Sixty implants were inserted in ten patients. Mean insertion torque was slightly lower for the 4-mm implants compared to the 10-mm implants. The marginal bone loss was lower for short implants three, six, and twelve months after the surgery without statistical difference. Implant stability was similar for extrashort and conventional implants. Marginal bone loss was lower for short implants three, six, and twelve months after the surgery without statistical significant difference. Conclusions: Within the limitations of this study, we conclude that short dental implants (8 mm or less in length) supporting single crowns or fixed bridges are a feasible treatment option with radiographic and clinical success rates similar to longer implants for patients with compromised ridges. Long-term data with larger number of implants and subjects are needed to confirm these preliminary results.

Dental implant treatment can be short, simple, beneficial, and highly predictable. However, the placement of dental implants can be limited due to physical situations, such as the size of the residual bone crest (Annibali et al. 2012).

The insertion of the implant after preparing the undersized osteotomy requires a considerable force, which is referred to as the insertion torque. Considering that primary implant stability is influenced by the mechanical interlocking between the implant and the receiving host bone bed, it has been suggested that the implant success can be accelerated and/or enhanced by a surgical protocol applying high insertion torques (Trisi et al. 2009).

The alveolar bone resorption (horizontal, vertical or, combined defects) is frequently observed in patients with edentulous arches of long evolution (Reich et al. 2011). The insertion of dental implants in patients with reduced alveolar bone is difficult and might require invasive procedures (Esposito et al. 2009) such as sinus lift, grafts, transposition of the dental nerve, bone regeneration, or even the use of nonconventional implants.
titled, zygomatic, pterygoid, and transmaxillary implants.

Extrashort implants are considered the type of implants less than 5 mm length. The introduction of short implants represents an important development and a new therapeutic alternative for these patients (Pommer et al. 2011; Lops et al. 2012; Anitua et al. 2014a,b). Short implants contribute to reduce advanced surgery (Menchero-Cantalejo et al. 2011; Neldam & Pinholt 2012) as well as facilitating situations characterized by difficult access, limited visibility, confined space, poor bone quality, and the risk of affecting anatomical structures (Maló et al. 2007; Rossi et al. 2010).

Modification of the design and length of the implants are the another approach to overcome jaw bone atrophy. The main benefit of short implants is to avoid bone augmentation surgeries as well as reducing the duration of treatment, patient morbidity (Sánchez-Garcés et al. 2012; Srinivasan et al. 2014), and the financial burden (Mendonça et al. 2014).

The biomechanical basics for the use of short implants is that the crestal portion of the implant body is the most involved in supporting the load, while less stress is transmitted through the apical portion (Kim et al. 2014). Moreover, the maximum bone stress is practically independent of the length of the implant, as arguably the width of the implant is more important than the length (Anitua et al. 2010).

New rough-surfaced implants and survival rates of short implants are comparable with those of 10–15 mm longer ones. Some authors showed that improvements on those surfaces technologies can increase implant stability quotient (fISQ) values and decrease the marginal bone loss (Sul et al. 2009; Karabuda et al. 2011).

Nonetheless, reports on the success of short dental implants restored with a single unit are limited to one implant system (Straumann SLA implants, Basel, Switzerland) in the posterior maxillary and mandibular regions, and only 1 study reported on the survival of 40 short implants over a 2-year period. Moreover, it was not clear whether these studies used bone grafting or used nonimplant restorative protocols (Rossi et al. 2010; Lai et al. 2013). Le et al. (2013) described that the survival rate of short implants restored with single-unit, nonimplant restorations over an average period of 37 months was favorable and comparable with longer implants.

Modern implant surfaces with microrough and hydrophilic properties allow more predictable outcomes with regard to primary stability and the speed of osseointegration (Lang et al. 2011). This allows to challenge the paradigm of long implants, because these surfaces produce a better contact interface between the bone and the implant (Botzenhart et al. 2015).

