td>
<td>338</td>
<td>0</td>
<td>448</td>
<td>100.0%</td>
<td>97.9%</td>
</tr>
<tr>
<td>5–6</td>
<td>101</td>
<td>0</td>
<td>237</td>
<td>100.0%</td>
<td>97.9%</td>
</tr>
<tr>
<td>6–7</td>
<td>27</td>
<td>0</td>
<td>74</td>
<td>100.0%</td>
<td>97.9%</td>
</tr>
<tr>
<td>7–8</td>
<td>1</td>
<td>0</td>
<td>26</td>
<td>100.0%</td>
<td>97.9%</td>
</tr>
</tbody>
</table>

Numbers in parentheses indicate implants that failed before loading.

ISR = interval survival rate; CSR = cumulative survival rate.
Another comparison of short and long implants was attempted using all available data presented in 24 studies that included both long and short implants (Table 10). The overall risk ratio for short versus long implants was 1.00 (pooled confidence interval of 0.98 to 1.01). In this broader analysis that included more diverse studies, the mean survival rates were similar for short and long implants.

### DISCUSSION

The main observation in this investigation was the reported survival of short implants, defined as ≤ 8.5 mm in length, for the treatment of posterior partial edentulism. This reiterates the findings of similar reports. Among the greatest confounding factor in evaluating these different reports is the definition of a ‘short’ dental

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**Table 7** Life Table Analysis for Short Versus Long Dental Implants from Papers that Included Both

<table>
<thead>
<tr>
<th>Interval (y)</th>
<th>Implants at risk</th>
<th>Failed</th>
<th>Censored</th>
<th>ISR</th>
<th>CSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–1</td>
<td>2,662</td>
<td>33 (30)</td>
<td>28</td>
<td>98.8%</td>
<td>98.8%</td>
</tr>
<tr>
<td>1–2</td>
<td>1,626</td>
<td>5</td>
<td>1,003</td>
<td>99.7%</td>
<td>98.5%</td>
</tr>
<tr>
<td>2–3</td>
<td>1,054</td>
<td>2</td>
<td>567</td>
<td>99.8%</td>
<td>98.3%</td>
</tr>
<tr>
<td>3–4</td>
<td>635</td>
<td>0</td>
<td>417</td>
<td>100.0%</td>
<td>98.3%</td>
</tr>
<tr>
<td>4–5</td>
<td>290</td>
<td>0</td>
<td>345</td>
<td>100.0%</td>
<td>98.3%</td>
</tr>
<tr>
<td>5–6</td>
<td>86</td>
<td>0</td>
<td>204</td>
<td>100.0%</td>
<td>98.3%</td>
</tr>
<tr>
<td>6–7</td>
<td>24</td>
<td>0</td>
<td>62</td>
<td>100.0%</td>
<td>98.3%</td>
</tr>
<tr>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–1</td>
<td>3,058</td>
<td>64 (35)</td>
<td>71</td>
<td>97.9%</td>
<td>97.9%</td>
</tr>
<tr>
<td>1–2</td>
<td>1,921</td>
<td>5</td>
<td>1,073</td>
<td>99.7%</td>
<td>97.7%</td>
</tr>
<tr>
<td>2–3</td>
<td>1,368</td>
<td>0</td>
<td>548</td>
<td>100.0%</td>
<td>97.7%</td>
</tr>
<tr>
<td>3–4</td>
<td>709</td>
<td>0</td>
<td>659</td>
<td>100.0%</td>
<td>97.7%</td>
</tr>
<tr>
<td>4–5</td>
<td>400</td>
<td>0</td>
<td>309</td>
<td>100.0%</td>
<td>97.7%</td>
</tr>
<tr>
<td>5–6</td>
<td>185</td>
<td>0</td>
<td>215</td>
<td>100.0%</td>
<td>97.7%</td>
</tr>
<tr>
<td>6–7</td>
<td>28</td>
<td>0</td>
<td>157</td>
<td>100.0%</td>
<td>97.7%</td>
</tr>
</tbody>
</table>

Numbers in parentheses indicate implants that failed before loading. ISR = interval survival rate; CSR = cumulative survival rate. Short was defined as ≤ 8.5 mm; long was defined as > 8.5 mm.

**Table 8** Life Table Analysis for Short Versus Short-Wide Dental Implants Using Combined Data from the Reviewed Papers

<table>
<thead>
<tr>
<th>Interval (y)</th>
<th>Implants at risk</th>
<th>Failed</th>
<th>Censored</th>
<th>ISR</th>
<th>CSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–1</td>
<td>351</td>
<td>4 (4)</td>
<td>11</td>
<td>98.9%</td>
<td>98.9%</td>
</tr>
<tr>
<td>1–2</td>
<td>269</td>
<td>0</td>
<td>78</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
<td>2–3</td>
<td>187</td>
<td>0</td>
<td>82</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
<td>3–4</td>
<td>135</td>
<td>0</td>
<td>52</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
<td>4–5</td>
<td>99</td>
<td>0</td>
<td>36</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
<td>Short-wide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–1</td>
<td>710</td>
<td>7 (7)</td>
<td>11</td>
<td>99.0%</td>
<td>99.0%</td>
</tr>
<tr>
<td>1–2</td>
<td>472</td>
<td>2</td>
<td>231</td>
<td>99.6%</td>
<td>98.6%</td>
</tr>
<tr>
<td>2–3</td>
<td>236</td>
<td>0</td>
<td>234</td>
<td>100.0%</td>
<td>98.6%</td>
</tr>
<tr>
<td>3–4</td>
<td>59</td>
<td>0</td>
<td>177</td>
<td>100.0%</td>
<td>98.6%</td>
</tr>
<tr>
<td>4–5</td>
<td>4</td>
<td>0</td>
<td>55</td>
<td>100.0%</td>
<td>98.6%</td>
</tr>
</tbody>
</table>

Numbers in parentheses indicate implants that failed before loading. ISR = interval survival rate; CSR = cumulative survival rate. Short-wide was defined as ≤ 8.5 mm in length and ≥ 4.8 mm in width.
implant. Studies have defined short implants to include a wide range, from 5 to 10 mm.6–8,33 The present investigation included studies reporting on the outcomes of implants 8.5 mm and shorter, for the pragmatic reason that the implant manufacturers who represent a large share of the international market include an 8.5-mm implant for selection. Many of the reports also included short implants with a range of diameters. While it was not feasible to segregate the different diameters, it was possible to report here on all short implants and short-wide implants, with "wide" defined as $\geq 4.8 \text{ mm}$. Again, the pragmatic reason for selecting 4.8 mm was that implant manufacturers representing the majority of the international market share include implant diameters $\geq 4.8 \text{ mm}$ for selection. The results of this and previous investigations indicate that there is little difference in

### Table 9 Meta-analytic Representation of Short versus Long Implant Survival Data from Comparative Studies

<table>
<thead>
<tr>
<th>Study/subgroup</th>
<th>Short implants</th>
<th>Long implants</th>
<th>Weight (%)</th>
<th>Risk ratio M-H, fixed, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>Total</td>
<td>Events</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Bischof et al11</td>
<td>78</td>
<td>81</td>
<td>157</td>
<td>159</td>
</tr>
<tr>
<td>Jung et al12</td>
<td>19</td>
<td>19</td>
<td>276</td>
<td>281</td>
</tr>
<tr>
<td>Fugazzotto13</td>
<td>1,835</td>
<td>1,851</td>
<td>327</td>
<td>330</td>
</tr>
<tr>
<td>Felice et al14</td>
<td>59</td>
<td>60</td>
<td>58</td>
<td>61</td>
</tr>
<tr>
<td>Sohn et al15</td>
<td>33</td>
<td>33</td>
<td>86</td>
<td>89</td>
</tr>
<tr>
<td>Koo et al16</td>
<td>122</td>
<td>122</td>
<td>384</td>
<td>399</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>2,166</td>
<td>1,319</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Total events</td>
<td>2,146</td>
<td>1,288</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity: $\chi^2 = 23.93, \text{ df } = 21 (P = .30), I^2 = 12\%$
Test for overall effect: $Z = 0.72 (P = .47)$

---

### Table 10 Meta-analytic Representation of Short versus Long Implant Survival Data from Studies Reporting

<table>
<thead>
<tr>
<th>Study/subgroup</th>
<th>Short implants</th>
<th>Long implants</th>
<th>Weight (%)</th>
<th>Risk ratio M-H, fixed, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>Total</td>
<td>Events</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Bahat and Handelsman17</td>
<td>27</td>
<td>27</td>
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<td>31</td>
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<tr>
<td>Renouard et al18</td>
<td>57</td>
<td>62</td>
<td>29</td>
<td>31</td>
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<tr>
<td>Wennenberg and Jemt19</td>
<td>60</td>
<td>69</td>
<td>337</td>
<td>353</td>
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<tr>
<td>Van Steenbergh et al20</td>
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<td>16</td>
<td>78</td>
<td>79</td>
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<tr>
<td>Deporter et al21</td>
<td>32</td>
<td>32</td>
<td>16</td>
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<td>Polizzi et al22</td>
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<td>13</td>
<td>44</td>
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<td>14</td>
<td>14</td>
<td>146</td>
<td>155</td>
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<td>Roccuzzo and Wilson24</td>
<td>9</td>
<td>9</td>
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<td>27</td>
</tr>
<tr>
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<td>10</td>
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<td>Salvi et al26</td>
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<td>3</td>
<td>64</td>
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<td>Bischof et al11</td>
<td>78</td>
<td>81</td>
<td>157</td>
<td>159</td>
</tr>
<tr>
<td>Misch et al27</td>
<td>30</td>
<td>30</td>
<td>707</td>
<td>715</td>
</tr>
<tr>
<td>Levine et al28</td>
<td>246</td>
<td>252</td>
<td>253</td>
<td>255</td>
</tr>
<tr>
<td>Jung et al12</td>
<td>19</td>
<td>19</td>
<td>276</td>
<td>281</td>
</tr>
<tr>
<td>Fugazzotto13</td>
<td>1,835</td>
<td>1,851</td>
<td>327</td>
<td>330</td>
</tr>
<tr>
<td>Nedir et al29</td>
<td>44</td>
<td>44</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Felice et al30</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Felice et al14</td>
<td>59</td>
<td>60</td>
<td>58</td>
<td>61</td>
</tr>
<tr>
<td>Zembic et al31</td>
<td>2</td>
<td>3</td>
<td>39</td>
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<td>Sohn et al15</td>
<td>33</td>
<td>33</td>
<td>86</td>
<td>89</td>
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<td>Koo et al16</td>
<td>122</td>
<td>122</td>
<td>384</td>
<td>399</td>
</tr>
<tr>
<td>Nedir et al32</td>
<td>4</td>
<td>4</td>
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<td>21</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>2,764</td>
<td>3,280</td>
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<tr>
<td>Total events</td>
<td>2,722</td>
<td>3,194</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity: $\chi^2 = 23.93, \text{ df } = 21 (P = .30), I^2 = 12\%$
Test for overall effect: $Z = 0.72 (P = .47)$
This systematic review was not limited to the inclusion of only randomized controlled clinical trials. The reviewed prospective and retrospective, nonrandomized, uncontrolled studies provide evidence of the high survival rate of short implants in posterior partially edentulous patients. The included studies are of relatively short duration. Despite this, the constructed life table analyses revealed a high cumulative survival rate of 98% after up to 7 years of loading. In the included studies, only one was a randomized clinical trial. It compared 7-mm (short) implants with ≥10-mm (long) implants, with placement dependent upon interpositional block grafting. Both procedures showed comparable clinical results 1 year after loading, and the authors advocated the use of short implants because of their advantages over long implants, which required additional surgical procedures, cost, and effort.

Some of the variables believed to affect therapy involving short implants may be relevant to these studies. Romeo et al indicated that the length and diameter of the implant, the surface topography of the implant, the crown-to-implant ratio, the prosthesis type, splinting to other implants, and occlusal/parafunctional loads are additional important factors to consider. The placement of implants in host vs grafted bone may also be important, and the impact of systemic factors and habits such as smoking are of additional consequence. It is also interesting to speculate that the length of bone-to-implant contact measured after prosthetic connection may be more relevant to the survival of the implant than the length of the implant placed into bone.

The forest plot of the studies that compared short and long dental implants (Table 9) showed that short dental implants have no more statistically significant risk of failure than their longer counterparts. This graphic representation of a meta-analysis is typically applied to randomized controlled trials of comparable data sets. Here, a variety of clinical reports were included. It appears from a previous analysis that the data were sufficiently homogenous to permit this meta-analytic approach, despite the obvious inclusion of studies using different definitions of “short implants.”

Several other investigations have recently analyzed the reported success of short implants. Most recently, Telleman et al defined short implants as less than 10 mm and evaluated a similar data set involving 29 studies involving 2,611 implants up to 9.5 mm in length. Three hundred six of the implants were 9 or 9.5 mm in length. Using a main outcome of survival rates after 2 years on a per-implant basis, the authors concluded that there was a significant negative association between implant length and failure rate within the range of 5 to 8.5 mm. In a recent meta-analysis of the survival of short implants, where short implants were the survival of short versus long implants, regardless of the definition of a short implant. Ultimately, it will be valuable to define a short implant according to known anatomic restrictions or, alternatively, by assignment of added risk to an implant of known alternative (shorter) dimension. The existing data suggest that, in the short term, implant survival rates are incrementally reduced below 8 mm (Table 11).
defined as 10 mm or less, a larger number of implants was included (7,392). The results were largely focused on implant surface–related effects on the cumulative success rate and did not report the effect of stratified implant length upon survival. A systematic review concluded that placement of short, rough-surfaced implants (< 8 mm) was not less efficacious than placement of rough-surface implants at least 10 mm long. A similar conclusion was developed by a recent literature review of 13 studies. The report of Tellem et al provided insight into factors affecting reported implant survival. The interactions of implant length (5 to 9.5 mm) with implant surface, maxilla versus mandible, smoking, and augmentation procedures were reported, and it was found that the heterogeneity was insufficient to reject the result of failure rates per implant length. They did conclude that, in partially edentulous patients, short dental implants had a better prognosis in the mandible than in the maxilla and that studies that excluded smokers achieved higher survival rates than those studies that included heavy smokers. Augmentation procedures preceding implant placement did not affect the survival of short implants. Surface topography has a controversial role in the survival of short implants. Mechereo-Cantalejo et al argued that the cumulative success rate of machined-surface implants is lower than that of rough-surfaced short implants. Studies that examined implant survival using machined implants for the treatment of posterior partial edentulism may be considered as a possible alternative to the use of longer implants, which require additional surgical procedures or involve safety concerns.

CONCLUSION

Short dental implants, defined as 8.5 mm or shorter, demonstrated success rates that were comparable to those of longer implants, irrespective of design, surface, and width. The use of implants that are 8.5 mm or shorter for the treatment of posterior partial edentulism may be considered as a possible alternative to the use of longer implants, which require additional surgical procedures or involve safety concerns.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

REFERENCES


Short (8-mm) locking-taper implants supporting single crowns in posterior region: a prospective clinical study with 1-to 10-years of follow-up

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Abstract
Objective: The aim of this study was to evaluate the long-term outcome of short (8-mm) locking-taper implants supporting single crowns in the posterior regions and to analyze the influence of different factors on implant survival and implant-crown success rates.

Materials and methods: Between June 2002 and September 2011, all patients referred to two private practices for treatment with short (8-mm) implants supporting single tooth restorations in posterior areas of both jaws were considered for inclusion in this study. At each annual follow-up session, clinical and radiographic parameters were assessed. Implant-crown success criteria included absence of pain, suppuration, mobility, and peri-implant radiolucency, distance between the implant shoulder and the first visible bone-to-implant contact (DIB) <1.5 mm after 12 months and not exceeding 0.2 mm for each following year, absence of prosthetic complications. The cumulative survival and implant-crown success were assessed using the Kaplan–Meier survival estimator; Chi-square test was applied to evaluate correlations between the study variables. The statistical analysis was performed at the patient and at the implant level.

Results: Two hundred and fifteen implants (124 maxilla; 91 mandible) were placed in 194 patients (104 men; 90 women). Three implants failed (2 maxilla; 1 mandible). The 10-year cumulative survival rate was 98.4% (patient-based) and 98.5% (implant-based). Among the surviving implants, the mean DIB was 0.31 (±0.24), 0.43 (±0.29), and 0.62 (±0.31) mm at the 1-, 5-, and 10-year follow-up session; two biologic and three prosthetic complications were reported, for a 10-year cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based). The implant survival and implant-crown success rates did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, and bone type.

Conclusions: The use of short (8-mm) locking-taper implants is a predictable treatment modality for the restoration of single tooth gaps of posterior segments of dentition.

Key words: implant survival, implant-crown success, locking-taper implants, short implants, single crowns

Osseointegrated implants have become a viable option for replacing missing teeth in totally and partially edentulous patients, particularly in the case of single tooth gaps [Jung et al. 2012]. However, reduced alveolar bone height can limit implant placement, especially in the posterior regions of the maxilla and mandible. In fact, the location of anatomical structures, such as the maxillary sinus and the inferior alveolar nerve, may limit the availability of sufficient bone volume to place dental implants [Morand & Irinakis 2007; Esposito et al. 2011; Annibali et al. 2012; Monje et al. 2012].

In the situation of extremely reduced bone height, it may be necessary to increase the geometry and volume of the alveolar bone before placement of dental implants. At present, this can be obtained by sinus elevation [Mangano et al. 2007], grafting techniques [Scarano et al. 2011], transposition of the inferior alveolar nerve [Chrcanovic & Custódio 2009], or by intrabony distraction of the alveolar process [Chiapasco et al. 2004]; however, these surgical procedures are technically demanding, and may increase postoperative morbidity and the total cost and duration of the therapy [Esposito et al. 2011].
An alternative therapy in situations with limited amounts of bone available is the placement of short implants (Annibali et al. 2012; Monje et al. 2012). The definitions of short implants vary in the literature, and authors have defined implant length <11-mm (das Neves et al. 2006), 10-mm (Morand & Irianiak 2007) or 8-mm (Renouard & Nisand 2006) as short implants. Tellem & Telleman (Telleman et al. 2011) argued that a short implant should be defined as an implant with a designed intrabony length of 8-mm or less [Renouard & Nisand 2006].

The use of short implants simplifies the restoration of posterior segments of dentition. In fact, it reduces the need for bone augmentation procedures prior to or in conjunction with implant placement in both jaws; furthermore, there is less surgical risk of sinus perforation, or mandibular paresthesia, with an overall reduction in surgical complexity (Tellem et al. 2011, Annibali et al. 2012, Monje et al. 2012).

In the past, short implants in the posterior maxilla or mandible have been associated with lower survival rates and unpredictable long-term outcomes (Naert et al. 2002; Pierre-risnard et al. 2003; Weng et al. 2003; Lee et al. 2005).

In spite of the aforementioned research demonstrating a lower predictability for short implants, recent studies have indicated that short implants can present a similar survival rate to standard length implants (Nedir et al. 2004; Misch et al. 2006, Anitua & Orive 2010; Tellem et al. 2011). In a recent systematic review by Monje et al. (2012), short implants had an estimated survival rate of 88.1% at 168 months, when standard implants had a similar estimated survival rate of 86.7%. These results are in accordance with those of two previous reviews, where no differences in the failure rates of short and standard implants were reported [Sun et al. 2011; Tellem et al. 2011].

However, only a few studies on short implants were about single tooth replacements in posterior region (Mericke-Stein et al. 2001; Rossi et al. 2010; Lai et al. 2013). In the last years, locking-taper implant-abutment connection has been introduced as an alternative to screw-retained abutment systems (Bozkaya & Muftu 2003). Locking-taper implant systems are composed of an implant and an abutment joined together by a self-locking connection. As a result of a Morse taper, this tappered fit implant-abutment connection is able to induce a self-locking mating between the parts (Bozkaya & Muftu 2003). Several studies have demonstrated that locking-taper implants can represent an ideal treatment option for single tooth replacement in the posterior areas of both arches (Mangano & Bartolucci 2001; Mangano et al. 2010, 2011; Urdaneta et al. 2012).

The aim of this prospective study was to evaluate the long-term outcomes of short (8-mm) locking-taper implants supporting single crowns in the posterior regions of the maxilla and mandible.

Materials and methods

Patient selection
Between June 2002 and September 2011, all patients referred to two private dental practices for treatment with dental implants were considered for inclusion in this study. All treatments were carried out by the same practitioner. Inclusion criteria were as follows: (i) age >18 years, (ii) good systemic and oral health, (iii) single tooth gaps in the posterior regions (premolars and molars) of maxilla/mandible (iv) at least 6 weeks of healing after tooth extraction, (v) installation of short dental implants with intrabony length of 8.0 mm, (vi) dentition in the opposing jaw to obtain occlusal contacts. Exclusion criteria consisted of: (i) poor oral hygiene, (ii) active periodontal infections or other oral disorders, (iii) insufficient bone quantity to place an implant of 8 mm length, (iv) bone augmentation procedures with autogenous bone or bone substitutes, (v) uncontrolled diabetes mellitus, (vi) systemic immune disorders. Smoking and bruxism were recorded but were not considered as an exclusion criteria for this study. Smokers were defined as patients who smoked cigarettes without considering the amount. Patients were advised that smoking is associated with an increased risk of implant failure. Bruxers were patients with a repetitive jaw-muscle activity characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible. Patients’ questionnaires, clinical examination, and electromyography were used for the diagnosis of bruxism (Lobbezoo et al. 2013). The study protocol was explained to each subject, and signed informed consent was obtained. The study protocol was approved by the local ethical committee and was performed according to the principles outlined in the World’s Medical Association’s Declaration of Helsinki on experimentation involving human subjects, as revised in 2000.

Preoperative work-up
A complete examination of the oral hard and soft tissues was carried out for each patient. Panoramic radiographs formed the basis for the primary investigation. Only in a few cases, computed tomography (CBCT) scans were used as the final investigation. CBCT datasets were acquired and then transferred to specific implant navigation software (Mimics®, Materialise, Leuven, Belgium), to perform a three-dimensional reconstruction of the maxillary bones. With this navigation software, it was possible to correctly assess the width of each implant site, the thickness and the density of the cortical plates and the cancellous bone, as well as the ridge angulation. On the basis of this information, surgical templates were manufactured. Preoperative work-ups also included an assessment of the edentulous ridges using casts and diagnostic wax-up.

Implant placement
Local anesthesia was obtained by infiltrating articaine (4%) containing 1 : 100.000 adrenalin [Ubistesin®, 3M Espe, St. Paul, MN, USA]. A midcrestal incision was made at the sites of implant placement. The mesial and distal aspects of the crestal incision were connected to two releasing incisions. Full thickness flaps were reflected exposing the alveolar ridge, and preparation of implant sites was carried out with spiral drills of increasing diameter (2.8 mm to place an implant with 3.3 mm diameter; 2.8 and 3.5 mm, to place an implant with 4.1 mm diameter; an additional 4.2 mm drill was used to prepare the site for 4.8 mm diameter implants), under constant irrigation. Short-length (8 mm) rough-surfaced implants, made of grade-5 titanium (Leone Implant Systems®, Florence, Italy), were placed in the prepared sites. The surface of these implants was blasted with 50 μm Al2O3 particles and acid-etched with HNO3, after which the average of roughness (i.e., the mean of the peak-valley distance on surface irregularities) was 0.5 μm. This implant system used a cone Morse taper-interference-fit locking-taper combined with an internal hexagon. The Morse taper presented a taper angle of 1.5° [Mangano et al. 2009, 2011]. All implants were positioned with good primary stability. Finally, sutures were performed [Supramid®, Novaxa Spa, Milan, Italy].

Postoperative treatment
All patients received oral antibiotics, 2 g each day for 6 days [Augmentin®; Glaxo-Smithkline Beecham, Brentford, UK].
Postoperative pain was controlled by administering 100 mg nimesulide (Aulin®, Roche Pharmaceutical, Basel, Switzerland) every 12 h for 2 days, and detailed instructions about oral hygiene were given, with mouthrinses with 0.12% chlorhexidine (Chlorexidine®, OralB, Boston, MA, USA) administered for 7 days. Suture removal was performed at 8–10 days.

**Healing period**

A two-stage technique was used to place the implants. The healing time was 3 months in the lower jaw and 4 months in the upper jaw. No early exposures before two-stage surgery were noted. Second-stage surgery was conducted to gain access to the underlying implants, and healing abutments were placed and activated, so that acrylic provisional restorations could be provided. The prosthetic restorations were all single crowns. Acrylic resin provisional restorations were used to monitor implant stability under a progressive load and to obtain good soft tissue healing around the implant before fabrication of the definitive restorations. The temporary restorations remained in situ for 3 months, and after this period, definitive restorations were placed. All definitive restorations were ceramo-metallic, cemented with temporary cement (Temp-Bond®, Kerr, Orange, CA, USA). All restorations were carefully evaluated for proper occlusion, and protrusion and laterotrusion were assessed on the articulator and intraorally.

**Clinical, radiographic and prosthetic evaluation**

The patients were recalled for clinical, radiographic, and prosthetic examination every 12 months. During each annual follow-up visit, the clinical assessment of implants, peri-implant tissues, and prostheses were conducted by a surgeon and a prosthodontist, who were not directly involved in the treatment for the patients. At each follow-up session, for two purposes: (i) to evaluate the presence/absence of continuous peri-implant radiolucencies; (ii) to measure the DIB in mm, at the mesial and distal implant site of each implant [Weber et al. 2000], by the aim of an ocular grid. A mean DIB value was obtained from the mesial and distal measurement at each radiograph, with this value, crestal bone level changes were recorded as changes in the vertical dimension of the bone around the implant, so that an evaluation of peri-implant crestal bone stability was gained with time. To correct for dimensional distortion in the radiograph, the apparent dimension of each implant [directly measured on the radiograph] was compared with the true implant length, and the following equation:

\[
R_x \text{ implant length} : \text{True implant length} = R_x \text{ DIB} : \text{True DIB}
\]

was used to establish, with adequate precision, the eventual amount of vertical bone loss at the mesial and distal site of the implant [Weber et al. 2000]. Finally, to test prosthesis function, at each annual scheduled check, static and dynamic occlusion were evaluated, using standard occluding papers (Bausch articulating paper®, Bausch Inc, Nashua, NH, USA). Careful attention was dedicated to the analysis of prosthetic complications, including any at the implant-abutment interface [abutment loosening, abutment fracture] and fracture of porcelain. All these mechanical complications were carefully registered, and if possible, managed during the follow-up visit; additional appointments were arranged if needed.

**Criteria of implant survival and implant-crown success**

Implant survival: an implant was classified as a “surviving implant” when it was still in function at the endpoint of this study. Implant losses comprised all failure categories. The conditions for which implant removal could be indicated included failure to osseointegrate, persistent peri-implant infections with pain/suppuration and implant loss due to mechanical overload [Albrektsson & Zarb 1998]. The implant failures were classified into two types: early failures (before the abutment connection) and late failures (after the abutment connection).

Implant-crown success: an implant was classified as a “successful implant” when it fulfilled all the following success criteria: (i) absence of pain/sensitivity; (ii) absence of suppuration/exudation; (iii) absence of clinically detectable implant mobility; (iv) absence of continuous peri-implant radiolucency; (v) DIB < 1.5 mm after 12 months of functional loading, and not exceeding 0.2 mm for each following year; (vi) absence of prosthetic complications [Albrektsson & Zarb 1998].

**Statistical analysis**

Data collection and analyses were performed by two independent examiners [a surgeon and a prosthodontist] who were not directly involved in the treatment for the patients. A database was created using Excel 2007 [Microsoft Excel®, Microsoft Corporation, Redmond, WA, USA] and used for the analysis. Descriptive statistics were obtained; absolute and relative frequency distributions were calculated for qualitative variables, and means, standard deviations (SD), medians, ranges, and confidence intervals (CI: 95%) were calculated for quantitative variables. Implant failure was the principal variable of this study. The cumulative survival and implant-crown success rate of implants were estimated both by an implant-based and a patient-based analysis. In the implant-based analysis, each inserted implant was considered as the analysis unit, whereas in the patient-based analysis, each patient was considered as the statistical unit. In the patient-based analysis, in case of multiple indications for implant therapy (with the same patient receiving more than one implant), the patient was classified as a failure even in the event a single implant loss. In both types of analysis, the implant survival and implant-crown success as a function of the time were analyzed using the Kaplan–Meier survival estimator [Kaplan & Meier 1958]. In addition, a Chi-square test was applied to assess the influence of variables on survival and success rates. Variables including age at surgery, gender, smoking habit (smokers or non-smokers), and para-functional habits [bruxists or non-bruxists] were analyzed at the patient-level. Variables including implant position [mandible or maxilla], implant diameter [3.3, 4.1 or 4.8 mm], and bone type were analyzed at the implant level. Bone quality was ascertained clinically by tactile evaluation at the time of implant placement, during drilling, according to the clinician’s judgment [Lai et al. 2013], and by radiographic assessment according to the criteria of Lekholm & Zarb [1985] index. In particular, following the withdrawal of an
ostectomy reamer, an assessment of the bone in the reamer flutes was conducted in terms of quality and appearance (Gentile et al. 2005). Bone quality was classified as type I if the bone was compact, near bloodless cortical bone. Type II bone was red and filled the flutes of the reamer. If no bone remained in the flutes, the bone quality was classified as type IV. If the findings were intermediate between those described for types II and IV, the bone was categorized as type III. Data analysis was performed with a statistical software package (SPSS 17.0®; SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05.

Results

Patient population and implant-supported restorations
One hundred and ninety-four patients (104 men and 90 women; aged between 24 and 74 years, mean 49.1 ± 11.5) were eligible for this study. Among these patients, 35 (18.0%) were smokers and 24 (12.3%) were bruxists. The average follow-up time was 5.6 ± 2.7 years. Ten of the 194 enrolled patients had multiple indications for implant therapy, such that a total of 215 short (8-mm) locking-taper implants were placed. One hundred and twenty-four implants [57.7%] were inserted in the maxilla, while 91 implants [42.3%] were inserted in the mandible. With regard to the position of the installed implants, 55 implants (25.6%) were maxillary premolars, 69 (32.1%) were maxillary molars, 20 (9.3%) were mandibular premolars, and 71 (33.0%) were mandibular molars. The most frequently used implant diameter was 4.8 mm, with 114 implants (53.0%), followed by 4.1 mm, with 96 implants (44.7%), and 3.3 mm, with only five implants (2.3%). The prosthetic restorations comprised 215 single crowns.

Implant survival
Three implants failed and had to be removed, in three different patients. Five of the 194 patients were classified as dropouts because they missed the last scheduled appointment. At the end of the study, an overall cumulative survival rate of 98.5% (implant-based) and 98.4% (patient-based) was achieved at 10-year follow-up, with 212 implants still in function. In the maxilla, the cumulative survival rate was 98.3%, with two implants failed and removed. In the mandible, the cumulative survival rate was 98.9%, with one implant failure. With regard to the position of the failed implants, 2 were maxillary first molars, and 1 was a mandibular first premolar. Two implants were lost within the healing period, before the abutment connection: these implants were classified as “early failures”, showing implant mobility due to lack of osseointegration, before functional loading. One implant failed after 2 years of prosthetic loading; this implant was classified as a “late failure”, because of progressive bone loss due to mechanical overloading, without clinical signs of peri-implant infection. The details of the failed implants are recorded in Table 1. The evaluation of the potential influence of different patient-related and implant-related variables on implant survival is reported in Tables 2 and 3, respectively. The survival rate did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, or bone type.

Table 1. Failed implants

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>Site</th>
<th>Bone type</th>
<th>Smoke</th>
<th>Bruxism</th>
<th>Diameter</th>
<th>Time of failure</th>
<th>Cause of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>54</td>
<td>1.6</td>
<td>IV</td>
<td>Yes</td>
<td>No</td>
<td>4.8 mm</td>
<td>4 months after surgery</td>
<td>Implant mobility-Lack of osseointegration</td>
</tr>
<tr>
<td>F</td>
<td>48</td>
<td>3.4</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.1 mm</td>
<td>3 months after surgery</td>
<td>Implant mobility-Lack of osseointegration</td>
</tr>
<tr>
<td>M</td>
<td>34</td>
<td>2.6</td>
<td>IV</td>
<td>No</td>
<td>Yes</td>
<td>4.1 mm</td>
<td>2 years after prosthetic loading</td>
<td>Progressive bone loss due to mechanical overload</td>
</tr>
</tbody>
</table>

Minimal changes were seen in the bone level between the 1-, 5-, and 10-year examinations. Only two implants showed bone loss ≥1.5 mm after the first year of functional loading; these implants were registered as unsuccessful implants, according to the established implant-crown success criteria. However, none of the implants showed a marginal bone loss ≥2.5 mm, at the final follow-up examination. A prosthetic abutment of a first mandibular molar became loose during the third year of function. This abutment was reinserted, and no further loosenings were observed; however, this was considered a prosthetic complication. The overall incidence of abutment loosening was 0.47%. No other prosthetic complications related to implant-abutment connection were evidenced. However, two porcelain fractures were reported. With regard to all these data, only five surviving implants could not fulfill the established success criteria with two implants revealing DIB >1.5 mm after the first year of function, one implant showing abutment loosening and two porcelain fractures, for an overall cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based) (Table 5). The evaluation of the potential influence of different patient-related and implant-related variables on implant-crown success rate is reported in Tables 6 and 7, respectively. The

Table 2. Implant survival: analysis of patient-related variables

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of patients</th>
<th>Failures</th>
<th>Cumulative survival rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>104</td>
<td>2</td>
<td>98.0</td>
<td>0.648</td>
</tr>
<tr>
<td>Female</td>
<td>90</td>
<td>1</td>
<td>98.9</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-34</td>
<td>14</td>
<td>1</td>
<td>92.9</td>
<td>0.224</td>
</tr>
<tr>
<td>35-44</td>
<td>46</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>45-54</td>
<td>65</td>
<td>2</td>
<td>96.9</td>
<td></td>
</tr>
<tr>
<td>55-64</td>
<td>46</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>23</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Smoking habit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smokers</td>
<td>35</td>
<td>1</td>
<td>97.1</td>
<td>0.488</td>
</tr>
<tr>
<td>Non-smokers</td>
<td>159</td>
<td>2</td>
<td>98.7</td>
<td></td>
</tr>
<tr>
<td>Parafunct. habit/bruxism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bruxists</td>
<td>24</td>
<td>1</td>
<td>95.5</td>
<td>0.266</td>
</tr>
<tr>
<td>Non-bruxists</td>
<td>170</td>
<td>2</td>
<td>98.8</td>
<td></td>
</tr>
</tbody>
</table>
In recent years, however, several clinical studies have reported excellent success rates with the use of short implants [Nedir et al. 2004; Misch et al. 2006; Anitua & Orive 2010; Urdaneta et al. 2012], and the recent literature has demonstrated a similar survival rate for short and standard length implants (Kotsovilis et al. 2009; Sun et al. 2011; Monje et al. 2012). A recent systematic review (Sun et al. 2011) found no differences in the failure rates of short and standard implants, with a long-term failure rate of 2.5% for 8-mm implants. In another review comparing short implants with conventional implants, Kotsovilis et al. (2009) concluded that short implants (≤8 mm) with rough surfaces are no less effective than implants of standard length (≥10 mm) with rough surfaces.

