The Use of 4-mm Implants Splinted to 10-mm Implants for Replacement of Multiple Missing Teeth in the Posterior Maxilla Region with Expanded Maxillary Sinus. An Observational Cases Series: Patient Characteristics and Preliminary Results

This study aimed to rehabilitate shortened maxillary dental arch with splinted crowns by connecting ultra-short implants with longer ones. In the posterior maxilla of 11 patients, one 10-mm (n = 11) and one or two ultra-short 4-mm (n = 17) dental implants were inserted. The insertion torque was lower than 20 Ncm in 55% of the 10-mm implants and in 94% of the 4-mm implants (P > .05). Median (range) implant stability quotients at the time of insertion and after 6 months were 61 (14 to 72) and 68 (51 to 79), respectively, for 4-mm implants, and 66 (52 to 78) and 78 (60 to 83), respectively, for 10-mm implants (P < .05). One 4-mm implant failed to integrate. All patients were restored with splinted metal-ceramic crowns connecting 4- and 10-mm implants. Median (range) clinical crown/implant ratios of 4-mm and 10-mm implants were 2.79 (1 to 3.66) and 1.06 (0.85 to 1.46), respectively (P < .05). Six months after prosthetic rehabilitation, the median (range) crestal bone loss was 0.3 mm (–0.7 to 1.7 mm) for 4-mm implants and was 0.5 mm (–0.8 to 3.5 mm) for 10-mm implants (P > .05). Splinted crowns combining 4- and 10-mm implants may contribute to a better force distribution in the treatment with ultra-short implant–supported prosthesis in the posterior maxilla. Int J Periodontics Restorative Dent 2021;41:261–268. doi: 10.11607/prd.4389

The posterior maxillary region with an expanded sinus and poor bone quality is a challenge for implant placement. In most cases, an expanded maxillary sinus requires an internal1,2 or a lateral sinus elevation3,4 in addition to adjusting the surgical technique to compensate for poor bone quality.5 As the sinus elevation procedure is associated with significant patient morbidity, a long recovery time, and high costs,6 short implants are suggested as an alternative.7,8 Even though there is increasing scientific evidence supporting their clinical use,9 a successful treatment with short or ultra-short implants in the posterior maxilla remains controversial.

Short implants are implants < 8 mm long, and implants < 6 mm long are defined as ultra-short implants.10 Clinical studies have shown that 3-year survival rates of 6-mm implants in the posterior maxillary region range between 86.7%11 and 100%.8 When placed in non-atrophic ridges, the short-term survival rate of 6-mm implants11,12 seems to be inferior to that of standard-length implants.13,14 However, when compared to bone augmentation procedures for using conventional implants in atrophic areas, as well as in conditions with a reduced bone quantity that would require sinus floor eleva-
tion in conjunction with the insertion of standard-sized implants, the 3- to 5-year survival rate of short implants is acceptable. In addition, the survival of 6-mm implants was evaluated in conditions with severe vertical bone resorption, necessitating the installation of very long clinical crowns, resulting in an unfavorable crown/implant (C/I) ratio. Furthermore, when multiple implants are placed in the posterior maxilla, the survival of splinted crowns might be better, as splinting provides protection against excessive masticatory loading.

As implant losses with short implants were predominately reported prior to prosthetic loading or in the early phase after loading, the local bone conditions—in particular the width of the alveolar ridge—may be among the most decisive factors that influence implant integration rates. Poor quality and limited bone quantity also adversely affect long-term survival of an implant. Therefore, correct evaluation of local conditions and a good surgical technique are important for successful osseointegration and rehabilitation with short and ultra-short dental implants.

Short-term studies already reported a 5-year survival rate of over 92% for 4-mm ultra-short implants placed in the posterior mandible, where the quality of the bone is significantly better than in the maxilla. The data evaluating the success rates of 4-mm ultra-short implants in the maxillary posterior region are, however, limited. Therefore, the purpose of the present study was to determine local criteria for the insertion of 4-mm ultra-short implants and to modify the surgical protocol, ensuring good primary implant stability at insertion. The authors hypothesized that with stringent local inclusion criteria and the correct surgical technique, the primary stability of 4-mm ultra-short implants placed in the posterior maxilla will be good enough to enable predictable osseointegration and rehabilitation of partially edentulous patients with multiple missing teeth in the posterior maxillary region, using splinted crowns that connect ultra-short implants with longer ones.