The predictability of short implants is controversial at present. Some studies report lower survival rates than longer implants (Romeo et al. 2010). However, there are many publications where the survival and success of short implants appears to be comparable to longer implants (Tellemann et al. 2011; Annibali et al. 2012; Atieh et al. 2012a,b).

Study of Slotte et al. (2012) shows that 4-mm-long titanium implants with an SLActive surface can be safely and successfully used to support a fixed dental prostheses in severely resorbed posterior mandibles for at least 2 years with healthy periodontal conditions. Short implant survival success rate with fixed, fiber-reinforced resin bridges on four ultrashort implants in highly atrophic jaws was 97.25%. The average mesial and distal bone level was 0.2 ± 0.3 mm in the atrophic mandibles and 0.4 ± 1.2 mm in the fibula transplants at the last follow-up visits (Seemann et al. 2015).

The justification of the present work is to evaluate the crestal bone loss and implant success rate of extrashort 4-mm implants compared with standard 10-mm implant length.

The aims of this preliminary report were to evaluate the primary stability, the secondary stability, the marginal bone loss, the survival, and the success criteria, of 4-mm-length implants compared with implants of 10 mm length supporting fixed prostheses.

**Material and methods**

This prospective clinical trial of 3 years was approved by the Bioethical Committee of the University of Murcia, Spain. The design of this study can be observed in Fig. 1.

**Patients**

Consecutively, 10 healthy patients, in need of a full-arch treatment in the mandible, were recruited. Six women and four men, with a mean age of 64 years (range 44–86), were selected for the treatment of their atrophic edentulous mandible. Each person was informed of the general requirements and purposes of the study, as well as the nature of the planned treatment and the alternative procedures. Based on a multislice CT scan, the patient was included if six implants could be placed in the mandible without the need for bone augmentation.

The potential risks, possible complications, and benefits of the proposed treatment were explained to the study patients. All the information was provided in written and oral. In addition, all the patients signed an informed consent.

**Inclusion criteria**

- **Age**: ≥18 years committed to participate up to 3-month follow-up.
- **Complete edentulism in the jaw to allow placement of six implants (two in the canines zones of 10 mm in length and four 4-mm implants placed in the resorbed sites behind the mental nerve).**
- **Full or partial dentition opposing the implants.**
- The implant site had to be edentulous for >2 months and healed, with evidence of bone resorption and atrophy.
- The minimal residual bone height should be appropriate in the canine zone and at least 8 mm in the posterior zone.

**Exclusion criteria**

**Systemic**

- Presence of blood, metabolic, endocrine, renal, or neoplastic diseases.
- Human immunodeficiency virus infection.
- Smoking >10 cigarettes per day.
- Alcoholism or drug abuse.

**Fig. 1.** Description of extrashort implants placement.
• Any conditions that might prevent study participation or interfere with analysis of results.

Local
• Mucosal diseases.
• History of irradiation therapy.
• Previous reconstruction, bone grafting, or failed GBR at the site of intended implant surgery.
• Severe bruxism/clenching.
• Inadequate oral hygiene or unmotivated for home care.
• Second exclusion criteria at surgery.
• Lack of primary stability.
• Insufficient bone or any abnormality that would contraindicate implant placement.

A timeline graphic with the time points for all the evaluations performed at day 0, 3 months, and twelve months during the study (Fig. 1).

A complete medical and dental history check was performed, and a radiological examination, which included a panoramic radiograph [8000C Digital Panoramic and Cephalometric System; Carestream, Rochester, NY, USA] and a cone beam tomography (CS 9300 System; Carestream), was carried out (Fig. 2). Besides, impressions were taken to produce the diagnostic wax-ups. The patient received oral hygiene instructions to ensure optimal presurgical conditions.