However, only a few studies have dealt with short implants supporting single crowns in posterior region [Mericske-Stern et al. 2001; Rossi et al. 2010; Lai et al. 2013].

In our present study, the use of short [8-mm] locking-taper implants for the restoration of single tooth gaps in posterior areas in both jaws resulted in a 10-year cumulative survival rate of 98.4% (patient-based) and 98.5% (implant-based), respectively. Over a 10-year period, in fact, only three implants failed and had to be removed; the survival rate did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, and bone type.

**Discussion**

The use of short implants has grown in popularity over the recent years, as an alternative treatment in patients with limited amounts of bone available. The main advantage of placing short implants is the avoidance of invasive bone augmentation procedures (which are associated with donor site morbidity, additional treatment duration, and financial burden) and reduced risk of interference with anatomic structures like the maxillary sinus or the inferior alveolar nerve [Nedir et al. 2004; Telleman et al. 2011; Monje et al. 2012].

In the past, short implants have been associated with lower survival rates and unpredictable long-term outcome [Lee et al. 2005]. In fact, it has been an axiom in implant dentistry that longer implants guarantee better success rates and prognosis [Lee et al. 2005], and some studies have shown that short implants placed in the posterior maxilla or mandible have statistically lower success rates [Naert et al. 2002; Weng et al. 2003]. Different reasons have been put forward to explain this situation. Firstly, compared with longer implants with a comparable diameter, there is less bone-to-implant contact when short implants are used, because there is less implant surface. Secondly, short implants are mostly placed in the posterior zone, where the quality of the alveolar bone is relatively poor (type III or IV), in the maxilla (Lekholm & Zarb 1985). Thirdly, a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which causes a higher crown-to-implant ratio. Crown-to-implant ratios between 0.5 and 1 were proposed to prevent peri-implant bone stress, crestal bone loss, and eventually implant failure [Lee et al. 2005].

In recent years, however, several clinical studies have reported excellent success rates with the use of short implants [Nedir et al. 2004; Misch et al. 2006; Anitua & Orive 2010; Urdaneta et al. 2012], and the recent literature has demonstrated a similar survival rate for short and standard length implants (Kotsovilis et al. 2009; Sun et al. 2011; Monje et al. 2012). A recent systematic review (Sun et al. 2011) found no differences in the failure rates of short and standard implants, with a long-term failure rate of 2.5% for 8-mm implants. In another review comparing short implants with conventional implants, Kotsovilis et al. (2009) concluded that short implants (≤8 mm) with rough surfaces are no less effective than implants of standard length (≥10 mm) with rough surfaces.

However, only a few studies have dealt with short implants supporting single crowns in posterior region [Mericske-Stern et al. 2001; Rossi et al. 2010; Lai et al. 2013].
implants supporting single crowns in posterior regions.

The success of short implants may be dependent on multiple biological and prosthetic factors (das Neves et al. 2006).

Biological factors, such as bone density and smoking, were found to influence the success of short implants (Tellman et al. 2011). In most studies, placement of short dental implants in the mandible had a better prognosis over installation in the maxilla (Renouard & Nisand 2005; Pomer et al. 2011; Sun et al. 2011). The higher survival rate of short implants in the mandible had a better prognosis, with only one implant failure in the mandible, but with such small failure rates the survival rate did not differ significantly with respect to implant location (P = 0.751). In the current literature, the results of studies excluding smokers revealed higher implant survival rates than studies including heavy smokers (>15 cigarettes/day) (Tellman et al. 2011). In our present study, only 35 patients were smokers. Among smoking patients, one implant failure was reported, in a heavy smoker (>15 cigarettes/day), for a cumulative survival rate of 97.1%; however, the survival rate did not differ significantly with respect to smoking habit (P = 0.488). Short implants with a roughened surface showed generally lower failure rates compared with machined surface ones (Pommer et al. 2011; Sun et al. 2011). In fact, surface geometry, composition, and hydrophilicity are key factors for the short- and long-term success of short dental implants. As demonstrated by Shalabi et al. (2006) and Wennerberg & Albrektsson (2009), a positive relationship between bone-to-implant contact and surface roughness exists, as surface roughness does influence bone response at the micro- and nanometer level. In our study, the influence of surface texture was not compared as similar rough-surfaced, sandblasted and acid-etched implants were used throughout, with satisfactory 10-year survival (98.4% patient-based, 98.5% implant-based) outcomes.

Prosthetic factors, such as crown-to-implant ratio, splinting, occlusal table, opposing dentition, and bruxism, did not prove to influence short implant failure rates in recent studies (Nedir et al. 2004; Tawil et al. 2006). Even if the use of short implants leads to a higher crown-to-implant ratio, no statistically significant relationship was found between crown-to-implant ratio and crestal bone levels (Blanes 2009; Birdi et al. 2010; Urdaneta et al. 2012). Splinting of implant-crowns may lead to less stress transmitted to each bone–implant interface compared with individual implant-crowns (Misch et al. 2006), but only a few studies support the capacity of short implants restored as single crowns to withstand biomechanical stresses (Rossi et al. 2010; Lai et al. 2013). While survival and success of short implants have been widely investigated, the studies on prosthetic aspects are limited. The majority of these have only focused on implant survival, without providing information about possible prosthetic complications. In our present study on 8-mm locking-taper implants supporting single crowns, only three implants were involved in prosthetic complications, over a 10-year period. A prosthetic abutment became loose during the third year of function, and this abutment was reinserted with no further loosening. In addition, two

Table 5. Unsuccessful implant-crown restorations

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>Site</th>
<th>Bone type</th>
<th>Smoke</th>
<th>Bruxism</th>
<th>Diameter (mm)</th>
<th>Time of failure</th>
<th>Cause of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>39</td>
<td>1.6</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.8</td>
<td>8 years after loading</td>
<td>Porcelain fracture</td>
</tr>
<tr>
<td>M</td>
<td>36</td>
<td>4.7</td>
<td>IV</td>
<td>No</td>
<td>Yes</td>
<td>4.8</td>
<td>6 years after loading</td>
<td>Porcelain fracture</td>
</tr>
<tr>
<td>M</td>
<td>56</td>
<td>4.6</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.1</td>
<td>3 years after loading</td>
<td>Abutment loosening</td>
</tr>
<tr>
<td>F</td>
<td>48</td>
<td>1.6</td>
<td>IV</td>
<td>Yes</td>
<td>Yes</td>
<td>4.1</td>
<td>1 year after loading</td>
<td>DIB &gt; 1.5 mm</td>
</tr>
<tr>
<td>M</td>
<td>58</td>
<td>2.7</td>
<td>III</td>
<td>Yes</td>
<td>No</td>
<td>4.8</td>
<td>1 year after loading</td>
<td>DIB &gt; 1.5 mm</td>
</tr>
</tbody>
</table>

DIB, distance between the implant shoulder and the first visible bone-to-implant contact.

Table 6. Implant-crown success: analysis of patient-related variables

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of patients</th>
<th>Unsuccessful patients</th>
<th>Cumulative implant-crown success rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>102</td>
<td>3</td>
<td>96.3</td>
<td>0.764</td>
</tr>
<tr>
<td>Female</td>
<td>89</td>
<td>2</td>
<td>94.4</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24–34</td>
<td>13</td>
<td>–</td>
<td>100</td>
<td>0.805</td>
</tr>
<tr>
<td>35–44</td>
<td>46</td>
<td>2</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>45–54</td>
<td>63</td>
<td>1</td>
<td>96.8</td>
<td></td>
</tr>
<tr>
<td>55–64</td>
<td>46</td>
<td>2</td>
<td>97.4</td>
<td></td>
</tr>
<tr>
<td>&gt;64</td>
<td>23</td>
<td>–</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Smoking habit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smokers</td>
<td>34</td>
<td>2</td>
<td>94.1</td>
<td>0.189</td>
</tr>
<tr>
<td>Non-smokers</td>
<td>157</td>
<td>3</td>
<td>95.9</td>
<td></td>
</tr>
<tr>
<td>Parafunctional habit/bruxism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bruxists</td>
<td>23</td>
<td>2</td>
<td>87.7</td>
<td>0.052</td>
</tr>
<tr>
<td>Non-bruxists</td>
<td>168</td>
<td>3</td>
<td>96.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Implant-crown success: analysis of implant-related variables

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of implants</th>
<th>Unsuccessful implants</th>
<th>Cumulative implant-crown success rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>122</td>
<td>3</td>
<td>96.0</td>
<td>0.911</td>
</tr>
<tr>
<td>Mandible</td>
<td>90</td>
<td>2</td>
<td>96.2</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 mm</td>
<td>5</td>
<td>–</td>
<td>100</td>
<td>0.911</td>
</tr>
<tr>
<td>4.1 mm</td>
<td>94</td>
<td>2</td>
<td>97.5</td>
<td></td>
</tr>
<tr>
<td>4.8 mm</td>
<td>113</td>
<td>3</td>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td>Bone type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.425</td>
</tr>
<tr>
<td>Type II</td>
<td>36</td>
<td>–</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>77</td>
<td>3</td>
<td>93.8</td>
<td></td>
</tr>
<tr>
<td>Type IV</td>
<td>99</td>
<td>2</td>
<td>97.1</td>
<td></td>
</tr>
</tbody>
</table>
porcelain fractures were reported, giving an overall incidence of prosthetic complication of 1.4%. In a recent review of the literature, the incidence of technical complication of single crowns on standard length (≥10 mm) implants was reported, with a cumulative incidence of 8.8% for implant–abutment screw loosening, 4.1% for loss of retention, and 3.5% for fracture of the ceramic material, after 5 years (Jung et al. 2012). The incidence of prosthetic complications reported in our study on short, locking-taper implants therefore seems to be lower [1.4%] in particular with regard to implant–abutment loosening (0.47%).

The locking-taper implant system used in the present study is composed of a fixture and an abutment joined together by a self-locking connection due to a Morse taper guided by an internal hexagon. The Morse taper presents a taper angle of 1.5° and is able to induce a self-locking mating between the parts, thus giving a higher implant–abutment mechanical stability (Bozkaya & Muftu 2003). Recent studies have demonstrated that the Morse taper implant–abutment connection can resist eccentric loading complexes and bending moments, ensuring absolute mechanical stability and significantly reducing the incidence of prosthetic complications at the implant–abutment interface (Bozkaya & Muftu 2003; Mangano et al. 2010, 2011; Urdaneta et al. 2012). In addition, the locking-taper implant–abutment connection can provide an efficient seal against microbial penetration. In fact, it is noteworthy that all implants with screw-type connections show a microgap of variable dimensions [40–100 µm] at the implant–abutment interface (Broggini et al. 2003; Piattelli et al. 2003). As this microgap is colonized by bacteria, capable of penetrating inside the internal hollow portion of the implant, the bacterial leakage and persistent colonization may be responsible for generating a chemotactic stimulus that initiates and sustains recruitment of inflammatory cells (Broggini et al. 2003; Piattelli et al. 2003). Eventually, this could result in the development of peri-implant inflammation and bone loss (Broggini et al. 2003; Piattelli et al. 2003). The tapered interference fit reduces microgap dimensions (1–3 µm) at the implant–abutment interface, providing an adequate biological seal, avoiding any kind of bacterial leakage (Dibart et al. 2005). This can contribute to a minimal level of peri-implant soft tissues inflammation and can guarantee long-term bone crest stability (Dibart et al. 2005). In the present study, a minimal marginal bone loss between implant installation and the 10 years’ follow-up visit was reported, with a mean DBL of 0.31 (±0.24), 0.43 (±0.29) and 0.62 (±0.31) mm at the 1-, 5-, and 10-year follow-up session, respectively. Only two implants failed due to biological complications, and neither of these was overtly due to infection, giving a 10-year cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based).

Conclusions

Short implants have widened the options for implant installation, as an alternative treatment to advanced bone augmentation surgeries. In recent years, several studies have been published in which short implants were compared with conventional implants; however, long-term observations on short implants supporting single crown prostheses in the posterior region are still missing. In our present study, the use of short (8-mm) locking-taper implants was a predictable treatment modality for the restoration of single tooth gaps of posterior segments of dentition, with a 10-year cumulative survival rate of 98.4% (patient-based) and 98.5% (implant-based), respectively. However, no randomized clinical trial on implants with lengths ≤8 mm supporting single crowns is present in the literature. In future, it will be therefore necessary to present randomized controlled clinical data on short-length (≤8 mm) implants, to be able to obtain definitive evidence.

Disclosure

The authors declare that they have no financial relationship with any commercial firm that may pose a conflict of interest for this study. No grants, equipment, or other sources of support were provided.

References


Mangano et al. Short locking-taper implants supporting single crowns

Paolo Trisi
Simona De Benedittis
Giorgio Perfetti
Davide Berardi

Primary stability, insertion torque and bone density of cylindric implant ad modum Branemark: Is there a relationship? An in vitro study

Key words: bone density, dental implants, insertion torque, micromotion, primary stability

Abstract

Objectives: Protocols of immediate loading have been reported in several studies. It has also been demonstrated that the cause of failure of immediate loaded implants is due to the micromotion on the bone–implant interface induced by immediate loading. There should be a minimum gap between the implant and the peri-implant bone, without micromotions occurring above a definite threshold risk as they induce bone resorption and fibrosis around the implant. Measurement of the torque necessary to insert an implant in the bone is a parameter for measuring initial stability. The higher the implant insertion torque, the higher the initial stability attained. The aim of this study was to evaluate in vitro the correlation between the micromotion of cylindric screw implants ad modum Branemark and the insertion torque in bone of different densities.

Material and methods: The test was carried out on 2 × 2 cm samples of fresh bovine bone of three different densities: hard (H), medium (M) and soft (S). One hundred and fifty hexa implants ad modum Branemark were used, 3.75 mm in diameter and 9 mm long. To screw in the implants, a customized manual key was used, controlled digitally to evaluate the peak insertion torques. Ten implants were prepared for each torque (20, 35, 45, 70 and 100 N/cm).

The bone sample was then fixed on a loading device, which allowed evaluating the micromotion. On each sample, we applied a 25 N horizontal force.

Results: The results indicate that the peak insertion torque and the implant micromotion are statistically correlated, and statistically significant differences in H and M bone were found compared with S bone. In S bone, we noted a micromotion significantly higher than the risk threshold, and it was not possible to reach peak insertion torque above 35 N/cm. In H and M bone, the micromotion is below the threshold of all insertion torques.

Conclusions: Increasing the peak insertion torque, we can reduce the extent of the micromotion between the implant and the bone when submitted to lateral forces in vitro. In soft bone, the micromotion was always high; hence, immediate loading of implants in low-density bone should be evaluated with care.

Protocols of early and immediate loading have been reported in several experimental [Deporter et al. 1986; Hashimoto et al. 1988; Lum et al. 1991; Akagawa et al. 1993; Piattelli et al. 1997; Corso et al. 1999] and clinical (Chiapasco et al. 1997; Tamow et al. 1997) studies.

It has also been demonstrated [Szmukler-Moncler et al. 1998] that the cause of failure of the implant osseointegration is not due to the immediate loading itself, but to the micromotion on the bone–implant interface induced by immediate loading. It is believed that the same mechanisms are responsible for failure of fracture healing, in agreement with the theory of deformation or “strain” [Perren 2002]. There should therefore be a minimum gap between the implant and the peri-implant bone, however, without micromotions occurring above the threshold risk as they induce a deformation of the newly formed tissue, which is able to destroy the new cells and vessels that have formed in the gap, which determine the penetration of the osteoclasts inducing bone resorption [Rahn 2002].

The threshold of the micromotion, experimentally evaluated in animals, is between 50 and 100 μm [Brunski 1999]. Exceeding the maximum threshold during bone healing can cause bone resorption at the interface and fibrosis around the implant [Soballe et al. 1992, 1993; Szmukler-Moncler et al. 2000].

Implant stability depends directly on the mechanical connection between the implant surface.
and the surrounding bone. Initial stability, a consequence of an immediate mechanical adaptation between the implant and the bone site, depends on the density of the bone tissue, congruity of the site and structure of the implant.

Measurement of the moment of force (torque) necessary to insert an implant in the bone is a parameter for measuring primary stability (O’Sullivan et al. 2000). The higher the implant insertion torque, the higher should be the initial stability attained.

To date, it has not been possible to measure clinically the primary stability of implants in the oral cavity. In the past, instruments such as the Periotest or the Osstell were proposed for these measurements.

Even though these instruments have been widely mentioned in the literature, they have never been used for measurements directly correlated to the implant micromotion, which presents the only direct measurement of initial stability; therefore, they must be considered only as being capable of approximate measurements. A recent study [Trisi et al. 2009] correlated insertion torque, bone density and micromotion, demonstrating that the latter can be measured in vitro on specially prepared mechanical models. The aim of this study is to evaluate in vitro the correlation between the micromotion of cylindrical screw implants ad modum Branemark and the insertion torque in fresh bovine bone of different densities.

Material and methods

The test was performed on 2 cm × 2 cm samples of fresh humid bovine bone representative of the following quality categories: hard, normal and soft. The bone qualities were selected according to drilling resistance [Trisi & Rao, 1999] and a preliminary histologic analysis of the bone structure. Hard bone is dense with a completely compact structure. Normal bone is average hard bone with a 2–3 mm cortical layer and a normal cancellous structure inside. Soft bone has low drilling resistance and a 1 mm cortical layer with a low-density cancellous structure.

One hundred and fifty Hexa implants were used [Nuova Geass srl, Pozzuolo del Friuli (UD), Italy], 3.75 mm in diameter and 9 mm long, with external hexagon, cylindrical profile and tapering neck, with a microporous surface ad modum Branemark. Fifty implants were provided for each bone density.

The implant sites were prepared for S bone with spiral cutters 2 and Ø2.8 mm; for the M bone, a final cutter Ø3 mm was used; and for H bone, a Ø3.75 mm tapper was also used. In none of these cases was a countersink used (which was unforeseen by the manufacturer’s surgical protocol) as it did not allow to reach the insertion torques necessary for our study. To screw in the implants, a customized manual key was used, controlled digitally to evaluate the peak insertion torques. The electronic components were a hand-operated key to measure the digital torque, equipped with calibrated strain gauges and connected to a PC, which registered the peak insertion torques every 0.5 s (Fig. 1). The signal was then elaborated with the appropriate software to obtain the peak insertion torque. Secondly, 10 implants were prepared for each torque (20, 35, 45, 70 and 100 N/cm). The sequence of the samples was repeated for the three different bone densities.

After insertion, the transfer was screwed in. The bone sample was then fixed on a loading device specially constructed for this in vitro study, which allowed us to evaluate the micromotion [Fig. 2]. This device has a digital dynamometer at one end (Akku force Cadet, range of 0–90 N and accuracy of 0.5%, Ametek, Wide, FL, USA) and a digital micrometer [gauge] (Mitutoyo, Kawasaki, Japan) at the other end and it measures the micromotions of the abutment during the application of lateral force.

On each sample, we applied a 25 N horizontal force, 10 mm from the bone crest, and we calculated the implant micromotion. On each implant, the load applied was repeated five times for two seconds, simulating the occlusal load in the mouth of a patient. The mean value of these five measurements was calculated for each implant.

Statistical analysis

Twenty implants in S bone with a Newton insertion torque (NIT) of 20 and 35 N and 80 implants, 40 in M bone and 40 in H bone, with an insertion torque between 20 and 70 NIT, were evaluated in this study.

For the soft (S) bone, only the micromotion observed at 20 and 35 NIT were evaluated because at higher NITs the site of implantation was compromised; for S bone, the micromotion was about twice that of the other two bone types (M and H), and then this type of bone was evaluated separately. Between group and within group differences in micromotion seen for the four levels of NIT (20, 35, 45 and 70) in the latter two types of bones were first globally analyzed using ANOVA two-way test, after having verified that the distribution of the data is symmetrical and then using a post hoc test.

All statistical analyses were conducted using SPSS Advanced Statistical™ 13 (SPSS Inc., Chicago, IL, USA) software package.

Results

The mean ± SD of the micromotions of the implants in the different bone densities, hard, medium and soft, at the different insertion torques are shown in Table 1.

In S bone, the values of the micromotion at 20 and at 35 N/cm insertion torque were 157.9 ± 1.6 and 135 ± 0.7 μm, respectively. The two-way ANOVA test resulted highly significant between bone groups ($P = 0.001$) and within NIT ($P = 0.001$) [Table 1]. The data reported in Table 1 show a significant difference between the values of micromotions registered in M bone compared with H bone at 45 and 70 N/cm of insertion torque, which were 63.1 vs. 61.1 and 53.8 vs. 52.2 μm, respectively ($P = 0.05$ Bonferroni correction). In none of the bone types was it possible to insert the implants at 100 N/cm because, over the threshold of 70 N/cm, screw breakage occurs due to unscrewing of the transfer-fixture connection.

These results shown in Fig. 3 indicate that the micromotion decreases uniformly (about 30%) in M and H bone when the NIT increases between...
20 to 70 N/cm, these reduction results are statistically significant ($P=0.05$ Bonferroni correction).

**Discussion**

In the past, in the orthopedic literature there was a common belief that implant failure was due to bone resorption on the interface, caused by excessive loading (Perren 2002). In conflict with this hypothesis, a series of experiments were carried out (Rieger et al. 1990; Hente et al. 2001; Perren 2002) in which it was demonstrated that the resorption was caused by implant micromotions, even when a minimum load was applied. These experiments showed that the cortical bone movement of the implant, even of only a few microns, induces resorption of the bone surface. For a given amount of instability, resorption increases the distance between the moving surfaces, thus reducing the deformation or “strain” of repair tissue (Hente et al. 2001; Perren 2002). The basic working hypothesis of the “strain” theory is that a tissue cannot be produced under strain conditions that exceed the elongation of rupture of the given tissue element, such as cells (Perren 2002).

It has been hypothesized that a similar mechanism may be involved in immediate loaded implant failure, as it would determine bone resorption at the interface, thus inducing fibrosis around the implant (Soballe et al. 1992, 1993; Szmukler-Moncler et al. 2000). A high peak torque was considered favorable to reach better initial stability (O’Sullivan et al. 2000), and this has been confirmed by other experiments (Trisi et al. 2009). For this reason, in this study we evaluated the dependence between the peak insertion torque and the micromotion measured in vitro in order to give the clinician an understanding of the initial stability of the implants, based on the peak insertion torque. As the peak insertion torque and the stability of the implant are linked to the bone density, it was necessary to evaluate these parameters for different kinds of bone. The micromotions were measured 10 mm above the bone crest. As it has already been demonstrated that the most frontal part of the bone, subjected to lateral loading, supports the highest strain (Rieger et al. 1990; Bidez & Misch 1992; Kitamura et al. 2004), it is possible to hypothesize that the fulcrum of the oscillation of the implant is the bone crest. The results of this study indicate that the peak insertion torque and the implant micromotion are statistically correlated, and statistically significant differences in hard and medium bone were found compared with soft bone. In S bone, we noted a micromotion significantly higher than the risk threshold, which is between 50 and 100 μm (Brunski 1999), and it was not possible to reach peak insertion torque above 35 N/cm of insertion torque because in this type of bone the meagre number of trabeculae offers scarce resistance to screwing in this type of implant, thus losing initial stability. For this reason, it was not possible to reach torques of 45, 70 and 100 N/cm. In H and M bone, the micromotion is below the threshold of all insertion torques. From our results, we can deduce that increasing by 10 NIT, the micromotion immediately decreases by approximately 4 μm for H and M densities, while there is a contraction of approximately 15 μm for S bone. Lastly, the regression lines for H and M bone are parallel and almost superimposable, constantly reducing the micromotion during the analysis time.

These results allow us to confirm that the use of high insertion force during surgical implants reduces the risk of micromotions above the risk threshold for immediate load.

On the other hand, in vivo animal studies showed carried out by our equipe showed that high compression in dense cortical bone, in sheep, induced by high insertion torque (150 peak insertion torque) did not induced implant failure, but only increased remodeling and stability. These results were also confirmed by clinical studies carried out by Ottoni (Ottoni et al. 2005), who demonstrated that an increase in peak insertion torque can significantly better the rate of success of immediate load implants. In a prospective controlled clinical trial, it was shown that increasing insertion torque to levels around 100 N/cm in patients did not result in an increased failure rate or bone resorption as

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**Table 1. Mean ± SD micromotion (μm) of implants (Geass) loaded with 25 N lateral force for S, M and H bone**

<table>
<thead>
<tr>
<th>Newton insertion torque (N)</th>
<th>Geass</th>
<th>S bone (n = 20)</th>
<th>M bone (n = 40)</th>
<th>H bone (n = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>157.9 ± 1.6</td>
<td>73.6 ± 3.6</td>
<td>71.2 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>135.0 ± 0.7</td>
<td>67.2 ± 1.1</td>
<td>66.6 ± 1.1</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>63.1 ± 0.7*</td>
<td>61.1 ± 1.3*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>53.8 ± 0.8*</td>
<td>52.2 ± 1.4*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANOVA test, $P<0.001$;
*Post hoc test $P=0.05$.
S, soft; M, medium; H, hard.

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**Fig. 2.** Loading device to evaluate the implant micromotion, at one end, there is a digital dynamometer (Akku force Cadet, range of 0–90 N and accuracy of 0.5%, Ametek) and there is a digital micrometer (guage) (Mitutoyo) at the other end, which measures the micromotions of the abutment during the application of lateral force.

**Fig. 3.** Mean reduction of micromotion [μm] in M and H bone (groups) in four Newton insertion torque levels.
compared with a standard inserted implant using 45 N/cm. Vertical occlusal forces measured in humans are approximately 800 N/cm (Van Eijden 1991) and horizontal ones approximately 20 N/cm (Graf 1975). The results of Engelke et al. (2004) show that, in type IV bone, lateral forces induce micromotion between 100 and 250 μm, depending on the force applied. These data were also confirmed in a recent study by Trisi et al (2009), which correlates the insertion torque to the bone density and micromotion, demonstrating that increasing the peak torque reduces the micromotion, but in S bone the micromotion is constantly high, which can lead to failure. For these reasons, we hypothesize that an implant placed in soft bone may be at higher risk of developing capsule fibrosis if it is immediately loaded without splitting.

The results of this study show that increasing the peak insertion torque can reduce the extent of the micromotion between the implant and the bone when submitted to lateral forces in vitro. Furthermore, it was observed that in soft bone the micromotion was always high.

The results of the present study are derived from an in vitro study and they are not directly comparable with the clinical situation. For this reason, care should be taken until clinical studies confirm the hypothesis coming from the present study.

References


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Purpose: To determine the effect of crown height space, crown-to-implant ratio, and offset placement of a prosthesis on implant survival, crestal bone loss, and prosthetic complications; and to determine whether detrimental values for crown height space and crown-to-implant ratio exist for implant-supported restorations.

Materials and Methods: Extra-short implants (length ≤ 6.5 mm) supporting a fixed denture in the posterior mandible and followed for at least 12 months were analyzed. Radiographic and clinical examinations were conducted to retrieve data about patients' dental and medical history, prosthetic complications, antagonist type, crown height space, crown-to-implant ratio, offset placement of the prosthesis, crestal bone loss, and implant failure.

Results: Thirty-four patients (mean age, 60 ± 10 years) with 45 extra-short implants participated in this study. Patients were followed for up to 4 years (mean, 2 years) and no implants were lost. The mean crown-to-implant ratio was 2.4 (range, 1.5 to 3.69). Mean crown height space was 17.05 ± 3.05 mm, and 65.4% of the implants had a crown height space in the range of 15 to 20 mm. About 90% of the implants had a distal or mesial offset placement greater than 1 mm. The type of antagonist significantly affected marginal bone loss around extra-short implants: bone loss was greatest for implants opposing a partial denture (mean, 1.28 ± 1.09 mm) and was lower for implants opposing a natural dentition (mean, 0.73 ± 0.60 mm) or a complete denture (mean, 0.89 ± 0.60 mm). Analysis of marginal bone loss and the factors crown-to-implant ratio, crown height space, and offset placement according to antagonist dentition indicated a significant positive correlation only between bone loss and crown height space. Conclusions: When an increased crown-to-implant ratio is present, crown height space may influence crestal bone loss more significantly.

Key words: biomechanics, bone loss, crown height space, crown-to-implant ratio, short implants

The periodontal ligament, whose principal function is to retain a tooth in the alveolar socket, gives the natural dentition a larger range of physiologic mobility than an osseointegrated dental implant. If a force of 0.1 N is applied to a tooth with a healthy periodontal ligament, the range of mobility is between 50 and 200 µm, whereas the application of the same force to a dental implant will result in mobility of 10 µm.1,2 The greater rigidity of a dental implant makes it more vulnerable to eccentric or excessive occlusal loads.3 Such loads will increase the stress transmitted to the peri-implant bone, which may lead to bone resorption and implant loss. Moreover, they will increase the risk of prosthetic complications such as screw loosening, implant or abutment fracture, chipping of ceramic, and fracture of the prosthesis. Thus, an implant-supported prosthesis must be designed to avoid overloading and ensure its survival.

An implant-supported prosthesis could be considered a type I lever; that is, any increase in crown height will increase the force moment that is endured by the implant and the surrounding bone.4,5 Accordingly, an increased crown-to-implant ratio could be associated with a higher risk of crestal bone loss and prosthetic complications. Rangert et al concluded that there was a positive correlation between an increased crown-to-implant ratio and the amount of crestal bone loss.6 In another study, Naert et al found a correlation for the first 6 months of loading between crestal bone loss and the placement of a long crown.7 Moreover, in prosthodontics, the ideal crown-to-root ratio is 1:2, and a minimum of 1:1 for a tooth abutment is...
recommended. These guidelines have been adapted in implant dentistry, such that clinicians tend to insert the longest implant that the bone volume will permit to avoid an unfavorable crown-to-implant ratio.

An unfavorable crown-to-implant ratio is considered a form of nonaxial loading and several studies have evaluated its influence on the stability of crestal bone and implant survival. Blanes et al evaluated 192 dental implants with a mean crown-to-implant ratio of 1.77:1; about 27% of the implants had a crown-to-implant ratio ≥ 2. The authors did not find a correlation between the increased crown-to-implant ratio and marginal bone loss or implant failure. Similar conclusions were reached in other studies.

The position of the fulcrum differentiates between an anatomical crown-to-implant ratio and clinical crown-to-implant ratio; in the former, the fulcrum is located at the implant shoulder, while in the latter the fulcrum is positioned at the bone crest. Nissan et al, in two in vitro studies, suggested that the use of crown height space is a more significant factor than the crown-to-implant ratio in assessing biomechanics-related detrimental effects on prosthetic complications. The crown height space is an anatomical parameter that is defined as the distance between the occlusal plane and the crestal bone. For each 1-mm increase in crown height space, the cervical load is increased by 20%. Biomechanically, a crown height space value greater than 15 mm is regarded as unfavorable; Nissan et al explained the absence of significant correlation between the crown-to-implant ratio and crestal bone loss in previous clinical studies by the fact that the value of crown height space was below the detrimental limit of 15 mm.

The aforementioned studies are heterogenous with respect to the type of implant-supported restorations, implant lengths, implant locations, and implant splinting. This, in addition to the narrow distribution of the crown-to-implant ratio, renders sound conclusions difficult. This led to the present research. To reduce heterogeneity of the sample, only extra-short implants supporting a fixed denture in the posterior mandible were considered. The main objectives were to assess the effect of crown height space, crown-to-implant ratio, and offset placement of the prosthesis on implant survival and crestal bone loss and to determine whether a detrimental value for crown height space exists when a fixed denture is used as an implant-supported restoration.

**MATERIALS AND METHODS**

A patient database was analyzed retrospectively to identify patients with extra-short implants, defined as those implants with lengths of 5.5 or 6.5 mm. Patients were selected for this study if the extra-short implant had been inserted in the posterior mandible, served as an abutment for a fixed denture, and had been followed for at least 12 months since loading. Patients who failed to meet any of these criteria were excluded from the study. The principal outcomes were marginal bone loss and implant survival.

The surgical technique performed to place the extra-short implants is described elsewhere. It is important to mention that the prosthesis was supported by transepithelial abutments (Multi-Im, BTI) and not directly by the implants. The bone type at the implant site was determined according to the Lekholm and Zarb classification using the bone density measured on preoperative cone beam computed tomographic scans (GALILEOS 3D scanner, BTI scan). Data on insertion torque and implant stability quotients (ISQs) were also analyzed. Two-stage implant placement was performed for all implants, and an average of 4 to 5 months was allowed to elapse before the provisional prosthesis was inserted. Forty-six extra-short implants served as abutments for fixed partial dentures (FPDs), and only six implants supported a fixed complete denture.

