Preliminary 2-Year Report on Treatment Outcomes for 6-mm-Long Implants in Posterior Atrophic Mandibles

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Purpose: The aim of this study was to prospectively evaluate clinical and radiographic outcomes of ultrashort implants (4-mm diameter, 6-mm length) supporting fixed partial dentures in severely atrophic posterior mandibles. ***Materials and Methods:*** Twenty-five patients with posterior edentulous mandibular spans and 7- to 8-mm residual bone heights above the mandibular canal were enrolled. In total, 61 submerged implants were placed and loaded 5 to 6 months later. Patients were followed for 2 years after prosthesis connection with clinical, radiographic, and resonance frequency analysis (RFA) examinations. ***Results:*** Two implants failed in one patient before loading; all other implants showed favorable clinical and radiographic findings throughout the observation period (2-year survival and success rate: 96.8%). Postoperative pain and swelling were negligible. Mean changes in marginal bone levels were stable (0.40 ± 0.23, 0.51 ± 0.38, and 0.60 ± 0.13 mm after 6 months and 1 and 2 years, respectively) and were unaffected by measured crown-to-implant ratios (range: 1.31 to 3.12). Mean RFA values increased significantly from implant placement (67.35 ± 6.67) to 2 years (72.91 ± 5.07, $P < .0001$). Prosthetic complications included two prosthesis decementations, three ceramic veneer chippings, and one prosthesis screw loosening. ***Conclusion:*** Within the limitations of the short follow-up period, the use of 6-mm-long implants was a predictable treatment method for patients with atrophic posterior mandibles and increased crown-to-implant ratios. *Int J Prosthodont 2012;25:279–289.*

Implant-supported rehabilitation of the posterior edentulous mandible is often complicated by the presence of advanced residual ridge resorption that may also include underlying basal bone.[1] In addition, the duration and wearing habits of distal-extension removable partial dentures risk further compromise of residual bone height.[2] Implant placement is difficult in such situations and carries a risk of inferior alveolar nerve damage. Various surgical techniques, such as inlay or onlay block grafts,[3] guided bone regeneration,[4] and inferior alveolar nerve repositioning,[5] have been used to increase the vertical height of the posterior mandible. However, complications associated with these augmentation procedures and the frequent need for additional grafting procedures (approximately 25%) remain too high to recommend their widespread use.[6] Moreover, the requirement for multiple surgeries adds considerably to treatment duration and costs and may discourage some patients from undergoing implant-supported rehabilitation.

Recent reports have described the placement of short dental implants in residual bone volumes as an alternative preprosthetic surgical approach with favorable results.[7,8] Moreover, reported implant failure rates were independent of implant length for ultrashort implants with roughened surfaces, and prosthetic outcomes were regarded as favorable in all locations tested.[9] The latter included the more challenging posterior areas of the arches where maximal occlusal forces are often accompanied by high crown-to-implant ratios. However, all of these studies used retrospective chart review protocols that precluded the observational details associated with progressive study protocols, including the precise time-dependent monitoring of circumimplant bone behavior. Scientific validation of the use of ultrashort implants, with prospective clinical trials focused specifically on severely atrophic posterior sites, is required before their routine use.

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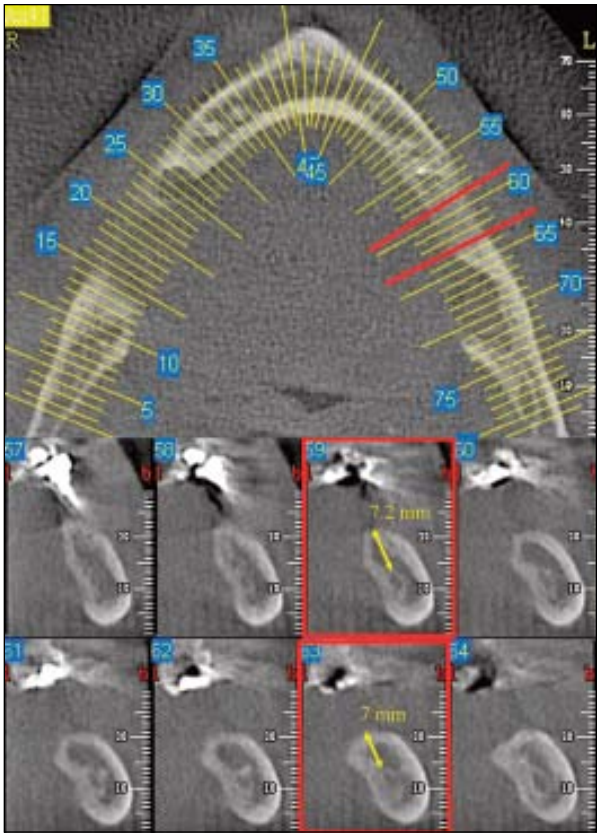

Fig 1 Preoperative CT scans used to evaluate patient eligibility: 7 to 8 mm of residual bone height above the left mandibular canal with a thickness of at least 6 mm. Red lines indicate two possible implant sites in the premolar/molar areas.

The aim of this prospective study was to evaluate the clinical and radiographic outcomes of 6-mm-long implants supporting fixed partial dentures (FPDs) in the atrophic posterior mandible after 5 years of loading. This preliminary 2-year assessment provides the necessary baseline information to underscore the merit of the proposed clinical protocol.