Implants
The implants used in this study were SP/4SI Straumann tissue-level implants Standard Plus RN, Roxolid® and SLActive® with a diameter of 4.1 mm and a length of either 4 mm or 10 mm [Institut Straumann AG, Basel, Switzerland]. All implants were used according to the manufacturer’s instructions.

Each patient received the following treatment in the edentulous jaw: Six dental implants were inserted, two anterior implants of conventional length (10 mm) in the interforaminal area and four posterior short implants of 4 mm length, by placing two in the right hemi-arch and two in the left hemi-arch (Figs 3 and 4).

The placement of the implants was performed through a single-stage surgery. Local anesthesia was reached by blocking the inferior alveolar nerve and administration of an appropriate dose of dental articaine 4% with epinephrine 1 : 100 000 [Inibsa®, Barcelona, Spain]. An incision was performed on the midline of the alveolar crest from the distal surface of the missing 1st molar zone. A full-thickness mucoperiosteal flap was performed, and the position of the inferior dental nerve was localized (Fig. 5).

The preparation of the locations of the implants was performed according to a defined sequence provided by the manufacturer [Institut Straumann AG]. This drilling protocol was first round bur at 800 RPM as marker, 2.2-mm pilot drill at 4 mm length 800 RPM, alignment pin, 2.8-mm-by-4-mm pilot drill at 600 RPM, 2.8-mm-depth gauge, twist drill short 3.5 mm by 4 mm at 500 RPM, SP/4SI profile drill, and S/SP Tap. Finally, four SP/4SI 4.1 mm diameter by 4 mm length and two SP/4SI 4.1 mm diameter by 10 mm length were placed in the edentulous mandible.

Under-preparation was used to achieve an insertion torque between 35 and 50 Ncm before final seating of the implant.

To determine primary stability, for each implant, peak IT was recorded by means of an electronic instrument [IMPLANTMED Unit E, W&H Dentalwerk GmbH, Burmoos, Austria] during low-speed insertion. Immediately after implant insertion, the implant stability coefficient, termed resonance frequency analysis [RFA] analysis, was measured by Osstell [Integration Diagnostics AB, Goteborg, Sweden]. RFA measures the rigidity and deflection of the bone–implant complex [Griffin & Cheung 2004]. The ISQ values range between 1 and 100. The measurements were performed in the mesiodistal, disto-mesial, vestibulo-lingual, and lingual-vestibular regions [Bischof et al. 2004]. The values obtained were noted in a spreadsheet, in which the patient’s name, measurement of implants, region of placement, and date of measurement were specified. ISQ values were obtained at the four time intervals indicated.

In addition, three one-piece temporary 2.8 mm diameter by 10-mm-length implants were inserted [Osseolite-Ziacom®, Fuenlabrada, Madrid, Spain] which served as support for a temporary prosthesis to avoid stress and load on the implants during osseointegration (Fig. 6).

Closure screws were placed in the implants, and the flaps were repositioned and sutured (Fig. 7). In addition, panoramic radiographs were performed, and RFA was measured by the Osstell Mentor® device after the surgery (Figs 8 and 9).

Amoxicillin 500 mg was prescribed, 1 tablet each 8 h and ibuprofen 600 mg each 8 h for 7 days. Patients were instructed to use a mouthwash with a solution of 0.12% chlorhexidine [Dentaid®, Barcelona, Spain]
visit consisted of an evaluation of the overall health and dental history. At the same time, health, peri-implant tissues, and oral hygiene were evaluated and radiographs were obtained as described above. All clinical parameters were measured by the same examiner. All patients’ complaints or complications related to implants or to the procedure, such as pain, paresthesia, and infection were monitored and registered as an adverse event.

Rate mesial and distal vertical bone level of the implants inserted (standardized radiographs).

The success rate will be evaluated according to the criteria of Buser et al. [1991]:

1. Absence of persistent subjective complaints such as pain, foreign body sensation, or dysesthesia.
2. Absence of peri-implant infection with suppuration.
3. Absence of mobility.
4. Absence of a continuous radiolucent area around the implant.