**Data Collection**

Patient records were analyzed to derive demographic data (gender, age); social habits (smoking, alcohol intake); parafunctional habits (eg, bruxism); relevant medical conditions; and any history of periodontal disease. Radiographic analysis was performed to measure the primary predictors of the study (crown height space, crown-to-implant ratio, and offset placement of the prosthesis) and marginal bone loss. To determine marginal bone loss, standardized panoramic radiographs were evaluated at baseline and at the most recent visit. Radiographs were obtained digitally, and the known implant length was used as a reference to transform the linear measurements into millimeters using Sidexis software. All radiographic measurements were performed by the same examiner (LP). First, the plane of occlusion was traced between the incisal edges of the anterior mandibular teeth and the most coronal point of the vestibular cusps of the mandibular premolars and molars, and the bone level was also traced by connecting the first bone-implant contact points on the mesial and the distal. The following measurements were made (Fig 1):

- Anatomical crown length, defined as the perpendicular distance between the implant shoulder and the most coronal aspect of the crown
- Crown height space, defined as the perpendicular distance between the plane of occlusion and the bone crest
• Distance between the mesial margins of the abutment and the implant
• Distance between the distal margins of the abutment and the implant
• Marginal bone loss, defined as the distance between the top of the implant shoulder and the first visible implant-bone contact and measured mesial and distal to the implant

These measurements were then used to calculate the following parameters:

• Anatomical crown-to-implant ratio: anatomical crown length divided by the implant length
• Offset placement of the prosthesis: difference between the mesial and distal distances between the margins of the abutment and the implant

Statistical Analysis
The patient was the statistical unit for the statistical description of demographic data, social habits, bruxism, medical history, and history of periodontal disease. Mean values, standard deviations, and ranges were calculated for age, while relative frequency was calculated for the remaining patient-related variables. The implant served as the statistical unit for the descriptions of implant length, diameter, location, insertion torque, ISQs, marginal bone loss, crown height space, crown-to-implant ratio, and offset placement of the prosthesis. Mean values, standard deviations, and ranges were calculated for insertion torque, ISQs, marginal bone loss, crown-to-implant ratio, crown height space, and offset placement of the prosthesis. Relative frequencies were calculated for implant length, diameter, and location.

The Shapiro-Wilk test was performed to determine whether the data of marginal bone loss followed a normal distribution. The effects of antagonist type and type of splinting of implants on marginal bone loss around the extra-short implants were first analyzed with the Kruskal-Wallis test if the data did not follow a normal distribution; analysis of variance was used if the data followed a normal distribution. This served as a criterion to determine whether subgrouping of the extra-short implants was required before the effects of crown-to-implant ratio, crown height space, and offset prosthesis placement on peri-implant bone loss could be studied.

Then, the Pearson correlation test and the Spearman correlation test were used to analyze the associations between marginal bone loss, crown-to-implant ratio, crown height space, and offset prosthesis placement. The results of the correlation test were then analyzed to identify any variables that had a significant correlation with marginal bone loss. If a variable had significant correlation with bone loss and at the same time had a significant correlation with other variables, a linear regression model with interaction effects was conducted to verify the presence of confounding factors. The level of statistical significance was set at \( P < .05 \). All statistical analyses were performed using the SPSS statistical software package (version 15.0 for Windows, SPSS).

RESULTS
Thirty-four patients (6 men, 28 women; mean age, 60 ± 10 years) with 45 extra-short implants fulfilled the inclusion criteria and were enrolled in this retrospective study. Two patients reported a smoking habit, and one reported daily consumption of alcohol. Two patients had a bruxism habit, and seven reported a history of periodontitis. Table 1 summarizes the data on the implants surveyed in this study.

Thirty implants received a screw-retained prosthesis, and 15 implants received a cemented prosthesis.

The descriptive analysis of predictors indicated that the mean crown-to-implant ratio was 2.44 (range, 1.5 to 3.69) and the mean crown height space was 17.05 ± 3.05 mm (range, 11.2 to 25.4 mm). The crown-to-implant ratio was less than 2 for 19.2% of the implants, between 2 and 3 for 67.3% of the implants, and greater than 3 for 13.5% of the implants. Meanwhile, the value of crown height space was below 15 mm for 25% of the implants, between 15 and 20 mm for 65.4% of the implants, and more than 20 mm for 9.6% of the implants (Fig 2).
Placement of the prosthesis was offset by less than 1 mm mesially or distally for 21.2% of the implants. A larger offset was presented mesially for 90.4% of the extra-short implants, while the remaining 9.6% showed a distal offset.

The average follow-up time since implant loading was 23.18 ± 7.7 months (range, 14.43 to 43.37 months) and no implants failed. Patients were screened for prosthetic complications (screw loosening/fracture, abutment/implant fracture, ceramic chipping, and prosthetic fracture); no complications were seen (Fig 3).

**Marginal Bone Loss**

Analysis of marginal bone loss data showed a mean of 1.01 ± 0.68 mm (range, 0 to 3.49 mm) of mesial bone loss and 0.89 ± 0.7 mm (range, 0 to 3.86 mm) of distal bone loss. Implants with mesial bone loss < 2 mm constituted 94% of the analyzed extra-short implants. Ninety-six percent of implants showed < 2 mm of distal crestal bone loss. This means that only 5 of 45 extra-short implants showed marginal bone loss greater than 2 mm. Those implants with marginal bone loss < 2 mm had an average crown height space of 17 ± 4 mm, versus an average crown height space of 21 ± 3 mm for implants with bone loss ≥ 2 mm.

The effect on marginal bone loss of the type of antagonist was analyzed. This served as a criterion to determine whether subgrouping of the extra-short implants was required before studying the effect of crown-to-implant ratio, crown height space, and offset placement on peri-implant bone loss.

Table 2 shows the distribution of the extra-short implants according to the type of antagonist and the type of implants that supported the denture. The implants splinting the extra-short implants were classified as “short” if all implants had a length ≤ 8.5 mm, “combined” if short and standard implants were used, and “standard” if all the supporting implants were longer than 8.5 mm. In all but one case, in which six implants were placed, two or three implants served as abutments.

The nonparametric Kruskal-Wallis test indicated a significant effect of the type of antagonist (P = .04), but not of the length of supporting implants (P = .38), on marginal bone loss. This bone loss was the highest for implants with an FPD as antagonist (mean, 1.28 ± 1.09 mm) and was lower for implants with natural dentition (mean, 0.73 ± 0.60 mm) or a complete denture (mean, 0.89 ± 0.60 mm) as antagonists. Because of this, extra-short implants were separated into three groups according to the type of antagonist (complete denture, natural dentition, and FPD) (Table 3).

For the 19 extra-short implants with a complete denture as antagonist, mean mesial bone loss was 0.91 ± 0.63 mm (range, 0 to 2.59 mm) and mean distal bone loss was 0.86 ± 0.52 mm (range, 0 to 2.32 mm). The Shapiro-Wilk test indicated that the data of mesial (P = .08) and distal (P = .06) bone loss followed a normal distribution. The Student t test indicated a significant difference (P = .00) between mesial and distal bone loss.

A Pearson correlation analysis indicated that only crown height space had a significant positive correlation with mesial (correlation coefficient = 0.54; P = .02) and distal (correlation coefficient = 0.49; P = .04) bone loss. However, there was no significant correlation between crown-to-implant ratio or offset placement and marginal bone loss (P > .05). Crown height space had a positive significant correlation with crown-to-implant ratio (correlation coefficient = 0.74; P = .00) and a negative correlation with offset placement (correlation coefficient = -0.56; P = .01).
To verify whether the crown-to-implant ratio and offset placement could act as confounding factors in the correlation between crown height space and mesial and distal marginal bone loss, a linear regression analysis with interaction effects was performed. The results indicated the absence of a significant interaction between both factors; only crown height space reached statistical significance. Thus, crown-to-implant ratio and offset placement were excluded as confounding factors.

The nine extra-short implants with a natural dentition as the antagonist had a mean mesial bone loss of 0.75 ± 0.57 mm (range, 0 to 1.67 mm) and a mean distal bone loss of 0.71 ± 0.22 mm (range, 0.4 to 1.10 mm). The data for marginal bone loss followed a normal distribution, as indicated by the Shapiro-Wilk test (P > .05). The Student t test indicated the presence of a significant difference (P = .00) between mesial and distal bone loss.

The Pearson correlation analysis did not find a significant correlation between marginal bone loss and crown height space, crown-to-implant ratio, or offset placement.

The 17 extra-short implants with an FPD as the antagonist had mean mesial bone loss of 1.37 ± 0.78 mm (range, 0 to 3 mm) and mean distal bone loss of 1.18 ± 1.00 mm (range, 0 to 4 mm). The Shapiro-Wilk test indicated that marginal bone loss data did not follow a normal distribution. The nonparametric Spearman test indicated the presence of a positive significant correlation between distal bone loss and crown height space (correlation coefficient = 0.55; P = .02) but not between distal bone loss and crown-to-implant ratio or offset placement. Crown height space had a significant correlation with crown-to-implant ratio (correlation coefficient = 0.90; P = .00). Further statistical analysis was performed to verify whether crown-to-implant ratio might act as a confounding factor in the correlation between distal bone loss and crown height space.

Thus, linear regression analysis was performed to see if the effect of crown height space, crown-to-implant ratio, and their interaction on distal bone loss reached statistical significance. The results indicated that only crown height space significantly affected distal bone loss (P = .02).

**DISCUSSION**

An increasing number of papers have shown the efficacy of implants with reduced length in permitting oral rehabilitation of severely atrophied jaws with implant-supported prostheses. The placement of implants with reduced length would imply the presence of increased crown-to-implant ratios, and several papers have shown no correlation with crestal bone loss and implant failure. In fact, a consensus group of the European Academy of Osseointegration accepted a crown-to-implant ratio of 2:1. This result would prevent the need for vertical bone augmentation to place longer implants and obtain a more favorable crown-to-implant ratio. In this sense, increased implant diameter has appeared to be more effective in reducing the stresses transmitted to the peri-implant bone than greater implant length. The majority of stress is concentrated in the crestal bone, regardless of implant design, and thus, increased implant length is not an effective measure to counterbalance the effect of crown height space.
length. Moreover, Rangert et al indicated that the stress distribution to multiple implants is influenced by the number and arrangement of implants supporting the prosthesis. These results were recently verified by three-dimensional geometric analysis. Both studies showed that the presence of a cantilever increases the stress endured by the implants, by a factor of almost 200%. Moreover, the effects of different occlusal schemes on the load withstood by implants supporting an FPD have been studied. Of the three anatomical variations of the occlusal scheme studied (steep cusps, flat cusps, and same cuspal inclination as the first but with narrow occlusal surface), narrowing the width of the occlusal surface by 30% resulted in a significant reduction in lateral force components.

According to the results of statistical analysis, the type of antagonist has a statistically significant effect on marginal bone loss around extra-short implants. Implants with fixed prostheses as antagonists had more bone loss than implants opposing complete dentures or a natural dentition. Thus, the extra-short implants analyzed here were classified according to the type of antagonist for analysis of the effects of crown-to-implant ratio, offset placement, and crown height space on marginal bone loss.

In this study, the authors chose to study extra-short implants supporting a fixed prosthesis, since the occurrence of extreme crown-to-implant ratios would be more likely and thus, the relationship, if any, with crestal bone loss and implant failure, could be established. Indeed, the average crown-to-implant ratio in this study was 2.4, which is substantially higher than the average crown-to-implant ratio of other studies, which featured average crown-to-implant ratios between 1.3 and 1.84. However, although some studies had shown an inverse relationship between crown-to-implant ratio and marginal bone loss, the statistical analysis revealed the absence of a significant effect of crown-to-implant ratio on crestal bone loss measured mesial and distal to the implants. The absence of a correlation could be related to the use of wide implants, as 90.4% of the implants placed here had a diameter of 4.5 or 5.0 mm. This may have helped to dissipate the increased stresses caused by the high crown-to-implant ratio. In addition, the fixed prostheses used here splinted the extra-short implants together, thus minimizing the lateral forces on the implants, enhancing force distribution, and reducing the stress exerted on short implants.

Cantilever extensions were not present in the prosthetic rehabilitations that were analyzed in this work because the insertion of extra-short implants in the atrophied posterior region prevented the need for cantilevers. The authors also studied the effect of offset placement of the prosthesis on the extra-short implants, and the statistical analysis revealed the absence of a significant correlation with crestal bone loss.

Another parameter related to the crown-to-implant ratio is the crown height space, which has been reported to be more significant to the biomechanics of implant-supported prosthesis. Misch and Bidez showed that an increase in crown length from 10 to 20 mm will increase the occlusal forces on an implant by 100%. Crown height space higher than 15 mm has been reported as unfavorable and to result in higher stress concentrations at the bone-implant interface.

This encouraged the current authors to further analyze the effect of crown height space on crestal bone loss around extra-short implants supporting a fixed prosthesis. The crown height space was related significantly to the crestal bone loss. This would indicate that crown height space is a more significant factor than crown-to-implant ratio in the bone loss seen around extra-short implants. The average crown height space in this study was 17 mm, higher than the recommended 15 mm. This indicates that the use of fixed dentures may help with the tolerance of increased crown height space. To determine the threshold at which excessive bone loss occurred, the authors compared the data for implants that exhibited bone loss above or below 2 mm. The results showed an average crown height space of about 17 mm for implants with bone loss < 2 mm and an average of about 21 mm for implants with bone loss > 2 mm. According to the health scale of dental implants, 97.9% of the extra-short implants had optimal health and could be considered successful.

Within the limitations of this study, the results show that crown height space is an effective parameter to study the effect of an increased crown-to-implant ratio on crestal bone loss and implant survival. Furthermore,
the use of extra-short implants to support a fixed denture to treat severe atrophy is a viable and effective treatment option\textsuperscript{19} (Fig 3).

The limitations of this study include its retrospective design, the small sample size, short follow-up time, and the variety of antagonists. The fact that extra-short implants were, in some cases, splinted by the prosthesis to other standard-length implants is an additional limitation. Further studies with more extra-short implants followed for a longer period of time are necessary to establish sound conclusions about the effect of increased crown-to-implant ratio on implant and prosthesis survival.

CONCLUSIONS

The effects of crown-to-implant ratio, crown height space, and offset placement of the prosthesis on crestal bone loss and implant loss were analyzed for 45 extra-short implants with a follow-up time up to about 4 years after loading (average of about 2 years). The following conclusions can be made:

- Increased crown-to-implant ratio and offset placement of the prosthesis were not significantly correlated to marginal bone loss around extra-short implants.
- Crown height space showed a positive significant correlation with marginal bone loss.

ACKNOWLEDGMENTS

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REFERENCES

Systematic Review and Meta-Analysis of Randomized Controlled Trials for the Management of Limited Vertical Height in the Posterior Region: Short Implants (5 to 8 mm) vs Longer Implants (> 8 mm) in Vertically Augmented Sites

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Waeil Elmisalati, BDS⁴/Sung-Kiang Chuang, DMD, MD, DMSc⁵

Purpose: The aim of this study was to undertake a systematic review with meta-analysis on randomized controlled trials (RCTs) to compare the rates of survival, success, and complications of short implants to those of longer implants in the posterior regions. Materials and Methods: Electronic literature searches were conducted through the MEDLINE (PubMed) and EMBASE databases to locate all relevant articles published between January 1, 1990, and April 30, 2013. Eligible studies were selected based on inclusion criteria, and quality assessments were conducted. After data extraction, meta-analyses were performed. Results: In total, 539 dental implants (265 short implants [length 5 to 8 mm] and 274 control implants [length > 8 mm]) from four RCTs were included. The fixed prostheses of multiple short and control implants were all splinted. The mean follow-up period was 2.1 years. The 1-year and 5-year cumulative survival rates (CSR) were 98.7% (95% confidence interval [CI], 97.8% to 99.5%) and 93.6% (95% CI, 89.8% to 97.5%), respectively, for the short implant group and 98.0% (95% CI, 96.9% to 99.1%) and 90.3% (95% CI, 85.2% to 95.4%), respectively, for the control implant group. The CSRs of the two groups did not demonstrate a statistically significant difference. There were also no statistically significant differences in success rates, failure rates, or complications between the two groups. Conclusion: Placement of short dental implants could be a predictable alternative to longer implants to reduce surgical complications and patient morbidity in situations where vertical augmentation procedures are needed. However, only four studies with potential risk of bias were selected in this meta-analysis. Within the limitations of this meta-analysis, these results should be confirmed with robust methodology and RCTs with longer follow-up duration. INT J ORAL MAXILLOFAC IMPLANTS 2014;29:1085–1097. doi: 10.11607/jomi.3504

Key words: complication, dental implant, failure rate, short implant, survival rate, systematic review

Restrictions on placing endosseous oral implants are common in the posterior regions of the maxilla and mandible because of lack of sufficient bone height. To address this issue of reduced bone height, several approaches have been proposed: (1) sinus lift, (2) vertical augmentation, (3) lateral transposition/reposition of inferior alveolar nerve, and (4) placement of short implants. Sinus lift is more predictable than other vertical augmentation procedures because the graft materials can be maintained in position by the sinus membrane and alveolar bone where sufficient blood supply is provided. However, augmentation procedures always increase cost, morbidity, and treatment time. Vertical augmentation procedures on compromised
alveolar ridges are technically sensitive and might cause significant postoperative morbidity and complications, such as severe postoperative pain, swelling, or graft resorption.² Nerve transposition is also a technically challenging procedure and may cause significant neurosensory disturbances. Short implants have been proposed as an alternative to avoid the disadvantages of vertical augmentation and nerve transposition, although the strong evidence on their long-term outcome is still limited.

A bone height 10 mm or greater is considered to be the minimal amount of bone required to place implants of standard length. In the past, the standard length of dental implants has been 10 mm or longer. These standard implants can also be called “long implants.” This is based on many clinical studies that used ≥ 10-mm Bränemark implants in the earlier days. Some clinical trials have demonstrated a higher failure rate for short implants (< 10 mm).³–⁵ However, these studies had several variables, such as machined-surface design and different surgical sites, which might cause the failures of short implants. Friberg et al⁶ demonstrated the first long-term successful outcomes of short Bränemark System implants. This study reestablished the possibility of using short dental implants. Currently, rough-surface implants made with new technology have demonstrated better mechanical and biologic characteristics than traditional machined-surface implants. Several clinical studies have demonstrated high success rates and predictable clinical outcomes for placement of short implants.⁷–¹⁰

Although most of the previous reviews have demonstrated that placement of short implants is a predictable treatment, comparing clinical outcomes between short and long implants based only on randomized controlled trials (RCTs) has not been explored. Many studies that were included in previous reviews were not prospective clinical trials,¹¹ or the studies did not have primary outcomes of comparing short and long implants.¹²–¹⁴ Sometimes, only data on short implants were extracted from included studies, and therefore, a comparison between short and long implants was not performed.¹⁵ Moreover, the definition of “short” implants was controversial in the studies or reviews, without uniform consensus.¹²,¹⁶ Implants with lengths ≤ 8 mm are defined as short implants in this meta-analysis because ≤ 8 mm was the length examined by the articles that were available and consequently selected. The control implant groups included all implants with lengths > 8 mm in this meta-analysis.

The specific aims of this review were (1) to undertake a thorough systematic review and meta-analysis based only on RCTs to compare the rates of survival, success, and complications of short implants to those of control implants; (2) to evaluate cumulative survival rates (CSRs) of short and control implants at 1 and 5 years through meta-analysis; and (3) to perform a comparative meta-analysis comparing clinical outcomes of short and control implants by evaluating risk ratios (RR) for failure (early and late), biologic complications (intraoperative, postoperative, and postloading), prosthetic complications, and overall complications between both groups. This review will analyze the clinical outcomes of short implants compared to control implants of selected RCTs.

**MATERIALS AND METHODS**

This systematic review was conducted by following previously outlined recommendations¹⁷ and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles.¹⁸ The focused question was, are the survival rate and other clinical outcomes different between short and long implants that support fixed prostheses in RCTs?

The survival rates of short and control implant groups were the primary outcomes to be extracted and analyzed by meta-analysis. The success rate, failure rate, and biologic/prosthetic complication rates were the secondary outcomes.

**Search Strategy**

Electronic searches were conducted through the MEDLINE (PubMed) database of the National Library of Medicine and EMBASE to locate all relevant articles published between January 1, 1990, and April 30, 2013. Key words used in this meta-analysis were “dental implant,” “short implant,” “ultra-short implant,” “success rate,” “survival rate,” “short implant failure,” “ultra short implant failure,” “endosseous implant,” “short length,” “ultra short length,” and “complication.” These terms were also combined with AND or OR to perform the searches. The reference lists of the articles in the previous systematic reviews, meta-analysis, and relevant papers were also manually searched. Titles, abstracts, and full-text articles were screened. Duplicated articles were eliminated. Studies not fulfilling the inclusion criteria were excluded from further review.

The following types of studies were included:

- **RCTs.**
- Randomized studies that included short and control implant groups, with the clinical outcomes of short implants as the primary investigated results of the studies. The lengths of control implants were longer than those of short implants.
- Studies that included the survival rate of implants and other detailed data regarding implant lengths, diameters, locations, and surgical techniques.
- Studies in which the implants were restored with fixed prostheses.
- Evaluations with a mean follow-up period of at least 1 year.
- Publications in English.

Excluded were cohort studies, case series, case reports, review articles, professional opinions, and all retrospective studies; animal studies; and studies that did not report on the primary and secondary outcomes listed previously.

**Overview of Selected Studies.** The present review will briefly summarize the characteristics of each study, including the characteristics of surgical sites, procedure timeline, patient exclusion criteria, and other clinical factors.

**Quality Assessment.** In all included RCTs, the risk of bias was assessed based on the Cochrane Collaboration tool. Any disagreement was resolved by discussion of four authors (S-AL, C-TL, MF, S-KC) until a final consensus was achieved.

**Data Extraction**

Primary outcomes (survival rate) and secondary outcomes (failure rate, biologic/prosthetic complication rate) were extracted from the studies. Success rate was defined by the proposed criteria in this review. The data were extracted by two authors (S-AL, C-TL) and examined by the other two authors (MF, S-KC). Agreement was reached by group discussion.

**Implant Survival.** Survival was defined as the presence of an implant with or without complications during the follow-up period; survival was quantified by the CSR.

**Implant Success.** Success was defined as the presence of all of the following:
- No pain or tenderness upon function and no history of exudate
- No mobility
- \(< 2 \text{ mm radiographic bone loss from initial surgery to 1-year follow-up}\)
- \(< 0.2 \text{ mm annual vertical bone loss following the first year postsurgery}\)
- No peri-implant radiolucency

**Implant Failure.** Implants were regarded as failures if they were no longer present in the mouth or did not fit any success criteria. Implant failures were further classified into “early implant failure” if the implant failed prior to loading and “late implant failure” if the implant failed after loading.

**Complications.** In this review, complications were divided into three categories: (1) biologic complications (intra- or postoperative); sinus membrane (or lining) perforations, persistent bleeding, sinusitis (or acute sinus infection), rupture of sinus membrane, soft tissue (graft) dehiscence, insufficient bone gain for long implant placement, abcess, pus, transient postoperative paresthesia, pain, swelling, and other adverse events; (2) biologic complications (postloading): peri-implant mucositis (heavily inflamed soft tissue without bone loss) or peri-implantitis (bone loss \(\geq 2 \text{ mm from the expected level with suppuratation, heavily inflamed tissues, or fistulas}\)); (3) prosthetic complications: fixed prosthetic device detachment, loosening of abutment screws or healing caps, and fracture of the screw, framework, or occlusal material.

Other relevant data such as implant locations, length, diameter, implant surface characteristics, surgical techniques, implant placement protocols, and restoration types were also extracted with a predesigned data collection form.

**Statistical Analysis**

For each study, the failure event rate for the short or control implants was calculated by dividing the total number of failure events by the total number of short or control implant exposure times (follow-up times) in years. For further analysis, the failure event rate estimates of the short or control implants were used to calculate the standard errors of the failure event rate estimates (standard errors were estimated by the standardized formula of failure rates divided by the square root of the number of failure cases of the short or control implants). With each study’s estimates and standard errors obtained, the authors computed further in order to reach the 95% confidence intervals (CIs) of the summary estimates of the failure event rates of the short or control implants. Studies without any failures in the implant group were excluded from the meta-analysis due to zero events. Heterogeneity between studies was assessed using \(I^2\) statistics to describe the variation in RR, which is attributable to the heterogeneity of the studies. All statistical analyses were performed using STATA (Stata Statistical Software, Version 11.2, Stata Corp), with the level of statistical significance set at \(\alpha = .05\). Using the METAN command in the STATA statistical computing environment, the heterogeneity of the study-specific failure event rates between the short or control implants was assessed. The estimated 1-year (\(T = 1\)) and 5-year (\(T = 5\)) CSRs were calculated via the relationship between the failure event rate of the short or control implants and the negative exponential survival function \(S_T = \exp(-T \cdot \text{failure event rate}),\) by assuming constant failure event rates. The CIs for the survival rates were then calculated using the 95% confidence limits of the failure event rates. The STATA software computed the \(I^2\) statistics to assess the heterogeneity between studies and the corresponding
Any disagreement was resolved by discussion until a final consensus was achieved. Risk-of-bias assessment of all RCTs is shown in Table 1. All studies randomized the subjects appropriately and reported the results clearly. Blinding of patients and surgeons. It was difficult to achieve blinding of patients and surgeons. Patients had the right to know which kinds of implants were used for treatments. Surgeons would know implant types while performing the surgical procedures. Every study was regarded as high risk for bias in this category. Blinding of outcome assessment. Clinical outcome assessments cannot be blinded completely. During radiographic assessment, independent investigators can note the specific shape and length of implants. In Gulje’s study, the use of an independent investigator to assess clinical outcomes was not mentioned. Group Imbalance. Each group used implants of different diameters in Esposito et al. and Cannizzaro et al. used implants with various diameters in both groups. Short implants generally had wider diameters than control implants in these two studies. The diameters of short and control implants in the other two studies were the same. Moreover, all multiple-

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<tr>
<td>Random sequence generation</td>
<td>Low risk</td>
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<td>Allocation concealment</td>
<td>Low risk</td>
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<tr>
<td>Blinding of patients and surgeons</td>
<td>High risk</td>
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<td>Blinding of outcome assessment</td>
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<td>Incomplete outcome data</td>
<td>Low risk</td>
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<td>Selective reporting</td>
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<td>Other sources of bias</td>
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<td>Group imbalance</td>
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<tr>
<td>Sample size</td>
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<td>High risk</td>
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<td>Follow-up time</td>
<td>High risk</td>
<td>High risk</td>
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<td>Low risk</td>
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<tr>
<td>Conflict of interest</td>
<td>N/A</td>
<td>N/A</td>
<td>Low risk</td>
<td>High risk</td>
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<tr>
<td>Radiographic outcome</td>
<td>High risk</td>
<td>High risk</td>
<td>High risk</td>
<td>High risk</td>
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<tr>
<td>Clinician bias</td>
<td>Low risk</td>
<td>Low risk</td>
<td>Low risk</td>
<td>High risk</td>
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</tbody>
</table>

RESULTS

Search Results
An initial search yielded 659 articles. Among these, 25 potentially pertinent articles were selected after screening the titles and abstracts. Full-text articles were obtained, and only four studies fulfilled the inclusion and exclusion criteria. The flow of the study selection process is shown in Fig 1.

Study Characteristics, Quality Assessment, and Heterogeneity Evaluation
The study selection process resulted in four RCTs. These four RCTs were then assessed by the Cochrane Collaboration tool. Any disagreement was resolved by discussion until a final consensus was achieved. Risk-of-bias assessment of all RCTs is shown in Table 1. All studies randomized the subjects appropriately and reported the results clearly.

Blinding of Patients and Surgeons. It was difficult to achieve blinding of patients and surgeons. Patients had the right to know which kinds of implants were used for treatments. Surgeons would know implant types while performing the surgical procedures. Every study was regarded as high risk for bias in this category.

The diameters of short and control implants in the other two studies were the same. Moreover, all multiple-

Fig 1 Flowchart of study selection process.
unit fixed prostheses were splinted in the four selected studies. These factors caused the outcome bias to be regarded as high risk for all studies.

**Sample Size.** If the study recruited enough patients to have 80% power, a low-risk evaluation would be given. However, the power calculation usually was conducted only for the primary outcomes, such as bone level change, which might not be the same outcome analyzed in the present review.

**Follow-up Time.** If the study had more than 5 years follow-up, it was determined to be low risk for bias in this category. Only Cannizzaro et al\(^{24}\) fits this criteria.

**Conflict of Interest.** None of the included studies addressed conflict of interest.

**Radiographic Outcome.** All radiographic assessments in the four studies were performed by parallel technique without bite registration. Also, the radiographic assessments could not be conducted blindly. Therefore, all studies were assessed to be at high risk of bias for radiographic outcome.

**Clinician Bias.** In three studies,\(^{22-24}\) the same surgeon and prosthodontist completed all the treatments; Gulje et al\(^{25}\) did not clearly address which clinicians performed the treatments.

The heterogeneity of cumulative survival rate, failure rate, and complications were not statistically significant (\(P > .05\)).

**Population Epidemiology**

In total, 225 patients were included, 123 women and 102 men, with ages ranging from 21 to 83 years. The summary of selected studies is described in Table 2.

Patients with uncontrolled diabetes, intravenous bisphosphonate treatment, or radiation and chemotherapy for malignant tumors were excluded in all the included studies in this review except Gulje et al,\(^{25}\) which did not specifically address bisphosphonate treatment.

More details regarding local infection, smoking, and bruxism history are shown in Table 2.

**Meta-Analysis**

**Implant Dimensions and Characteristics.** Five hundred thirty-nine implants were included in this review. Among those, 265 were short implants with implant lengths ranging from 5 to 8 mm. The distribution of short implant lengths is shown in Fig 2. Comparatively, there were 274 control implants with lengths greater than 8 mm. The distribution of control implant lengths is shown in Fig 3. The implant diameters ranged from 4 to 6 mm for short dental implants; of 265 short implants, 167 implants were 4 mm in diameter (63.0%), 15 implants were 4.7 mm in diameter (5.7%), and 83 implants were 6 mm in diameter (31.3%). In regard to implant connection types, 205 short implants had an internal connection (205 / 265, 77.4%), and 60 short implants had an external connection (60 / 265, 22.6%). Two hundred thirteen control implants had an internal connection (213 / 274, 77.7%), and 61 control implants had an external connection (61 / 274, 22.3%). All implants included in this review had either grit-blasted or acid-etched rough surfaces (NanoTite [Biomet 3i], OsseoSpeed [Dentsply AstraTech], MTX Microtextured Titanium [Zimmer], or Super RBM [MegaGen]).

**Implant Location.** All 539 implants were placed in the posterior region, either maxillary or mandibular. Of the short implants in three selected studies, 72 implants were placed in the posterior maxillary region, and 86 implants were placed in the posterior mandibular region. However, it was not clear how many implants were placed either in the posterior maxillary or mandibular region in Gulje et al.\(^{25}\)

**Characteristics of the Implant Sites.** In Cannizzaro et al\(^{24}\) and Esposito et al,\(^{22}\) short implants were placed in native bone. Bone grafting was allowed if a small dehiscence was detected during the site preparation in Gulje et al.\(^{25}\) In Esposito et al,\(^{23}\) short implants were placed and bone grafting was performed in the sinus simultaneously. Comparatively, in the control implant group, bone augmentation steps were performed prior to implant placement because of lack of bone height in partially or fully edentulous posterior maxillary or mandibular regions, except in Gulje et al.\(^{25}\)

**Prophylactic Antibiotics and Surgical Procedures.** Amoxicillin 2 g was given 1 hour prior to the surgical procedures in all included studies. Clindamycin 600 mg, clarithromycin 500 mg, or erythromycin 500 mg was given when the patient was allergic to penicillin. Except in Gulje et al,\(^{25}\) in which 107 (40.4%) short implants were placed through a single-stage surgery, two-stage procedures were used in the placement of 158 (59.6%) short implants in other studies.

**Healing Time, Prosthetic Restorations, and Follow-up Period.** The healing time between implant placement and provisional loading in these studies was either 3 to 4 months\(^{22,23}\) or 6 weeks,\(^{24,25}\) The former loading protocol can be called delayed or conventional loading, and the latter group can be called immediate-delayed or early loading.\(^{27,28}\)

All multiple short and control implant restorations were splinted together in all selected studies. The mean follow-up period from all four RCTs was 2.1 years (24.7 months), ranging from 1 to 5 years.