Materials and Methods

Patient Selection

A convenience sample of 25 patients (11 men, 14 women; age range: 53 to 74 years; mean age: 64.5 ± 6 years) presenting with uni- (n = 22) or bilateral (n = 3) partial edentulism in the posterior mandible, 7 to 8 mm of residual bone height, ≥ 6-mm bone width above the inferior alveolar canal (measured using a computed tomography [CT] scan, Fig 1), and requiring an FPD supported by two or three 6-mm-long implants were consecutively included in this study. Additional inclusion criteria were at least 50 years of age at enrollment, minimum 6-month history with edentulism in the study area, presence of a natural tooth adjacent to the planned FPD with a complete occlusal surface and no periodontal or endodontic infection, and presence of natural teeth or fixed restorations in the maxilla that would be in occlusal contact with the planned FPD. Patients were excluded if one of the following were present: severe blood, renal, or liver disease; immunosuppressive disorders; known or suspected current malignant disease; history of radiotherapy in the head and neck region; history of antitumor chemotherapy within the previous 12 months; uncontrolled diabetes (glycosylated hemoglobin level > 8 mg/%)[10]; pregnancy or lactation; alcohol or drug abuse; smoking more than 10 cigarettes/day; psychiatric problems or unrealistic expectations; previous treatment with intravenous aminobisphosphonates; current corticosteroid use; active periodontal infection; poor oral hygiene and motivation (full-mouth plaque and bleeding scores > 20%); inflammatory or autoimmune diseases of the oral cavity; and previous augmentation procedures in the study area.

A reported history of bruxism was recorded but not considered a limiting criterion, with 6 patients recorded as bruxers and 19 as nonbruxers. The presence of any parafunction was established based on clearly visible occlusal facets, patients' self-reported bruxism habits, and signs of temporomandibular joint disorders.[11] Bruxers were managed with acrylic resin nightguards to minimize excessive nocturnal forces. Twenty-one patients (84%) were nonsmokers and 4 patients (16%) smoked up to 10 cigarettes a day. A majority of the study participants wore Kennedy Class I (8%) or II (64%) removable partial dentures of the mandible for at least 1 year; 7 patients (28%) did not wear any dentures. The opposing dentition was also assessed: 15 patients (60%) had natural teeth, 5 (20%) had a tooth-supported FPD, and 5 (20%) had an implant-supported FPD.

Patients were recruited and treated by the same operator in a private dental office in Cesena, Italy, in close collaboration with the Oral and Maxillofacial Surgery Unit, Department of Dental Sciences, University of Bologna, Bologna, Italy, between January and August 2008. Preliminary screening was performed using clinical records, casts and diagnostic wax-ups, and radiographic evaluations (periapical and panoramic radiographs, CT scans). Periodontal and restorative procedures were undertaken when necessary to establish a healthy oral environment. Prosthetic needs related to the missing teeth were determined, and patients were advised of treatment alternatives.

The study protocol and consent form were reviewed and approved by the institutional review board of the Department of Dental Sciences, University of Bologna. This study adhered to the principles outlined in the Declaration of Helsinki for clinical research. All patients provided written informed consent prior to enrollment in the trial and agreed to participate in a postoperative control program for ongoing care and data collection.

Implant Treatment

Within 1 month before implant placement, all patients underwent at least one session of oral hygiene instruction and professionally delivered debridement. All patients took amoxicillin and clavulanic acid (Augmentin 2 g, GlaxoSmithKline) as a prophylactic measure 1 hour before surgery and continued to take 1 g twice a day for 6 days. Patients allergic to penicillin were given clarithromycin (Klacid 500 mg, Abbott Laboratories). Patients rinsed with 0.2% chlorhexidine digluconate (Corsodyl, GlaxoSmithKline) mouthwash for 1 minute before the intervention.

The two-stage surgical approach to implant placement followed that described in the Astra Tech Implant System manual. Local anesthesia was induced by infiltrating with 4% articaine chlorhydrate containing 1:100,000 adrenaline (Citocartin, Molteni Dental). A midcrestal incision was performed, and full-thickness flaps were elevated to expose the alveolar bone. In each treated mandibular site, two or three 4 × 6-mm platform-switched implants (OsseoSpeed, Astra Tech) with a Morse taper connection were placed alone in 22 patients or in association with a longer implant anterior to the mental foramen in 3 patients using a surgical template with the smooth collar positioned at the bone crest level. Bone quality at the time of surgery was recorded using the criteria of Trisi and Rao[12]: 4 implants (6.6%) were placed in soft bone, 38 (62.3%) in normal bone, and 19 (31.1%) in dense bone. Every effort was made to maintain a parallel orientation between the implants and remaining dentition. The flaps were repositioned and sutured to allow submerged healing.

Postoperative medication included an oral cavity rinse with 0.2% chlorhexidine digluconate for 1 minute twice a day and an analgesic agent (Brufen 600 mg, Abbott Laboratories) up to three times a day or when needed. Patients were additionally instructed to avoid mechanical toothbrushing and chewing at the surgical site until removal of the sutures 7 days after surgery. To avoid loading of the surgical area, no provisional removable partial dentures were used during the healing period.

