A partially edentulous posterior maxilla is normally a challenge for implant-prosthetic rehabilitation because of the compromised alveolar ridge in the vertical and horizontal dimensions, together with poor bone quality, which is often classified as type III and type IV.1 Due to increased sinus pneumatization, transcresal2,3 or lateral sinus elevation,4,5 to compensate for poor bone characteristics,6 it is often necessary to insert standard-sized implants.7 As a sinus elevation procedure is associated with significant morbidity of patients, long recovery times, and increased costs,2 the use of shorter implants for rehabilitation of the posterior maxilla was examined over the past decade.2,8,9 There are many definitions, but short implants are mostly defined as < 8 mm in length, with standard implants being ≥ 8 mm in length. In addition, extrashort implants are defined as < 6 mm in length.10 Clinical studies have demonstrated favorable survival of short implants in the posterior maxillary region,9,11–15 even though their performance was mostly evaluated in conditions with severe vertical bone resorption, necessitating rehabilitation with the help of very long clinical crowns, resulting in an unfavorable crown-to-implant ratio.15 To overcome the unfavorable effects of long clinical crowns, Guichet et al16 recommended the splinting of multiple implants in posterior regions for better load sharing in comparison to nonsplinted restorations. The beneficial effects of splinting are obvious from a recently published in vitro study using three-dimensional finite element analyses, suggesting that all extrashort 4-mm implants should be splinted to each other or connected to a longer implant to prevent the harmful effects of...
masticatory oblique loads. Therefore, when multiple extrashort implants are placed in the posterior maxilla, the survival of splinted crowns might be better in comparison to nonsplinted implants, as splinting provides protection against excessive masticatory loading. It should be mentioned, however, that the splinting of implants is of particular importance in patients with chewing parafunctions.

There have been several case series studies reporting the high (92% to 100%) short-term survival of nonsplinted or splinted 4-mm implants in posterior areas of the mandible and maxilla. However, these data are scarce, particularly for a shortened dental arch in the maxilla, where the negative effects of poor bone characteristics and the biomechanical consequences of long clinical crowns coincide with large masticatory forces. In such conditions, careful case selection seems to be a decisive factor for the long-term success of short and extrashort implant-borne rehabilitations.

The objective of the presented case series was to rehabilitate patients with a shortened maxillary dental arch with restorations supported by extrashort 4-mm implants splinted to 10-mm implants and to assess the 1-year survival and success rates of such a rehabilitation. The hypothesis was that the splinted 4-mm implants would achieve similar 1-year survival and success rates as 10-mm implants that were placed during the same surgical procedure.

MATERIALS AND METHODS

This case series was performed between June 21, 2016, when the first patients had a surgical procedure for implant placement, and October 20, 2018, when the last patient received an implant-supported prosthesis. CARE guidelines were followed for the systematic collection of data and reporting. Each participant was thoroughly informed about the overall requirements and procedures and signed an informed consent. The study protocol was approved by the National Ethics Committee of the Republic of Slovenia (No. 30/10/2015). The institutional review board of the University of Ljubljana approved the study. The study was registered at the National Center for Biomedical Research (No. 30/10/2015). The protocol was approved by the National Ethics Committee of the Republic of Slovenia (No. 30/10/2015). The study was registered at the National Center for Biomedical Research (No. 30/10/2015). The description of the surgical procedure for implant placement with a single-stage surgery was already published. Briefly, after local anesthesia (Ultracain, Hoechst), a midcrestal incision was made, full-thickness mucoperiosteal flaps were raised, and the implant locations were prepared according to a defined sequence provided by the manufacturer (Institut Straumann). Finally, one 10-mm × 4.1-mm-diameter and one or two 4-mm × 4.1-mm-diameter tissue-level (SP) titanium-zirconium alloy SLActive implants (Institut Straumann) were inserted manually with a hand ratchet. Special efforts were made to prevent the positioning of the transition between the machined part (collar) and the moderately rough part below the bone crest. To determine the primary stability, the insertion torque was evaluated with a torque wrench (Institut Straumann). The implant stability coefficient (resonance frequency analysis [RFA]) was determined using an Osstell device (Integration Diagnostics). Closure screws were placed on the implants, while the flaps were repositioned and sutured (Fig 1a). All surgeries were performed by the same therapist (R.G.). Radiographs were taken immediately and after 6 months, when the implants were considered for prosthetic rehabilitation (Fig 1b). After 6 months, RFA measurements were repeated to determine the secondary implant stability.