**Implant Failure.** Seven of 265 short implants failed (2.6%). Of 7 failed implants, 5 were early failures (71.4%), and 2 were late failures (28.6%). Comparatively, in the control group, 11 of 274 control implants failed (4.0%). Of 11 failed implants, 9 implants failed prior to loading, ie, early failures (81.8%), and 2 implants failed after loading, ie, late failures (18.2%).
### Table 2  Summary of Selected Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Total no. implants (N) (short, control)</th>
<th>Surgical site</th>
<th>Healing time*</th>
<th>Provisional to definitive loading</th>
<th>Presurgical prophylaxis</th>
<th>Definitive restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esposito et al (2011)²²</td>
<td>RCT</td>
<td>N = 128 (60, 68)</td>
<td>Partially edentulous in the posterior mandible and maxilla</td>
<td>3 mo</td>
<td>4 mo</td>
<td>Amoxicillin 2 g, 1 h prior to surgery</td>
<td>Splinted for multiple short and control implants</td>
</tr>
<tr>
<td></td>
<td>Split mouth</td>
<td></td>
<td>VBH: 4–6 mm below maxillary sinus; 5–7 mm above mandibular canal</td>
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<tr>
<td></td>
<td>Short: 5 mm</td>
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<td>Minimum ridge width: 8 mm</td>
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<tr>
<td></td>
<td>Control: ≥ 10 mm (mean = 10.4 mm; mean length of maxillary implants = 12.4 mm)</td>
<td></td>
<td>All extraction sites heal naturally 3 months before implant placement</td>
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<td></td>
<td></td>
<td></td>
<td>Short: native sites</td>
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<td></td>
<td>Control: sinus-augmented sites in maxilla (Bio-Oss + Bio-Gide); vertically augmented sites in mandible (Bio-Oss + Bio-Gide)⁵</td>
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<tr>
<td>Esposito et al (2011)²³</td>
<td>RCT</td>
<td>N = 121 (60, 61)</td>
<td>Partially edentulous in the posterior mandible</td>
<td>4 mo</td>
<td>4 mo</td>
<td>Amoxicillin 2 g, 1 h prior to surgery</td>
<td>Splinted for multiple short and control implants</td>
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<tr>
<td></td>
<td>Short: 6.3 mm</td>
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<td>VBH: 7–8 mm above mandibular canal</td>
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<tr>
<td></td>
<td>Control: ≥ 9.3 mm (mean = 10.5 mm)</td>
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<td>Minimum ridge width: 5.5 mm</td>
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<td>All extraction sites heal naturally 3 months before implant placement</td>
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<td>Short: native sites</td>
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<td></td>
<td></td>
<td></td>
<td>Control: vertically augmented sites (Bio-Oss + Bio-Gide)</td>
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<tr>
<td>Cannizzaro et al (2013)²⁴</td>
<td>RCT</td>
<td>N = 82 (38, 44)</td>
<td>Partially or fully edentulous in the posterior maxilla</td>
<td>6 wk</td>
<td>6 wk</td>
<td>Amoxicillin 2 g, 1 h prior to surgery</td>
<td>Splinted for multiple short and control implants</td>
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<tr>
<td></td>
<td>Short: 8 mm</td>
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<td>VBH: 3–6 mm below maxillary sinus</td>
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<td></td>
<td>Control: 10–16 mm (mean = 11.35 mm)</td>
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<td>Minimum ridge width: 4 mm</td>
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<td>All extraction sites heal naturally 3 months before implant placement</td>
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<td></td>
<td></td>
<td>Short: native sites with sinus augmentation (autogenous graft) during implant placement</td>
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<td></td>
<td></td>
<td></td>
<td>Control: sinus augmented sites (autogenous graft + Bio-Oss + BioMend)</td>
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<tr>
<td>Gulje et al (2012)²⁵</td>
<td>RCT</td>
<td>N = 208 (107, 101)</td>
<td>Partially edentulous in the posterior maxilla or mandible</td>
<td>6 wk⁴</td>
<td>6 mo</td>
<td>Amoxicillin 2 g, prior to surgery</td>
<td>Splinted for multiple short and control implants</td>
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<tr>
<td></td>
<td>Multicenter</td>
<td></td>
<td>VBH: 11 mm below maxillary sinus; 11 mm above mandibular canal</td>
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<tr>
<td></td>
<td>Short: 6 mm</td>
<td></td>
<td>Minimum ridge width: 6 mm</td>
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<tr>
<td></td>
<td>Control: 11 mm</td>
<td></td>
<td>All extraction sites heal naturally 3 months before implant placement</td>
<td></td>
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<td></td>
<td></td>
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<td>Short: native sites</td>
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<td></td>
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<td></td>
<td>Control: native sites (autogenous graft is used in some implant sites with small bony defects during site preparation)</td>
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</tbody>
</table>

B = biologic complications; C = control implants; MBL = mean interproximal bone level change; NA = not applicable; P = prosthetic complications; S = short implants; VBH = vertical bone height. *Between implant placement and stage-two surgery (implant exposure and temporary loading). ¹Negative values signify gain in mean bone level. ²Mentioned in the selected studies regarding patient medical history or habit. ³Signifies that patients were excluded.
<table>
<thead>
<tr>
<th>Failed implants</th>
<th>MBL ± SD</th>
<th>Complications</th>
<th>Radiation/Chemotherapy</th>
<th>Bisphosphonate (IV or oral)</th>
<th>Untreated periodontitis/Acute infection</th>
<th>Diabetes</th>
<th>Bruxism</th>
<th>Smoking**</th>
</tr>
</thead>
<tbody>
<tr>
<td>S: 1 C: 2</td>
<td>S: 0.97 ± 0.56 mm C: 1.16 ± 0.46 mm 1 year follow-up after loading</td>
<td>Short implant group: B (intra-/postsurgical): 3 perforations of the sinus membrane at implant placement B (postloading): 1 symptomatic peri-implant bone loss around a mandibular implant Control implant group: B (intra-/postsurgical): 1 sinus membrane perforation in maxilla, 1 dehiscence of mandibular grafted site prior to implant placement</td>
<td>+</td>
<td>+ (IV)</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>Group</td>
</tr>
<tr>
<td>S: 2 C: 3</td>
<td>S: 1.24 ± 0.36 mm C: 1.76 ± 0.72 mm 3 years follow-up after loading</td>
<td>Short implant group: B (intra-/postsurgical): 2 transient postimplantation paresthesia P: 2 loose abutment screws, 1 ceramic lining of the fixed dental prosthesis fracture Control implant group: B (intra-/postsurgical): 16 cases of transient postoperative paresthesia of the mental nerve, 4 soft tissue dehiscence prior to implant placement P: 1 loose abutment screw and 1 fractured ceramic lining</td>
<td>+</td>
<td>+ (IV)</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>Group</td>
</tr>
<tr>
<td>S: 1 C: 5</td>
<td>S: 0.72 ± 0.42 mm C: 0.72 ± 0.41 mm 5 years follow-up after loading</td>
<td>Short implant group: B (postloading): 1 peri-implant bone loss, 1 peri-implantitis P: 1 fracture of ceramic coating of a bridge, 1 abutment screw fracture Control implant group: B (intra-/postsurgical): 2 sinus membrane perforations, 2 severe postoperative complications (1 abscess and 1 sinusitis) B (postloading): 1 peri-implant mucositis P: 1 repeated decementation of crown, 1 food accumulation, 1 fracture of the connecting screw</td>
<td>+</td>
<td>+ (IV)</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>Group</td>
</tr>
<tr>
<td>S: 3 C: 1</td>
<td>S: ~0.06 ± 0.27 mm C: ~0.02 ± 0.60 mm 1 year follow-up after loading</td>
<td>Short implant group: B: none P: 3 loose abutment screws, 3 loose healing caps, 1 fractured provisional prosthesis Control implant group: B: none P: 3 loose abutment screws, 1 loose healing cap, 1 fractured provisional prosthesis, 3 loose fixed prostheses</td>
<td>+</td>
<td>NA</td>
<td>+**</td>
<td>+</td>
<td>NA</td>
<td>&lt; 10/day</td>
</tr>
</tbody>
</table>

*Geistlich. ^Zimmer. Most implants had abutment attached immediately after implant placement (single-stage surgery) except for two implants in each group (two-stage). Gulje et al** stated that patients having uncontrolled pathologic processes were excluded. **Patients were divided into groups based on smoking habits, or patients who had smoked more than 10 cigarettes per day were excluded.
Meta-analysis was performed to compare the results in two groups. The pooled risk ratio (RR) for implant failure between the short implant group and the control implant group was 0.68 (95% CI, 0.24 to 1.93) (Fig 4), indicating that short implants are more favorable, but with no statistical significance ($P = .47$). More specifically, the pooled RR for early failure was 0.58 (95% CI, 0.17 to 2.00), implying that short implants are preferable, with no statistical significance ($P = .39$). In late failure, the pooled RR was 1.02 (95% CI, 0.18 to 5.83), meaning that long implants are more favorable, with no statistical significance ($P = .98$). Therefore, there is no statistically significant difference in failure rates between short and control implant groups.

**Cumulative Survival Rate.** Forest plots showed that the 1-year CSR was 98.7% (95% CI, 97.8 to 99.5) for the short implant group and 98.0% (95% CI, 96.9 to 99.1) for the control implant group. The 5-year CSR was 93.6% (95% CI, 89.8 to 97.5) for the short implant group and 90.3% (95% CI, 85.2 to 95.4) for the control implant group, as shown in Figs 5 and 6.

There was no statistically significant difference in CSRs between the short and control implant groups. The survival rate was equal to the success rate because all the implants, which survived in the included studies, fit the success criteria.

**Peri-implant Marginal Bone Level Change.** All studies reported the change in marginal bone level (MBL). The mean MBL change of both groups was less than 0.3 mm from 1 year to 5 years follow-up in Cannizzaro’s study. Esposito et al. reported that the mean MBL change between baseline and 3-year follow-up.
was 1.2 mm in short implants and 1.8 mm in control implants. Esposito et al\textsuperscript{22} reported that the mean MBL change between baseline and 1-year follow-up was 1 mm in short implants and 1.2 mm in control implants. Gulje et al\textsuperscript{25} reported bone gain rather than bone loss during follow-up. There was no statistically significant difference in MBL change between short and control implant groups in the four studies.

\textbf{Complication Rates.} Total complication rates were 7.6% (20/265) in the short implant group and 15.3% (42/274) in the control implant group. Within the total 7.6% complication rate in the short implant group, 1.9% (25.0% of total) was from biologic complications (intra- and postoperative complications), 1.1% (15.0% of total) was from biologic complications (postloading) such as peri-implantitis and peri-implant mucositis, and 4.5% (60.0% of total) resulted from prosthetic complications (Fig 7a). Within the total 15.3% complication rate in the control implant group, 10.2% (66.7% of total) resulted from biologic complications (intra- and postsurgical complications), 0.4% (2.4% of total) resulted from biologic complications (postloading), and 4.7% (31.0% of...
total) resulted from prosthetic complications (Fig 7b). There was no statistically significant difference in all complications between the two groups.

The pooled RR for intra- and postoperative biologic complications between the short implant group and the control implant group was 0.27 (95% CI, 0.04 to 2.08), indicating that short implants are more favorable, but without statistical significance ($P = .21$). The pooled RR for biologic complications after loading between the short implant group and the control implant group was 2.65 (95% CI, 0.40 to 17.66) with no statistical significance ($P = .31$). The pooled RR for prosthetic complications between the two groups was 0.92 (95% CI, 0.43 to 1.97) with no statistical significance ($P = .82$).

**DISCUSSION**

This is the first systematic review and meta-analysis of short and control implants based on RCTs, and these RCTs primarily compared the clinical outcomes of rough-surface short and control implant groups.
It was surprising that the CSRs of the short implant group were comparable to the control implant group at 1 year (98.7% vs 98.0%) and 5 years (93.6% vs 90.3%). The traditional notion of placing “long” or “standard” implants as the golden rule of implant placement has been challenged.

A higher incidence of implant failure before loading was demonstrated in many studies. The ratio of early failure to late failure in the control implant group was 4.5 (81.8%/18.2%), which was higher than that of the short implant group, which was 2.5 (71.4%/28.6%). Short implants were expected to have more failures than control implants after loading because of their mechanical disadvantage. However, the results from the included RCTs did not demonstrate this effect. The high success rate with low early failure rate of short implants might be attributed to improved surface treatments and manufacturing techniques because most unfavorable outcomes of short implants were derived from machined-surface implants. However, the results of the findings should be interpreted with caution because of the small numbers of failed implants in the two groups.

Short implants placed in the maxilla showed similar failure rates (2.8%) compared to short implants placed in the mandible (2.3%). This differs from several studies showing that implants failed more often in the maxilla. However, these early studies usually used machined-surface implants, which were different from the implants currently used. Increasing numbers of studies have shown equally successful clinical results for implant placement in the maxilla as in the mandible. The cause of more implant failures in the maxilla is most likely the low bone density in this area or its different trabecular orientation. Either reason could cause an implant to have low primary stability. The present implants were self-threading and usually had high primary stability during placement. The new design might change the success rate of implants.

Implant diameter could be a factor that affected the survival rates of the implants. In the current review, short implants 4 mm in diameter had higher failure rates (3.0%) compared to short implants 6 mm in diameter (1.7%), with no statistically significant difference. No conclusion could be made about the influence of implant diameter on short implant survival/success rates because the 6-mm implants were only utilized by Esposito et al. Implants with an external connection demonstrated a similar failure rate (3.3%) as implants with an external connection (2.4%) in the short implant group. This result was expected because the external connection usually only causes prosthetic complications but not any biologic healing problems.

In the present meta-analysis, implants placed using a single-stage surgical technique showed a similar failure rate (2.8%) compared to those placed using a two-stage surgical technique (2.5%). Early loading of short implants also had a similar failure rate (2.8%) compared to that of conventional loading (2.5%), with no statistical significance. The results showed the predictable clinical outcomes of short implants with single-stage surgery or early loading protocols. Nevertheless, further investigation is needed because of the small number of failed implants.

**Effect of Crown Splinting**

It has been suggested that multiple short implants should be splinted to distribute the high occlusal forces, which are caused by an unfavorably high crown-implant ratio. The in vitro model studies demonstrated better force distribution in splinted implants than individual implants. However, there was no strong clinical evidence supporting the claim that splinted implants can provide better clinical outcomes, such as survival rate and marginal bone level change, than individual implants. Because all multiple fixed prosthetic restorations of short and control implants were splinted in the selected studies, it was impossible to...
compare the clinical outcomes of splinted versus non-splinted multiple implants.

Complications
The total complication rate was 7.6% in the short implant group and 15.3% in the control implant group with no statistically significant difference. Prosthetic complication rates were low in both groups and did not have a statistically significant difference (short implant group, 4.5%; control implant group, 4.7%; \( P = .82 \)). Short implants do not have additional prosthetic complications even though they may have unfavorable loading forces compared to control implants in an in vitro model.\(^5\)

The pooled RR for intra- and postoperative biologic complications between the short implant and control implant groups was 0.27 (95% CI, 0.04 to 2.08). These results might be caused by the bone augmentation procedures that were needed prior to placing control implants in alveolar ridges with insufficient vertical bone height. From previous reviews, the implant survival rate when vertical augmentation procedures are performed on the compromised alveolar ridge ranges from 83.8% to 90.4%,\(^5\) with high complication rates (>10%) in various ranges.\(^52,53\) Significant resorption of bone grafting materials utilized in vertical augmentation is also a potential problem.\(^54\) Therefore, clinicians who place short implants can benefit from decreased complications, reduced procedure times, and reduced patient morbidity without the need to perform significant bone augmentation procedures.

In three\(^22,23,25\) out of four included studies, short implants were placed in the native bone to avoid bone augmentation procedures, and these had high success rates. The successful clinical outcomes might not be applicable when short implants are placed in augmented sites. More studies are needed to validate the prognosis of short implants placed in grafted or augmented sites.

Limitations
First, the threshold of crown-implant ratio for successful short implants cannot be evaluated in the present review because no selected study reported on this aspect.

Second, the results of the present review cannot be applied in every clinical situation because of the potential bias of selected studies, such as the inclusion of only splinted multiple-unit prostheses.

Moreover, although all selected studies were RCTs, the small number of selected studies could potentially bias the results. The reader should interpret the results with caution regarding the early to late implant failure ratio because of the small numbers of failed implants.

CONCLUSION
This review demonstrated that short implant placement had the same predictability as control implant placement. Also, short implants did not have disadvantages of early failure, loading failure, or prosthetic complications compared to control implants. Placement of short dental implants could be a predictable alternative treatment to control dental implants in the situations where vertical augmentation procedures are needed. However, only four studies were selected in this review, and only one study had more than a 1-year follow-up. These results should be confirmed with controlled trials with larger sample sizes and longer duration of follow-up.

ACKNOWLEDGMENTS
The authors reported no conflicts of interest related to this study.

REFERENCES


Implant Treatment in Atrophic Posterior Mandibles: Vertical Regeneration with Block Bone Grafts Versus Implants with 5.5-mm Intrabony Length

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Purpose: To retrospectively compare the outcomes of implants placed in posterior mandibles vertically regenerated with onlay autogenous block bone grafts and short dental implants.

Materials and Methods: Consecutive patients with vertical bone atrophy in edentulous mandibular posterior regions (7 to 8 mm of bone above the inferior alveolar nerve) were treated with either implants placed in regenerated bone using autologous block bone grafts (group 1) or short implants (with 5.5-mm intrabony length) in native bone (group 2) between 2005 and 2010 and followed for 12 months after loading. The procedure used was the established treatment protocol for this type of patient at the Oral Surgery Unit (University of Valencia, Spain) at the time of surgery. All grafts were obtained using piezosurgery. The outcomes assessed were: complications related to the procedure, implant survival, implant success, and peri-implant marginal bone loss. Statistical analysis was done using the Fisher exact test and the Mann-Whitney test.

Results: Thirty-seven patients were included, 20 (45 implants) in group 1 and 17 (35 implants) in group 2. In group 1, 13 implants were less than 10 mm long (2 were 7 mm and 11 were 8.5 mm), and 32 were 10 mm or longer; the diameter was 3.6 mm in 6 implants, 4.2 mm in 31, and 5.5 mm in 8. In group 2 all implants were 7 mm long; the diameter measured 4.2 mm in 14 implants and 5.5 mm in 21 implants. Complications related to the block bone grafting procedure were temporary hypoesthesia in one patient, wound dehiscence with graft exposure in three patients, and exposure of the osteosynthesis screw without bone graft exposure in one patient. After 12 months, implant survival rates were 95.6% in group 1 and 97.1% in group 2; success rates were 91.1% and 97.1%, respectively. The average marginal bone loss was 0.7 ± 1.1 mm in group 1 and 0.6 ± 0.3 mm in group 2.

Conclusions: When residual bone height over the mandibular canal is between 7 and 8 mm, short implants (with 5.5-mm intrabony length) might be a preferable treatment option over vertical augmentation, reducing chair time, expense, and morbidity.

Key words: atrophied mandible, block bone graft, short dental implants

In cases of reduced bone height in the posterior mandible, two treatment options involving implants have been proposed: the placement of implants subsequent to vertical augmentation with block bone grafts and the use of short implants.1,2 The definition of short implants is controversial; some authors consider implants with a length within the range of 7 to 10 mm as short,2,3 while for others short means an intrabony length of 8 mm or less.4,5 Recent systematic reviews of short implants in the posterior atrophic mandible have evidenced high survival and success rates.6-8 The main advantages of placing short implants are the avoidance of invasive bone augmentation surgeries associated with donor site morbidity and reductions in treatment duration and economic cost.5 However, the choice of treatment for vertical bone defect restoration remains a
subject of discussion. No clear evidence is available as to whether short implants are preferable to augmentation procedures using block bone grafts, and few studies have compared the two treatment alternatives. The largest series were published by Felice et al with 4- and 12-month follow-ups after loading and by Esposito et al with a 3-year follow-up. These reports included 60 patients, treated with either short implants (with 6.3-mm intrabony length) or 10-mm or longer implants. There are only two series with shorter implants (of 5-mm intrabony length); these studies reported 4- and 12-month postloading follow-ups. Short implants could be a simpler, cheaper, and faster alternative to bone augmentation procedures for the rehabilitation of posterior mandibles with limited bone height, providing they can be shown to produce similar implant success rates. Although previous reports have suggested that short implants may have outcomes comparable to implants placed after augmentation procedures, more controlled clinical studies and longer follow-up times are necessary to draw definitive conclusions.

The purpose of the present retrospective study was to evaluate the outcome of implant therapy in posterior mandibular regions with localized vertical bone atrophy, making a comparison between the outcomes of implants placed following alveolar ridge augmentation with autologous block bone grafts and short dental implant placement with a minimum follow-up of 1 year.

MATERIALS AND METHODS

The present study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Patient Selection

The study included consecutive patients with vertical bone atrophy in the posterior edentulous mandibular regions with localized vertical bone atrophy, indicating adequate width but inadequate height; 7 to 8 mm of bone available above the mandibular canal; (2) treatment involving vertical ridge augmentation with autologous block bone grafts and delayed implant placement or with short implants (with 5.5-mm intrabony length); (3) rehabilitation with fixed implant-supported prosthesis; (4) age > 18 years; (5) no relevant medical conditions; (6) non-smoking or smoking ≤ 20 cigarettes/day (all pipe or cigar smokers were excluded); (7) follow-up for at least 12 months after prosthetic loading. Patient and site exclusion criteria were: (1) patients with systemic or local conditions contraindicating implant therapy (eg, previous chemotherapy, previous irradiation of the head and neck region, or active progressive periodontitis and/or immunosuppression); (2) pregnant or lactating patients; (3) sites with acute infection; (4) poor oral hygiene; (5) horizontal alveolar ridge augmentation; (6) patients failing to attend follow-up visits up to and including the 12-month mark. The procedure performed was determined by the established treatment protocol for this type of patient at the Oral Surgery Unit at the time of surgery. Therefore, group 1 patients were treated between January 2005 and July 2008, and group 2 patients were treated between August 2008 and December 2010.

Description of Procedures

All procedures were performed under local anesthesia using 4% articaine 1:100,000 adrenalin (Inibsa) and intravenous conscious sedation with 1% propofol solution, administered by an anesthesiologist.

Bone Graft Harvesting

All augmentation procedures were performed using autogenous block bone grafts harvested from intraoral mandibular regions: the mandibular symphysis and mandibular ramus. All grafts were obtained using the ultrasonic Piezon Master Surgery System (EMS Electro Medical Systems).

When the lateral ramus was used as a donor site, an incision was made from the anterior part of the ramus continuing into the alveolar sulcus of the mandibular second and first molar. The lateral part of the ramus was exposed, and mainly cortical bone was harvested from the lateral cortex of the ramus as described by Misch.

Bone from the mandibular symphysis was harvested through an incision from canine to canine about 5 mm below the mucogingival line. The anterior part of the mandible was exposed, and a monocortocancellous bone block was harvested, with a safety distance of 5 mm from the teeth apices and the basal border of the mandible and 5 mm from the mental foramina.
Augmentation Procedure
An initial incision was made slightly lingual of the alveolar crest. One or two releasing incisions were made at adjacent teeth, and a mucoperiosteal flap was raised. The exposed alveolar bone was curetted to remove all soft tissues.

The cortical bone at the recipient site was perforated at multiple sites with a thin cylindrical bur to increase bleeding. The bone block was adjusted to the bone contour at the recipient site and fixed with one or two osteosynthesis screws (Osteoplac) to render the graft immobile. Discrepancies between the block graft and the recipient site were rated at multiple sites with a thin cylindric bur to insoft tissues.

The exposed alveolar bone was curetted to remove all autogenous bone combined with β-tricalcium phosphate (Kera-Os, Keramat). The augmented sites were protected with a textured collagen membrane (Lyopstic, B. Braun). Periosteal incisions were made to allow flap mobilization and tension-free primary wound closure. Flaps were closed with horizontal sutures using Polisoft 4/0 sutures (Sweden & Martina).

Implant Placement
All implants used in the study were TSA implants with Avantblast surface (Phibo Dental Solutions) and were installed using the standard procedure according to the manufacturer's guidelines. These implants have a polished surface portion of 1.5 mm.

In group 1, the aim of the bone grafting was to obtain enough bone to place 10-mm or longer implants with a minimum intrabony length of 8.5 mm (Fig 1). However, for any case in which grafting failed to achieve sufficient bone volume, shorter implants were inserted. Implants were placed after an average healing period of 6.8 months (range, 5 to 8 months) following the block bone grafting procedure. In group 2, all implants had an intrabony length of 5.5 mm (Fig 2). All implants (both groups) were placed with adequate primary stability (≥35 Ncm). Following a two-stage protocol, cover screws were placed on all implants (both groups), and flap closure was performed using Polisoft 4/0 sutures.

Preoperative prophylaxis was administered to all patients (2 g amoxicillin, 2 hours prior to augmentation and implant placement surgeries). Furthermore, when block bone grafting was performed or whenever implant placement involved grafting with particulate bone, postoperative antibiotic treatment was prescribed (500 mg amoxicillin, three times daily for 5 days)^19^. Six hundred milligrams ibuprofen was prescribed to be taken three times daily if required. Patients were also instructed to rinse with 0.12% chlorhexidine digluconate three times daily for 2 weeks following bone grafting and implant placement surgeries. Patients were not allowed to use removable prostheses for 3 weeks after bone grafting surgeries. A soft diet was recommended for 1 week, and patients were instructed to avoid brushing and any trauma to the surgical sites. Sutures were removed 2 weeks after surgery. Second surgeries were performed 2 months after implant placement, and definitive fixed prostheses were placed 1 month later.

Data Collection and Follow-up
All data collection was performed by a single trained clinician, different from the surgeon or the prosthodontist, following a preestablished protocol.

Patient age (at implant placement), sex, and smoking habits (none, <10 cigarettes/day, or 10 to 20 cigarettes/day) were registered.

All patients were included in a maintenance program involving annual examinations and professional prophylaxis. The time of control was 1 year after loading. The following outcome measures were recorded.

Complications related to the procedure. These included sensory disturbances (paresthesia, hypoaesthesia), wound dehiscence with bone graft exposure or exposure of osteosynthesis screw without graft exposure, graft loss, and peri-implant bone defects at implant insertion.

Graft success. The graft was considered successful when there was no infection or graft loss and 10-mm or longer implants (with at least 8.5-mm intrabony length) could be placed.

Implant survival. The criteria for implant failure were implant mobility or the removal of stable implants due to progressive peri-implant marginal bone loss or infection.

Implant success. The definition of implant success was based on the clinical and radiographic criteria put forward by Buser et al^19^: (1) absence of clinically detectable mobility; (2) absence of pain or any subjective sensation; (3) absence of recurrent peri-implant infection; and (4) absence of ongoing radiolucency around the implant after 6 and 12 months of prosthetic loading.

Radiographic peri-implant marginal bone loss. Intraoral radiographs were taken at the moment of prosthetic loading (baseline) and at the 1-year control visit using the X-Mind intraoral system (Acteon) and an RVG intraoral digital receptor (Dürr Dental) with the aid of a Rinn XCP (Dentsply Rinn) to achieve parallelism. Evaluation of the marginal bone level around implants was performed using image analysis software (AutoCAD 2006 version Z.54.10, Autodesk) able to compensate for radiographic distortion. Each image was calibrated using the known length of the implants. The vertical distance from the outer edge of the implant shoulder (reference point) to the most coronal bone-to-implant contact was assessed at the mesial and distal aspect of each implant to the nearest 0.1 mm. Peri-implant mar-
Original bone resorption was calculated from the change in bone level between the baseline and the 1-year control radiograph; for each pair of measurements (mesial and distal) the largest value was used. Intra-examiner calibration was analyzed before evaluating the entire implant sample by reassessing bone loss at a total of...
30 randomly selected sites (using the random function of Microsoft Excel 2010) on duplicate measurements performed on different days. An intraclass correlation coefficient of 0.891 was obtained, showing a high concordance between the two sets of data. According to the Dahlberg d value, a 0.047-mm error was estimated in the measurement method.

**Statistical Analysis.** Homogeneity between patient groups was analyzed using nonparametric tests due to the small sample size. The Fisher exact test was used to evaluate homogeneity regarding sex and smoking habits, and the Mann-Whitney test was used to evaluate homogeneity regarding age. Nonparametric tests were used to analyze differences in implant survival and success rates (as these were noncontinuous variables) and marginal bone loss (as this was a continuous variable with asymmetric distribution). The Fisher exact test was used to evaluate differences between both groups with respect to implant success and survival rates. The Mann-Whitney test was used to compare bone loss between groups. The statistical power for this test was 80.8% to detect an effect of 0.7 with a confidence of 95% and alpha set at 0.05. Statistical analysis was performed using SPSS 17.0 software (SPSS).

**RESULTS**

A total of 42 patients with vertical atrophy in the posterior mandibular edentulous regions (with 7 to 8 mm of bone available above the inferior alveolar nerve) were treated with either implants placed in grafted bone or short implants (with 5.5-mm intrabony length) placed in native bone during the study period. Five patients were excluded as a result of insufficient follow-up or failing to attend the 12-month postloading control visit. The final study sample included 37 patients (25 women and 12 men) with a mean age of 48.4 ± 8.9 years (range, 27 to 60 years), who received a total of 80 implants. Group 1 comprised 20 patients. Twenty-six sites were augmented with block bone grafts: 8 were obtained from the mandibular symphysis and 18 from the mandibular ramus. Forty-five implants were inserted in grafted bone. Group 2 comprised 17 patients who received 35 short implants placed in native bone. Nineteen patients were nonsmokers, 14 smoked up to ten cigarettes per day, and 4 smoked between 11 and 20 cigarettes. Patient demographics and smoking habits are detailed by group in Table 1; the study groups were homogeneous in terms of sex, age, and smoking habits. In group 1, 13 implants were less than 10 mm long (2 were 7 mm and 11 were 8.5 mm), and 32 were 10 mm or longer; the diameter was 3.6 mm in 6 implants, 4.2 mm in 31, and 5.5 mm in 8. In group 2, all implants were 7 mm long; the diameter measured 4.2 mm in 14 implants and 5.5 mm in 21 implants.

**Complications Related to the Procedure**

In group 1, complications at the recipient site of block bone grafting procedures occurred in 6 out of 26 sites. Temporary hypoesthesia of the chin occurred in one patient during the postoperative period after harvesting a block bone graft from the mandibular symphysis; vitamin B complex (30 mg/day for 2 months) was
administered, and symptoms had completely disappeared after 2 months. Wound dehiscence with bone graft exposure occurred in four grafted sites in four patients; 0.2% chlorhexidine gel was prescribed three times daily, and all sites re-epithelialized uneventfully. Exposure of one osteosynthesis screw without bone graft exposure occurred in one patient. No postoperative complications at donor sites were registered. No graft was lost, although in seven patients, 10-mm-long implants could not be placed: of these patients, six received eleven 8.5-mm-long implants (with 7-mm intrabony length), and one patient needed two 7-mm-long implants (with 5.5-mm intrabony length). All patients were rehabilitated successfully, but according to the proposed success criteria for the grafting procedures, these cases were considered failures. Despite the successful outcome of the block bone grafts, in 21 of the 45 implants, particulate bone graft was used during the insertion procedure to cover peri-implant buccal bone dehiscences; in all cases these dehiscences measured less than 3 mm in height.

In group 2, vestibular dehiscences were observed in nine implants, with this being the most frequent complication. In all cases, the bone defects were less than 3 mm, and particulate bone graft was used to cover the exposed threads.

### Implant Survival, Success Rates, and Peri-Implant Marginal Bone Loss

Two implants in group 1 were lost, both before loading. One implant failed to osseointegrate in group 2 and was removed 1 month after placement. It was immediately replaced with a new implant in a more distal position. No implant was lost after loading. Thus, implant survival rates were 95.6% in group 1 and 97.1% in group 2. However, 1 year after loading, two implants in group 1 showed radiographic marginal bone loss of 4 to 5 mm; these implants remained in place until the end of the observation period but were not considered successful according to Buser et al’s criteria. Implant success rates were 91.1% in group 1 and 97.1% in group 2. There were no statistically significant differences between the two groups for implant survival (\(P = .59\)) or success rates (\(P = .27\)).

Mean peri-implant marginal bone loss 1 year after loading was 0.7 ± 0.8 mm; 0.7 ± 1.1 mm (range, 0 to 5.2 mm) for group 1 and 0.6 ± 0.3 mm (range, 0.1 to 1.2 mm) for group 2. Bone loss was higher for implants placed in grafted bone, although differences were not statistically significant (\(P = .21\)). All implants could be prosthetically rehabilitated, and no prosthesis had to be removed.

Patient age and smoking habit had no statistically significant influence on implant success and survival rates or on mean peri-implant marginal bone loss. In both groups the mean bone loss was higher among men than among women; however, this difference was only statistically significant in group 1 (1.7 ± 1.7 in men, 0.3 ± 0.5 in women; \(P = .02\)).

### DISCUSSION

The present study was designed to retrospectively evaluate and compare the outcome, after a 1-year follow-up, of implants placed in regenerated bone using autologous block bone grafts with that of short implants (with 5.5-mm intrabony length) placed in native bone. The study analyzed complications associated with both types of procedures, implant survival and success rates, and peri-implant marginal bone loss.

With regard to complications related to the bone grafting procedure, one of the main problems is soft tissue management, given that it is necessary to perform tensionless wound closure in order to minimize the risk of dehiscence. The treatment of prematurely exposed bone is complicated; resuturing the flap may lead to increased exposure of the graft. Von Arx and Buser recommend the application of chlorhexidine solution or gel several times a day to reduce the bacterial load; when reepithelialization does not occur spontaneously, some research has reported the removal of the exposed bone with rotary instruments. When comparing the use of short implants and augmentation
procedures, most authors agree that augmentation procedures are related with higher morbidity. In a study by Felice et al, no patient suffered from permanent disruption of alveolar inferior nerve function, but significant numbers of patients in the group that underwent augmentation suffered paraesthesia for up to 3 days. In a further study, Felice et al studied approximately 60 patients, finding no paresthesia, although four wound dehiscences occurred during graft healing in the augmentation group, while none occurred in the 7-mm-long implant group. Esposito et al, in a study of 60 patients, found 22 complications in 20 augmented patients versus 5 complications in 5 patients in the short implant group, with this difference being statistically significant. In the present study, no complications were found in group 2. In group 1, one patient reported temporary hypoesthesia of the chin, and four wound dehiscences with graft exposure occurred, all of which reepithelialized after application of 0.2% chlorhexidine gel three times daily.

Bone augmentation with block bone grafts is generally associated with some subsequent bone resorption. Evidence exists that membranes are useful to limit resorption, but this still occurs to some extent. Cases of inadequate bone gain for placement of 10-mm or longer implants have been reported in most studies. In a study by Esposito et al, in 5 out of 15 patients with bilateral atrophic mandibles, the planned 10-mm-long implants could not be placed, and shorter implants (7- and 8.5-mm) had to be used instead. Similarly, Felice et al were unable to place 10-mm-long implants in 5 out of 15 patients, and therefore, shorter implants were used. In the present study, the augmentation procedure was considered a failure in seven patients because the bone gain obtained did not allow the planned 10-mm or longer implants. Furthermore, almost half (21 out of 45) of the implants placed in grafted mandibles needed the addition of particulate bone graft to cover peri-implant dehiscences at the implant insertion site.

Several studies report similar survival and success rates for implant treatment in sites with vertical bone defects involving either block bone grafts or short dental implants. Esposito et al found no statistically significant differences for implant and prosthesis failures 3 years after loading, comparing 6.3-mm-long implants and 10-mm or longer implants placed in regenerated bone. However, in the same study, short implants lost an average of 1.24 mm of peri-implant bone, while 1 year after loading, patients in both groups had lost an average of 1 mm. In the present study, both procedures yielded similarly high implant survival rates (95.6% for group 1 and 97.1% for group 2). However, two implants placed in grafted bone showed a bone loss far above the limits established by Buser et al for implant success and were considered failures, yielding a 91.1% implant success rate for this group. Considering the success rates currently achieved with dental implants, even though the difference in implant success rates was not statistically significant due to the small sample size, a 6% difference should be considered clinically relevant.

The use of short implants offers the advantage of a shorter treatment time and a reduction in the required number of surgical interventions. The use of short implants has been questioned on numerous occasions because of higher failure rates than implants of conventional length. Hypothetically, on conventional implants a better distribution of functional forces throughout the entire length of the implant was assumed. However, clinical studies and recent literature reviews approve short implants, reporting success rates close to 100%. The augmentation procedure involves more complex and expensive surgery and is related to higher morbidity. Although both techniques achieved the planned treatment outcomes, short implants placed in native bone did so in a shorter time. All procedures were performed by the same oral surgeon with extensive clinical experience in regenerative procedures, which should limit the extrapolation of the results. Nevertheless, trials with larger sample sizes and longer follow-ups are needed in order to confirm or reject these findings.