After 3 months, the surgical sites were reentered. Healing abutments were screwed onto each implant and left in situ for approximately 4 to 5 weeks to allow soft tissue healing before impressions were taken. At sites with inadequate keratinized mucosa width (< 2 mm),[13] soft tissue enhancement was performed with a free gingival graft harvested from the palate to attain a wide band of keratinized tissue at the time of abutment insertion. In these cases, impressions were taken 7 to 8 weeks after the enhancement procedure. The study protocol employed a screw-retained (n = 13) or cemented (n = 15) prosthetic approach. To reduce stress and the risk of fracture, all FPDs featured a ratio of one implant per prosthetic unit, and tooth-implant connection was avoided. Screw-retained metal-ceramic restorations (Wieland) were connected directly to the implant platform. Cemented metal-ceramic restorations were made on customized computer-aided design/computer-assisted manufacture titanium abutments and temporarily cemented using zinc oxide–eugenol cement (Temp Bond, Kerr). Retaining screws (Abutment Screw Design 3.5/4.0, Astra Tech) were secured using a torque wrench (Astra Tech) set at 20 Ncm. Static and dynamic occlusion were evaluated using 20-μm occluding papers (Arti-Fol II, Bausch Articulating Papers). Care was taken to ensure a flat occlusal plane and to achieve canine guidance or group function occlusion without working or nonworking interference during lateral movements.[14]

After delivery of the prosthetic restorations, all patients received oral hygiene instructions for implant cleaning with a regular toothbrush and interdental brushes. Throughout the 2-year follow-up, patients were enrolled in individually designed supportive periodontal/peri-implant maintenance programs that called for examination of the periodontal and peri-implant soft tissues and professional oral hygiene every 6 months. Occlusion was checked carefully at each follow-up examination, and prosthetic adjustments were made when indicated. Figures 2a to 2d present a representative case.

Pain and Edema Measurement

Levels of postoperative pain and edema were assessed at the first control visit 3 days after implant placement. The patients rated pain according to the following 4-point verbal descriptive scale: 1 = no pain, 2 = slight pain, 3 = moderate pain, and 4 = severe pain. The number of analgesics used for pain control was also recorded. Edema was scored by the surgeon according to the following scale: 1 = no visible edema, 2 = slight edema, 3 = moderate edema, 4 = severe edema and/or visible hematoma and ecchymosis.[15]

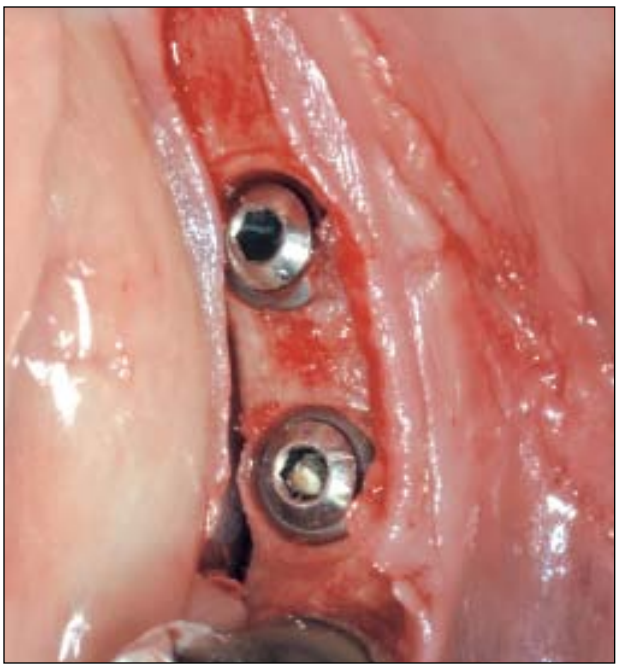

Fig 2a Two 6-mm-long implants placed in the second premolar and first molar sites.

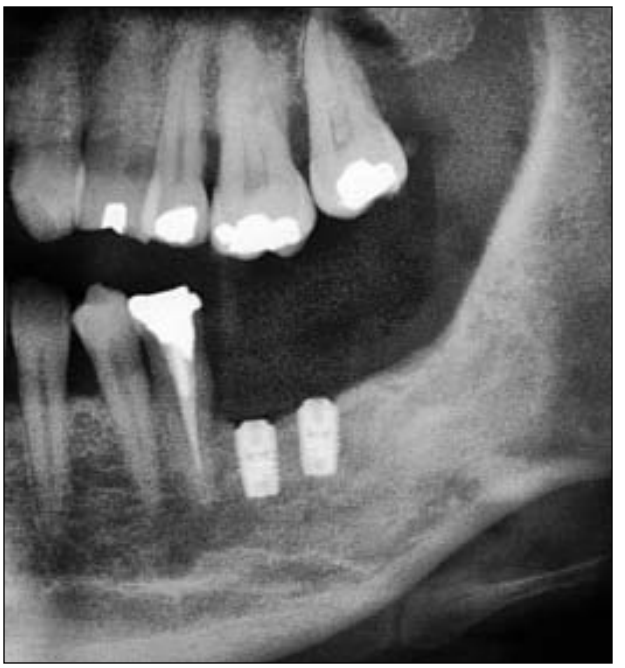

Fig 2b Postoperative panoramic radiograph.