Materials and Methods

Patients and Study Criteria

Eleven patients with a unilaterally shortened dental arch in the maxilla, no major vertical ridge resorption, sufficient alveolar ridge width, and expanded antrum of the maxillary sinus were recruited in a case series group to be supplied with one or two 4-mm ultra-short implants. In addition to this, one site with sufficient vertical bone dimension for the placement of a 10-mm–long implant was required.

Each participant was thoroughly informed of the overall requirements and procedures and signed an informed consent. The study protocol was approved by the National Ethic Committee of the Republic of Slovenia (No. 30/10/2015).

Inclusion criteria were as follows: Aged ≥ 18 years; good general health; absence of pathologies of soft tissues, alveolar bone, or teeth; unilaterally or bilaterally shortened dental arch in the maxilla; presence of teeth or denture in the opposing arch to reach occlusal contacts at each implant-supported crown; sufficient bone to insert a 10-mm–long (4.1-mm diameter) implant at one implant site; and one or more implant sites with reduced vertical dimension (< 8 mm).

Exclusion criteria were as follows: insufficient bone volume in the region to install one 10-mm–long (4.1-mm diameter) implant and previous implant or graft placement at the surgical site. Smoking and successfully treated periodontitis were not among the exclusion criteria.

Surgical Procedure

Implant placement was performed using single-stage surgery. Briefly, local anesthesia was achieved by infiltration of the buccal and palatal mucosa (Ultracain, Hoechst). A midcrestal incision was made from the most posterior tooth in the arch to approximately 1 cm posterior to the planned implant site. Full-thickness mucoperiosteal flaps were raised, and preparation of implant locations was performed according to a defined sequence provided by the manufacturer (Straumann). The drilling protocol ended using the SP Profile Drill (Straumann) for both 4-mm and 10-mm implant sites. Finally, one 10 × 4.1-mm and one or two 4 × 4.1-mm implants (Roxolid, SLActive, Straumann) were inserted manually with a hand ratchet.

The median (range) alveolar bone width of the future 4-mm
implant sites was 7.4 mm (4.1 to 8.6) and the height was 6.2 mm (4.2 to 11); the corresponding median widths and heights of the future 10-mm implant sites were 5.7 mm (5.2 to 7.4; \( P = .09 \)) and 11.7 (9 to 16.5; \( P > .001 \)). The surgical sites had type 3 bone quality in 10/11 cases and type 4 in 1/11 cases (a 67-year-old woman with osteoporosis). A total of 28 Standard Plus Roxolid implants were placed, all with a 4.1-mm diameter: 17 were 4 mm long and 11 were 10 mm long. The number of implants placed in the unilateral shortened maxilla of each patient ranged between 2 and 3 implants, with an average of 2.6 implants per patient. Forty-seven percent \( (n = 8) \) of 4-mm implants were placed in a first molar site, 41% \( (n = 7) \) in a second premolar site, and 12% \( (n = 2) \) in a second molar site. Seventy-two percent \( (72\%, n = 8) \) of 10-mm implants were placed in a first premolar site, 19% \( (n = 2) \) in a second premolar site, and 9% \( (n = 1) \) in a first molar site.

To determine primary stability, insertion torque was evaluated with the Straumann Torque Wrench. The proportion of implants with an insertion torque < 20 Ncm was 16/17 (94%) for 4-mm implants and 6/11 (55%) for 10-mm implants \( (P > .05) \). Implant stability quotient (ISQ) was estimated by the frequency analysis of Osstell. All implants were evaluated in the mesiodistal and vestibulopalatal aspect, and the average ISQ value was calculated from multiple measurements. At the time of insertion, the median (range) ISQ value was 5 units lower for 4-mm implants \( (61 \text{ [14 to 72]} \) than for 10-mm implants \( (66 \text{ [52 to 78]} \)).