CONCLUSIONS

After a 1-year follow-up, implant survival and success rates and peri-implant bone loss were slightly lower for short implants placed in native bone than for longer implants placed in regenerated bone, although differences were not statistically significant. Moreover, with short implants, the complications associated with
block bone grafting procedures were avoided. When residual bone height over the mandibular canal is sufficient to anchor short implants, these might be a preferable choice to vertical augmentation with block bone grafts.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

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Analysis of the biomechanical behavior of short implants: The photo-elasticity method

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A B S T R A C T

The aim of this study was to analyze the stress distribution of short implants supporting single unit or splinted crowns by the photo-elasticity method. Four photo-elastic models were produced: A (3.75 × 7 mm); B (3.75 × 7 mm, 3.75 × 7 mm and 3.75 × 7 mm); C (3.75 × 10 mm, 3.75 × 7 mm and 3.75 × 7 mm); D (3.75 × 13 mm, 3.75 × 7 mm and 3.75 × 7 mm). The prostheses were made with Ni–Cr alloy. A load of 100 N in the axial and oblique directions was applied, totaling 380 applications, individually capturing their images in each model. The data were randomized and analyzed qualitatively and quantitatively by 2 examiners. The oblique loading was significantly more damaging. The increase in length was favorable for stress distribution (p < 0.05). The splinting was beneficial for the transmission of stresses mainly (p < 0.05). The splinting of the crowns, as well as increasing the length of the first implant and axial loading was most beneficial in the stress distribution. Short splinted implants behaved better than single unit implants. Increasing of the length of the first implant significantly improved the stress distribution in all analyzed situations.

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1. Introduction

The installation of short implants (<10 mm) in borderline situations of vertical resorption of the alveolar ridge in the posterior maxilla and mandible regions has been a widely used treatment modality based on clinical and scientific evidence [1,2]. Furthermore, the literature presents no consensus on the advantage of the concept of splinting for implant-supported prostheses. Different methodologies are used to evaluate the biomechanical behavior of implants, which include: extensometry [3], tri-dimensional finite [4], and photo-elastic elements [5]. Among them, Yang et al. [3] observed no significant differences in the distribution of the stress generated between the single unit and splinted implant prostheses. In contrast, other groups of authors are concise about the benefits that the splinted crowns can bring to the peri-implant bone [6,7]. Furthermore, the placement of short implants is often a viable option for the dentist due to the high prevalence of bilateral posterior edentulous patients class I Kennedy patients [8] with extensive resorption and typical users of removable partial dentures who require the placement of a prosthesis supported by implants to optimize the masticatory function. In this sense, we seek to further elucidate which biomechanics are more favorable for short implants, while they are together supporting splinted or single unit crowns.

Thus, the aim of this study was to analyze the biomechanical behavior of short implants (7 mm) compared to implants of different dimensions (10 mm and 13 mm), with single unit or splinted crowns and axial and oblique loading by the photo-elasticity method. Furthermore, the results directly correlate with the clinical application of bilateral posterior edentulous patients with limited bone. The hypothesis of this study is that the splinting for short implants facilitates the distribution of stresses in the photo-elastic model.

2. Materials and methods

2.1. Preparation of the samples and load application

This research work follows the design methodology previously performed by the Pellizzer et al. [9] study group, which had the intention to analyze the stress distribution in short implants that supported splinted or single unit prostheses under axial and oblique loading.

Four photo-elastic models were developed totaling 38 sample units, with 10 load applications applied for each unit, totaling 380 applications, as shown in Table 1.

From a rectangular metal matrix (10 × 40 × 45 mm), duplicated with laboratory condensation silicone (Sapecia Artesanato, Bauru, SP,
Brazilian), a mold was obtained and poured with type IV special plaster (Durone, Dentsply, Rio de Janeiro, RJ, Brasil), and subsequently the plaster model was drilled to receive the analogs (Conexão Master Screw, Arujá, SP, Brasil), which were connected to the transfers and united with Durayal resin (Duralay, Morris, IL, USA). The set was then fixed on a glass plate adapted with a circular PVC matrix with laboratory silicone (Zetalabor, Zhermack Badia, RO, Italy). The manipulation of the silicone was performed according to the manufacturer’s instructions.

The proper settlement of the components was verified and the photo-elastic resin (PL-2 Vishay, Wendell, NC, USA) was arranged and manipulated according to the manufacturer’s instructions. For removal of internal voids, the set was put under a pressure of 40 psi and the manipulations were repeated according to the manufacturer’s instructions. For removal of internal voids, the set was put under a pressure of 40 psi and the manipulations were repeated according to the manufacturer’s instructions. For removal of internal voids, the set was put under a pressure of 40 psi and the manipulations were repeated according to the manufacturer’s instructions.

The loading of 100 N in the axial and oblique directions was applied, and the patients were formed in each model, corresponding to the captured fringes and tensions that were formed.

Table 1

<table>
<thead>
<tr>
<th>Sampling unit</th>
<th>Loading Type of prosthesis</th>
<th>Model</th>
<th>Application load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Axial</td>
<td>Control</td>
<td>A 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>2 Axial</td>
<td>Splinted</td>
<td>B 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>3 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>4 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>5 Axial</td>
<td></td>
<td>3.75 × 10 mm</td>
<td>4° implant</td>
</tr>
<tr>
<td>6 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>7 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>8 Axial</td>
<td></td>
<td>3.75 × 15 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>9 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>10 Axial</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>11 Unitary</td>
<td></td>
<td>B 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>12 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>13 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>14 Unitary</td>
<td></td>
<td>3.75 × 10 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>15 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>16 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>17 Unitary</td>
<td></td>
<td>3.75 × 15 mm</td>
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</tr>
<tr>
<td>18 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>19 Unitary</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>20 Oblique</td>
<td>Control</td>
<td>A 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>21 Oblique</td>
<td>Splinted</td>
<td>B 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>22 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>23 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>24 Oblique</td>
<td></td>
<td>3.75 × 10 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>25 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>26 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>27 Oblique</td>
<td></td>
<td>3.75 × 15 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>28 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>29 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>30 Oblique</td>
<td></td>
<td>B 3.75 × 7 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>31 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>32 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>33 Oblique</td>
<td></td>
<td>3.75 × 10 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>34 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>35 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
<tr>
<td>36 Oblique</td>
<td></td>
<td>3.75 × 15 mm</td>
<td>1° implant</td>
</tr>
<tr>
<td>37 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>2° implant</td>
</tr>
<tr>
<td>38 Oblique</td>
<td></td>
<td>3.75 × 7 mm</td>
<td>3° implant</td>
</tr>
</tbody>
</table>

Ten load applications were prepared in each sample unit, totaling 380 applications.
3.2. Analysis of model A (3.75 × 7 mm)

A descriptive analysis of the total average of fringes formed for each proposed situation is presented individually for the short implant model under conditions of axial and oblique loading, as shown in Table 2.

The average total of fringes for model A mainly differed in the question of the intensity of fringes (Table 2), and for this reason, the next step is aimed to specifically analyze the fringes of high and very high intensities (harmful to bone tissue). A three criteria analysis of variance test was performed and it was observed that the oblique loading was most damaging when compared to the axial load, showing a statistically significant difference ($p = 0.012$). In addition, there was a higher concentration of high intensity fringes in the coronal region of the examined implant when compared with the middle third ($p < 0.001$), but in the comparison of the coronal third with the apical third, there was no statistically significant difference ($p = 0.553$), power of the test $\alpha = 1$.

Other relevant information was that the oblique loading showed the highest intensity of fringes in the coronal region, as shown in Fig. 1A.

In the correlation analysis, the total number of fringes was quantified by the load application and its corresponding fringe coefficient, and the Pearson correlation test showed a very strong correlation for these magnitudes ($r = 0.8$).

3.3. Analysis of the models with three implants (B, C and D)

3.3.1. Effect of splinting

In analyzing the effect of the splinting of models B, C and D, under axial and oblique loading, the three criteria analysis of variance was conducted. The models with splinted implants presented less quantity of tension compared to models with single unit implants ($p < 0.001$). The effect of splinting was significantly effective in the reduction of stresses, especially for models B and C ($p < 0.001$) when compared to single unit implants (Fig. 1B–C), but model D showed no statistically significant difference in the different unions ($p = 0.191$) (Figs. 1D and 2).

3.3.2. Effect of loading and effect of increasing the length

In analyzing the effect of loading on models B, C and D with single unit crowns, a two criteria analysis of variance was performed. The oblique loading was significantly more damaging for the stress distribution in model B ($p < 0.001$) (Fig. 3A); however, model C showed no statistically significant difference between loads ($p = 0.323$) (Fig. 3B).

Analysis of model D revealed a statistically significant difference between the loads, in which the axial load concentrated a greater amount of fringes in the coronal and apical third when compared to the oblique load ($p < 0.001$) (Fig. 3C).

In analyzing the effect of loading of models B, C, and D, in the condition of splinting, a two criteria analysis of variance was performed. The oblique loading showed a more effective distribution of the stresses for

![Fig. 1](image)

Fig. 1. (A) Fringes of high and very high intensities (harmful to bone tissue) were observed in the oblique loading, in the coronal region (arrows). The models with splinted implants presented less quantity of tension compared to models with single unit implants ($p < 0.001$), especially for models B (B) and C (C) ($p < 0.001$); however for model D (d), no statistically significant difference was observed in the different unions.

<table>
<thead>
<tr>
<th>Model A</th>
<th>Loading</th>
<th>Average total of fringes/Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Average</td>
</tr>
<tr>
<td>Axial</td>
<td>5</td>
<td>4.4</td>
</tr>
<tr>
<td>Oblique</td>
<td>3.7</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2
Average total of fringes for model A.
the adjacent implants, while the axial loading showed a trend of centralization of stresses along the implant axis of the load application. Therefore, the axial loading showed a statistically significant difference when compared to the oblique loading \((p < 0.001)\), mainly for models C \((p < 0.001)\) and D \((p < 0.001)\) (Table 3).

In the analysis of the effect of increasing the length of models B, C and D, under axial and oblique loading, a three criteria analysis of variance was performed, observing a statistically significant difference between the models. Model D showed the lowest coefficient of stress when compared with models B \((p < 0.001)\) and C \((p < 0.001)\) (Fig. 4).

3.3.3. Analysis of the residual effect

In the analysis of the residual effect of the stresses transmitted to the adjacent implants, a three criteria analysis of variance was performed. Increasing the length acted favorably in the transmission of stresses to the adjacent implants, while model B was statistically more damaging when compared to models C \((p < 0.001)\) and D \((p < 0.001)\), but when comparing models C and D, there was no statistically significant difference in the transmission of stresses to the adjacent implants \((p = 0.830)\), power of the test \(\alpha = 1\) (Fig. 5).

In the analysis of the splinting factor, it was found that the use of splinted implants acted favorably in the transmission of stresses to the adjacent implants compared to the single unit implants \((p < 0.001)\), especially for model B, as shown in Fig. 5.

In the specific analysis of loading, there was no statistically significant difference in the transmission of fringes when comparing both loads \((p = 0.218)\).

4. Discussion

In this study was simulated a classic situation of a class I Kennedy mandibular, where patients routinely seek dental professionals with the goal of installing implants in the edentulous region, eliminating free-end removable partial dentures. Often, in these situations, the bone tissue is severely resorbed, and patients may not be likely to want more invasive surgeries such as bone grafting at the hospital level and lateralization of the alveolar nerve. However, in accordance with the performed planning and the ratio of the crown/implant, the rehabilitation can be successful.

<table>
<thead>
<tr>
<th>Model</th>
<th>Force</th>
<th>Union factor</th>
<th>Coefficient of fringes (average)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Axial</td>
<td>Unitary</td>
<td>19.86</td>
<td>3.03</td>
</tr>
<tr>
<td>B</td>
<td>Axial</td>
<td>Splinted</td>
<td>15.86</td>
<td>8.06</td>
</tr>
<tr>
<td>B</td>
<td>Oblique</td>
<td>Unitary</td>
<td>19.76</td>
<td>6.88</td>
</tr>
<tr>
<td>B</td>
<td>Oblique</td>
<td>Splinted</td>
<td>13</td>
<td>9.04</td>
</tr>
<tr>
<td>C</td>
<td>Axial</td>
<td>Unitary</td>
<td>26.66</td>
<td>5.90</td>
</tr>
<tr>
<td>C</td>
<td>Axial</td>
<td>Splinted</td>
<td>18.56</td>
<td>12.21</td>
</tr>
<tr>
<td>C</td>
<td>Oblique</td>
<td>Unitary</td>
<td>22.53</td>
<td>5.02</td>
</tr>
<tr>
<td>C</td>
<td>Oblique</td>
<td>Splinted</td>
<td>13.96</td>
<td>14.06</td>
</tr>
<tr>
<td>D</td>
<td>Axial</td>
<td>Unitary</td>
<td>17.33</td>
<td>6.79</td>
</tr>
<tr>
<td>D</td>
<td>Axial</td>
<td>Splinted</td>
<td>15.93</td>
<td>11.04</td>
</tr>
<tr>
<td>D</td>
<td>Oblique</td>
<td>Unitary</td>
<td>11.86</td>
<td>4.42</td>
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<tr>
<td>D</td>
<td>Oblique</td>
<td>Splinted</td>
<td>9.24</td>
<td>6.04</td>
</tr>
</tbody>
</table>

Fig. 3. (A) The oblique loading was the most damaging for stress distribution in model B \((p < 0.001)\) (arrows). (B) Model C showed no statistical difference between loads \((p = 0.323)\). (C) Model D showed that the axial load concentrated a greater amount of fringes in the coronal and apical third (arrow).
and proves the positive and short implants have less area to dissipate and Huang et al. who, in a and Menani et al. this type of loading. Different letters indicate statistically signiﬁcant differences (a, b; a, c; b, c).

The initial hypothesis formulated for this study was rejected. The oblique loading was presented as more damaging for the short implants, which is consistent with the results recently found by other studies using different methodologies [17,18] and proves the positive action of the greater commitment of implants to the bone tissue for this type of loading [19,20].

The coronal third of short implants showed a higher magnitude of stress (higher amount of formed fringes) and this is a region of higher concentration of stresses in external hexagon implants [18]. This distribution pattern underscores the concern about an increased risk of failure, since there is an inherent bone resorption of the external hexagon implants [21] and short implants have less area to dissipate the tensions. In the qualitative and quantitative analyses of models B and C, regarding the question of loading, it can be observed that the oblique loading also showed a greater number of strains. This is in agreement with the literature [7,9,11,19,20] with respect to the harmful effect on the peri-implant tissue and the large part of the masticatory forces that behave like oblique forces.

However, in the specific analysis of model D, a difference was observed with respect to the stress distribution, which, during axial loading focused on the load receiving the implant and thus had a higher amount of tension as compared to the oblique load. Similar results were also observed in the study of Toniollo et al. [22].

Regarding the union factor, the main results pointed to the beneficial effect of the splinting technique in reducing tensions around the peri-implant region, which is consistent with the literature [4,7,23,24]. This is especially true of Guichet et al. [6] and Menani et al. [25] who, in a photo-elastic test, found similar results to our study, with regard to the pattern of stress distribution for implants with splinted crowns compared to single unit crowns.

However, for the greater length, the standard stress distribution was similar in the different situations of splinting or single unit and we believe that increasing the length of the ﬁrst implant behaved as the main inﬂuence in this result. These results agree with the ﬁndings of Clelland et al. [26] and Huang et al. [27], which found no signiﬁcant biomechanical advantages in different situations of the union in implants with greater lengths.

As for the residual effect of the studied models, there was a promising biomechanical behavior in relation to the increased length of the ﬁrst implant and splinting factor. The results showed that the splinting to the implant-supported crowns beneﬁted the stress distribution models in general, as has been reported in other studies using the same methodologies [6,25]. Therefore, it is possible that a length over 10 mm may not effectively interfere in the stress distribution in splinted implants when compared to single unit implants.

The photo-elastic method has the ability to analyze the specimen (e.g., dental implant) under tension [9]. However, implant-resin contact and the loading conditions are a study limitation. The condition of the contact between the implant and the photo-elastic resin, which simulates bone tissue, was considered 100%; therefore, this did not simulate accurately the real situation of osseointegration [26]. Furthermore, the simulated situation around implant is not a real biological condition. Regarding loading conditions, the literature shows different manners of loading applications in order to simulate the situation nearest of the clinical reality [9,23,28]. In our study, the loading application was determined according to previously published studies [9,29,30] to allow comparison of results and proper discussion. Thus, the information of this study must be carefully extrapolated for clinical routine. We believe that the association of different biomechanical essays and randomized clinical trials is necessary to guide the best clinical protocol for rehabilitation of the class I Kennedy mandibular since they are complementary.

Extrapolating the clinical situation, we can accomplish a successful rehabilitation of the class I Kennedy mandibular if we splint the short hexagonal external implants and the length of the ﬁrst implant is above 10 mm. We believe that the crown/implant ratio often found unfavorable in these clinical situations will be offset by the splinting and the greater length of the ﬁrst implant, which would receive a portion of the load directed toward the short implant [31,32]. In some situations, a premature extraction of the last tooth of the free end is possible, followed by the insertion of an implant of greater length on the site, making the rehabilitation viable with splinted short implants without the need for more invasive surgeries.

5. Conclusions

Given the limitations of this study, it can be concluded that:

- The splinting was effective to reduce tensions, especially in implants with less than 10 mm in length;
- The oblique loading was more damaging for short implants;
- Increasing of the length of the ﬁrst implant signiﬁcantly improved the stress distribution in all analyzed situations.

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The authors would like to express gratitude to Professor Dr. Heitor Marques Honório (Department of Pediatrics Dentistry, Orthodontics and Public Health, Discipline of Research Methodology and Statistics,
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References


Retrospective Assessment of Survival Rate for Short Endosseous Dental Implants

Mohamed Tarek A. Omran, BDS, MSD,* Douglas D. Miley, DMD, MSD,† Dwight E. McLeod, DDS, MS,‡ and M. Nathalia Garcia, DDS, MS§

Purpose: The aim of this study was to determine the survival rate of short implants that were placed in a residency program. In addition, the potential influence of diabetes, smoking, sinus grafting, guided bone regeneration, and implant type on survival was analyzed.

Methods: Through a retrospective chart review, patient information and parameters for short implants being equal or less than 10 mm and regular implants being more than 10 mm were collected. The cumulative survival rate and implant and patient information from 213 consecutively placed implants from May 2002 through October 2011 were analyzed.

Results: The average survival time for short implants was 47.3 months, with a range of 6 to 141 months. The implant survival rate was 95.77% for short implants, which was not statistically significant from the regular implants. Smoking had a statistically significant negative effect on the survival rate of short implants. No statistical differences were found with implant survival rates for other factors.

Conclusion: It can be concluded that short implants can be predictably placed in the mouth with a high survival rate and that smoking has a negative influence on the survival rate of the short implants. (Implant Dent 2015;24:185–191)

Key Words: short implant, survival of implant

In patients with severe alveolar resorption, there are different surgical procedures designed to create more bone volume and to facilitate future implant placement. More complex grafting or implant techniques include the use of bone grafts, distraction osteogenesis, zygomatic implants, transmandibular implants, and transpositioning of the inferior alveolar nerve. Other options include pterygoid implants, guided bone regeneration, monocortical partial grafts, maxillary sinus lift, and short implants.14–25 At present, minimally invasive surgical techniques are advocated to improve patient comfort during the postoperative period while reducing morbidity and possible complications.26 The use of short implants could avoid aggressive surgical procedures that may be unnecessary in some cases. Some authors have concluded that short implants should be considered as an alternative to advanced bone augmentation surgeries, as these procedures can involve higher morbidity, require extended treatment time, and involve higher cost to the patient.27–34

The most commonly used implants are the endosteal screw design root form implants. There is no consensus regarding the definition of a short
implant. Some authors define short implants as 7 mm or less. Others define short implants to be up to 10 mm in length.27 Some authors have related short implants to low success rates.35-38 In a study that included 213 consecutive partially edentulous patients, the failure rate of 7-mm length implants was 9.5% compared with 3.8% for implants of greater lengths.39 However, there were clinical studies that presented better results with endosseous root form implants that were ≤10 mm long.40 One study included 269 screw type Brånemark system implants that were 10 mm or shorter and placed in 111 patients. The overall survival rate was 95.5%.41 Another study reported on the 4-year clinical performance of the Osseotite dental implant. A total of 485 Osseotite implants were placed in 181 patients. Short implants (10 mm or less) represented 31.5% of all implants placed in this study. Only one of the short implants failed to integrate. Clinical success of implants 10 mm or shorter was comparable with that of implants greater than 10 mm in length.42 Monje et al43 compared the survival rate of short and standard dental implants under functional loading, and they found that the failure rate of short dental implants was found to occur between 4 and 6 years of function. It can be noted from these studies that the failures of the short implants occurred after prosthetic loading, so the failure rates were not initial osseointegration failure or surgical failure.

Implant success is usually assessed according to the Albrektsson criteria as follows: the implant is immobile, the radiograph does not demonstrate any evidence of periimplant radiolucency, the vertical bone loss is less than 0.2 mm annually after the first year of service, and the implant is characterized by an absence of persistent or irreversible signs and symptoms such as pain, infection, neuropathy, paresthesia, or violation of the mandibular canal. Success rates of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are the minimum criteria for success.44 The success criterion most commonly reported is the survival rate, which only indicates if the implant is still physically in the mouth or if it has been removed.

The aim of this study was to determine the survival rate of implants for patients treated by the use of short implants in a university environment. In addition, the potential influence of diabetes, smoking, sinus-grafted sites, guided bone regenerated sites, and implant manufacturer type of implant on implant survival was analyzed.

**MATERIALS AND METHODS**

This retrospective analysis was conducted at Saint Louis University, Center for Advanced Dental Education. The clinical files and radiographs of all patients who underwent dental implant placement in the Department of Periodontics from 2002 through October 2011 were analyzed. After implant placement, data concerning the implant manufacturer, location in the mouth, implant diameter, implant length, implant placed with sinus graft, implant placed with guided bone regeneration, smoking history, history of diabetes, and survival time were collected and entered into a database. From this database, the cumulative survival rate and implant and patient information from 213 consecutively short implants placed were analyzed.

Implant failure was defined as any implant removed for any reason during the observation period. Implant survival was defined as any implant physically still in the patient’s mouth. The length of the implants was classified as short if the implant was equal to or less than 10 mm. The study protocol was reviewed and approved by the Saint Louis University Institutional Review Board.

The dental implants in this retrospective study consisted of Astra Tech Osseospeed, Biomet 3i, and NobelReplace implants that were placed in Periodontal Department at Saint Louis University Center for Advanced Dental Education. Patients were referred from

<table>
<thead>
<tr>
<th>Table 1. Description of Failed Implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient With Failed Implants</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
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</table>

<table>
<thead>
<tr>
<th>Table 2. Effect of Different Factors on Short Implant Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Diabetes</td>
</tr>
<tr>
<td>Sinus-grafted sites</td>
</tr>
<tr>
<td>Guided bone regenerated sites</td>
</tr>
<tr>
<td>Smoking</td>
</tr>
</tbody>
</table>

*Statistically significant difference.
private practice to the Department of Periodontics for implant placement and assigned to periodontal residents. All patients were accepted for treatment, unless an absolute contraindication to surgical treatment was present. Patients with tobacco use, diabetes, history of treated periodontal disease, and other systemic conditions were included. The surgical technique consisted of a standard protocol for implant placement under sterile conditions, and the manufacturer’s recommendations for placement were followed. Implants were placed for a variety of restorative situations, including single tooth replacement, fixed partial dentures, and overdentures. Implants were placed in a variety of bone qualities and quantities. Implants of all diameters and lengths were placed in both arches ranging from 3.0 to 6.0 mm in diameter and 6.5 to 15 mm in length.

Inclusion Criteria
- Subjects had to have treatment with 1 or more implants of 10 mm or less.
- Available pretreatment data.
- The patients were 18 years of age or older.

Exclusion Criteria
- The patients were still in treatment.
- The patients had not yet undergone implant placement.
- The final examination before restorative/prosthetic treatment was not performed.

Statistics
Statistical analysis was conducted using the Shapiro-Wilk W test. For normally distributed data, mean values and 95% confidence intervals were calculated. For nonnormally distributed data, medians and 25% and 75% quartiles were calculated. For categorical data, proportions and 95% confidence intervals were calculated. Because data were nonnormally distributed, the Wilcoxon rank-sum and log-rank tests were used to assess differences between groups. Differences between groups for categorical data were assessed with the Fisher exact test. The semiparametric, regression, proportional hazards model was used to examine the effect of explanatory variables on survival times. As part of this testing, effect likelihood ratio tests were used to assess variables. Statistical analyses were performed with JMP Statistical Software Release 10.0.0 (SAS Institute, Inc., Cary, NC).

RESULTS
A total of 213 short implants were reviewed, consisting of 81 Biomet 3i, 70 Nobel Biocare, and 62 Astra Tech implants placed and uncovered from May 2002 to October 2011. Average survival time was 47.3 months, with a range of 6 to 141 months. A total of 56 implants were placed in sinus-grafted sites, 39 implants in guided bone regenerated sites, 14 implants in smokers, and 10 in patients with diabetes.

The overall short implant survival rate was 95.77%. Nine implants were removed, and the average time to removal was 45.9 months with a range of 7 to 102 months. Most failed implants were considered late failures. The implants were categorized based on the length into 2 groups: 8.5 mm and less as group 1 and 9 to 10 mm as group 2. Group 1 included 56 implants, 9 implants were failed, 3 implants were 9 mm length, and 5 were 10 mm length. Statistical analysis was performed using the 2-sample test, and the length of implant did not influence the survival rate for the short implants. The influence was tested and was not statistically significant ($P = 0.619$). The implants were categorized based on the width into 2 groups: less than 5 mm as group 1 and 5 to 6 mm as group 2. Group 1 included 95 implants, 5 implants were failed, 3 implants were 4 mm width, and 2 were 3.5 mm width. Group 2 included 118 implants, and the 4 implants that failed were of 5 mm width. Statistical analysis was performed using the 2-sample test, and the width of implant did not influence the survival rate for the short implants. The influence was tested and was not statistically significant. The description of the failed implants is presented in Table 1.

For all short implant groups, no short implants failed in patients with diabetes, resulting in a 100% survival rate. Three short implants failed in sinus-grafted sites, resulting in a 94.64% survival rate. Two short implants failed in guided bone regenerated sites, resulting in a 94.87% survival rate. Four short implants failed in patients who smoked.

Table 3. Implant Survival or Failure by Implant System

<table>
<thead>
<tr>
<th>Implant System</th>
<th>Failure</th>
<th>Survival</th>
<th>Total</th>
<th>Percentage Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomet 3i</td>
<td>4</td>
<td>77</td>
<td>81</td>
<td>95.06</td>
</tr>
<tr>
<td>Astra Tech</td>
<td>3</td>
<td>59</td>
<td>62</td>
<td>95.16</td>
</tr>
<tr>
<td>Nobel Biocare</td>
<td>2</td>
<td>68</td>
<td>70</td>
<td>97.14</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>204</td>
<td>213</td>
<td>95.77</td>
</tr>
</tbody>
</table>

Fig. 1. Impact of different implant systems on the implant survival. There was no statistically significant difference among implant systems.
resulting in a 71.42% survival rate. There was no statistically significant effect of diabetes (P = 1.000), sinus-grafted sites (P = 0.7006), and guided bone regenerated sites (P = 0.6849) on the survival rate of short implants. There was a statistically significant effect of smoking on the survival rate of short implants (P = 0.0012). The effect of different factors on short implant survival is presented in Table 2.

Implant survival by system is presented in Table 3. Four Biomet 3i implants failed, resulting in a survival rate of 95.06%. Three Astra Tech implants failed, resulting in a survival rate of 95.16%. Two Nobel Biocare implants failed, resulting in a survival rate of 97.14%. There was no statistically significant difference among implant systems (P = 1.0000). Implant survival rate by system is presented in Figure 1.

Implant survival between the mandible and maxilla is presented in Table 4. A total of 109 implants were placed in the maxilla, and 6 implants failed, resulting in a survival rate of 94.49%. A total of 104 implants were placed in the mandible, and 3 implants failed, resulting in a survival rate of 97.11%. There was no statistically significant difference between the maxilla and mandible (P = 0.51). Implant survival rate by arch is presented in Figure 2.

**Table 4. Implant Survival or Failure by Arch**

<table>
<thead>
<tr>
<th>Arch</th>
<th>Failure</th>
<th>Survival</th>
<th>Total</th>
<th>Percentage Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>6</td>
<td>103</td>
<td>109</td>
<td>94.49</td>
</tr>
<tr>
<td>Mandible</td>
<td>3</td>
<td>101</td>
<td>104</td>
<td>97.11</td>
</tr>
</tbody>
</table>

**Fig. 2.** Impact of arch type on the implant survival. There was no statistically significant difference between the maxilla and mandible.

**Discussion**

The biomechanical rational for the acceptability of short implants is that most of the prosthetic load will be distributed to the crestal part of the osseointegrated implant body. The use of finite element analysis showed that most strains occur in the crestal region of the implant and only a small amount is transferred to the apical region. Based on this information, implant length may not be a primary factor for implant failure. The primary aim of this retrospective analysis was to determine the survival rate of implants for patients treated by the use of short implants in a residency program. In addition, the potential influence of diabetes, smoking, sinus-grafted sites, guided bone regenerated sites, and type of implant on implant survival was analyzed. The overall survival rate for short implants (95.77%) in this study was found to be comparable with the overall survival rate for regular implants (96.61%) in a previous study that was performed in the same clinic. There was no significant difference in survival rates between short implants and regular implants.

The results of this study may give more evidence on the validity and efficacy of short implants. Some studies showed that the survival rate for short implants is less than the regular length implants. Other studies showed similar outcomes for both short and regular length implants. Renouard and Nisand evaluated 85 patients with 96 short (6–8.5 mm) implants supporting single-tooth and partial reconstructions. The patients were followed for at least 2 years after loading. The cumulative survival rate was 94.6%. The study demonstrates that the consideration of a specific treatment plan for each patient and applying a good surgical protocol improves the overall survival rate of short implants. Tellemann et al in a systematic review of the literature evaluated the prognosis of short implants placed in partially edentulous patients. This study included 29 articles that evaluated 2611 short implants and found that as the implant length increases the survival rate will increase (from 93.1% to 98.6%). There is fair evidence that short implants can be placed successfully in partially edentulous patients, and the prognosis is better when short implants are placed in the mandible of nonsmoking patients.

The short implant option provides several surgical advantages to the patient and the surgeon. There is a reduction in the need for bone augmentation procedures. In addition, there is less risk for sinus perforation or mandibular paresthesia. There is significant cost savings, decreased treatment time, and less discomfort for the patient. For the surgeon, there is the ability to place implants in more areas of the mouth and for a larger patient population.

In this study, the survival rates of different short implant systems were comparable. Astrand et al found that there was no significant difference in the survival rates of Astra Tech and Bränemark dental implant systems after 5 years, and these results were in agreement to our results. The survival rate was also not significant in implants placed in grafted sites compared with implants placed in nongrafted sites. This result was in agreement with different studies reporting that success rates of implants placed in regenerated bone have been shown to be comparable with success rates of implants placed in native bone over time. The use of either autogenous or nonautogenous materials does not seem to affect...
the success rates of bone augmentation. Intraoral and extraoral autogenous bone grafts and various allografts and xenografts have been used with different types of membranes.54-55

The majority of failed implants were considered late failures. Nine implants were removed, and average time to removal was 45.9 months with a range of 7 to 102 months. No diabetic conditions affecting implant healing were observed in any patient with a failed implant, as it is shown in Table 2. Anner et al56 evaluated the factors associated with long-term implant survival in a large cohort of patients up to 10 years, and he found that diabetes mellitus was not related to implant survival, and these results are in agreement with our results. Bone resorption around implants is usually accompanied by an unfavorable interjaw relationship with an increased mandibular-maxillary space, which as a consequence will cause prosthetic complications such as increased crown height and an increased occlusal table. Misch et al evaluated implant survival in a case series study, and they decreased stress to the bone-implant interface using a biomechanical approach. The study retrospectively evaluated 273 partially edentulous patients treated with 745 implants (7-9 mm long) supporting 338 restorations for a 1- to 5-year period. Stress was decreased on the posterior implants by splinting the implants together, using no cantilever crowns, restoring the patient with a mutually protected or canine guidance occlusion, and choosing implants that have a large bone-implant surface area. A survival rate of 98.9% was recorded from stage 1 surgery to the prosthetic follow-up. They concluded that short implants might be used to support fixed restorations in the posterior partially edentulous region in a predictable manner, provided that techniques to reduce the biomechanical stress on the bone-implant interface are applied.55

Four implants failed in patients who smoked, resulting in a 71.42% survival rate. The difference in survival rates was statistically significant. The majority of the past and current literature reports smoking as one of the risk factors compromising the success rate of dental implants. There is a statistically significant difference between smokers and nonsmokers in the failure rate of dental implants, as being more than twice in smokers than in nonsmokers. Smokers, in general, have higher failure rates and complications after dental implant placement and implant-related surgical procedures.58-61

A higher survival rate was observed for mandibular implants compared with maxillary implants at 97.11% and 94.49%, respectively. However, the difference was not statistically significant. This result is in an agreement with Ozkan et al who could not find a statistically significant difference in implant survival rates between the maxilla and mandible when evaluating different implant systems.5 This result is different from that of many other authors who have reported statistically higher survival rates in the mandible compared with the maxilla.6,9,62,63

A unique aspect to this study was that implants were all placed by periodontal residents with less than 2 years of implant experience, and many implants in this study were the first implants placed by the resident.

One important limitation of this study is that it is a retrospective study. These studies rely on the completeness of data in the charts. In addition, no information is available on the implant restorations in this retrospective analysis.