Statistical analysis

Descriptive statistics – mean, standard deviation, median, and range – were used to present bone-level measurements.

Differences regarding radiographic bone levels at the various re-examinations were analyzed using Mann–Whitney U-test. The level of significance was set at $\alpha = 0.05$. Data from clinical evaluations and implant/crown ratio were considered as descriptors.

Results

This research involved the study of sixty Standard Plus implants, of which 40 had length of 4.1 mm diameter by 4 mm length and 20 were 4.1 mm diameter by 10 mm long. Implants’ distribution can be seen in Table 1.

The implant survival rate of forty, 4-mm implants placed in edentulous was 97.5% at 12 months after surgery. One extrashort 4 mm length was lost after 2 months in the healing phase and was replaced by another one 2 weeks later.

Insertion torque and bone quality

The mean insertion torque for short 4-mm implants was 42.45 ± 2.17 Ncm, whereas for conventional 10-mm implants, it was 42.50 ± 2.16 Ncm. Using a two-sample paired $t$-test, significant differences were not found between pairs of insertion’s means ($P = 0.005$).

Resonance frequency analysis

At the time of surgery, the mean RFA value measured with Osstell Mentor® was 75.22 ± 1.23 ISQ values [95% CI: 72.64–77.81] for 4-mm implants. Whereas for 10-mm implants, it was 78.72 ± 2.13 ISQ values [95% CI: 76.59–80.85] at the day of implant placement (Day 0).

At 3 months after surgery, the mean RFA value increased to 78.33 ± 1.76 ISQ values [95% CI: 75.70–80.96] for 4-mm implants. For 10-mm implants, the mean value was 81.67 ± 1.22 ISQ values [95% IC: 79.37–83.86].

At 6 months, the mean RFA values for 4-mm implants stabilized at 79.65 ± 0.56 ISQ values [95% IC: 76.57–81.23]. For 10-mm implants, the mean value also stabilized at 82.45 ± 0.78 [95% IC: 80.14–84.22] (Table 2).

At 12 months after surgery, the mean RFA value increased to 80.20 ± 0.44 ISQ values [95% IC: 78.45–82.13] for 4-mm implants. For 10-mm implants, the mean value was 82.34 ± 0.67 [95% IC: 80.67–84.51]. No significant differences were detected between the implant lengths at none of the

<table>
<thead>
<tr>
<th>Table 1. Complete distribution of extrashort and standard implants included into the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
</tr>
<tr>
<td>4-mm implants</td>
</tr>
<tr>
<td>First premolar</td>
</tr>
<tr>
<td>Second premolar</td>
</tr>
<tr>
<td>First molar</td>
</tr>
<tr>
<td>Second molar</td>
</tr>
<tr>
<td>10-mm implants</td>
</tr>
<tr>
<td>Lateral incisor</td>
</tr>
<tr>
<td>Canine</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Descriptive data of median, mean, and standard deviation of insertion torque of extrashort and standard implants used in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of implants (mm)</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>4.1 x 10</td>
</tr>
<tr>
<td>4.1 x 4</td>
</tr>
</tbody>
</table>
measurements, but significant differences were detected between 4-mm implants at different time of ISQ measurements \( |P \leq 0.005 \) (Table 3).

The mean RFA was also evaluated individually for each patient at the day of the surgery and 3, 6, and 12 months after surgery. All patients showed a pattern of increasing and then stabilizing RFA values at the measured intervals.

### Marginal bone loss

Radiographs obtained at baseline and at 3-month follow-up revealed a mean marginal bone loss of 0.58 ± 0.11 mm for 4-mm implants. The mean bone loss for 10-mm implants was 0.85 ± 0.23 mm at 3-month follow-up. At 6-month follow-up, the marginal bone loss was only slightly higher with a mean value of 0.64 ± 0.38 mm for 4-mm implants and a mean of 0.86 ± 0.56 mm (0.43 mm) for 10-mm implants. The mean bone loss for 10-mm implants was 0.89 ± 0.23 mm at 12-month follow-up. For 4-mm implants, the mean bone loss was 0.71 ± 0.11 mm (Table 4).