Closure screws were placed on the implants, and flaps were repositioned and sutured. Radiographs were taken immediately and after 6 months, when implants were considered for prosthetic rehabilitation. Additional clinical and radiographic evaluations were done during follow-up visits 6 months later (12 months after insertion; Fig 1). All radiographs were digitalized as TIFFs (Tag Image File Format) to determine the position of the most coronal, radio-dense contact between the bone and the implant, the level of the implant platform, and the highest cusp of the metal framework. All radiographs were assessed by one experienced examiner (R.G.) with the aid of the MCID computer program (Imaging Research). The software was calibrated for each image using the implant length as a reference. Measurements of the most coronal, radio-dense contact between the bone and the implant were made on the mesial and distal aspects of each implant, then averaged for each implant. Crestal bone loss was calculated as the difference of distances from the implant platform and the most coronal, radio-dense contact between the bone and the implant between radiographs taken immediately after the insertion and after 6 months (at loading) or 12 months (6 months after loading). The data were also used to calculate the anatomical C/I ratio (measured from the level of the implant platform) and the clinical C/I ratio (measured from the level of the most coronal bone-to-implant contact).

**Statistical Analysis**

Differences in the alveolar bone width and height, ISQ values, C/I ratio, and crestal bone loss between different implant lengths (4 mm and 10 mm) and different time points were analyzed by nonparametric Wilcoxon test. Insertion torque data were dichotomized, and differences in proportions of implants with insertion torque < 20 Ncm were evaluated by Fisher exact test. The level of significance was set at \( P < .05 \).

**Results**

Eleven consecutive patients were included, with an average age of 61 ± 8 years (range: 49 to 73 years). Of them, 5 (45%) were men, and 3 (27%) were smokers. One patient (a 67-year-old woman) reported osteoporosis and received denosumab (30 mg/6 months; Prolia, Amgen); one patient (a 63-year-old woman) reported hypothyroidism and received supplemental hormone therapy; and one patient (a 67-year-old man) reported borderline hypertension and hypoglycaemia without the need for medical therapy. All other patients were healthy with no chronic systemic diseases or pharmacologic therapy.

All 11 patients had a unilaterally shortened maxillary arch, while 6 (55%) patients needed complex rehabilitation of severely worn or/
and damaged dentition. The same 6 patients finished active periodontal therapy before recruitment, 1 of them (a 64-year-old woman) also received fixed orthodontic appliance therapy, and they were all maintained every 4 months.

The healing period was uneventful for seven patients. Of the remaining patients, the first (a 67-year-old man with smoking habits and borderline hypertension and borderline hyperglycaemia), in whom two short implants were inserted, reported pain after 2 weeks.

Fig 1 Clinical case of a 67-year-old woman with osteoporosis and denosumab therapy. (a) Maxillary arch. (b) Interarch relationship. (c) CBCT scan of future implant sites with corresponding alveolar bone width and height measurements. (d) Alveolar ridge after elevation of mucoperiosteal flap. (e) Ultra-short implant in situ. (f) Radiograph taken immediately after implant insertion. (g) Framework check-in after 6 months of healing. (h) Three splinted, porcelain-fused-to-metal crowns. (i) Control radiograph after 15 months in function.
in the short-implant area, which lasted for 2 weeks. At that time, one of the 4-mm implants became mobile and was easily removed. After removal, the pain normalized within 1 day. The second patient (a 67-year-old woman with osteoporosis) suffered from mucosal pain and outbreak of intraoral herpetic vesicles 3 days after surgical procedure, and she was treated with valacyclovir (500 mg twice per day; Valtrex, GlaxoSmithKline) for 2 weeks. The third patient (a 63-year-old woman with hypothyroidism and smoking habits) suffered from three events in the healing period: after 2 weeks, one of the closure screws became loosened and was immediately retightened; after 2 months, she reported pulpitic pain of the neighboring premolar tooth, which was later extracted due to unsuccessful endodontic treatment; and after 3 months, she was diagnosed with breast cancer, which was surgically treated without the need for chemo- or radiotherapy. Six months after breast cancer surgery, the extracted premolar was replaced with a new implant. The fourth patient (a 73-year-old man) reported pain of the endodontically treated neighboring canine, which was extracted and replaced with a pontic between the new implant on the position of the second incisor and first premolar.