CONCLUSION

This report consists of 213 short implants placed in a periodontal residency program at Saint Louis University over 112 months. A total of 9 implants failed, which resulted in a survival rate of 95.77%. Implant survival rate was similar for all areas of the mouth and for all manufacturers. Our findings demonstrate that the potential influence of diabetes, sinus-grafted sites, guided bone regeneration, and the type of implant on implant survival was not significant. Smoking, however, did significantly affect the survival rate of short implants.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

REFERENCES


Short implants compared to implants in vertically augmented bone: a systematic review

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Key words: short dental implants, systematic review, vertical ridge augmentation

Abstract
Objectives: To assess relevant data comparing short implants or implants associated with vertical ridge augmentation derived from RCT’s and CCT’s.

Material and methods: A PubMed and hand search was performed to identify all RCT’s and CCT’s published in English language comparing short implants to implants associated with vertical ridge augmentation.

Results: The initial search resulted in 3387 articles. A total of 17 articles were eligible for full-text analysis and four were finally included. This review tends to demonstrate similar implant survival rates between implants placed in vertically augmented bone and short implants (95.09% vs. 96.24%, respectively) with a follow-up ranging from 1 to 5 years. In terms of prosthetic survival rates, there were no differences between the treatments. More surgical complications were reported when using implants placed in vertically augmented bone compared to short implants (56 patients with surgical complications compared to 18 patients, respectively).

Conclusions: This evidence should, however, be interpreted with caution as it is derived from four RCT’s with limited sample size (ranging from 15 to 30 per group), limited follow-up and performed by the same research group.

Implant supported restorations require an adequate volume of bone for successful osseointegration. The term “adequate” has often been interpreted in different ways leading researchers and clinicians to develop techniques to augment bone in deficient sites.

Bone regenerative techniques have developed rapidly trying to decrease as much as possible patients’ morbidity, without compromising the end-goal resolution of severe alveolar defects. On the other hand, the use of short implants to completely avoid bone grafting has been proven successful over the long term (Nisand & Renouard 2014).

The latter requires an initial bone volume to achieve primary stability of the implants as well as complete bone coverage around them. However, often the patient presents with a complete lack of bone where the only option is to apply regenerative techniques to re-create the lost volume of bone. Clearly, these are two different indications that may not be comparable.

The “gray area” stands where the clinical scenario is presenting with an insufficient alveolar bone volume to position standard-length dental implants (>8 mm), but sufficient to allow short implant placement (≤8 mm).

Several surgical techniques have been described over the years to vertically augment the bone: guided bone regeneration, distraction osteogenesis, intra-oral or extra-oral bone grafting, interpositional grafts and combinations (Rocchietta et al. 2008).

Favorable clinical and histological outcomes have been reported in cases series (Simion et al. 1994; Proussaefs et al. 2002; Raghoebar et al. 2002; Bormann et al. 2010) and in few randomized controlled clinical trials (Chiapasco et al. 2007; Bianchi et al. 2008; Merli et al. 2014; Ronda et al. 2014). As such, a retrospective multicenter study (Simion et al. 2001) of 1–5 years of prosthetic loading evaluated 123 implants inserted in atrophic alveolar ridges at either bone augmentation or coincident with implant placement. An overall success rate of 97.5% was reported, leading the authors to conclude that vertically regenerated bone with GBR techniques respond to implant placement such as native, non-regenerated bone.

Regenerating lost bone in a three-dimensional direction with the aim of re-establish-
Material and methods

A detailed protocol was developed based on the PRISMA statement (Moher et al. 2009).

Focus question

Are short implants comparable to longer implants placed in vertically augmented bone in terms of survival and complication rates of implants and reconstructions, radiographic bone levels, and patient-reported outcome measures [PROMs]?

Inclusion criteria

Studies to be included in this review had to fulfill the following inclusion criteria:

- Short implants (less or equal than 8 mm) supported fixed reconstructions
- Controlled groups:
  - Implants >8 mm placed in vertically augmented bone and supported fixed reconstructions.

Outcome variables

- Implant and reconstruction survival rate
- Implant and reconstruction complication rate
- Radiographic bone levels
- Patient-reported outcome measures

Quality assessment

Two reviewers [DN, NP] independently evaluated the methodological quality and risk of bias of the included studies using the Cochrane Collaboration’s tool for assessing risk of bias in randomized trials (Higgins et al. 2011). The following parameters: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting and other sources of bias [sample size, radiographic outcome, follow-up time, clinician bias] were evaluated as low risk, unclear risk or high risk of bias. If all parameters were judged as low risk of bias, the studies were included at low risk of bias.

Exclusion criteria

All studies not meeting all inclusion criteria as well as in vitro, preclinical, cohort, and case series were excluded from the review.

Search strategy

An electronic MEDLINE [PubMed] search was performed between January 1st, 1976 to January 1st, 2015 to identify all relevant human randomized controlled trial and controlled clinical trials published in English language comparing implants associated with vertical ridge augmentation to short implants.

The following search terms were applied: “short dental implant” AND “reduced implant length” AND “ultra-short implant” AND “short implant length” AND “vertical ridge augmentation” OR “bone graft” OR “guided bone regeneration” OR “bone augmentation” OR “block graft” OR “interpositional bone graft” OR distraction osteogenesis”.

A further manual search was performed through the references of all relevant articles and reviews.

Selection of studies

Two reviewers (D.N and N.P) independently screened the titles and the abstracts of the search results. The full text of the eligible articles was obtained and analyzed using the stated inclusion criteria to set a final list of articles. When multiple reports were referring to the same data, the most recent article was used.

Data extraction and method of analysis

Two reviewers independently extracted the data of the included studies using data extraction tables. Any disagreement was discussed until consensus was achieved.

Whenever possible, the following data were extracted from the selected articles: author(s), year of publication, study design, number of patients, age range, mean age, operator(s), dropouts, number of implants, implant length, implant diameter, surgical technique, healing protocol, loading protocol, mean follow-up time of implants, implant survival, early failures, late failures, number of reconstructions, reconstruction type, mean follow-up time of reconstruction, reconstruction survival, marginal bone level changes, the number of complications, PROMs.
The primary outcomes included survival rate of implants and reconstructions. Secondary outcomes included complication rates for implants and reconstructions, radiographic bone levels, and PROMs.

Statistical analysis
Survival rates were derived using implant as unit, hence as number of failures divided by number of implants.

Search results
The initial electronic search resulted in 3387 articles. After assessing the title, 3350 articles were excluded. Of the 37 abstracts obtained, a total of 14 articles were eligible for full-text analysis. Hand searching provided three more articles (Stellingsma et al. 2004, 2014; Peñarrocha-Oltra et al. 2014).

Of these 17 articles, two were removed because implants were >8 mm (Stellingsma et al. 2004, 2014), one article was excluded because of the retrospective study design (Peñarrocha-Oltra et al. 2014), two articles were removed as they compared short implants and longer implants without vertical ridge augmentation (Guljé et al. 2013; Romeo et al. 2014), five articles were excluded according to the follow-up <1 year (Felice et al. 2009a,b, 2011, 2012; Esposito et al. 2012) and three studies were finally removed as they reported similar data of ongoing studies with more recent publications (Felice et al. 2010; Esposito et al. 2011a,b). The selection process is outlined in Fig. 1.

Finally, four articles were selected for data extraction (Table 1): two of these articles with a split-mouth design (Pistilli et al. 2013b, Esposito et al. 2014) and two articles with a parallel design (Pistilli et al. 2013a; Felice et al. 2014). All included articles compared short implants to implants placed in vertically augmented bone by means of interpositional block xenografts in the posterior mandible.

Quality assessment
The quality assessment of all the included studies is presented in Table 2. All included studies were evaluated at low risk for random sequence generation, allocation concealment, blinding of outcome assessment, incomplete outcome data, selective reporting, and clinician bias. All studies included in this review were considered at high risk of bias for participants and personnel blinding despite this being impossible to achieve (Higgins et al. 2011).

Regarding sample size and radiographic outcome, all of the studies had a high risk of bias. Regarding follow-up time, only the publications from Felice et al. (2014) were evaluated at low risk of bias.

Based on the quality assessment, the results of the present systematic review should be interpreted with caution as none of the trial included have qualified for a low risk of bias for each domain.

Patient population and analysis
The four selected studies involved a total of 135 patients, including 89 women and 46 men, with a mean age of 55.4 years (ranging from 37 to 93 years) restored with 328 implants (Table 3a,b). Eighty-five patients with a mean age of 56.2 years ranging from 37 to 93 years received a total of 163 short implants with a mean length of 5.65 mm (ranging from 5 to 6.6 mm) and a mean diameter of 4.75 (ranging from 4 to 6 mm).

Eighty-five patients with a mean age of 54.4 years ranging from 37 to 70 years were reconstructed with interpositional block xenografts to received a total of 165 long implants with a mean length of 10.62 mm (ranging from 9.6 to 15 mm) and a mean diameter of 4.75 mm (ranging from 4 to 6 mm).

All implants were placed in the posterior mandible using a submerged technique with a healing time of 3–4 months and restored with either screw or cemented fixed restoration.

The implants were followed for a mean of 2.5 years (ranging from 1 year to 5 years). In the grafted group, eight patients dropped out compared to five patients in the short-length implant group. Nine long implants failed in the augmented group (one implant failed twice in the same location) together with nine prosthetic restorations whereas in the short implant group, seven implants and six prosthesis restorations failed.

No statistically significant differences in terms of implant and prosthesis failure were reported in any of the selected studies when comparing short implant with longer implants placed in augmented bone. In the augmented group, 11 grafting procedures failed. Six grafting procedures failed completely leading to the placement of short-length implants (four patients), to new grafting procedures (one patient) or to a patient dropout. Five grafting procedures failed partially allowing the placement of shorter implants than what was initially planned (7 and 8.5 mm implants).

A total of 56 patients of 85 experienced complications in the augmented groups compared to 18 patients in the short implants groups. Temporary paresthesia were reported in 56.24% of the patients in the augmented group and 16.66% in the short implant group. Three publication of four reported significantly more complication in the augmented groups.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Patients</th>
<th>Implant dimension: length and diameter</th>
<th>Total no. implant (short, long)</th>
<th>Surgical site</th>
<th>Follow-up (year)</th>
<th>Healing period for vertical augmentation</th>
<th>Healing period for implants</th>
<th>Mean length of placed implants Short implants Long implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felice et al.</td>
<td>RCT (parallel design)</td>
<td>60 patients 30 patients per group</td>
<td>Short implants: 6.6 × 4 mm Long implant: 9.6 mm or longer (11.2 mm, 12.6 mm and 14.6 mm) × 4 mm</td>
<td>121 (60, 61)</td>
<td>Partially edentulous patients having 7-8 mm of residual crestal height above the mandibular canal and at least 5.5 mm thickness measured on CT scan Short implant: native bone Long implant: vertically augmented site with bio-oss and bio-guide</td>
<td>5</td>
<td>5 months</td>
<td>4 months of submerged healing</td>
<td>Short: 6.6 mm Long: 10.8 mm</td>
</tr>
<tr>
<td>Pistilli et al.</td>
<td>RCT (split-mouth design)</td>
<td>20 patients with bilateral atrophic mandibles</td>
<td>Short implants: 6 × 4 mm Long implants: 10 mm or longer (11.5, 13 and 15 mm) × 4 mm</td>
<td>88 (41, 47)</td>
<td>Partially edentulous patients having 5-7 mm of residual crestal height above the mandibular canal and at least 5 mm thickness measured on CT scan Short implant: native bone Long implant: vertically augmented site with equine bone block and resorbable membrane</td>
<td>1</td>
<td>3 months</td>
<td>3 months of submerged healing</td>
<td>Short: 6 mm Long: 10.78 mm SD 1.73</td>
</tr>
<tr>
<td>Esposito et al.</td>
<td>RCT (split-mouth design)</td>
<td>15 patients with bilateral atrophic mandibles</td>
<td>Short implants: 5 × 6 mm Long implants: 10 mm or longer (11.5 and 13 mm) × 6 mm</td>
<td>56 (30, 26)</td>
<td>Partially edentulous patients having 7-8 mm of residual crestal height above the mandibular canal and at least 8 mm thickness measured on CT scan Short implant: native bone Long implant: vertically augmented site with bio-oss and bio-guide</td>
<td>3</td>
<td>4 months</td>
<td>3 months of submerged healing</td>
<td>Short: 5 mm Long: 10.4 mm</td>
</tr>
<tr>
<td>Pistilli et al.</td>
<td>RCT (parallel design)</td>
<td>40 patients 20 patients per group</td>
<td>Short implants: 5 × 5 mm Long implants: 10 mm or longer (11.5, 13 and 15 mm) × 5 mm</td>
<td>63 (32, 31)</td>
<td>Partially edentulous patients having 7-8 mm of residual crestal height above the mandibular canal and at least 6 mm thickness measured on CT scan Short implant: native bone Long implant: vertically augmented site bovine bone block and resorbable membrane</td>
<td>1</td>
<td>4 months</td>
<td>3 months of submerged healing</td>
<td>Short: 5 mm Long: 10.7 mm</td>
</tr>
<tr>
<td>Failure of augmentation procedure</td>
<td>Prosthetic restoration</td>
<td>Failed implants (no. patients)</td>
<td>Complications (no. patients)</td>
<td>Complications intrasurgical</td>
<td>Complications postsurgical</td>
<td>Patients dropped out</td>
<td>Mean change in peri-implant marginal bone level</td>
<td>Prosthesis failure (patients)</td>
<td></td>
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<tr>
<td>Two patients:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.6 mm long implants were placed instead</td>
<td>Splinted, screw retained or provisionally cemented</td>
<td>Short: 5 (3)</td>
<td>Short: 6 (6)</td>
<td>Short: Two patients with transient paresthesia</td>
<td>Short: Two patients with screw loosening</td>
<td>Short: 3</td>
<td>Short (25 patients): 1.49 mm (SD 0.40)</td>
<td>Short: 5 (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three patients:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One patient receive two short implants</td>
<td>Provisionally cemented splinted ceramic or resin crown</td>
<td>Short: 0</td>
<td>Short: 0</td>
<td>Short: none</td>
<td>Short: none</td>
<td>1</td>
<td>Short (19 patients): 1.05 mm (SD 0.06)</td>
<td>Short: 0</td>
<td>Long: Two delayed prosthesis placement (2)</td>
</tr>
<tr>
<td>One patient receive three short implants</td>
<td></td>
<td>Long: 3 (1)</td>
<td>Long: 10 (8)</td>
<td>Long: Three patients with graft failure</td>
<td>Long: Three patients with temporary paresthesia</td>
<td></td>
<td>Long (14 patients): 1.07 mm (SD 0.06)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One patient was regraft and receive two long implants and one short implant</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>0 patient</td>
<td></td>
<td>Short: 2 (1)</td>
<td>Short: 9 (4)</td>
<td>Short: none</td>
<td>Short: none</td>
<td>1</td>
<td>Short (13 patients): 1.44 mm (SD 0.44)</td>
<td>Short: 1</td>
</tr>
<tr>
<td></td>
<td>Provisionally cemented splinted ceramic or resin crown</td>
<td>Long: 1 (1)</td>
<td>Long: 12 (9)</td>
<td>Long: Five patients receive short implant instead of planned 10 mm long</td>
<td>Long: One patient with discomfort when chewing</td>
<td></td>
<td>Long (14 patients): 1.63 mm (SD 0.52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One patient</td>
<td></td>
<td>Short: 0</td>
<td>Short: 8 (17)</td>
<td>Short: none</td>
<td>Short: none</td>
<td>1</td>
<td>Short (20 patients): 0.94 mm (SD 0.05)</td>
<td>Short: 0</td>
<td>Long: 2</td>
</tr>
<tr>
<td>Splinted, screw retained or provisionally cemented</td>
<td>Long: Two implants in the same site (1)</td>
<td>Short: (8)</td>
<td>Long (17)</td>
<td>Long: One patient with fracture of the bone plate (graft failure)</td>
<td>Long: Eight patients with temporary paresthesia</td>
<td></td>
<td>Long (18 patients): 1.03 mm (SD 0.08)</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
A mean peri-implant bone loss of 1.23 mm (ranging from 0.94 to 1.49 mm) occurred in the short-length implant group as compared to a mean peri-implant bone loss of 1.51 mm (ranging from 1.03 to 2.34 mm) in the augmented group. A statistically significant difference in bone loss was reported in only one publication with 0.82 mm reduction in bone loss in the short implant group as compared to the long implant group (Felice et al. 2014).

Discussion

The aim of this systematic review was to assess the available data extrapolated from randomized controlled clinical trials and controlled clinical trials to compare the clinical, radiographic, and patient centered outcomes of short implants or implants positioned in vertically augmented bone.

This systematic review included four papers comparing in the posterior mandible short implants and implants placed in vertically augmented bone by means of interpositional graft.

This review reported no statistically significant differences in implant and prostheses failures.

Of the four studies included in this review, three papers (Pistilli et al. 2013a,b; Felice et al. 2014) reported significantly more complications in the grafted group. One of the main complication reported in the four studies was temporary paresthesia that occurred in 56.24% of the patients of the augmented group as compared to 16.66% in the short implant group. Interestingly, Peñarrocha-Oltra et al. (2014) did not report any temporary paresthesia of the grafted area. This discrepancy may be explained by the different surgical procedure used to vertically augment the bone. In the same way, Peñarrocha-Oltra et al. (2014) did not report any temporary paresthesia in the short implant group. This difference might be related to the accuracy of the surgical technique used for implant bed preparation: Interestingly, in the paper from Felice et al. (2009a), the surgical technique for implant site preparation used drills of increasing diameter up to 4.3 mm to place implant of 4 mm diameter, whereas in the same study, published with a longer follow-up (Felice et al. 2014), they reported the used of drill only up to 3.5 mm.

Moreover, the selection of the implant length in the short implant group may also explain the difference in terms of postoperative paresthesia: As such in the paper from Felice et al. (2014) (also published at 4 months follow-up, 1 year, and 3 years) the implant length of the short implant group changed from 7 [Felice et al. 2009a] to 6.3 mm [Esposito et al. 2011b] and finally 6.6 mm [Felice et al. 2014].

Contradictory results were reported in the systematic review from Lee et al. (2014) with no significant differences in terms of complication between the two treatment modalities. This difference might be explained by the inclusion of one study in which long implants were placed in native bone (Gülj et al. 2013).

In the paper from Esposito et al. (2014), there were no statistically significant differences in complications. Nevertheless, 66.66% of the patients in the augmented group reported temporary paresthesia as compared to 20% in the short implants group. Furthermore, in five augmented mandibles of 15, shorter implants have to be placed instead of standard-length implants. Similarly, in the paper from Peñarrocha-Oltra et al. (2014), seven patients of the augmented group had to be restored with 13 short implants instead. Moreover, 21 of 45 implants in the augmented group needed a
### Table 2. Quality assessment of the included studies

<table>
<thead>
<tr>
<th></th>
<th>Felice et al. (2014)</th>
<th>Pistilli et al. (2013a)</th>
<th>Esposito et al. (2014)</th>
<th>Pistilli et al. (2013b)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Random sequence generation</strong></td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
</tr>
<tr>
<td></td>
<td>A computer generated</td>
<td>A computer generated</td>
<td>A computer generated</td>
<td>A computer generated</td>
</tr>
<tr>
<td></td>
<td>restricted randomization list was created</td>
<td>restricted randomization list was created</td>
<td>restricted randomization list was created</td>
<td>restricted randomization list was created</td>
</tr>
<tr>
<td><strong>Allocation concealment</strong></td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
</tr>
<tr>
<td></td>
<td>The information on how to treat each patient was enclosed in sequentially numbered, identical, opaque, sealed envelopes</td>
<td>The information on how to treat each patient was enclosed in sequentially numbered, identical, opaque, sealed envelopes</td>
<td>The information on how to treat each patient was enclosed in sequentially numbered, identical, opaque, sealed envelopes</td>
<td>The information on how to treat each patient was enclosed in sequentially numbered, identical, opaque, sealed envelopes</td>
</tr>
<tr>
<td><strong>Blinding of participants and personnel</strong></td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
</tr>
<tr>
<td></td>
<td>Blinding of key participants and personnel attempted but impossible to achieve</td>
<td>Blinding of key participants and personnel attempted but impossible to achieve</td>
<td>Blinding of key participants and personnel attempted but impossible to achieve</td>
<td>Blinding of key participants and personnel attempted but impossible to achieve</td>
</tr>
<tr>
<td><strong>Blinding of outcome assessment</strong></td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
</tr>
<tr>
<td></td>
<td>Two dentists not involved in the treatment of the patients performed all clinical measurements without knowing group allocation</td>
<td>Two dentists not involved in the treatment of the patients performed all clinical measurements without knowing group allocation</td>
<td>Two dentists not involved in the treatment of the patients performed all clinical measurements without knowing group allocation</td>
<td>Two dentists not involved in the treatment of the patients performed all clinical measurements without knowing group allocation</td>
</tr>
<tr>
<td><strong>Incomplete outcome data</strong></td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
</tr>
<tr>
<td></td>
<td>Losses to follow-up were disclosed (eight patients dropped out)</td>
<td>Losses to follow-up were disclosed (one patient dropped out)</td>
<td>Losses to follow-up were disclosed (one patient dropped out)</td>
<td>Losses to follow-up were disclosed (one patient dropped out)</td>
</tr>
<tr>
<td><strong>Selective reporting</strong></td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
<td>Low risk:</td>
</tr>
<tr>
<td></td>
<td>All prespecified outcomes were reported</td>
<td>All prespecified outcomes were reported</td>
<td>All prespecified outcomes were reported</td>
<td>All prespecified outcomes were reported</td>
</tr>
<tr>
<td><strong>Other bias</strong></td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
</tr>
<tr>
<td><strong>Sample size</strong></td>
<td>Sample size was calculated for a primary outcome but not achieved</td>
<td>No sample size calculation was performed</td>
<td>Sample size was calculated for a secondary outcome</td>
<td>Sample size was calculated for a secondary outcome</td>
</tr>
<tr>
<td><strong>Radiographic outcome</strong></td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
</tr>
<tr>
<td></td>
<td>No blinding possible</td>
<td>No blinding possible</td>
<td>No blinding possible</td>
<td>No blinding possible</td>
</tr>
<tr>
<td><strong>Follow-up time</strong></td>
<td>Low risk:</td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
</tr>
<tr>
<td></td>
<td>5 years follow-up</td>
<td>1 year follow-up</td>
<td>3 years follow-up</td>
<td>1 year follow-up</td>
</tr>
<tr>
<td><strong>Clinicians bias</strong></td>
<td>Low risk:</td>
<td>High risk:</td>
<td>High risk:</td>
<td>High risk:</td>
</tr>
<tr>
<td></td>
<td>One surgeon and one prosthodontist performed similar and standardized procedures</td>
<td>Two surgeons/prosthodontists performed the treatments with standardized procedures</td>
<td>One surgeon, the study did not address which clinician performed the prosthetic treatment</td>
<td>Two surgeons/prosthodontists performed the treatments with standardized procedures</td>
</tr>
</tbody>
</table>
second bone graft procedure at the time of implant placement.

In the present review, a significant increase of complications was experienced in the grafted group despite the experience of the involved surgeon raising the question of the feasibility and the generalizability of this approach in daily clinical practice.

Peri-implant bone loss was experienced in all studies and in both groups. In the short implant group, a mean peri-implant bone loss of 1.23 mm ranging from 0.94 to 1.49 mm was reported as compared to a mean peri-implant bone loss of 1.51 mm ranging from 1.03 to 2.34 mm in the augmented group. In contrast, Rossi et al. (2015) reported only 0.7 mm of peri-implant bone loss around short implants (6 mm) after 5 year of loading. Such differences in the amount of peri-implant bone loss may be related to the two-step surgical technique used in the studies included in this review [Van Assche et al. 2008]. Interestingly, only one publication with 5 years of follow-up (Felice et al. 2014) reported statistically significantly less peri-implant bone loss around short-length implants. Furthermore, in this paper, significantly more short implants became exposed spontaneously during the healing period as compared to longer implants.

Treatment time and cost may also influence patient decision and willingness to be treated with a vertical ridge augmentation. In all of the included study, vertical ridge augmentation increased the treatment time by 4 months as compared to short implants procedures.

In one of the study [Pistilli et al. 2013b], the patient preferred option was registered. Not surprisingly, 100% of patients preferred the short implant option over the vertical ridge augmentation emphasizing the importance of morbidity, treatment time, and cost in the patient decision.

The outcome of this review should be interpreted with great caution in relation to the small sample size and short follow-up time. In addition, the four papers included derived from the same clinical and research

<table>
<thead>
<tr>
<th>Table 3. Comparison of the selected studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felice et al. (2014)</td>
</tr>
<tr>
<td>Follow-up</td>
</tr>
<tr>
<td>Short implants length</td>
</tr>
<tr>
<td>Long implants length (range)</td>
</tr>
<tr>
<td>Short implants survival rate</td>
</tr>
<tr>
<td>Long implants survival rate</td>
</tr>
<tr>
<td>Mean change in peri-implant bone loss short group</td>
</tr>
<tr>
<td>Mean change in peri-implant bone loss long group</td>
</tr>
<tr>
<td>Complete failure of vertical augmentation nb of patients (%))</td>
</tr>
<tr>
<td>Temporary paresthesia short group (%)</td>
</tr>
<tr>
<td>Temporary paresthesia long group (%)</td>
</tr>
<tr>
<td>Prosthesis failure short group (%)</td>
</tr>
<tr>
<td>Prosthesis failure long group (%)</td>
</tr>
<tr>
<td>Dropout (number of patients)</td>
</tr>
</tbody>
</table>
group, making it hard to explore data from different centers. This is even more emphasized by the fact that the vertical bone augmentation was performed using the same technique all throughout the 4 papers. Further RCT should involve other groups of clinicians and compare short implants to implants placed in bone restored by bone blocks, guided bone regeneration, and other techniques. Moreover, an effort should be made to develop clinical guidelines for RCT’s to ensure a proper evaluation of implant and prosthetic success rates and a reliable assessment of the peri-implant bone loss.

Conclusion

This review tends to demonstrate similar implant and prosthetic survival rates between short implants and longer implants placed in vertically augmented bone. Nevertheless, vertical ridge augmentation by means of interpositional bone substitute blocks seems to be associated with an increased treatment time and cost together with an increased rate of complications.

Those results should, however, be interpreted with caution due to the small sample size, limited follow-up, and the same group of authors.

Further studies, using different surgical protocols for vertical ridge augmentation, improved clinical guidelines, larger sample size, and longer follow-up should be performed to draw definitive conclusions. These would serve very useful to guide clinicians in the decision process when ideally both therapeutic options can be applied, that is, when the available bone height in nonesthetic areas ranges between 5 and 8 mm.

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Merli, M., Moscatelli, M., Mariotti, G., Rotundo, R., Bernardelli, F. & Nieri, M. [2014] Bone level variation after vertical ridge augmentation: re-
A Finite Element Study of Short Dental Implants in the Posterior Maxilla

Rudi C. van Staden, BEng, PhD/Xiaona Li, DDS, PhD/Hong Guan, BEng, PhD/Newell W. Johnson, MDSc (Melb), PhD (Bristol), FDSRCS (Eng), FRACDS, FRPath (UK), FFOP (RCPA), FICD, FILT, FMedSci/Peter Reher, BDS, MSC, PhD/Yew-Chaye Loo, BScEng, MEng, PhD/FIEAust, FICE, FISTRuctE, CEng, CPEng, NPER

Purpose: Elevated bite forces and reduced bone densities and dimensions associated with posterior regions of the maxilla cause relatively high failure rates when short dental implants are placed to substitute missing teeth. This study uses the finite element method to evaluate four distinctly different short implant designs (Bicon, Neodent, Nobel Biocare, and Straumann) for their influences on the von Mises stress characteristics within the posterior maxilla. Materials and Methods: Finite element models of the supporting bone and tooth crowns are developed based on computed tomography data, and implant geometries are obtained from manufacturers’ catalogs. The finite element models are meshed using three-dimensional hexahedral and wedge-shaped brick elements. Assumptions made in the analyses are: linear elastic material properties for bone, 50% osseointegration between bone and implant, and crown height–implant length ratio of 2:1. Results: Bicon’s neck indentation produced reduced stress in the cortical bone when compared with the Nobel Biocare and Straumann systems. The increased taper of the Neodent design decreased the stress level in cancellous bone. Nobel Biocare’s rounded thread crest and reduced thread pitch produced a smoother stress profile. Straumann’s increased thread pitch produced elevated stress in the cancellous bone. Generally, stresses were concentrated in the crestal bone region around the implant neck, attributable to the inclined nature of the masticatory force. Conclusion: Nobel Biocare and Bicon systems are recommended for use in type 4 cancellous and cortical bone, respectively. Int J Oral Maxillofac Implants 2014;29:e147–e154. doi: 10.11607/jomi.3234

Key words: finite element analysis, posterior maxilla, short dental implant, stress characteristics

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Dr R. C. van Staden and Associate Prof X. Li contributed equally to this work and are to be considered the first authors.

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Implant length seems to have a significant influence on stress distributions within bone.\textsuperscript{4,12} Guan et al.\textsuperscript{20,21} found that (1) compared with increasing implant diameter, increasing the length leads to a greater area of contact between the cancellous bone and implant, thereby reducing the magnitude of stresses; (2) in terms of differences between the minimum and maximum stress values, the applied masticatory force is most influential amongst all parameters concerned; and (3) implant length is the most influential parameter affecting the stress within bone.

Additionally, recent systematic literature reviews indicate that micro-rough-surfaced short implants (6- to 7.5-mm length) can have favorable survival (or retention) rates in the posterior alveolus.\textsuperscript{2,22–24} Other reviews suggest that initial survival rates for short implants used for posterior partial edentulism are intrinsically high and do not relate to implant surface, design, or width.\textsuperscript{25} The performances of specific types of short implants have been extensively evaluated clinically\textsuperscript{8–11} and modeled numerically,\textsuperscript{4,12–21} as previously stated. Short implants do seem to be viable in the posterior maxilla, obviating the need for bone grafting and sinus elevation. Nevertheless, limited finite element analysis (FEA) has been conducted to evaluate and compare the stress characteristics in the posterior maxilla for short implants of different designs. As such, this study examines the stress characteristics and the risk of bone fracture around four commonly used, but distinctly different, short implants placed in the posterior maxilla. The selected implants are those of Bicon, Neodent, Nobel Biocare, and Straumann. Also taken into account in this study are normal and traumatic masticatory forces and high crown height–implant length (C/I) ratios. The outcomes of this study enhance understanding of the stress characteristics in the maxilla surrounding different types of short implants and provide a rationale for selection of the most appropriate implant design for use in the posterior maxilla.

**MATERIALS AND METHODS**

**Finite Element Modeling Details**

A three-dimensional (3D) representation of the bone and implant is analyzed using the Strand7 (Strand7 Pty) FEA system. Data for bone and crown dimensions are based on computed tomography (CT) images. CT is also used to distinguish cancellous and cortical bone and their boundaries. The bone is categorized as “soft quality” or type 4 bone. To simulate a single crown supported by a single implant, a 3D section of the maxilla surrounding the first molar in the maxillary right quadrant is segmented from a model of the entire maxilla.

Figures 1a to 1c show a section of the maxilla with an implant replacing a first molar, its internal components, and the loading and restraint conditions. Three-dimensional hexahedral and wedge-shaped brick elements are used for meshing. Mesh convergence was undertaken on similar models in the authors’ previous work.\textsuperscript{26} An implant system typically consists of an implant, abutment, abutment screw, and crown, as illustrated in Fig 1d. To accurately represent the mechanical behavior of the bone-implant system, the nodes on the anterior and posterior faces of the model are fixed in all six degrees of freedom (see Fig 1c). Note that the influence of teeth adjacent to the first molar is not considered herein.

Figure 2 illustrates the designs of Bicon, Neodent, Nobel Biocare, and Straumann implants. The top portions of the figures present the finite element models for the four implants, while the bottom portions illustrate the internal configurations of the corresponding implant. Length and diameter are taken from their respective catalogs; however, the thread pitch is measured from enlarged images of each implant. Unique features of the Bicon implant include a fin or square-like thread crest, an indent at the implant neck, and a flat base. Neodent has a triangular thread design with a relatively large taper. The Nobel Biocare implant has a reduced thread pitch and smoothed-out thread profile. Straumann has an increased implant neck height and a similar thread design to Bicon; however, the thread thickness is reduced. Note that the internal configurations for the thread region are identical. For a particular bone-implant-crown finite element model, for example, the Bicon implant, the total numbers of brick elements are 27,642 for the implant; 11,528 for the cancellous bone; 115,568 for the cortical bone; 1,728 for the blood interface; 83,792 for the crown; 8,820 for the abutment; and 22,752 for the abutment screw. The total number of nodal points in the entire model is 192,340.

Material properties are specified in Table 1 in terms of Young modulus, Poisson ratio, and density for the bone, blood interface, crown, and implant components. All materials in the bone-implant-crown system are assumed to be linear elastic and homogenous. To replicate a more challenging scenario, the lower bound strength of the cancellous bone and an average strength of the cortical bone are selected.\textsuperscript{21} In addition, a small cortical bone thickness is also considered. Previous finite element studies have commonly assumed that osseointegrated implants are in direct contact with the cancellous bone without a blood interface.\textsuperscript{31–33} In this study, however, half of the cancellous bone to implant thread interface is assumed to consist of blood, with the remainder in direct contact, as illustrated in Fig 1d. After healing, the authors as-
Fig 1  Finite element model of the bone and implant. (a) Isometric view. (b) Lateral view. (c) Occlusal view. (d) Isometric view along section AA in a.