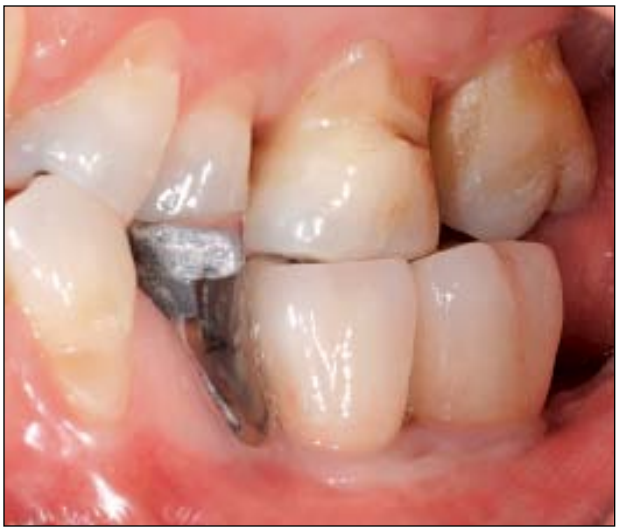

Fig 2c Lateral view after definitive FPD delivery.

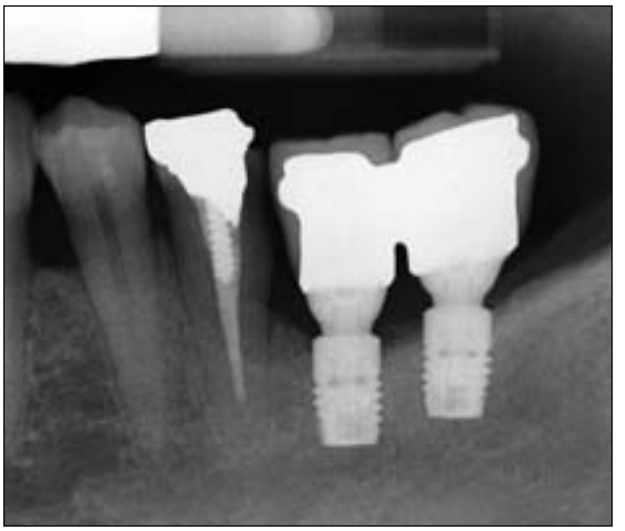

Fig 2d Periapical radiograph taken after 2 years of functional loading showing minimal crestal bone loss.

Peri-Implant Clinical Evaluation

Reports on implant treatment outcomes frequently employ periodontal surrogate measurement protocols on the assumption that there may be relevant similarities of prognostic importance between soft tissue behavior around implants and natural teeth. While this continues to be a contentious issue, the authors chose to record these clinical variables in case future evidence evolves regarding their significance. The following clinical variables were therefore collected at 1, 12, and 24 months after prosthesis placement: *(1)* modified Plaque Index (MPI) and *(2)* modified Sulcus Bleeding Index (MBI) assessed at four sites around the implants (mesial, buccal, distal, lingual); *(3)* peri-implant probing pocket depth (PPD) measured to the nearest 0.5 mm with a calibrated mechanical probe (Florida Probe, Florida Probes) at a constant probing force (0.15 N); and *(4)* width of keratinized mucosa (WKM) measured to the nearest 1 mm at the midfacial aspect of each implant. For each implant, mean MPI, MBI, and PPD values were derived from the four values obtained. All clinical assessments were performed by a periodontist.

Implant Stability

Resonance frequency analysis (RFA; measured using an Osstell Mentor [Osstell]) was used as a clinical method to measure implant stability, although there is still controversy regarding the correlation between the quality of osseointegration and RFA.[16] Immediately after implant placement, RFA was performed by the surgeon to obtain baseline values for each implant. The transducer (type F6) was hand-screwed into the implant body, as recommended by the manufacturer. Results were expressed as an implant stability quotient (ISQ), with values ranging from 1 (minimum stability) to 100 (maximum stability). The RFA measurements were repeated by the same investigator for each implant at the time of FPD placement and at 2 years postloading after FPD removal. Each measurement was taken twice, and the mean value was used.

Radiographic Analysis

Digital periapical radiographs (Digora Optime, Soredex/Orion) were taken using the long-cone paralleling technique, and an individual film holder was fabricated through a bite block in polyvinyl siloxane (Regisil, Caulk Dentsply) attached to an aiming device (Rinn XCP, Dentsply Rinn) immediately after prosthesis placement and at 6, 12, and 24 months. Radiographs were taken to provide clear mesial and distal visibility of the platform and threads. Image analysis software (Digora for Windows v 2.1, Soredex/Orion) was used to measure the distance between the implant-abutment junction and the most coronal level of the bone deemed to be in contact with the implant surface using an on-screen cursor after 3× magnification of the digital radiograph.[17] This cursor was calibrated using the known diameter of the implant head, and marginal bone resorption was measured to the nearest 0.01 mm at the mesial and distal sites of each implant. Mean marginal bone resorption for each implant was derived from the mesial and distal values.