Table 1  Inclusion and Exclusion Criteria

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
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<tr>
<td>At least 18 years of age</td>
<td>Insufficient bone volume in the region to place one 10-mm-long implant with a 4.1-mm diameter</td>
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<tr>
<td>In good general health</td>
<td>Previous implant or graft placement at the surgical site</td>
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<tr>
<td>Absence of pathologies of soft tissues, alveolar bone, or teeth</td>
<td>Smoking and successfully treated periodontitis were not among the exclusion criteria</td>
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<tr>
<td>Unilaterally or bilaterally shortened dental arch in the maxilla</td>
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<tr>
<td>Presence of teeth or denture in the opposing arch to reach occlusal contacts at each implant-supported crown</td>
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<tr>
<td>Sufficient bone to insert an implant 10 mm long and 4.1 mm in diameter on one implantation site, one or more sites for an implantation with a reduced vertical dimension to &lt; 8 mm</td>
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<tr>
<td>Alveolar ridge width with a minimum of 7 mm</td>
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Patients and Inclusion and Exclusion Criteria

Eleven (n = 11) patients with a unilaterally shortened dental arch in the maxilla, no major vertical ridge resorption, a sufficient alveolar ridge width, and an expanded antrum of the maxillary sinus were recruited in a case series group to be supplied with one or two extrashort 4-mm implants, depending on the presence of teeth in the opposing dental arch. In addition to this, one site with a sufficient vertical bone dimension was required to enable the insertion of a 10-mm implant. Inclusion and exclusion criteria are listed in Table 1.

Clinical Procedure and Stability Assessment

The description of the surgical procedure for implant placement with a single-stage surgery was already published. Briefly, after local anesthesia (Ultracain, Hoechst), a midcrestal incision was made, full-thickness mucoperiosteal flaps were raised, and the implant locations were prepared according to a defined sequence provided by the manufacturer (Institut Straumann). Finally, one 10-mm × 4.1-mm-diameter and one or two 4-mm × 4.1-mm-diameter tissue-level (SP) titanium-zirconium alloy SLActive implants (Institut Straumann) were inserted manually with a hand ratchet. Special efforts were made to prevent the positioning of the transition between the machined part (collar) and the moderately rough part below the bone crest. To determine the primary stability, the insertion torque was evaluated with a torque wrench (Institut Straumann). The implant stability coefficient (resonance frequency analysis [RFA]) was determined using an Osstell device (Integration Diagnostics). Closure screws were placed on the implants, while the flaps were repositioned and sutured (Fig 1a). All surgeries were performed by the same therapist (R.G.). Radiographs were taken immediately and after 6 months, when the implants were considered for prosthetic rehabilitation (Fig 1b). After 6 months, RFA measurements were repeated to determine the secondary implant stability.
After 6 months, all the patients were restored with metal-ceramic fixed dental prostheses (FDPs). The metal frameworks were computer designed and milled from a cobalt-chromium alloy called Coron (Institut Straumann). All the abutments/suprastructures were screwed into implants with a torque of 35 Ncm.

One-Year Postloading Measurements

One year after the loading of the implants, a clinical evaluation of the teeth and the implants was made by an experienced periodontist (R.G.) using a calibrated, manual Williams probe (POW6, Hu-Friedy). On six sites per tooth and four sites per implant, the following parameters were measured: probing pocket depth (PPD), bleeding on probing (BOP), and recession (REC) with the cementoenamel junction and implant-crown junction as the reference points for the teeth and implants, respectively.

In addition, radiographic evaluations were made on the basis of standard periapical radiographs (Fig 1c). All the radiographs were digitalized in TIFF format to determine the position of the most coronal radiodense contact between the bone and the implant, the level of the implant platform, and the highest cusp of the metal framework. All the radiographs were assessed by an experienced examiner (R.G.) with the aid of a computer program (ImageJ, US National Institutes of Health, version 1.48u4). The software was calibrated for each image using the implant length as a reference (5.8 mm for the ultrashort and 11.8 mm for the standard-sized implant, taking into consideration the 1.8-mm machined collar). Each image was calibrated in this way to control for changes in the projection between images. All the periapical radiographs were classified to the Good score, according to the Radiographic Quality Index.30 Measurements of the most coronal radiodense contacts between the bone and the implant were made on the mesial and distal aspects of each implant and averaged for each implant. The crestal bone loss was calculated as the difference in the distances from the implant platform and the most coronal radiodense contact between the bone and the implant with respect to radiographs taken immediately after loading and 12 months after loading.