Fig 2  Details of implant designs (all units in mm). (a) Bicon. (b) Neodent. (c) Nobel Biocare. (d) Straumann.
sume 50% osseointegration, an outcome found clinically\(^\text{34}\) and numerically.\(^\text{35}\)

The C/I ratio is determined by dividing the clinical height of the crown by the section of the implant that resides in the bone. In this study, the crown height is assumed to be 12 mm, giving relatively high C/I ratios of 2 for Bicon, Neodent, and Straumann implants and 1.7 for Nobel Biocare. It is generally accepted that the appropriate, and commonly used, C/I ratio is 1 for relatively long implants.\(^\text{36}\) For short implants, the C/I ratio can be as large as 3 for some extreme situations.\(^\text{37}\)

### Stress Evaluation

The von Mises stresses are evaluated within cancellous and cortical bone for the four different implant systems, designated as BI (Bicon), ND (Neodent), NB (Nobel Biocare), and ST (Straumann). As shown in Fig 3, the stresses along the lines, eg, \(\text{BI}_{1-2}\) and \(\text{BI}_{3-4}\), are measured in the

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Young modulus, (E) (GPa)</th>
<th>Poisson ratio, (v)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant and abutment</td>
<td>Titanium (grade 4)</td>
<td>105.00</td>
<td>0.30</td>
<td>Perez del Palomar et al(^\text{27})</td>
</tr>
<tr>
<td>Abutment screw</td>
<td>Gold (precision alloy)</td>
<td>93.00</td>
<td>0.30</td>
<td>—</td>
</tr>
<tr>
<td>Blood interface</td>
<td>See Fig 1d</td>
<td>0.07</td>
<td>0.30</td>
<td>van Staden et al(^\text{28})</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>Type 4</td>
<td>1.00</td>
<td>0.35</td>
<td>Rho et al(^\text{29})</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>Cortical thickness = 0.5 mm</td>
<td>13.00</td>
<td>0.30</td>
<td>Okumura et al(^\text{30})</td>
</tr>
<tr>
<td>Crown</td>
<td>Zirconia (Y-TZP)</td>
<td>172.00</td>
<td>0.33</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^\text{—}\) = information not available; Y-TZP = yttria-stabilized tetragonal zirconia polycrystal.

---

**Fig 3** Stress measurement lines within cancellous and cortical bone: (a) Bicon. (b) Neodent. (c) Nobel Biocare. (d) Straumann.
cancellous and cortical bone, respectively (see Fig 3a). The relative locations of these lines are considered by clinicians to be critical for examining the stress magnitudes and understanding the response of bone to these stimuli. Both stress measurement lines are chosen on the right side of the implant, where the stress magnitude is higher than on the left because of the direction of the oblique masticatory force. Note also that the distance of the stress measurement lines in the cancellous bone is fixed at 0.2 mm away from the thread tip (ie, the crest) in an attempt to capture the stresses at the most critical location. The stress measurement line in the cortical bone is positioned to capture the stress in the crestal bone. The start and finish points of, for example, BL 1–2 (ie, BL 1 and BL 2) and BL 3–4 (ie, BL 3 and BL 4) are also identified in Fig 3a for ease of discussion.

**Applied Mechanical Forces**

The implant-crown system is subject to a combination of masticatory forces and abutment screw torque. During normal masticatory function the crown is subjected to oblique loads acting on the occlusal surface of the crown. A masticatory force ($F_M$) of 200 or 1,000 N is uniformly applied across the four crown cusps at a 45-degree inclination with respect to the x- and y-axes (see Fig 1a). According to Bozkaya et al, these forces may be considered normal and traumatic loading scenarios, respectively.

The torque applied to the abutment screw causes a preload ($F_P$) or clamping force between the implant and abutment. This torque is simulated in the finite element model by applying an $F_P$ through the use of temperature-sensitive elements. A temperature coefficient of $-3.37 \times 10^{-2}$ causes element shrinkage within the abutment screw that produces the desired $F_P$ of 598.33 N or torque of 320 Nmm. It should be noted that the same temperature coefficient is used for all the implant systems because the abutment screws are identical.

**RESULTS**

The von Mises stresses were evaluated within both the cancellous and cortical bone for four short implant designs under the applied masticatory forces and abutment screw preload. The distribution of stresses along the lines BI, ND, NB, and ST within the cancellous and cortical bone are shown in Figs 4 and 5, respectively. Figures 4a to 4d indicate that when $F_M$ was increased, the stresses also increased proportionally in the cancellous bone because of the linear elastic material behavior. This phenomenon was the same for the stress variations in the cortical bone (see Figs 5a to 5d). Increasing $F_M$ also caused increased stress oscillations along the implant for all the systems. Shown in Table 2 are the von Mises stresses in cancellous bone, summarizing the relationship between the

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**Fig 4** Stress characteristics in cancellous bone with varying $F_M$. (a to d) Profiles, (e to h) Contours. Min = minimum, max = maximum.
implant designs and different levels of $F_M$. It should be noted that only the stresses at the start (eg, BI$_1$) and finish (eg, BI$_2$) points of the stress measurement lines in the cancellous bone are presented in the table. Note also that the stress values at finish points are given in parentheses.

For the cancellous bone, local stress peaks are evident along the implant threads for all the implant systems (see Figs 4a to 4d). For Nobel Biocare, the local peaks are less prominent due to its more rounded thread crest, in comparison with the other three systems, in which the thread crests are more square. The figures for Bicon, Nobel Biocare, and Straumann also showed that the stresses are at a maximum at the starting points of the stress measurement lines, which are closer to the implant neck and loading point. Table 2 gives the actual values of stresses for these three implant systems, demonstrating that for both levels of $F_M$, Straumann had the greatest amount of stress at the starting point. Bicon had the greatest amount of stress at the finishing point of the measurement lines amongst all the implant systems (see Table 2). The stresses again peaked in the vicinity of points A, B, C, and D for the Bicon, Neodent, Nobel Biocare, and Straumann implant systems, respectively, as a result of the inclined nature of the masticatory force inducing a bending moment in the close vicinity of the implant base. Previous research has also found stress concentrations close to the implant neck and base.$^{13,20,21,40}$ Further, for Bicon and Straumann systems, the more narrow thread crests caused larger variations in the local stress peaks. For the Neodent design, the stress at ND$_1$ was the lowest among the four implant systems, which may be attributable to the smoothed-out design of the implant neck (see Fig 4b and Table 2). For Nobel Biocare, the rounded implant thread crest de-

| Table 2 von Mises Stresses in Cancellous Bone for the Different Implant Designs* |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $F_M$ (N)       | BI$_1$ (BI$_2$) | ND$_1$ (ND$_2$) | NB$_1$ (NB$_2$) | ST$_1$ (ST$_2$) |
| 200             | 6.60 (2.06)     | 5.72 (1.58)     | 6.50 (1.88)     | 7.79 (1.75)     |
| 1,000           | 32.99 (10.29)   | 28.60 (7.91)    | 32.48 (9.42)    | 38.96 (8.73)    |

*Values in parentheses are those at the finish point.
sign and reduced pitch (0.53 mm) were favorable, thus giving a smoothed-out stress variation. The apex of the implant also has a rounded geometry, thereby giving a stress peak at point C (see Figs 4c and 4g) that was less distinct than that of the other systems. The Straumann system not only gave the highest stress close to the implant neck but also the most significant peak at point D (see Figs 4d and 4h). This was because point ST\textsubscript{3} is very close to the first thread crest, and the taper is relatively slight compared with the other three systems.

Table 3 summarizes the stresses in the cortical bone at the start (eg, BI\textsubscript{3}) and finish (eg, BI\textsubscript{4}) points of the stress measurement lines.

For the cortical bone, the maximum stress occurred at or in close vicinity to the starting point of the stress measurement lines for all the implant systems as a result of the adjacent stress concentration within the cancellous bone (see Fig 5 and Table 3). Local stress peaks were identified at points E, F, G, and H and were attributable to the geometric shape of the cortical bone, as illustrated in Fig 5. The maximum stresses at Points BI\textsubscript{3} (for Bicon) and ND\textsubscript{3} (for Neodent) are lower than that of all the other implants, as shown in Figs 5a and 5b. The indentation on the Bicon implant neck and the straight edge of the Neodent neck were believed to contribute to the reduced stresses. The stress profile characteristics of all the systems are similar, as demonstrated in Figs 5e to 5h.

**DISCUSSION**

Comparing the results of the current study with those of Guan et al.,\textsuperscript{21} it can be demonstrated that the von Mises stress levels in the cancellous and cortical bone produced by the short implants are, respectively, two and three times larger than those of longer implants (ie, 7 to 15 mm in length). Note that other implant and bone variables have been deliberately taken as similar. This study thus offers insight into the performance of typical short implants and their impact on the stresses in the surrounding bone. The findings are in close agreement with manufacturers’ design objectives. Bicon’s design aim is to increase the surface contact area and thus maintain cortical bone height by virtue of an indentation on the implant neck; the contact area is indeed increased, and the stress in the cortical bone reduced. This is supported by the results shown in Fig 5a, where the stress level is shown to be reduced compared with the Nobel Biocare and Straumann systems. The philosophy of the Neodent design is to introduce a relatively large taper that helps to reduce the stresses in the cancellous bone, as evident in Fig 4b. As a desirable objective for weak cancellous bone, Nobel Biocare’s small thread pitch increases surface contact area of the implant, leading to reduced stress in the cancellous bone. This was also confirmed by the results shown in Fig 4c. The Straumann catalog indicates that the increased thread pitch results in a reduced surface contact area. This in turn leads to increased stress in the cancellous bone (as demonstrated in Fig 4d).

**CONCLUSION**

This study evaluates the stress characteristics in the posterior maxilla for four short implant systems (Bicon, Neodent, Nobel Biocare, and Straumann) subject to normal and traumatic masticatory loads, average abutment screw preloads, high crown height–implant length ratios, low Young modulus for cancellous bone, and small cortical bone thicknesses. The findings in relation to the stress characteristics were in close agreement with manufacturers’ design objectives. Overall, the Nobel Biocare and Bicon systems are recommended for type 4 cancellous and cortical bone, respectively. The placement of dental implants commonly results in damage to, and loss of, crestal bone around the implant neck. Research\textsuperscript{15} has suggested that occlusal overload is a common cause of this. The present study showed that increased stress in the crestal bone region was attributable to the combination of crown height–implant length ratio and the inclined nature of the masticatory force, which induced a bending moment pivoting on the crestal bone around the head of the implant itself. Careful attention therefore should
be paid when choosing implants for placement in posterior regions with weak bone.

ACKNOWLEDGMENTS

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REFERENCES


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Influence of Implant Length and Bicortical Anchorage on Implant Stress Distribution

Laurent Pierrisnard, DDS;* Franck Renouard, DDS;† Patrick Renault, DDS;* Michel Barquins‡

ABSTRACT

Background: Short implants present superior failure rates for everybody.

Purpose: The aim of this theoretic study was to assess to what extent implant length and bicortical anchorage affect the way stress is transferred to implant components, the implant proper, and the surrounding bone.

Materials and Methods: Stress analysis was performed using finite element analysis. A three-dimensional linear elastic model was generated. All implants modeled were of the same diameter (3.75 mm) but varied in length, at 6, 7, 8, 9, 10, 11, and 12 mm (Bränemark System®, Nobel Biocare AB, Gothenburg, Sweden). Each implant was modeled with a titanium abutment screw and abutment, a gold cylinder and prosthetic screw, and a ceramic crown. The implants were seated in a supporting bone structure consisting of cortical and cancellous bone. An occlusal load of 100 N was applied at a 30° angle to the buccolingual plane.

Results: With the selected model and bone properties, the coronal cortical anchorage was dominating, and the bone stress concentrated to that area.

Conclusions: The maximum bone stress was virtually constant, independent of implant length and bicortical anchorage. The maximum implant stress, however, increased somewhat with implant length and bicortical anchorage.

KEY WORDS: bicortical anchorage, bone stress, finite element analysis, implant length, implant stress

It has often been argued that the use of long implants (length ≥ 10 mm) is a positive factor in osseointegration, and many authors have reported on failures with short implants.1,2 However, few studies that analyze the long-term performance of short implants have been conducted.3,4 A retrospective clinical analysis on different implant dimensions2 has strengthened the authors' belief that using long implants probably does not always present a biomechanical advantage and that, in fact, shorter (6, 7, or 8.5 mm) implants may offer enhanced long-term performance in some situations.

Lack of initial stability has often been assumed to be the causative factor for early implant failures.5–7 When an implant has become integrated, however, the loss of integration is most often attributed to overload. In some overload situations the implant components may fail, but this does not occur until after several years.8 Therefore, bone stress may have both short- and long-term influence on implant survival. If the implant anchorage has a good prognosis, the mechanical stress in the components might be the next criterion to consider.

The purpose of this theoretic study using the finite element method is to assess to what extent implant length and bicortical anchorage affect the way stress is transferred to implant components, the implant proper, and the surrounding bone. With better knowledge in this area, it would be possible to improve both short- and long-term implant prognoses, considering both the aspect of osseointegration and mechanical integrity. It is the hypothesis of the authors that short implants may be an effective alternative in many clinical situations.

MATERIALS AND METHODS

Finite element analysis is a computer-based method used to calculate and visually represent stresses and strains in complex structures subjected to simulated loads. The software package used in this study was CADSAP® (CADLM, Gif-sur-Yvette, France), a French version of
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Figure 1 Plane view of the seven modeled implants. The 12 mm implant was studied first with a monocortical anchorage and then with a bicortical anchorage.

SUPERSAP® (ALGOR Interactive Systems, Inc., Pittsburgh, PA, USA), running on a compatible personal computer. Three-dimensional modeling assuming linear elasticity was carried out. All implants modeled were of the same diameter (3.75 mm) but varied in length (6, 7, 8, 9, 10, 11, and 12 mm) (Figure 1). The number of elements for each model is shown in Table 1. The bone and implant elements were firmly attached to each other, mimicking a complete osseointegration.

The implants and their components were modeled on the basis of drawings provided by Nobel Biocare AB (Gothenburg, Sweden). The implant was fitted with a titanium abutment screw and abutment, a gold cylinder and a prosthetic screw, and a ceramic crown (Figure 2). The threads were modeled as grooves for facilitating the calculations.

The calculations required knowledge of the mechanical materials properties of the models, such as Young's modulus (E) and Poisson's ratio (v). Bone tissue presents many mechanical variables, and there exists a wide variety of data regarding the mechanical properties of bone.9 In this study 14 GPa was selected for cortical bone and 2.5 GPa for cancellous bone. The material data used in the calculations are presented in Table 2.

The implant was seated in a supporting structure of cortical and cancellous bone (Figure 3). In the model, the implant neck is anchored in a cortical layer of 1 mm in thickness, and the remaining apical support is cancellous bone. In the case of bicortical anchorage, the apical implant end is anchored in cortical bone as well. An occlusal load of 100 N was applied to the implant at a 30° angle to the buccolingual plane (Figure 4).

The location and intensity of stress and the implant displacement in bone were calculated. It was hypothesized that compression is the most detrimental stress type for bone tissue and has a potential to lead to bone resorption whereas von Mises stress (maximum shear stress) was assumed to be the critical stress for the implant components. The color code is indicated in the illustrations; red and orange indicate high-intensity stresses.

RESULTS

Bone Stress

The bone compressive stress intensity for the model is shown in Figures 5 and 6 for different implant lengths (6 mm and 12 mm, respectively). The implant length did not influence the bone stress location. Whatever the implant length, the stress was located at the implant neck level. Beyond the 3 cervical millimeters, the stress intensity was low.

The peak stress was local and was positioned in the groove of the first thread. The difference in bone stress between a 6 mm, a 12 mm, and a 12 mm bicortical implant varies from 2.4 to 7.4% (Figure 7). The bone stress in the cortical portion was virtually constant.

Implant Displacement in Bone

The displacement of the implant in the bone is somewhat reduced by increasing implant length, but at the implant neck level the difference of the displacement between long and short implants is small (Figures 8 and 9). The bicortical anchorage, however, reduces the displacement somewhat (the bicortical implant has 5.8% less displacement compared with a 12 mm monocortical implant and has 8.4% less displacement compared with a 6 mm monocortical implant). At the apical level, the difference is more important (Figure 10). The displacement of a 12 mm bicortical implant is 88% lower compared with a 6 mm monocortical implant.

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Models 7, 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>No. of elements</td>
<td>4,322</td>
<td>4,982</td>
<td>5,570</td>
<td>6,142</td>
<td>6,842</td>
<td>7,302</td>
</tr>
</tbody>
</table>
Implant Component Stress

Implant. Figures 11 and 12 illustrate stresses in the 6 mm and 12 mm implants. Irrespective of the models, the cervical areas were submitted to the most intense stress (red and orange zones) whereas the apical areas were under less stress; stress intensity was seen to decrease progressively from the cervical to the apical area. Beyond 8 mm, increased implant length led to higher stress intensity (16.8%), up to an implant length of 12 mm. Bicortical anchorage at the 12 mm implant resulted in a 29% stress increase (Figure 13).

Abutment Screw. Figures 14 and 15 illustrate stresses in the 6 mm and 12 mm implant abutment screws. In the case of the 6 mm implant screw, the highest stress area (red and orange zones) is found at the narrowing of the screw diameter. Increased implant length has a negative effect; a stress increase of 9.6% is seen between 6 mm and 12 mm. Compared to an implant of the same length, bicortical anchorage of the 12 mm implant leads to a 12.2% stress increase in the abutment screw (Figure 16).

Gold Screw. Figure 17 illustrates stresses in a randomly selected gold screw. Irrespective of the models, the narrow junction between the shaft and head of the screw was subjected to the most intense stresses. Regardless of anchorage type and implant length, no differences were noted in the intensity of the stresses to which the gold screws were subjected.

Figure 18 provides a comparison of the maximum intensities of von Mises stresses for each model. It was concluded from this analysis that (1) implant length and bicortical anchorage have an impact on the intensity of stresses transferred to the abutment screw and the implant proper, (2) implant length and bicortical anchorage have no impact on the intensity of stresses transferred to the gold screw, and (3) the most intensive stresses are found in the titanium abutment screw.

Table 2: Mechanical Properties of Materials Used in Study

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus E (GPa)</th>
<th>Poisson's Ratio</th>
<th>Gold Alloy</th>
<th>Ceramic</th>
<th>Cancellous Bone</th>
<th>Cortical Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>110.0</td>
<td>0.3</td>
<td>86.0</td>
<td>96.0</td>
<td>2.5</td>
<td>14.0</td>
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<tr>
<td>Ceramic Bone</td>
<td>14.0</td>
<td>0.35</td>
<td>0.33</td>
<td>0.28</td>
<td>0.3</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure 3 Cross-section of the 12 mm implant inserted into the bony supporting structure. A, Monocortical anchorage. B, Bicortical anchorage.

Figure 4 Cross-section of the assembled model. An occlusal load of 100 N is applied at a 30° angle to the buccolingual plane (arrow).
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Stress intensities

Figure 5 Localization of stress in the bone supporting the 6 mm implant. Positive values represent tensile stress; negative values represent compressive stress.

Figure 6 Localization of stress in the bone supporting the 12 mm implant. Positive values represent tensile stress; negative values represent compressive stress.

DISCUSSION
In the present model the bone stress is concentrated to the cervical area. It is assumed that the implant is completely integrated to bone and that the 1 mm cervical cortical layer serves as the major anchoring for the implant. Consequently, any variation in the length of the implant in the softer cancellous bone has little influence on bone stress. This is understandable because the cortical bone is about five times stiffer than the cancellous bone. The fact that there is a slightly higher stress level in the bone for the longer implants should be interpreted with care as this stress is local and isolated; it might as well be a consequence of a model limitation per se.

This finding of bone stress concentration to the cervical area confirms the previous work of several authors. Meijer and colleagues10 studied the distribution of stresses around dental implants. The main stress peak was found in the cortical bone layer around the neck of the implant. Nishihara and Nakagiri11 observed a concentration of stresses at the neck of the implant and also noted that implant geometry had a significant impact on stress distribution. Hedias12 has observed a higher level of stress in cortical bone surrounding the neck of the implant.

Figure 7 Histogram displaying stress intensities in the bone.
This study also highlights the fact that implant length and bicortical anchorage improve the initial stability (measured as implant displacement) of the apical portion of the implant but have very little influence on the difference of displacement of the coronal part of the implant. That could explain how van Oosterwyck and colleagues, using finite element analysis, showed that bicortical anchorage did not reduce the risk of marginal bone loss when implants were submitted to lateral forces. Rangert and colleagues demonstrated that the cervical area is critical, with concentrated high-intensity stresses, particularly when the implant is subjected to lateral forces. That means that the first three to five threads are most involved in the stress absorption.

Figure 8 Diagram showing the movement of implants of different lengths in the bone (amplified x300). Left, a 6 mm implant; middle, a 12 mm monocortical implant; right, a 12 mm bicortical implant. The initial positions of the implants are shown in black.

Figure 9 Histogram displaying implant displacement at the cervical level.

Figure 10 Histogram displaying implant displacement at the apical level.
Pierrisnard and colleagues,\textsuperscript{16} using the finite element method, showed that greater implant length did not positively affect the way stresses were transferred to the implant. However, they also found that increasing implant diameter reduced the intensity of stresses along the length of the implant. Therefore, to increase the load-bearing capacity of implant prostheses, one could suggest using wider implants instead of longer implants. Iplikcioglu and Akca used the same method\textsuperscript{17} and showed that the change in the length of implants did not decrease the stress levels whereas lower stress values were observed in the bone for wider implant placement configurations.

In a recent retrospective clinical study, Ivanoff and colleagues\textsuperscript{18} challenged the theory that bicortical anchorage increases the long-term resistance of implants to occlusal load. The authors conducted a 15-year retrospective study analyzing the performance of same-length mono- or bicortically anchored implants. They found that failures were four times more frequent in bicortically anchored constructions, especially in regard to the rate of implant fractures. This finding
challenges one of the fundamental principles of implant surgery. Regardless of implant length, most authors have consistently pointed out that bicortical anchorage enhances implant stability.\textsuperscript{19,20}

The result presented in the study by Ivanoff and colleagues\textsuperscript{18} could be explained by the higher mobility in the bone at short implants when compared with longer implants, as shown in Figure 13. With short implants bone may flex more and act as a stress breaker.

Work by Morgan and colleagues\textsuperscript{21} has demonstrated that the mechanical failure of an implant is linked to fatigue. Submitted to the same load, long implants may take a larger load share owing to their stiffer anchorage whereas shorter implants may be subjected to lower stress and a lower risk of screw loosening and/or component fracture, owing to the greater flexion in bone.
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This finite element analysis shows that maximum shear stresses, as measured in the implant and in the abutment screw, are higher in long implants (> 8 mm) than in short devices (6, 7, and 8 mm). Compared with a 6 mm device, stresses measured were 17% greater in a 12 mm implant and 29% higher in a bicortically anchored 12 mm implant. Similar ratios were found when shear stresses in the abutment screw were analyzed. These findings may appear paradoxical as they imply that increased implant length results in greater stresses to the implant and the abutment screw. The explanation is, however, logical. A short implant anchored in cortical bone at the neck will have less force reaction from the medullar cancellous bone than will a long implant or an apically anchored implant. That the gold screw does not change with implant bone anchorage is also logical as this screw is completely above the bone structure.

Long bicortical implants tend to bend when loaded whereas short monocortical implants may move and rotate slightly, with a small deformation of the bone. This micromotion could be a risk for the bone healing process. Therefore, the use of a short implant in the immediate function protocol should be confirmed. However, when implants are fully osseointegrated, the capacity of short implants to move when submitted to load could become an advantage. It could be assumed that in case of overload, long implants should present mainly mechanical complications whereas short implants should fail owing to biologic problems.

A clinical requirement, based on the importance of the cervical anchorage, is to be careful during the preparation of the crestal part of the implant site. When possible, it seems better to avoid the use of a countersink to maintain the crestal cortical layer to ensure the load-bearing capacity at the implant neck and to engage implant threads in that strong bone. However, the model adopted represents a simplification of prob-
lem formulation, and other selections of cortical bone dimension or assumed bone stiffness might lead to other conclusions. Consequently, the results cannot suggest clinical protocols, but the analysis developed offers a comparison of results and suggests explanations for some of the biomechanical behavior of implants.

CONCLUSION

This finite element analysis comparing implants of different lengths and anchorage is theoretic but helps in assessing risk factors. It has often been argued that the use of long implants (≥ 10 mm) is a positive factor in osseointegration as higher success rates have been demonstrated for long implants. This could be explained by the greater stability of the apical part of long implants when compared with shorter implants. However, this theoretic analysis shows that increased implant length does not always result in a better distribution of stresses to implant, abutment, and bone. If the cortical anchorage of the implant neck is high, the influence of implant length becomes less important. Further, in some situations the lower anchorage stiffness of short implants might reduce the mechanical stress to the implant because of the flexibility of the bone. The study’s results encourage the use of short implants in selected cases.

REFERENCES

Short (8-mm) locking-taper implants supporting single crowns in posterior region: a prospective clinical study with 1-to 10-years of follow-up

Key words: implant survival, implant-crown success, locking-taper implants, short implants, single crowns

Abstract

Objective: The aim of this study was to evaluate the long-term outcome of short (8-mm) locking-taper implants supporting single crowns in the posterior regions and to analyze the influence of different factors on implant survival and implant-crown success rates.

Materials and methods: Between June 2002 and September 2011, all patients referred to two private practices for treatment with short (8-mm) implants supporting single tooth restorations in posterior areas of both jaws were considered for inclusion in this study. At each annual follow-up session, clinical and radiographic parameters were assessed. Implant-crown success criteria included absence of pain, suppuration, mobility, and peri-implant radiolucency, distance between the implant shoulder and the first visible bone-to-implant contact (DIB) <1.5 mm after 12 months and not exceeding 0.2 mm for each following year, absence of prosthetic complications. The cumulative survival and implant-crown success were assessed using the Kaplan-Meier survival estimator; Chi-square test was applied to evaluate correlations between the study variables. The statistical analysis was performed at the patient and at the implant level.

Results: Two hundred and fifteen implants (124 maxilla; 91 mandible) were placed in 194 patients (104 men; 90 women). Three implants failed (2 maxilla; 1 mandible). The 10-year cumulative survival rate was 98.4% (patient-based) and 98.5% (implant-based). Among the surviving implants, the mean DIB was 0.31 (±0.24), 0.43 (±0.29), and 0.62 (±0.31) mm at the 1-, 5-, and 10-year follow-up session; two biologic and three prosthetic complications were reported, for a 10-year cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based). The implant survival and implant-crown success rates did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, and bone type.

Conclusions: The use of short (8-mm) locking-taper implants is a predictable treatment modality for the restoration of single tooth gaps of posterior segments of dentition.

Osseointegrated implants have become a viable option for replacing missing teeth in totally and partially edentulous patients, particularly in the case of single tooth gaps [Jung et al. 2012].

However, reduced alveolar bone height can limit implant placement, especially in the posterior regions of the maxilla and mandible. In fact, the location of anatomical structures, such as the maxillary sinus and the inferior alveolar nerve, may limit the availability of sufficient bone volume to place dental implants [Morand & Irinakis 2007; Esposito et al. 2011; Annibali et al. 2012; Monje et al. 2012].

In the situation of extremely reduced bone height, it may be necessary to increase the geometry and volume of the alveolar bone before placement of dental implants. At present, this can be obtained by sinus elevation [Mangano et al. 2007], grafting techniques [Scarano et al. 2011], transposition of the inferior alveolar nerve [Chrcanovic & Custódio 2009], or by intrabony distraction of the alveolar process [Chiapasco et al. 2004]; however, these surgical procedures are technically demanding, and may increase postoperative morbidity and the total cost and duration of the therapy [Esposito et al. 2011].
An alternative therapy in situations with limited amounts of bone available is the placement of short implants (Annibali et al. 2012, Monje et al. 2012). The definitions of short implants vary in the literature, and authors have defined implant length <11-mm (das Neves et al. 2006), 10-mm (Morand & Irinakis 2007) or 8-mm (Renouard & Nisand 2006) as short implants. Tellemann [Tellemann et al. 2011] argued that a short implant should be defined as an implant with a designed intrabony length of 8-mm or less [Renouard & Nisand 2006].

The use of short implants simplifies the restoration of posterior segments of dentition. In fact, it reduces the need for bone augmentation procedures prior to or in conjunction with implant placement in both jaws; furthermore, there is less surgical risk of sinus perforation, or mandibular paresthesia, with an overall reduction in surgical complexity [Tellemann et al. 2011, Annibali et al. 2012, Monje et al. 2012].

In the past, short implants in the posterior maxilla or mandible have been associated with lower survival rates and unpredictable long-term outcomes (Naert et al. 2002, Perrarisard et al. 2003, Weng et al. 2003, Lee et al. 2005).

In spite of the aforementioned research demonstrating a lower predictability for short implants, recent studies have indicated that short implants can present a similar survival rate to standard length implants (Nedir et al. 2004, Misch et al. 2006, Anitua & Otive 2010, Tellemann et al. 2011). In a recent systematic review by Monje et al. (2012), short implants had an estimated survival rate of 88.1% at 168 months, when standard implants had a similar estimated survival rate of 86.7%. These results are in accordance with those of two previous reviews, where no differences in the failure rates of short and standard implants were reported [Sun et al. 2011; Tellemann et al. 2011].

However, only a few studies on short implants were about single tooth replacements in posterior region [Mericckse-Stern et al. 2001, Rossi et al. 2010, Lai et al. 2013].

In the last years, locking-taper implant-abutment connection has been introduced as an alternative to screw-retained abutment systems (Bozkaya & Muftu 2003). Locking-taper implant systems are composed of an implant and an abutment joined together by a self-locking connection. As a result of a Morse taper, this tapered fit implant-abutment connection is able to induce a self-locking mating between the parts (Bozkaya & Muftu 2003). Several studies have demonstrated that locking-taper implants can represent an ideal treatment option for single tooth replacement in the posterior areas of both arches (Mangano & Bartolucci 2001, Mangano et al. 2010, 2011; Urdaneta et al. 2012).

The aim of this prospective study was to evaluate the long-term outcomes of short (8-mm) locking-taper implants supporting single crowns in the posterior regions of the maxilla and mandible.

Materials and methods

Patient selection
Between June 2002 and September 2011, all patients referred to two private dental practices for treatment with dental implants were considered for inclusion in this study. All treatments were carried out by the same practitioner. Inclusion criteria were as follows: [i] age >18 years, (ii) good systemic and oral health, (iii) single tooth gaps in the posterior regions (premolars and molars) of maxilla/mandible (iv) at least 6 weeks of healing after tooth extraction, (v) installation of short dental implants with intrabony length of 8.0 mm, (vi) dentition in the opposing jaw to obtain occlusal contacts. Exclusion criteria consisted of: (i) poor oral hygiene, (ii) active periodontal infections or other oral disorders, (iii) insufficient bone quantity to place an implant of 8 mm length, (iv) bone augmentation procedures with autogenous bone or bone substitutes, (v) uncontrolled diabetes mellitus, (vi) systemic immune disorders. Smoking and bruxism were recorded but were not considered as an exclusion criteria for this study. Smokers were defined as patients who smoked cigarettes without considering the amount. Patients were advised that smoking is associated with an increased risk of implant failure. Bruxers were patients with a repetitive jaw-muscle activity characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible. Patients’ questionnaires, clinical examination, and electro- myography were used for the diagnosis of bruxism (Lobbezoo et al. 2013). The study protocol was explained to each subject, and signed informed consent was obtained. The study protocol was approved by the local ethical committee and was performed according to the principles outlined in the World’s Medical Association’s Declaration of Helsinki on experimentation involving human subjects, as revised in 2000.

Preoperative work-up
A complete examination of the oral hard and soft tissues was carried out for each patient. Panoramic radiographs formed the basis for the primary investigation. Only in a few cases, computed tomography (CBCT) scans were used as the final investigation. CBCT datasets were acquired and then transferred to specific implant navigation software [Mimics®, Materialise, Leuven, Belgium], to perform a three-dimensional reconstruction of the maxillary bones. With this navigation software, it was possible to correctly assess the width of each implant site, the thickness and the density of the cortical plates and the cancellous bone, as well as the ridge angulation. On the basis of this information, surgical templates were manufactured. Preoperative work-ups also included an assessment of the edentulous ridges using casts and diagnostic wax-up.

Implant placement
Local anesthesia was obtained by infiltrating articaine (4%) containing 1 : 100.000 adrenalin [Ubiestin®, 3M Espe, St. Paul, MN, USA]. A midcrestal incision was made at the sites of implant placement. The mesial and distal aspects of the crestal incision were connected to two releasing incisions. Full thickness flaps were reflected exposing the alveolar ridge, and preparation of implant sites was carried out with spiral drills of increasing diameter (2.8 mm to place an implant with 3.3 mm diameter; 2.8 and 3.5 mm, to place an implant with 4.1 mm diameter; an additional 4.2 mm drill was used to prepare the site for 4.8 mm diameter implants), under constant irrigation. Short-length (8 mm) rough-surfaced implants, made of grade-5 titanium [Leone Implant System®, Florence, Italy], were placed in the prepared sites. The surface of these implants was blasted with 50 µm Al₂O₃ particles and acid-etched with HNO₃, after which the average of roughness (i.e., the mean of the peak-valley distance on surface irregularities) was 0.5 µm. This implant system used a cone Morse taper-interference-fit locking-taper combined with an internal hexagon. The Morse taper presented a taper angle of 1.5° [Mangano et al. 2009, 2011]. All implants were positioned with good primary stability. Finally, sutures were performed [Supramid®, Novaxa Spa, Milan, Italy].

Postoperative treatment
All patients received oral antibiotics, 2 g each day for 6 days [Augmentin®; GlaxoSmithKline Beecham, Brentford, UK].

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Postoperative pain was controlled by administering 100 mg nimesulide (Aulin®; Roche Pharmaceutical, Basel, Switzerland) every 12 h for 2 days, and detailed instructions about oral hygiene were given, with mouthrinses with 0.12% chlorhexidine (Chlorexidine®; Oralib, Boston, MA, USA) administered for 7 days. Suture removal was performed at 8–10 days.

Healing period
A two-stage technique was used to place the implants. The healing time was 3 months in the lower jaw and 4 months in the upper jaw. No early exposures before two-stage surgery were noted. Second-stage surgery was conducted to gain access to the underlying implants, and healing abutments were placed and activated, so that acrylic provisional restorations could be provided. The prosthetic restorations were all single crowns. Acrylic resin provisional restorations were used to monitor implant stability under a progressive load and to obtain good soft tissue healing around the implant before fabrication of the definitive restorations. The temporary restorations remained in situ for 3 months, and after this period, definitive restorations were placed. All definitive restorations were ceramo-metallic, cemented with temporary cement (Temp-Bond®, Kerr, Orange, CA, USA). All restorations were carefully evaluated for proper occlusion, and protrusion and laterotrusion were assessed on the articulator and intraorally.