The crown-to-implant ratio at the time of prosthetic restoration was also calculated, taking into account the relationship between the mesial and distal lengths of the restoration and those of the bone-embedded implant. Accordingly, implant length was defined as the distance from the apex to the most coronal bone-to-implant contact, and crown length was defined as the distance from the top of the restoration to the most coronal bone-to-implant contact.[18] A mean mesiodistal crown-to-implant ratio was obtained for each implant. Three categories of crown-to-implant ratios were used for descriptive analysis: ≤ 1.5, 1.5 to 2.5, and ≥ 2.5.

Radiographic assessment error was determined by the duplicate measurement of one randomly selected implant in each patient at the first follow-up examination (immediately after prosthesis placement). The mean difference between the two readings was 0.03 mm (standard deviation: 0.24). All radiographic measurements were performed by one experienced examiner who was not involved in the surgical procedures. The observation intervals of radiographs from the same patient were masked.

Biologic and Prosthetic Complications

The following complication parameters were assessed at each follow-up examination: intraoperative and postoperative biologic complications such as hemorrhages, neurosensory alterations, or damage to teeth or roots adjacent to the implant; biologic complications during maintenance such as peri-implant mucositis (heavily inflamed soft tissue without bone loss) or peri-implantitis (bone loss with suppuration or heavily inflamed tissues or fistulas); and prosthetic complications such as implant or prosthetic component fracture, prosthesis detachment, abutment screw loosening, or ceramic veneer fracture.

Success and Failure Criteria

An implant was deemed successful when it fulfilled all of the following criteria[19]: *(1)* absence of persistent subjective complaints such as pain, foreign-body sensation, and/or dysesthesia; *(2)* absence of peri-implant infection with suppuration; *(3)* absence of mobility; *(4)* absence of continuous radiolucency around the implant; and *(5)* marginal bone resorption < 1.5 mm in the first year of function and < 0.2 mm in the second year. An implant was classified as survived when it complied with all of the aforementioned criteria but exhibited marginal bone resorption greater than the established parameters. Implants requiring removal for any reason were regarded as failures.

An FPD was classified as successful when it could be placed as planned and its function was maintained over time without modification. A prosthesis was considered a failure when it was not possible to place as planned (because of implant failure) or when its function was compromised by one of the following conditions: fracture of the prosthetic framework, abutment, connecting screw, or implant or implant failure.

Patient Satisfaction

Patients completed self-administered questionnaires 1 month after delivery of the definitive FPD to

assess satisfaction with the dental implant experience.[20] The questionnaire consisted of seven items in five domains: *(1)* esthetics, *(2)* ability to chew food, *(3)* ability to clean implants, *(4)* cost of treatment, and *(5)* overall satisfaction. Subjects were asked to rate their satisfaction on a 5-point Likert scale for each item (1 = absolutely to 5 = absolutely not).

Statistical Analysis

All clinical and radiographic parameters are reported as means ± standard deviations. Data were analyzed using SPSS software (v 16.0, IBM). The implant was the statistical unit of the analysis. Potential differences in clinical parameters and marginal bone resorption values over time were analyzed using the Friedman test and adjusted according to the step-down Bonferroni method of Holm. Differences in marginal bone resoption values between the three crown-to-implant ratio groups were tested using the Kruskal-Wallis test. Cross-tabular analysis used the chi-square test to determine whether prosthetic complications were dependent on crown-to-implant ratio and bruxism. The level of significance was set at $P = .05$ for all statistical tests.

Results

All 25 patients participated until the end of the study; no clinical dropouts occurred (Table 1). One implant each in 2 patients showed limited peri-implant dehiscence; these were treated by packing autologous bone chips collected during drilling and covered with a collagen membrane (Bio-Gide, Geistlich).

Three days after surgery, 6 patients reported no postsurgical pain and 19 reported mild pain; 10 patients reported no swelling and 15 reported mild swelling. The patients consumed an average of 4.95 ± 1.68 analgesic tablets (range: 3 to 9 tablets). The only biologic complication encountered was transient paresthesia of the alveolar inferior nerve (3.5%), which abated after 1 month; no definitive sensory disturbance was recorded.

Survival and Success Rates

All patients were followed-up for 2 years after prosthetic loading. No patient dropped out of the study. Two implant failures were recorded during the osseointegration phase in a light smoker (< 10 cigarettes/day). This patient had two 6-mm implants placed in very dense bone at the mandibular right second premolar and first molar sites. High insertion torque was achieved for both implants (≥ 60 Ncm). At the 1-month follow-up evaluation, abnormal and delayed wound healing was noted at the implant sites, with early cover screw exposure and mucosal inflammation. Radiographs of the implants revealed severe bone loss (50% to 70%) around both implants, necessitating their immediate removal. One week following this procedure, amoxicillin and clavulanic acid antibiotic therapy was administered to the patient. Both implants were replaced with 8-mm-long implants after a 6-month healing period using a simultaneous vertical ridge augmentation procedure with autologous mandibular bone and titanium micromesh. Eight months after implant placement, the patient was provided with the definitive FPD. The remaining 59 implants in the sample fulfilled the established success criteria at the end of the 2-year follow-up period. This resulted in 2-year survival and success rates of 96.8%. As a consequence of the two implant failures, 1 of 28 FPDs could not be placed, resulting in an overall prosthesis success rate of 96.5%.