### Survival and success rate

Before loading of the implants (3 months), the survival rate for all implants was 98.15%. The survival rate for conventional implants was 100%. The survival rate for short implants was 97.5%. There were no statistically significant differences between the implant lengths. Only one implant was lost. Remaining implants did not show mobility, radiolucent areas, or infection.

### Discussion

In our study, short implants were presented as an alternative for cases of severe bone resorption in both maxilla and mandible. Primary stability of implants and its related clinical implication are not dependent only on the implant geometry and host bone density, but also on surgical techniques (Javed & Romanos 2010, Tabassum et al. 2010a, b, 2014). The mean values of peak insertion torque and RFA primarily show that the implants used in our study are able to obtain a good primary stability with a standard insertion protocol.

As discussed by different authors, the reason for the good results with short implants may be related to high initial stability and effective use of the residual bone volume with high primary bone-to-implant contact in dense bone structures. Similar results were reported by Misch et al. (2006), who placed 745 of 7- to 9-mm-long implants in 273 patients. After 1–5 years, the authors reported a 98.9% survival rate.

The data collected so far in this study did not show significant differences in implant success rate and survival rate regarding length during the 12-month follow-up. The survival of short implants was comparable with the results of numerous studies, where the high success and survival rates of these implants are predicted. Santis et al. in a study realized in 2012 about short implants of 8.5 mm achieved a high survival rate (De Santis et al. 2011). All implants were successful 18 months after surgery. These results provide survival rates similar for that of our research. The short implant survival rate after 12 months was 97.5%, and the regular implant survival rate after 12 months was 100%.

Six-mm implants used in the study of Rodrigo et al. (2013) with 1- to 6-year follow-up research show high long-term predictability when the implants were placed in mandible and splinted. The survival rate for splinted implants was of 99.5% and for unsplinted implants 92.9%.

Insersion torque and the implant micromotion are statistically correlated, and statistically significant differences in hard and medium bone were found compared with soft bone. In soft bone, we noted a micromotion significantly higher than the risk threshold, which is between 50 and 100 mm, and it was not possible to reach peak insersion torque above 35 Ncm of insertion torque because in this type of bone, the meager number of trabeculae offers scarce resistance to screwing in this type of implant, thus losing initial stability (Trisi et al. 2009). It has been suggested that depending on the implant system, the low levels of rotational stability at the time of implant insertion may not be an indication for high micromotion (Norton 2011, 2013; Freitas et al. 2012; Duyck et al. 2015).

In our clinical study, no statistically significant correlation was found between initial BIC after insertion and average of insertion torque values measured at the placement site after implant insertion. This may be regarded very helpful for the clinician because it showed up the areas of greater or lesser resistance along the surgical site by their degree.
of corticalization (crestal, intermediate, and apical) [Liu et al. 2012].

Barone and coworkers suggested that implants inserted with high IT (higher than 50 Ncm) in healed bone ridges showed more peri-implant bone remodeling and buccal soft tissue recession than implants inserted with a regular IT (lower than 50 Ncm). Moreover, sites with a thick buccal bone wall (greater than 1 mm) – after implant osteotomy preparation – seemed to be less prone to buccal soft tissue recession, at the 12-month evaluation, than sites with thin buccal bone wall (lower than 1 mm) [Barone et al. 2015].