For both implant lengths, the ISQ values increased after 6 months of healing ($P < .05$). At 6 months, the median (range) ISQ values were 10 units lower for 4-mm implants (68 [51 to 79]) than for 10-mm implants (78 [60 to 83]; $P < .05$). All abutments/suprastructures were screwed to implants with a torque of 35 Ncm. Ten patients were restored with metal-ceramic fixed dental prostheses (FDPs). In 1 patient, the prosthetic rehabilitation has not yet been completed due to the complex treatment plan; however, his implants support the temporary acrylic prosthetic restoration. Metal frameworks of the FDPs were computer-designed and milled from the cobalt-chromium alloy Coron (Straumann). Three FDPs were fixed on cementable abutments, and eight FDP frameworks were screwed directly to implants without abutments. Seven three-unit FDPs were supported on one 10-mm implant and two 4-mm implants. Three two-unit FDPs were supported on one 10-mm implant and one 4-mm implant.

The median (range) anatomical C/I ratio was 1.57 (0.8 to 3.0) for 4-mm implants and 0.76 (0.44 to 1.0) for 10-mm implants. The corresponding clinical C/I ratios were 2.79 (1.0 to 3.66) and 1.57 (0.85 to 1.46). The differences in anatomical and clinical C/I ratios between both lengths were statistically significant ($P < .001$).

Crestal Bone Loss

Radiographs obtained at baseline and 6 months later revealed a median (range) crestal bone loss of 0.3 mm (−0.6 to 1.8 mm) for 4-mm implants and 0.9 mm (−0.7 to 2.9 mm) for 10-mm implants. Six months after prosthetic rehabilitation, these values were 0.3 mm (−0.8 to 1.7 mm) for 4-mm implants and 0.5 mm (−0.8 to 3.5 mm) for 10-mm implants. The differences between both groups and both time intervals were not statistically significant ($P > .05$).

Survival and Success Rates

The successful osseointegration rate for implants placed in the posterior maxillae was 94% (16/17) for 4-mm implants and 100% (11/11) for 10-mm implants. All implant-supported restorations were in function at the 6-month follow-up. After 6 months of function, the probing depths around 4-mm and 10-mm implants were 2.9 ± 0.4 mm and 3 ± 0.7 mm ($P > .05$), respectively, and the bleeding on probing seen at corresponding sites were 10% and 16%, respectively ($P > .05$).

Discussion

In this prospective case series study, 4-mm ultra-short titanium-zirconium alloy implants with SLActive surface characteristics and Standard Plus (SP) design were inserted in the pristine bone of the maxillary posterior region. Wide general inclusion criteria (real-world evidence concept) and strict inclusion criteria regarding the alveolar ridge dimensions were implemented. In the vicinity of the 4-mm–implant site, one 10-mm implant was inserted to reduce bone strain associated with off-axis loading of ultra-short implants. The present authors adjusted the surgical procedure, modifying only the final steps of the standard pro-
procedure recommended for insertion of SP implants of normal lengths, to ensure the adequate primary stability of the ultra-short implants in the posterior maxillary region. In order to obtain a slightly better primary stability, the threading process was omitted and the bony bed/osteotomy was adjusted to the profile of the implant with a profile drill. Some authors recommend using a manual osteotomy or a final drill with a diameter somewhat smaller than the implants, as well as bone condensation instead of drilling when preparing a bony bed for a short implant.22,23 Besides contributing to primary stability, the present authors believe that such a process may also lead to excessive compression of the bone and osteonecrosis, which may be associated with a subsequent remodeling process that slows down initial osseointegration. Furthermore, as the classic implant loading protocol with a 6-month healing period was used in the present study, the relative importance of primary stability for successful osseointegration is lower than in the fast implant-loading protocols.

The adequacy of the surgical protocol was evaluated by assessing the primary stability of ultra-short implants, as determined by a torque wrench and radiofrequency ablation (RFA) magnetic device. Both values were much lower than the values reported by Calvo-Guirado et al.,24 who tested similar ultra-short implants in the posterior mandible. In one very extreme case in the present study, when two ultra-short implants were inserted in an osteoporotic patient with type 4 bone quality, the primary stability of one of the implants was indeed minimal (RFA value of 14). However, because the implants were made of titanium-zirconium alloy25 with an SLActive surface,26 both characteristics that contribute to faster healing and greater bone-to-implant contact, it was decided to retain the implant with the hope of successful osseointegration.