Peri-Implant Clinical Parameters

All patients maintained good oral hygiene throughout the study period. Mean MPI at the 1-month examination was 0.45 ± 0.38. This value decreased slightly at the 1- and 2-year follow-up examinations (0.43 ± 0.37 and 0.40 ± 0.38, respectively). The peri-implant soft tissues showed little tendency to bleed after probing in the majority of patients. At the 1-month examination, the mean MBI was 0.40 ± 0.60; this value decreased slightly over the follow-up period to 0.33 ± 0.35 after 2 years. Mean PPD increased slightly from 2.39 ± 0.69 mm at the 1-month examination to 2.51 ± 0.54 mm at the 2-year examination. Mean WKM remained stable during the study period, averaging 1.89 ± 0.58 mm and 1.96 ± 0.60 mm after 1 and 2 years, respectively (Table 2).

At the 2-year examination, 49 implants (83.1%) had MPI values of 0 to 1, whereas 10 implants (16.9%) exhibited a greater amount of plaque (MPI ≥ 1). Fifty-one implants (86.4%) had MBI values of 0 to 1, and 8 implants (13.6%) showed a bleeding score ≥ 1. PPD was < 2 mm in 17 implants (28.8%), 2 to 3 mm in 37 implants (66.2%), and > 3 mm in 3 implants (5%). Only 3.3% of investigated sites (2 implants) exhibited minimal WKM (1 mm). The remaining sites exhibited an adequate band of KM (WKM ≥ 2 mm).

Implant Stability Evaluation

RFA measurements were performed on all implants at implant placement and abutment connection. At the 2-year follow-up examination, measurements from

Table 1 Summary of Patient Data and Implants Placed

Patient	Age (y), sex	No. of 6-mm-long implants	Short-length (6 mm) implant sites*	Standard-length (≥ 11 mm) implant sites*	Site of lost implant*	Type of FPD
1	61, M	2	35, 36	34		Cemented
2	71, F	2	36, 37			Cemented
3	55, F	2	35, 36			Screw-retained
4	53, F	2	46, 47			Screw-retained
5	65, M	2	45, 46		45, 46	
6	68, F	3	45, 46, 47			Screw-retained
7	66, F	2	35, 36			Cemented
		2	45, 46			Cemented
8	71, M	3	45, 46, 47			Screw-retained
9	72, M	2	36, 37			Screw-retained
10	67, F	2	35, 36	34		Cemented
11	61, F	2	46, 47			Screw-retained
12	62, F	3	35, 36, 37			Cemented
		2	45, 46			Cemented
13	56, F	2	45, 46			Screw-retained
14	63, M	2	46, 47			Screw-retained
15	68, F	3	35, 36, 37			Screw-retained
		2	45, 46			Screw-retained
16	59, F	2	45, 46			Cemented
17	71, F	2	35, 36			Screw-retained
18	65, M	2	36, 37			Cemented
19	57, M	2	46, 47			Cemented
20	66, F	3	45, 46, 47			Screw-retained
21	73, F	2	45, 46	44		Cemented
22	56, M	2	36, 37			Cemented
23	74, M	2	46, 47			Cemented
24	66, M	2	46, 47			Cemented
25	73, M	2	36, 37			Cemented

M = male; F = female; FPD = fixed partial denture.
*FDI tooth-numbering system.

Table 2 Mean Changes in Clinical Parameters Over 2 Years of Loading (Mean ± Standard Deviation)

Parameters	1 mo	1 y	2 y	*P*
MPI	0.45 ± 0.38	0.43 ± 0.37	0.40 ± 0.38	.9082
MBI	0.40 ± 0.60	0.38 ± 0.38	0.33 ± 0.35	.5466
PPD (mm)	2.39 ± 0.69	2.43 ± 0.85	2.51 ± 0.54	.0122*
WKM (mm)	1.88 ± 0.58	1.89 ± 0.58	1.96 ± 0.60	.4060

MPI = modified Plaque Index; MBI = modified Sulcus Bleeding Index; PPD = probing pocket depth; WKM = width of keratinized mucosa.
*Statistically significant difference over time (Friedman test, $P < .05$).

Table 3 Change in Marginal Bone Resorption (MBR) of 6-mm Implants in Relation to Crown-to-Implant (C/I) Ratio Over 2 Years of Loading*

C/I ratio	No. of implants (%)	Mean C/I ratio	Mean MBR (mm)
≤ 1.5	14 (22.9)	1.38 ± 0.06	0.59 ± 0.09
1.5–2.5	33 (57.4)	1.90 ± 0.24	0.62 ± 0.15
≥ 2.5	12 (19.7)	2.68 ± 0.18	0.55 ± 0.13

*Unpaired *t* tests showed no significant differences among groups ($P = .335$).

the two failed implants were missing. The mean ISQ values at implant placement, abutment connection, and 2 years after the start of prosthetic loading were 67.35 ± 6.67, 69.59 ± 5.42, and 72.91 ± 5.07, respectively. A significant increase in mean ISQ was observed over time ($P < .0001$).