Clinical, radiographic and prosthetic evaluation
The patients were recalled for clinical, radiographic, and prosthetic examination every 12 months. During each annual follow-up visit, the clinical assessment of implants, peri-implant tissues, and prostheses were conducted by a surgeon and a prosthodontist, who were not directly involved in the treatment for the patients. At each follow-up session, for each single implant, the following success criteria: (i) absence of pain/sensitivity; (ii) absence of suppur-ration/exudation; (iii) absence of clinically detectable implant mobility; (iv) absence of continuous peri-implant radiolucency; (v) DIB < 1.5 mm after 12 months of functional loading, and not exceeding 0.2 mm for each following year; (vi) absence of prosthetic complications (Albrektsson & Zarb 1998).

Statistical analysis
Data collection and analyses were performed by two independent examiners (a surgeon and a prosthodontist) who were not directly involved in the treatment for the patients. A database was created using Excel 2007 (Microsoft Excel®, Microsoft Corporation, Redmond, WA, USA) and used for the analysis. Descriptive statistics were obtained, absolute and relative frequency distributions were calculated for qualitative variables, and means, standard deviations (SD), medians, ranges, and confidence intervals (CI: 95%) were calculated for quantitative variables. Implant failure was the principal variable of this study. The cumulative survival and implant-crown success rate of implants were estimated both by an implant-based and a patient-based analysis. In the implant-based analysis, each inserted implant was consid-ered as the analysis unit, whereas in the patient-based analysis, each patient was considered as the statistical unit. In the patient-based analysis, in case of multiple indications for implant therapy (with the same patient receiving more than one implant), the patient was classified as a failure even in the event a single implant loss. In both types of analysis, the implant survival and implant-crown success as a function of the time were analyzed using the Kaplan–Meier survival estimator (Kaplan & Meier 1958). In addition, a Chi-square test was applied to assess the influence of variables on survival and success rates. Variables including age at surgery, gender, smoking habit (smokers or non-smokers), and parafunctional habits (bruxists or non-bruxists) were analyzed at the patient-level. Variables including implant position (mandible or maxilla), implant diameter (3.3, 4.1 or 4.8 mm), and bone type were analyzed at the implant level. Bone quality was ascertained clinically by tactile evaluation at the time of implant placement, during drilling, according to the clinician’s judgment (Lai et al. 2013), and by radiographic assessment according to the criteria of Lekholm & Zarb (1985) index. In particular, following the withdrawal of an
osteotomy reamer, an assessment of the bone in the reamer flutes was conducted in terms of quality and appearance (Gentile et al. 2005). Bone quality was classified as type I if the bone was compact, near bloodless cortical bone. Type II bone was red and filled the flutes of the reamer. If no bone remained in the flutes, the bone quality was classified as type IV. If the findings were intermediate between those described for types II and IV, the bone was categorized as type III. Data analysis was performed with a statistical software package (SPSS 17.0; SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05.

Results

Patient population and implant-supported restorations

One hundred and ninety-four patients (104 men and 90 women, aged between 24 and 74 years, mean 49.1 ± 11.5) were eligible for this study. Among these patients, 35 (18.0%) were smokers and 24 (12.3%) were bruxists. The average follow-up time was 5.6 ± 2.7 years. Ten of the 194 enrolled patients had multiple indications for implant therapy, such that a total of 215 short (8-mm) locking-taper implants were placed. One hundred and twenty-four implants (57.7%) were inserted in the maxilla, while 91 implants (42.3%) were inserted in the mandible. With regard to the position of the installed implants, 55 implants (25.6%) were maxillary premolars, 69 (32.1%) were maxillary molars, 20 (9.3%) were mandibular premolars, and 71 (33.0%) were mandibular molars. The most frequently used implant diameter was 4.8 mm, with 114 implants (53.0%), followed by 4.1 mm, with 96 implants (44.7%), and 3.3 mm, with only five implants (2.3%). The prosthetic restorations comprised 215 single crowns.

Implant survival

Three implants failed and had to be removed, in three different patients. Five of the 194 patients were classified as dropouts because they missed the last scheduled appointment. At the end of the study, an overall cumulative survival rate of 98.5% (implant-based) and 98.4% (patient-based) was achieved at 10-year follow-up, with 212 implants still in function. In the maxilla, the cumulative survival rate was 98.3%, with two implants failed and removed. In the mandible, the cumulative survival rate was 98.9%, with one implant failure. With regard to the position of the failed implants, 2 were maxillary first molars, and 1 was a mandibular first premolar. Two implants were lost within the healing period, before the abutment connection: these implants were classified as “early failures”, showing implant mobility due to lack of osseointegration, before functional loading. One implant failed after 2 years of prosthetic loading, this implant was classified as a “late failure”, because of progressive bone loss due to mechanical overloading, without clinical signs of peri-implant infection. The details of the failed implants are recorded in Table 1. The evaluation of the potential influence of different patient-related and implant-related variables on implant survival is reported in Tables 2 and 3, respectively. The survival rate did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, or bone type.

Implant-crown success

Among the surviving implants (212), the radiographic evaluation revealed a mean distance from the implant shoulder to the first visible bone-to-implant contact (DIB) of 0.31 ± 0.24 [range: 0–1.8; CI 95%: 0.28–0.34], 0.43 ± 0.29 [range: 0–2.2; CI 95%: 0.38–0.48], and 0.62 ± 0.31 [range: 0–1.2; CI 95%: 0.46–0.78] at the 1-, 5-, and 10-year follow-up session, respectively [Fig. 1a-d, Table 4]. Minimal changes were seen in the bone level between the 1-, 5-, and 10-year examinations. Only two implants showed bone loss ≥ 1.5 mm after the first year of functional loading: these implants were registered as unsuccessful implants, according to the established implant-crown survival criteria. However, none of the implants showed a marginal bone loss >2.5 mm, at the final follow-up examination. A prosthetic abutment of a first mandibular molar became loose during the third year of function. This abutment was reinserted, and no further loosenings were observed, however, this was considered a prosthetic complication. The overall incidence of abutment loosening was 0.47%. No other prosthetic complications related to implant-abutment connection were evidenced. However, two porcelain fractures were reported. With regard to all these data, only five surviving implants could not fulfill the established success criteria [with two implants revealing DIB >1.5 mm after the first year of function, one implant showing abutment loosening and two porcelain fractures], for a overall cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based) [Table 5]. The evaluation of the potential influence of different patient-related and implant-related variables on implant-crown success rate is reported in Tables 6 and 7, respectively. The

Table 1. Failed implants

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>Site</th>
<th>Bone type</th>
<th>Smoke</th>
<th>Bruxism</th>
<th>Diameter</th>
<th>Time of failure</th>
<th>Cause of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>54</td>
<td>1.6</td>
<td>IV</td>
<td>Yes</td>
<td>No</td>
<td>4.8 mm</td>
<td>4 months after surgery</td>
<td>Implant mobility - Lack of osseointegration</td>
</tr>
<tr>
<td>F</td>
<td>48</td>
<td>3.4</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.1 mm</td>
<td>3 months after surgery</td>
<td>Implant mobility - Lack of osseointegration</td>
</tr>
<tr>
<td>M</td>
<td>34</td>
<td>2.6</td>
<td>IV</td>
<td>No</td>
<td>Yes</td>
<td>4.1 mm</td>
<td>2 years after prosthetic loading</td>
<td>Progressive bone loss due to mechanical overload</td>
</tr>
</tbody>
</table>

Table 2. Implant survival: analysis of patient-related variables

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of patients</th>
<th>Failures</th>
<th>Cumulative survival rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>104</td>
<td>2</td>
<td>98.0</td>
<td>0.648</td>
</tr>
<tr>
<td>Female</td>
<td>90</td>
<td>1</td>
<td>98.9</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-34</td>
<td>14</td>
<td>1</td>
<td>92.9</td>
<td>0.224</td>
</tr>
<tr>
<td>35-44</td>
<td>46</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>45-54</td>
<td>65</td>
<td>2</td>
<td>96.9</td>
<td></td>
</tr>
<tr>
<td>55-64</td>
<td>46</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>64+</td>
<td>23</td>
<td>–</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Smoking habit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smokers</td>
<td>35</td>
<td>1</td>
<td>97.1</td>
<td>0.488</td>
</tr>
<tr>
<td>Non-smokers</td>
<td>159</td>
<td>2</td>
<td>98.7</td>
<td></td>
</tr>
<tr>
<td>Parafunctional habit/bruxism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bruxists</td>
<td>24</td>
<td>1</td>
<td>95.5</td>
<td>0.266</td>
</tr>
<tr>
<td>Non-bruxists</td>
<td>170</td>
<td>2</td>
<td>98.8</td>
<td></td>
</tr>
</tbody>
</table>
In recent years, however, several clinical studies have reported excellent success rates with the use of short implants (Nedir et al. 2004; Misch et al. 2006; Anitua & Orive 2010; Urdaneta et al. 2012), and the recent literature has demonstrated a similar survival rate for short and standard length implants (Kotsovilis et al. 2009; Sun et al. 2011; Monje et al. 2012). A recent systematic review (Sun et al. 2011) found no differences in the failure rates of short and standard implants, with a long-term failure rate of 2.5% for 8-mm implants. In another review comparing short implants with conventional implants, Kotsovilis et al. (2009) concluded that short implants (≤ 8 mm) with rough surfaces are no less effective than implants of standard length (≥ 10 mm) with rough surfaces.

Different reasons have been put forward to explain this situation. Firstly, compared with longer implants with a comparable diameter, there is less bone-to-implant contact when short implants are used, because there is less implant surface. Secondly, short implants are mostly placed in the posterior zone, where the quality of the alveolar bone is relatively poor (type III or IV), in the maxilla (Lekholm & Zarb 1985). Thirdly, a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which causes a higher crown-to-implant ratio. Crown-to-implant ratios between 0.5 and 1 were proposed to prevent peri-implant bone stress, crestal bone loss, and eventually implant failure (Lee et al. 2005).

In recent years, however, several clinical studies have reported excellent success rates with the use of short implants (Nedir et al. 2004; Misch et al. 2006; Anitua & Orive 2010; Urdaneta et al. 2012), and the recent literature has demonstrated a similar survival rate for short and standard length implants (Kotsovilis et al. 2009; Sun et al. 2011; Monje et al. 2012). A recent systematic review (Sun et al. 2011) found no differences in the failure rates of short and standard implants, with a long-term failure rate of 2.5% for 8-mm implants. In another review comparing short implants with conventional implants, Kotsovilis et al. (2009) concluded that short implants (≤ 8 mm) with rough surfaces are no less effective than implants of standard length (≥ 10 mm) with rough surfaces.

However, only a few studies have dealt with short implants supporting single crowns in posterior region (Mericcske-Stern et al. 2001; Rossi et al. 2010; Lai et al. 2013).

In our present study, the use of short [8-mm] locking-taper implants for the restoration of single tooth gaps in posterior areas in both jaws resulted in a 10-year cumulative survival rate of 98.4% (patient-based) and 98.5% (implant-based), respectively. Over a 10-year period, in fact, only three implants failed and had to be removed; the survival rate did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, and bone type.

Discussion

The use of short implants has grown in popularity over the recent years, as an alternative to longer implants, because there is less bone-to-implant contact when short implants are used, because there is less implant surface. Secondly, short implants are mostly placed in the posterior zone, where the quality of the alveolar bone is relatively poor (type III or IV), in the maxilla (Lekholm & Zarb 1985). Thirdly, a very outsized crown has to be made to reach occlusion, because of the extensive resorption in the posterior region, which causes a higher crown-to-implant ratio. Crown-to-implant ratios between 0.5 and 1 were proposed to prevent peri-implant bone stress, crestal bone loss, and eventually implant failure (Lee et al. 2005).

Table 3. Implant survival: analysis of implant-related variables

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of implants</th>
<th>Failures</th>
<th>Cumulative survival rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>124</td>
<td>2</td>
<td>98.3</td>
<td>0.751</td>
</tr>
<tr>
<td>Mandible</td>
<td>91</td>
<td>1</td>
<td>98.9</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 mm</td>
<td>5</td>
<td>100</td>
<td></td>
<td>0.732</td>
</tr>
<tr>
<td>4.1 mm</td>
<td>96</td>
<td>2</td>
<td>97.8</td>
<td></td>
</tr>
<tr>
<td>4.8 mm</td>
<td>114</td>
<td>1</td>
<td>99.1</td>
<td></td>
</tr>
<tr>
<td>Bone type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>–</td>
<td>–</td>
<td></td>
<td>0.681</td>
</tr>
<tr>
<td>Type II</td>
<td>36</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>78</td>
<td>1</td>
<td>98.7</td>
<td></td>
</tr>
<tr>
<td>Type IV</td>
<td>101</td>
<td>2</td>
<td>97.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Detailed data of bone crest remodeling (distance between the implant shoulder and the first visible bone-to-implant contact) of the implants evaluated in the study (in mm)

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>CI (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.31</td>
<td>0.24</td>
<td>0.3</td>
<td>0.28-0.34</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
<td>0.29</td>
<td>0.5</td>
<td>0.38-0.48</td>
</tr>
<tr>
<td>10</td>
<td>0.62</td>
<td>0.31</td>
<td>0.6</td>
<td>0.46-0.78</td>
</tr>
</tbody>
</table>

In the past, short implants have been associated with lower survival rates and unpredictable long-term outcome (Lee et al. 2005). In fact, it has been an axiom in implant dentistry that longer implants guarantee better success rates and prognosis (Lee et al. 2005), and some studies have shown that short implants placed in the posterior maxilla or mandible have statistically lower success rates (Naert et al. 2002; Weng et al. 2003).

In our present study, the use of short [8-mm] locking-taper implants for the restoration of single tooth gaps in posterior areas in both jaws resulted in a 10-year cumulative survival rate of 98.4% (patient-based) and 98.5% (implant-based), respectively. Over a 10-year period, in fact, only three implants failed and had to be removed; the survival rate did not differ significantly with respect to patients’ gender, age, smoking habit, parafunctional habit, implant location, implant diameter, and bone type. These results are similar to those reported in a retrospective long-term follow-up study by Lai et al. (2013), who found a 10-year cumulative survival rate of 98.3% (implant-based) and 97.6% (patient-based), with short dental
implants supporting single crowns in posterior regions.

The success of short implants may be dependent on multiple biological and prosthesis factors (Das Neves et al. 2006).

Biological factors, such as bone density and smoking, were found to influence the success of short implants (Telleman et al. 2011). In most studies, placement of short dental implants in the mandible had a better prognosis compared to implantation in the maxilla (Renouard & Nisand 2005; Pommier et al. 2011; Sun et al. 2011). The higher survival rate of short implants in the mandible had a better prognosis (Telleman et al. 2011). In our present study, two implants failed in the maxilla, with only one implant failure in the mandible; but with such small sample sizes the survival rate did not differ significantly with respect to implant location ($P = 0.751$). In the current literature, the results of studies excluding smokers revealed higher implant survival rates than studies including heavy smokers (>15 cigarettes/day) (Telleman et al. 2011). In our present study, only 35 patients were smokers. Among smoking patients, one implant failure was reported, in a heavy smoker (>15 cigarettes/day), for a cumulative survival rate of 97.1%, however, the survival rate did not differ significantly with respect to smoking habit ($P = 0.488$). Short implants with a roughened surface showed generally lower failure rates compared with machined surface ones (Pommier et al. 2011; Sun et al. 2011). In fact, surface geometry, composition, and hydrophilicity are key factors for the short- and long-term success of short dental implants. As demonstrated by Shalabi et al. (2006) and Wennberg & Albrektsson (2009), a positive relationship between bone-to-implant contact and surface roughness exists, as surface roughness does influence bone response at the micro- and nanometer level. In our study, the influence of surface texture was not compared as similar rough-surfaced, sandblasted and acid-etched implants were used throughout, with satisfactory 10-year survival (98.4% patient-based, 98.5% implant-based) outcomes.

Prosthetic factors, such as crown-to-implant ratio, splinting, occlusal table, opposing dentition, and bruxism, did not prove to influence short implant failure rates in recent studies (Nedir et al. 2004; Tawil et al. 2006). Even if the use of short implants leads to a higher crown-to-implant ratio, no statistically significant relationship was found between crown-to-implant ratio and crestal bone levels (Blanes 2009; Birdi et al. 2010, Urdaneta et al. 2012). Splinting of implant-crowns may lead to less stress transmitted to each bond-implant interface compared with individual implant-crowns (Misch et al. 2006), but only a few studies support the capacity of short implants restored as single crowns to withstand biomechanical stresses (Rossi et al. 2010; Lai et al. 2013). While survival and success of short implants have been widely investigated, the studies on prosthetic aspects are limited. The majority of these have only focused on implant survival, without providing information about possible prosthetic complications. In our present study on 8-mm locking-taper implants supporting single crowns, only three implants were involved in prosthetic complications, over a 10-year period. A prosthetic abutment became loose during the third year of function, and this abutment was reinserted with no further loosening. In addition, two

Table 5. Unsuccessful implant-crown restorations

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>Site</th>
<th>Bone type</th>
<th>Smoke</th>
<th>Bruxism</th>
<th>Diameter (mm)</th>
<th>Time of failure</th>
<th>Cause of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>39</td>
<td>1.6</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.8</td>
<td>8 years after loading</td>
<td>Porcelain fracture</td>
</tr>
<tr>
<td>M</td>
<td>36</td>
<td>4.7</td>
<td>IV</td>
<td>No</td>
<td>Yes</td>
<td>4.8</td>
<td>6 years after loading</td>
<td>Porcelain fracture</td>
</tr>
<tr>
<td>M</td>
<td>56</td>
<td>4.6</td>
<td>III</td>
<td>No</td>
<td>No</td>
<td>4.1</td>
<td>3 years after loading</td>
<td>Abutment loosening</td>
</tr>
<tr>
<td>F</td>
<td>48</td>
<td>1.6</td>
<td>IV</td>
<td>Yes</td>
<td>Yes</td>
<td>4.1</td>
<td>1 year after loading</td>
<td>DIB &gt; 1.5 mm</td>
</tr>
<tr>
<td>M</td>
<td>58</td>
<td>2.7</td>
<td>III</td>
<td>Yes</td>
<td>No</td>
<td>4.8</td>
<td>1 year after loading</td>
<td>DIB &gt; 1.5 mm</td>
</tr>
</tbody>
</table>

DIB, distance between the implant shoulder and the first visible bone-to-implant contact.

Table 6. Implant-crown success: analysis of patient-related variables

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Unsuccessful patients</th>
<th>Cumulative implant-crown success rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>102</td>
<td>3</td>
<td>96.3</td>
</tr>
<tr>
<td>Female</td>
<td>89</td>
<td>2</td>
<td>94.4</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24–34</td>
<td>13</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>35–44</td>
<td>46</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>45–54</td>
<td>63</td>
<td>1</td>
<td>96.8</td>
</tr>
<tr>
<td>55–64</td>
<td>46</td>
<td>2</td>
<td>97.4</td>
</tr>
<tr>
<td>64</td>
<td>23</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>Smoking habit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smokers</td>
<td>34</td>
<td>2</td>
<td>94.1</td>
</tr>
<tr>
<td>Non-smokers</td>
<td>157</td>
<td>3</td>
<td>95.9</td>
</tr>
<tr>
<td>Parafuncational habit/bruxism</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bruxists</td>
<td>23</td>
<td>2</td>
<td>87.7</td>
</tr>
<tr>
<td>Non-bruxists</td>
<td>168</td>
<td>3</td>
<td>96.9</td>
</tr>
</tbody>
</table>

Table 7. Implant-crown success: analysis of implant-related variables

<table>
<thead>
<tr>
<th>Number of implants</th>
<th>Unsuccessful implants</th>
<th>Cumulative implant-crown success rate (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxilla</td>
<td>122</td>
<td>3</td>
<td>96.0</td>
</tr>
<tr>
<td>Mandible</td>
<td>90</td>
<td>2</td>
<td>96.2</td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 mm</td>
<td>5</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>4.1 mm</td>
<td>94</td>
<td>2</td>
<td>97.5</td>
</tr>
<tr>
<td>4.8 mm</td>
<td>113</td>
<td>3</td>
<td>94.5</td>
</tr>
<tr>
<td>Bone type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>–</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>Type II</td>
<td>36</td>
<td>–</td>
<td>93.8</td>
</tr>
<tr>
<td>Type III</td>
<td>77</td>
<td>3</td>
<td>93.8</td>
</tr>
<tr>
<td>Type IV</td>
<td>99</td>
<td>2</td>
<td>97.1</td>
</tr>
</tbody>
</table>
porcelain fractures were reported, giving an overall incidence of prosthetic complication of 1.4%. In a recent review of the literature, the incidence of technical complication of single crowns on standard length (≥10 mm) implants was reported, with a cumulative incidence of 8.8% for implant–abutment screw loosening, 4.1% for loss of retention, and 3.5% for fracture of the ceramic material, after 5 years (Jung et al. 2012). The incidence of prosthetic complications reported in our study on short, locking-taper implants therefore seems to be lower [1.4%] in particular with regard to implant–abutment loosening (0.47%).

The locking-taper implant system used in the present study is composed of a fixture and an abutment joined together by a taper–taper connection guided by an internal hexagon. The Morse taper presents a taper angle of 1.5° and is able to induce a self-locking mating between the parts, thus giving a higher implant–abutment mechanical stability (Bozkaya & Muftu 2003). Recent studies have demonstrated that the Morse taper implant–abutment connection can resist eccentric loading complexes and bending moments, ensuring absolute mechanical stability and significantly reducing the incidence of prosthetic complications at the implant–abutment interface (Bozkaya & Muftu 2003; Mangano et al. 2010, 2011; Urdaneta et al. 2012). In addition, the locking-taper implant–abutment connection can provide an efficient seal against microbial penetration. In fact, it is noteworthy that all implants with screw-type connections show a microgap of variable dimensions (40–100 μm) at the implant–abutment interface (Broggini et al. 2003; Piattelli et al. 2003). As this microgap is colonized by bacteria, capable of penetrating inside the internal hollow portion of the implant, the bacterial leakage and persistent colonization may be responsible for generating a chemotactic stimulus that initiates and sustains recruitment of inflammatory cells (Broggini et al. 2003; Piattelli et al. 2003). Eventually, this could result in the development of peri-implant inflammation and bone loss (Broggini et al. 2003; Piattelli et al. 2003). The tapered interference fit reduces the microgap dimensions (1–3 μm) at the implant–abutment interface, providing an adequate biological seal, avoiding any kind of bacterial leakage (Dibart et al. 2005). This can contribute to a minimal level of peri-implant soft tissues inflammation and can guarantee long-term bone crest stability (Dibart et al. 2005). In the present study, a minimal marginal bone loss between implant installation and the 10 years’ follow-up visit was reported, with a mean DB of 0.31 (±0.24), 0.43 (±0.29) and 0.62 (±0.31) mm at the 1-, 5-, and 10-year follow-up session, respectively. Only two implants failed due to biological complications, and neither of these was overtly due to infection, giving a 10-year cumulative implant-crown success rate of 95.8% (patient-based) and 95.9% (implant-based).

Conclusions
Short implants have widened the options for implant installation, as an alternative treatment to advanced bone augmentation surgeries. In recent years, several studies have been published in which short implants were compared with conventional implants; however, long-term observations on short implants supporting single crown prostheses in the posterior region are still missing. In our present study, the use of short (8-mm) locking-taper implants was a predictable treatment modality for the restoration of single tooth gaps of posterior segments of dentition, with a 10-year cumulative survival rate of 98.4% [patient-based] and 98.5% [implant-based], respectively. However, no randomized clinical trial on implants with lengths ≤8 mm supporting single crowns is present in the literature. In future, it will be therefore necessary to present randomized controlled clinical data on short-length (<8 mm) implants, to be able to obtain definitive evidence.

Disclosure
The authors declare that they have no financial relationship with any commercial firm that may pose a conflict of interest for this study. No grants, equipment, or other sources of support were provided.

References

Mangano et al: Short locking-taper implants supporting single crowns


Assessment of Bacterial Leakage at the Implant-Abutment Interface of Internal and External Connection Implants: An In Vitro Study

Eduardo Cláudio Lopes de Chaves e Mello Dias*, Isabela Rodrigues Teixeira Silva-Olívio, Abílio Coppedé and Mário Groisman

Abstract

Objective: The presence of misfit at the implant-abutment interface can cause the accumulation of a bacterial biofilm, which leads to peri-implant bone loss, thereby compromising the long-term outcome of osseointegrated implants. The aim of this in vitro study was to assess bacterial leakage in external and internal connection implants.

Methods: Twenty-four samples were analyzed, including 12 external connection implants (Group 1) and 12 internal connection implants (Group 2). In order to assess bacterial leakage, 0.3 μL of a suspension containing Escherichia coli was inoculated in the hollow internal part of the implants. The prosthetic abutments were then installed and provided the torque recommended by the manufacturer. The samples were placed in test tubes containing a brain-heart infusion medium, and bacterial leakage was observed at 24, 48, and 72 hours, and at 7 and 14 days.

Results: No leakage was observed in Group 1 throughout the study period, whereas Group 2 showed leakage in 1 sample.

Conclusion: The low amount of bacterial leakage observed at the implant-abutment interface of these samples highlights the appropriate sealing.

Keywords

Bacterial leakage; Prosthetic implant-abutment interface; Osseointegration; Dental implant; Escherichia coli; Microgap; Hexagonal external; Internal prosthetic connection

Introduction

Several longitudinal studies have shown the long-term success of osseointegrated implants [1,2]. However, certain factors can have a negative influence on long time success rate of implants, including the adaptation between the implant and the prosthetic abutment.

The existence of empty spaces at the prosthetic implant-abutment interface (I-A interface) favors the accumulation of a bacterial biofilm, which can result in inflammation of the peri-implant tissue. In vitro [3-6] and in vivo [7-10] studies have shown the capacity of bacteria to infiltrate the implant-abutment interface in different prosthetic systems. The accumulation of a bacterial biofilm at the interface can affect the progress of treatment and interfere with the esthetic and functional long-term success of a prosthetic device. Quirynen et al. [11] observed that a wide range of microorganisms seem to be able to penetrate implant components, from gram-positive cocci to gram-negative rods. The authors found bacteria such as Streptococcus constellatus, Bacteroides sp., Peptostreptococcus micros, and Fusobacterium sp. associated with peri-implantitis inside Branemark System implants. The presence of microorganisms at the I-A interface can lead to the presence of inflammatory infiltrates close to the interface [12,13].

A classic study assessed the interfaces of different implants and their respective prosthetic abutments in 13 systems, applying different models of the prosthetic interface in relation to bacterial leakage and its critical aspects. In all systems, except one, Escherichia coli was found in the solution on the first day in at least one of the samples [3].

Considering that the biofilm that accumulates in cases of misfit of the I-A interface can lead to bone loss, it is important to assess the possibility of bacterial leakage at the interfaces. Thus, the aim of this study was to assess the possibility of bacterial leakage at the I-A interface of two implant systems: one external connection and one internal connection.

Material and Methods

Sample selection

In this study, implants and abutments of two different implant models from the same system were used, which are manufactured and commercialized in Brazil. The selected samples were purchased through the representatives of the respective manufacturer (Table 1).

Twelve test specimens of each model were used, each comprising one implant and its respective prosthetic abutment, for a total of 24 test specimens. These samples were divided into two groups, according to the implant model. Group 1 was comprised of implants of model Kort HEX (4.0 × 7 mm) (Dérig Implantes, Barueri, São Paulo) with an external hexagon prosthetic connection, and Group 2 was comprised of implants of model Bioneck TRI (3.5 × 13 mm) (Dérig Implantes, Barueri, São Paulo) with an internal tri-channel connection.

Microbiological tests

The assessment of the possibility of bacterial leakage at the I-A interface was performed according to the methodology previously described [4].

Twelve samples from each group were used: 10 samples for testing, one for a positive control, and one for negative control. Implants were provided in their original packaging, previously sterilized by their respective manufacturer, in addition to their respective prosthetic abutments. The prosthetic abutments were not sterilized by the manufacturer; therefore, they were sterilized using an autoclave (Cristófoli Lister 12L, Cristófoli, Paraná, Brazil) for 22 minutes at 121°C with a pressure of 1.0 KGF/cm², 24 hours before the test.
full procedure was performed in sterile conditions, in a disinfected laminar flow cabinet. The operator was properly dressed and stayed within a safety zone provided by the flame of a Bunsen burner. The test specimens were inoculated with 0.3 μL of E. coli suspension (reference strain ATCC 25922), applied in the hollow part inside the implant (Figure 1), with the help of a 77FAA10 micropipette (Prolab, Santiago, Chile). The bacteria were kept frozen before use. They were then activated by inoculation in a brain-heart infusion medium (BHI, Kasvi, Italy) and maintained in an incubator at 37°C for 24 hours before the inoculation.

Immediately after inoculation, the prosthetic abutments were connected to their respective implants, and then the torque recommended by the manufacturer was applied to the abutment fixation screw (Figure 2), as described in Table 1. In order to apply the torque to the prosthetic abutment fixation screw, a torque driver from the same manufacturer was used, coupled to the respective manual torque meter.

After applying the torque, a sterile microbrush (KG Sorensen, Cotia, SP, Brazil) dipped in saline solution was used on the implant platform in order to test the possibility of contamination during inoculation or leakage of the suspension when applying the torque to the abutment (Figure 3). A sterile plastic bit was then mounted at the edge of the prosthetic abutments to prevent them from falling into the test tubes. The test specimens and microbrushes were placed in sterile test tubes containing BHI culture medium, covering approximately 1 mm above the I-A surface (Figure 4).

E. coli is a mobile, bacillus-shaped, gram-negative bacterium that is facultative anaerobic, which has a diameter of 1.1–1.5 μm and a length between 2 and 6 μm. It is widely used in microbiology studies regarding sterilization, disinfection, and in vitro contamination [3].

A positive control and a negative control assay were performed for each group. In the positive control assay, 0.3 μL of the solution containing E. coli was inoculated directly in the hollow part of the implant, and then the implant was immediately placed in a sterile test tube with the culture medium (BHI) without installing the prosthetic abutment. In the negative control assay, the prosthetic I-A set was placed directly in the test tube with the culture medium without inoculation of E. coli.

The test tubes containing the inoculated test specimens and the culture medium, as well as microbrushes and positive and negative controls were incubated in a biological incubator (model Q-316M2 - Quimis Aparelhos Científicos Ltd., Diadema, SP) at 37°C. They were checked for bacteria in the culture medium after 24, 48, and 72 hours and at days 5, 7, and 14 after the inoculation by determining the turbidity of the culture medium (positive or negative) (Figure 5).

From each sample that showed positive results for bacterial leakage, a portion of the contaminated culture medium was collected and transplanted to a petri dish containing an agar/BHI medium, in order to confirm the growth of colonies compatible with E. coli growth. The Gram staining method was also applied and the results were observed under an optical microscope, in order to confirm the growth of gram-negative bacillus.

### Table 1: Characterization of the test specimens.

<table>
<thead>
<tr>
<th>System</th>
<th>Implant Model</th>
<th>Prosthetic Abutment</th>
<th>Screwing Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dérig</td>
<td>KORT HEX 4.0×7 mm</td>
<td>02.03.04.112</td>
<td>32 Ncm</td>
</tr>
<tr>
<td>Dérig</td>
<td>BONECK TRI 3.5×13 mm</td>
<td>02.04.04.112</td>
<td>32 Ncm</td>
</tr>
</tbody>
</table>

### Results

No sample in Group 1 showed bacterial leakage or microbrush contamination during the 14 days of observation. In Group 2, one sample (B-9) showed bacterial leakage after 24 hours. Subsequently, none of the other samples showed leakage. The microbrush used for sample B-6 in Group 2 tested positive for contamination in the first 24 hours, but the implant did not show evidence of bacterial leakage until the end of the observation period.

### Discussion

The long-term success of osseointegrated implants depends on the integration between the components of the implant system and oral tissues. Bone loss around the implant is expected in the first year [1,14]. Some potential causes to explain the etiology of this bone loss around the implant have been postulated, including surgical trauma, occlusal overload, peri-implantitis, biological width, and the presence of a misfit at the I-A interface [15].

The inflammatory infiltrate present in the connective tissue at the level of the I-A interface found by Broggini et al. [13] suggested the existence of a chemotactic stimulus that originated in that area or close to it, which could initiate and sustain the recruitment of inflammatory cells. Considering that the leakage of bacteria and/or fluids at the I-A interface has been previously demonstrated [2,3,7,11,16-18].
in only one sample. These results are in agreement with those obtained in a previous study involving external hexagon implants [4], which also failed to find bacterial leakage in 4 out of the 5 systems tested. External hex is still the most used implant platform design and some studies consider it more prone to bacterial leakage through I-A interface [5]. In the present study none of the external hex samples (Group 1) showed bacterial leakage, indicating that it can be safely used when we choose a good implant system.

It was proven that the torque applied to the prosthetic screw might influence bacterial leakage at the prosthetic I-A interface [18-21]. In this study, the torque recommended by manufacturer was applied to the screws in the prosthetic abutments, thus avoiding potential variables that might interfere with the results.

The size of the misfit on the I-A interface might also influence bacterial leakage; however, in vitro studies have not shown a direct correlation between the adjustment of the I-A interface and bacterial leakage [3,4].

The microbrush used for implant sample B6 presented a positive result for contamination but the implant showed no contamination during the whole period of observation. We believe that this fact may be due to a very small accidental contamination outside of the implant at the time of inoculation with E. coli suspension, which has been removed by the microbrush saline, washing the surface. Thus, there was no bacterial growth on the implant.

Several methods have been used to assess the leakage in I-A interfaces, including inoculation of the internal part of the implant with a suspension containing bacteria [3,4,22], immersion in saliva [23], immersion in culture medium containing bacteria [6], and inoculation of the internal part of the implant with a colony of bacteria [24]. In this study, the method chosen was the inoculation of 0.3 μL of a suspension containing E. coli, since this is the method most frequently used in other studies with similar goals, because it is easy to handle in laboratories and has a short proliferation time (about 20 minutes). It can be found in the buccal medium of healthy individuals [3].

Conclusion

The implants in Group 1 (external hexagon) did not show bacterial leakage at the prosthetic I-A interface in any sample, while the implants in Group 2 showed leakage in 1 out of 10 samples tested, demonstrating the benefit of appropriate sealing of the prosthetic I-A interface.

References


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