Statistical Analysis

Only a descriptive analysis of 1-year results was included. Absolute numbers were provided to describe the survival and success rates. Since numerical data were not normally distributed, they were presented with medians and interquartile ranges (IQR). The differences in the RFA values between the different lengths of implants (4 mm or 10 mm) and the different time points were analyzed using a nonparametric Wilcoxon test. The insertion torque data with a normal distribution were analyzed with the Student t test. The level of significance was set at \( P < .05 \).

RESULTS

Patients and General and Oral Health

The 11 patients were 61 ± 8 years of age (range: 49 to 73 years), 5 (45%) were men, and 3 (27%) were smokers. All 11 patients had a unilaterally shortened dental arch in the maxilla; however, 6 (55%) patients needed a complex rehabilitation of severely worn and/or damaged dentition, including periodontal therapy before recruitment (one of them also had fixed orthodontic appliance therapy) and were maintained every 4 months. Detailed patient characteristics have been presented elsewhere.29

The mean insertion torque for the short 4-mm implants was 15 ± 4 Ncm. This value was significantly lower \((P = .024)\) than the insertion torque \((21 ± 7 \text{ Ncm})\) for the standard-size 10-mm implants. At the time of insertion, the median RFA value was 5 units lower for the short 4-mm implants (median: 61 [IQR: 59 to 64]) than for the 10-mm implants (median: 66 [IQR: 64 to 72]; \(P = .020\)). Two weeks after the implantation, one of the 4-mm implants became mobile and was easily removed. Healing was uneventful for the remaining 16 4-mm-long implants and 11 10-mm implants. At 6 months, the mean RFA value for the 4-mm implants was 68 (IQR: 62 to 72). This value was 10 units lower than for the 10-mm implants: 78 (IQR: 77 to 80; \(P = .002\)). Of the 17 4-mm-long implants placed in the posterior maxillae, 16 successfully osseointegrated,
and of the 11 10-mm-long implants, all successfully osseointegrated.

Ten patients (10/11) were restored according to the study protocol with splinted crowns, each supported by an implant. The crown on the lost 4-mm implant site was replaced with a pontic between crowns supported by one 4-mm implant and one 10-mm implant. Seven 3-unit FDPs were supplied, six on one 10-mm implant and two short (4-mm) implants, and one on one 10-mm and one 4-mm implant. Four two-unit FDPs were supported on one 10-mm implant and one 4-mm implant. Three FDPs were fixed on cementable abutments, and eight FDP frameworks were screwed directly into the implants without any abutments. The cemented reconstructions were designed for inclined implants in order to avoid the buccal screw fixation.

In the first year after the loading of the implants, the patient who had lost one of the 4-mm implants experienced a general health problem that was not implant-related. Streptococcus pneumoniae–caused pneumonia lasting 3 months, requiring systemic treatment with several different antibiotics, including amoxicillin, and ending with a diagnosis of chronic obstructive pulmonary disease. All the other patients had a history of oral issues that were not related to the 4-mm implants and that did not affect the survival of those implants nor the continuation of the study (one patient experienced the progression of periodontitis with two newly affected teeth with a PPD > 5 mm that required conservative treatment; one patient was restored with a new implant at the position of the maxillary right lateral incisor after the extraction of an endodontically treated maxillary right canine, neighboring the testing 10-mm implant; one patient experienced severe peri-implantitis developed on a nontested implant neighboring a tested 10-mm implant, which was explanted; one patient needed a new implant at the maxillary right second premolar position [contralateral site] due to the root fracture of an endodontically treated premolar; one patient received two more implants in contralateral maxillary positions; one patient received three more implants and one patient two more implants, both on the contralateral side of the mandible; one patient had two mucogingival procedures [bilaminar technique] due to gingival recession; and the last patient received a free gingival graft to the position of the contralateral mandibular premolar for gingival augmentation).

All the patients benefited from a prophylactic supragingival and subgingival debridement every 4 months. One year after rehabilitation, more than 50% of the included patients (n = 11) still had more than 20 teeth (median: 20, IQR: 18 to 23.5), and more than 50% had no site with PPD > 4 mm (median: 0, IQR: 0 to 1.75). More than half of the patients had a BOP index of < 6% (median: 6%, IQR 1% to 12%), an average PPD of < 2.6 mm (median: 2.6 mm, IQR: 2.25 to 2.8 mm), and an average REC of < 0.45 mm (median: 0.45, IQR: 0.16 to 0.93).