Table 4 Patient Satisfaction 1 Month After Definitive Prosthesis Delivery

Item	Question	Absolutely yes	Yes	Not sure	No	Absolutely not
1	Are you satisfied with tooth size, color, and arrangement?	4	21	0	0	0
2	Are you satisfied with the chewing capacity obtained after implant prosthesis placement?	10	15	0	0	0
3	Is it easy to clean your implant prosthesis?	0	16	9	0	0
4	Is your implant prosthesis comfortable?	10	14	1	0	0
5	Has the implant prosthesis improved your lifestyle?	13	12	0	0	0
6	Was implant therapy worth the cost?	2	22	1	0	0
7	Would you undergo the same therapy again?	4	20	1	0	0

Radiographic Findings

Radiographs showed normal peri-implant bone structure with no signs of continuous radiolucency around the implant threads during the 2-year observation period. Mean clinical crown length was 11.16 ± 2.72 mm (range: 7.42 to 17.34 mm) and mean crown-to-implant ratio was 1.94 ± 0.46 (range: 1.31 to 3.12). The majority of implants (n = 35, 57.4%) had crown-to-implant ratios of 1.5 to 2.5. Fourteen implants (22.9%) had a crown-to-implant ratio ≤ 1.5, and 12 (19.7%) displayed high crown-to-implant ratios (≥ 2.5). Comparison of peri-implant bone resorption to crown-to-implant ratios showed no significant differences among groups (P = .335) (Table 3).

Mean marginal bone resorption at the start of prosthetic loading was 0.27 ± 0.10 mm; this value increased to 0.40 ± 0.23 mm, 0.51 ± 0.38 mm, and 0.60 ± 0.13 mm after 6 months and 1 and 2 years, respectively. Marginal bone resorption values increased significantly between the start of prosthetic loading and the 6-month and 1-year examinations (P < .001) but not between the 1- and 2-year examinations (P = .1011). Sixteen implants (27.1%) showed values ≤ 0.5 mm after 2 years of functional loading, and 42 (72.9%) showed values of 0.5 to 1.0 mm.

Prosthetic Complications

Minor prosthetic complications were recorded in 6 (22.2%) of 27 FPDs. Two (7.4%) FPD decementations were observed after 2 to 3 months of loading. The FPDs were recemented with zinc phosphate cement (Harvard Cement, Harvard Dental). Two patients showed small ceramic fractures on a total of 3 (11.1%) FPDs, which were treated by polishing to the patients' satisfaction. Two (3.7%) abutment screws in a screw-retained FPD became loose after 1 month of loading. Both screws were retightened while keeping the original prosthesis intact. All prosthetic complications were resolved with no laboratory cost on the same day of the patients' visits.

Two of 8 (25%) FPDs in the bruxing group had complications and 4 of 19 (21%) FPDs in the nonbruxing group required intervention. This difference between groups was not statistically significant (P = .1).

Evaluation of the effect of increased crown-to-implant ratio on the number of prosthetic complications revealed one complication (20%) in the ≥ 2.5 group, three (18.7%) in the 1.5 to 2.5 group, and two (33.3%) in the ≤ 1.5 group. The difference in proportions was not significant (P = .7579).

Patient Satisfaction

Table 4 summarizes patient satisfaction assessed 1 month after delivery of the definitive FPDs. All patients reported that their chewing capacity, lifestyle, and overall comfort improved greatly with the implant-supported mandibular prostheses. All patients but one stated that the rehabilitation was worth the cost and that they would undergo the same therapy again. Patients reported lower scores than others in one category: cleansing ability; they reported initial difficulties in performing normal oral hygiene.

Discussion

This preliminary report on a prospective clinical trial suggests that 6-mm-long implants placed in severely atrophic posterior mandibles resulted in predictable clinical and radiographic outcomes after 2 years of loading, thus offering a reasonable alternative to higher risk, more time-consuming, and costly treatment alternatives. Patients in the present study were treated under local anesthesia with a two-stage implant procedure and loaded with a definitive FPD within 5 months after implant placement. Given these

benefits, the surgeon can offer implant therapy to a greater number of patients who may have refused other preprosthetic surgical treatments because of their inherent morbidity. Few postoperative complications and no relevant side effects were observed, and most patients reported negligible pain and swelling after implant surgery, confirming the minimal invasiveness of 6-mm implant placement. Furthermore, more than 95% of patients were highly satisfied with implant therapy and declared that it was worth the cost and they would undergo the same procedure again.

The overall implant survival rate observed in the present prospective study (96.8%) compares favorably with published reports[12,21] and confirms the 2-year clinical predictability of 6-mm implants for prosthetic rehabilitation of atrophic posterior mandibles. This favorable result can be explained on the basis of careful patient selection, professional skill, and meticulous attention paid to every phase of implant surgery and prosthodontic procedures. In the present study, two early implant failures occurred in the same 72-year-old patient, who was a light smoker, 1 month after implantation. These implants may have failed as a result of overheating of the alveolar bone during implant site preparation and/or overcompression during implant placement. These findings confirmed the assumptions of other authors that dense bone quality in atrophic mandibles, encountered in approximately 40% of the included cases, increased the risk for overheating and compression necrosis of the bone tissue during implant surgery.[22] Systemic factors that decrease vascularity or contribute to delayed wound healing, such as those seen in smokers and elderly patients, may also have contributed to the necrosis because of overheating/overcompression of the peri-implant bone. A precise surgical technique should be adopted to prevent implant failures resulting from overheating/overcompression, including the use of well-sharpened drills and copious refrigerated saline irrigation. Care should also be taken to follow the standard drilling sequence suggested by the manufacturer. Additionally, the authors suggest reversing the implant by one-quarter turn after placement to minimize stress on the adjacent bone, especially with high levels of insertion torque (> 6 Ncm). The two implant failures in this investigation occurred before the start of prosthetic loading. This implant failure pattern is consistent with the results of other long-term clinical studies of standard-length implants used in larger bone volumes and suggests that a low frequency of additional implant failures might be expected in subsequent years.[7,23] However, longer-term follow-up studies (≥ 5 years) are required to confirm this because the benefits of using ultrashort implants may be reversed by increasing failure rates after a few years of function.