After 6 months, the stability values of 4-mm and 10-mm implants increased, with both implants groups reaching ISQ values near or above 60, which provided safe loading for splinted suprastructures.20,27,28 Finally, all patients were successfully rehabilitated with two- or three-unit splinted crowns, with the exception of the first patient who, after the failure of an ultra-short implant, received a three-unit FPD connecting the crowns above the 10-mm and 4-mm implants, with a pontic in between. Most of the frameworks were milled and directly screwed to the implants. The advantage of such a construction is that it reduces the number of intermediate elements. Individual restorations can also be considered when the interarch space is reduced. However, the prosthetic design may limit the access for daily cleaning due to splinting.

Crestal bone resorption during the initial healing indicates that a certain bone remodeling process occurred that may be partially attributed to surgical trauma associated with flap elevation29,30 and partially to biologic width establishment around tissue-level SP implants with a 1.8-mm highly polished collar that protrudes above the bone, allowing transmucosal (one-stage) healing. Similar crestal bone remodeling was also reported in other studies with the same21 and different6 implant types.

To evaluate biomechanical characteristics of implant-supported suprastructures, C/I ratios for 4-mm and 10-mm implants were calculated. For ultra-short 4-mm implants, the anatomical C/I ratios were between 0.8 and 3, and the corresponding clinical C/I ratios were between 1 and 3.7. It was traditionally considered that the C/I ratio should not be greater than 1 in order to ensure long-term stability of the implant-supported restorations.31 However, with the development of contemporary implant designs and surface characteristics, the critical upper limit now lies below the value of the anatomical C/I ratio of 3.1 and clinical C/I ratio of 3.4.32 Furthermore, opinions on the importance of the C/I ratio are by no means uniform, as some authors advocate for an inverse relationship between the C/I ratio and marginal bone resorption (within clinical C/I ratio values of 0.6 and 2.26), which would mean that a greater C/I ratio is associated with lower resorption of the marginal bone.33 This is likely because the crestal bone receives favorable physiologic forces within this C/I interval. It can be assumed that the impact of the C/I ratio is less important for splinted than for non-splinted implants. However, with the increased C/I ratio, more prosthetic complications and screw loosening may be expected.34,35

The C/I ratio values were also reported in many other studies considering the ultra-short and short
implants. Slotte et al., who restored the severely resorbed shortened mandible with three or four splinted, ultra-short, 4-mm implants, reported mean anatomical C/I ratios of 2.5. Even though they also included patients with a significant vertical bone loss, which is proportionally related to the increased C/I values of their restorations supported by ultra-short implants, they were able to reach a 5-year survival rate of more than 92% in their multicenter study. An important difference between Slotte et al’s protocol and the present study’s protocol is that the other study did not use standard-length implants to support ultra-short implants. The influence of the C/I ratio on marginal bone resorption around short implants was also presented by Anitua et al., who managed to ensure a 98% implant survival rate over a 12-year observation period, irrespective of the C/I values ranging between 0.9 and 2.5. Anitua et al. concluded that the relationship between the crown height and marginal bone loss is much more important than the C/I ratio. However, no conclusion could be made on the C/I ratio impact on marginal bone loss based on data collected by the present authors thus far, and therefore a long-term evaluation is necessary.

Conclusions

Considering the study’s inclusion criteria (sufficiently wide alveolar ridge and no major vertical bone loss), splinted crowns combining ultra-short and standard-length implants represent a possible solution for the replacement of multiple missing teeth in the posterior maxilla. Further follow-ups of the included patients and other long-term and comparative studies are required to support this treatment solution for a partially edentulous posterior maxilla.

Acknowledgments

Implants were donated by Straumann, Basel, Switzerland, and suprastructures by Dentalia Company, Ljubljana, Slovenia, a local Straumann distributor. Author contributions: Conception and design of study: R.G., Cˇ.O., and M.D. Clinical procedures and data acquisition: R.G., Č.O., and Č.O. Drafting of the article: R.G., Č.O., and S.C. Article revision: S.C. and M.D. All authors read and approved the final article.

References