One-Year Postloading Results

All the implant-supported prostheses (11/11) were functioning at the 12-month re-examination, including the one that required modification due to the loss of one 4-mm implant (Fig 2). The overall survival rates evaluated for 1 year postloading were 16/17 for the 4-mm and 11/11 for the 10-mm implants. From 17 4-mm implants, 11 were considered as primary and 6 as secondary, and 10 and 6 of these implants were functional at 12-month re-examinations, respectively. Due to tissue recession close to the implant-extraction site, the 1-year postloading success rate was reduced to 10/11 for the 10-mm implants. A detailed analysis of the peri-implant soft tissue parameters and the crestal bone loss 1 year after loading with the splinted crowns revealed values within the expected range that could be considered a consequence of the physiologic remodeling processes (Table 2). As mentioned earlier, the only exception was a measuring site close to the site of a lost implant, not included in the study material. Radiographs of six cases taken at the time of implant insertion, immediately postloading, and 1 year postloading are presented in Fig 3.

DISCUSSION

This case series study showed favorable healing and high survival rates after a 1-year follow-up period for the tested FDPs supported by one or two 4-mm extrashort implants inserted into the pristine bone of a posteriorly shortened, maxillary dental arch region, splinted to standard 10-mm implants. Based on these promising short-term results, the use of 4-mm implants splinted to longer ones seems to be a viable treatment option when bone quantity and quality preclude the use of longer implants, without the potentially extensive bone grafting that increases the invasiveness as well as the morbidity and treatment time. Even though one 4-mm implant was lost in the early healing period and others demonstrated moderate primary stability, the 6-month healing period in most of the cases resulted in secondary stability above a value of 60 RFA units, which is generally considered as a guarantee for the safe loading of splinted implant-supported prostheses.28,31,32 The obtained initial mean RFA values for the 4-mm implants were, nevertheless, much lower than the values reported by Calvo-Guirado et al,23 who tested similar extrashort implants in the posterior mandible. These values were slightly above the RFA values reported by Torassa et al,25 who also evaluated the performance of 4-mm implants in partially edentulous posterior
maxillae. Furthermore, Torassa et al.\textsuperscript{25} reported an increase in the RFA values above 60 RFA units after just 2 months, enabling provisional loading with splinted provisional acrylic crowns that were replaced with the definitive restorations after 6 months. As only the initial and 6-month (before loading) RFA values were measured in the present study, no conclusion about the stability changes during the 6-month healing period could be drawn from the results. Finally, 10 out of 11 cases could be restored according to the original study protocol, and after 1 year, all the restorations, including the modified one resulting from the loss of one 4-mm implant, were still functional without any sign of peri-implant soft tissue or bone pathology.

Due to the positive outcomes reported in several studies, the use of extrashort implants has recently become a popular treatment option in the management of vertical ridge deficiencies in mandibles where vertical augmentation procedures are more challenging and less predictable in comparison to a sinus floor elevation in the maxilla that allows the placement of standard-size implants.\textsuperscript{2,3,9,11,15,24} Despite the lack of long-term data, this opinion is supported by several recent systematic reviews comparing short implants (≤ 8 mm) with longer ones (> 8 mm),\textsuperscript{33,34} as well as extrashort implants (≤ 6 mm) and long implants (> 10 mm)\textsuperscript{13} that undoubtedly demonstrated comparable short-term survival rates and few biologic complications attributed to the short and extrashort implants. However, as Papaspyridakos et al.\textsuperscript{35} reported on the higher variability and lower predictability in survival rates of extrashort implants, with a 29% higher risk of failure compared to the longer ones over a 1- to 5-year period, patients for rehabilitations with extrashort implants should be selected carefully.