Slotte et al. (2012) conducted a study with 4-mm-long implants where hundred implants were placed. Four implants were lost before loading. After 1 year, a survival rate of 95.7% was obtained, and at 2-year follow-up, a survival rate of 92.3% was obtained, respectively. These survival rates are similar to those of 4-mm implants obtained in this research for 180 days (6 months). However, it takes long-term monitoring to demonstrate effectiveness. The mean value of the change in crestal bone levels to 1-year follow-up by Slotte et al. was 0.43 mm. This result is slightly lower than reported by this research. However, the bone loss at 6 months is similar to or even better than in investigations with longer implants [Draenert et al. 2012, Van Assche et al. 2012].

Other researchers demonstrate the feasibility and efficacy of unsplinted 5.0 × 5.0 mm and 4.5 × 6.0 mm short implants not only exhibited osseointegration comparable to that of conventional length implants but also contributed to the patient’s satisfaction with treatment time, esthetics, and cost [Yi et al. 2011].

Anitua and coworkers founded no associations between crown-to-implant ratio of implant-supported prostheses in short implants in posterior regions and marginal bone loss were found [Anitua et al. 2015]. Furthermore, when an increased crown-to-implant ratio is present, crown height space may influence crestal bone loss more significantly [Anitua et al. 2015].

The RFA is an implant–bone interface bending test. This diagnostic device has been extensively used in experimental and clinical research for the last 10 years and has demonstrated a good correlation between the ISQ values obtained and the degree of stiffness between the implant and the bone [Becker et al. 2005, Zix et al. 2005, 2008; Kessler-Liechti et al. 2008; Sennerby & Meredith 2008; Rodrigo et al. 2010, Kumar et al. 2012; Sennerby et al. 2013, Filho et al. 2014]. In fact, studies that have monitored ISQ values during implant healing have demonstrated a good correlation between clinical stability assessed by ISQ values and the biologic events leading to osseointegration. However, Atsumi et al. 2007 concluded that although the theory behind RFA is sound, the technology cannot provide a critical value that is capable of determining the long-term prognosis of an implant. Moreover, one of the limitations of this diagnostic method is that RFA measurements made at the time of implant placement are not good predictors of failure after immediate loading (Atieh et al. 2012a, b).

A randomized controlled trial by Esposito et al. compared prostheses supported by 5-mm implants or by longer implants in augmented bone in posterior atrophic edentulous jaws [Esposito et al. 2014]. There were no statistically significant differences in the failure rates. The bone loss was lower for short implants (mean 1.44 mm) than for long implants (mean 1.63 mm). Furthermore, a 5-year study conducted by Felice found statistically significant differences between bone loss in short implants and bone loss of implants placed in augmented bone [Felice et al. 2014]. The short implants showed a lower bone loss that the implants placed in augmented bone augmentation. Short implants with oxidized surface in posterior areas of atrophic jaws were evaluated during 3–5 years to restore posterior teeth, such as a viable solution to simplify and shorten the treatment of patients with partial edentulous jaws. Long-term follow-up is recommended to definitively establish the predictability and efficiency of this kind of implant-supported rehabilitation [De Santis et al. 2015]. Survival rate of short implants restored with single-unit, nonsplinted restorations over an average period of 37 months was favorable and comparable with longer implants [Le et al. 2013].

The use of short implants was to demonstrate that all the extrashort implants are placed in cortical bone and may reduce crestal bone resorption by a new surface and reduced micromotion. The results of the present study demonstrate that the survival rate of short implants after 12 months was lower than that of regular implants. However, short implants may be considered a reasonable alternative for rehabilitation of severely resorbed mandibles with reduced height to avoid bone reconstruction before implant placement in posterior areas.

Conclusion
Within the limitations of this short-term study, we conclude that extra-short dental implants (4 mm in length) are a feasible treatment option with radiographic and clinical success rates similar to longer implants for patients with compromised ridges. Long-term data with larger number of implants and subjects are needed to confirm these preliminary results.

References


Anitua, E., Piñas, L. & Orive, G. [2015] Retrospective study of short and extra-short implants placed in posterior regions: influence of crown-to-


Implant Dentistry & Related Research.