For the selection of clinical cases in the present series, wide general inclusion criteria (a real-world evidence concept, including patients with risk factors) and strict inclusion criteria regarding the alveolar ridge dimensions were implemented. The first inclusion criterion was a sufficient width (horizontal dimension) of the alveolar ridge, allowing for the preservation of at least 2 mm of buccal bone after the insertion of the implant, which served as protection against resorption. As complications due to a high C/I ratio present the most important concern associated with short implants, the second inclusion criterion aiming at minimizing the harmful consequences of an unfavorable C/I ratio was the lack of any major vertical alveolar ridge resorption.\textsuperscript{29} It has to be stressed, however, that most of the studies investigating the importance of the C/I ratio associated with short/extrashort implants failed to prove the negative effect of an unfavorable C/I value on crestal bone loss and implant survival,\textsuperscript{36} but still provided evidence for the higher risk of prosthetic complications (screw loosening and fractures). As the impact of the C/I ratio is clearly less important for splinted than for nonsplinted implants, the third important inclusion
Fig 3 Radiographs of six cases at implant placement, start of prosthetic loading, and 1 year postloading. (a) Male patient 51 years of age, nonsmoker. (b) Female patient 49 years of age, nonsmoker. (c) Male patient 55 years of age, nonsmoker, treated periodontitis. (d) Female patient 65 years of age, smoker, treated periodontitis. (e) Female patient 51 years of age, nonsmoker. (f) Female patient 67 years of age with osteoporosis and denosumab therapy.
criterion was sufficient bone volume in the vicinity of the 4-mm-implant site for the insertion of a 10-mm-long implant that served to reduce the bone strains as well as the mechanical forces on individual implants and components associated with the off-axis loading of ultrashort implants. It should be emphasized that higher rates of prosthetic complications associated with short implants clearly resulted from the inclusion of nonsplinted implants. The aforementioned inclusion criteria considered in the present study yielded favorable 1-year survival and success rates for splinted crowns combining extrashort and standard-sized implants, despite several systemic factors (osteoporosis, denosumab therapy, smoking, periodontitis history) that might jeopardize implant survival. Patient characteristics and preliminary results describing in detail the variabilities of the alveolar ridge dimensions, the primary and secondary stability values, and the C/I ratios of the tested 4-mm implants and the 10-mm control implants were already described elsewhere, and were thus just briefly mentioned in this report.

At the 1-year evaluation, all successfully osseointegrated 4-mm implants demonstrated stability and no signs of peri-implant pathology. The obtained peri-implant soft tissue and crestal bone parameters were in line with previous clinical studies evaluating the performance of implants with similar designs. In the present study, radiographic bone level changes in the first year of loading resulted in a median bone loss magnitude of 0.22 mm. Similar crestal bone remodeling was also reported in other studies with the same type of implants, as well as with other types of implants, indicating that a certain bone remodeling process occurred that can be partially attributed to the surgical trauma associated with flap elevation and partially by the biologic width establishment around tissue-level SP implants with a 1.8-mm highly polished collar that protrudes above the bone, allowing for transmucosal (one-stage) healing. The observed bone-associated adaptive changes could be additionally supported by the obtained soft tissue parameters (PPD, REC, and BOP) that were also within physiologic values.

In comparison to the 4-mm implants, higher bone loss (median value of 0.75 mm) attributed to the formation of an adaptive biologic width occurred around the 10-mm-long implants. A similar observation emerged from a systematic review written by Ravida et al. who also noted more marginal bone loss associated with the standard-sized control-group implants in comparison to the tested short/extrashort implants. In addition to several associated critical factors, an inferior horizontal dimension of the alveolar ridge in the premolar region, where all the 10-mm implants were inserted, could explain the higher marginal bone loss in comparison to the 4-mm implants, which were mostly inserted into the molar area. It should be noted, however, that a high heterogeneity was reported regarding the marginal bone loss associated with the short implants in the systematic review conducted by Papaspyridakos et al., precluding the possibility of a comparison between the short and standard-sized implants. Nevertheless, as the soft tissue parameters after 1 year were also within the physiologic values for the 10-mm implants, most of the crestal bone remodeling can be attributed to the adaptive biologic width–associated bone resorption of the narrower coronal part of the alveolar ridge. It could be speculated that similar results would be achieved if 8-mm-long or 12-mm-long implants were used instead of the 10-mm implants.

To the best of the authors’ knowledge, there are no earlier reports about the short-term survival and success rates after the rehabilitation of a shortened maxillary dental arch using 4-mm implants splinted to implants of standard size. The results of the present study complement several other case series and case-control studies describing the performance of extrashort implants replacing single teeth or many teeth in a partially edentulous maxilla with a gap between the premolar and the distal molar. Although facing the challenging clinical condition of shortened dental arches with multiple missing teeth and high masticatory loading area, the results of this study corroborate a reasonable and valid alternative to conventional implant restorations.

CONCLUSIONS

The 1-year data of this study demonstrated similar survival rates and radiographic marginal bone loss for the 4-mm implants compared with the standard implants. Within the limitations of this short-term study, it was concluded that using 4-mm extrashort implants splinted to 10-mm implants can provide a feasible treatment option for the rehabilitation of shortened posterior maxillary regions with an expanded maxillary sinus.

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