Prosthetic complications occurred in 22.2% of implants during the follow-up period, including ceramic chipping, screw loosening, and cementation failure. All prosthetic complications were minor and readily resolved on the day of the patients' visits. In contrast to other studies, implant or prosthetic component fracture was not observed.[24] The authors took great care to obtain mutually protected occlusion through canine guidance or group function and to follow generally accepted guidelines for implant-supported posterior restorations, such as placing one implant for each missing tooth and splinting implants together with no cantilever.[14] The rate of prosthetic complications was lower than that reported by De Boever et al[11] (35%) for three- to four-unit FPDs after a minimum follow-up period of 40 months. However, the follow-up period of the present study was only 24 months. Clinical studies generally show increased rates of complication with longer (> 5 years) follow-up periods.[25] The results should thus be compared to those obtained after a longer follow-up period, which would also bring more objectivity to the study.

No biologic complications were observed throughout the follow-up period. Measurable peri-implant soft tissue parameters were comparable to those found by previous clinical studies in posterior areas.[26] All patients maintained satisfactory levels of oral hygiene, with MPI values decreasing slightly throughout the 2-year follow-up period. Furthermore, the clinical results show adequate maintenance of healthy peri-implant soft tissues; no tendency for increased bleeding on probing was found in the tissues surrounding the implant-supported restorations. These data were confirmed by PPD and WKM values, with more than 95% of implants showing PPD ≤ 3 mm and WKM ≥ 2 mm after 2 years.

Mean marginal bone resorption around implants from the start of prosthetic loading to the 2-year follow-up examination was 0.60 ± 0.13 mm. This low rate after 2 years is consistent with other authors who reported similar data for conventional lengths of the same implant system at posterior sites.[27] However, an important question is whether bone resorption around the 6-mm implants reached a steady state reflected by minimum annual change. According to the success criteria proposed by Zarb and Albrektsson,[19] bone resorption during the first year of function should be ≤ 1.5 mm and annual bone resorption should be < 0.2 mm thereafter. Our mean values show that most bone resorption in this study occurred during the preloading period (0.27 ± 0.10 mm), and a steady state was subsequently reached. A mean

radiographic bone level change of 0.24 ± 0.36 mm was observed during the first year, and this value decreased to 0.14 ± 0.09 mm during the second year of function. The present study adopted a platform-switching approach that may have affected the stability of the marginal bone level. Preliminary research suggests that implants restored by platform switching may exhibit less vertical and horizontal marginal bone loss than conventionally restored implants.[28] However, rigorously documented long-term outcomes associated with the technique are unavailable. All 59 functioning implants in this study showed less than 1 mm of bone resorption and were considered to be successfully integrated at the 2-year follow-up. Additionally, the presence of microthreads may optimally distribute the occlusal load in the region of the implant neck, minimizing further bone loss in this region.[29] However, the 6-mm implants were observed for only 2 years; ongoing remodeling of marginal bone around implants may be detected over longer follow-up periods. Considering the limited portion of the implants engaged in bone, a regular maintenance program is mandatory to reduce the risk of excessive marginal bone resorption, including peri-implantitis, in the long term.

The results of this study demonstrated nearly equivalent marginal bone resorption in all crown-to-implant ratio groups, suggesting that a large crown-to-implant ratio is not detrimental to the continued health of 6-mm implants under functional loading. The mean crown-to-implant ratio in the present study was 1.94 ± 0.46 (range: 1.31 to 3.12). In particular, 14 (22.9%) implants had a ratio > 2.5. Despite the high load-factor risk, these implants displayed no signs of increased marginal bone loss because of overloading in comparison with implants with lower ratios. This observation is in accordance with the results of a previous longitudinal study[30] in which short (≤ 10 mm) machined-surface splinted implants with crown-to-implant ratios of 0.88 to 2.36 did not affect marginal bone levels, even though different methods were used to calculate the ratios.

Conclusion

The results of this prospective study indicate that 6-mm implants are a predictable therapeutic option for atrophic posterior mandibles, although this needs to be confirmed with a longer follow-up period.

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Literature Abstract

In vivo biofilm formation on different dental ceramics

This study investigated the in vivo accumulation of oral biofilm on five different dental ceramics. Samples of five different dental ceramics cut to a standardized size ($3 \times 3 \times 1.5$ mm) and ground to a mean roughness of 0.04 µm were placed on individually designed acrylic resin appliances and worn by five healthy volunteers over a period of 24 hours. The ceramic samples were a veneering glass-ceramic (Imagine Reflex, Wieland Dental Ceramics), a lithium disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent), a yttrium-stabilized zirconia dioxide (Y-TZP) ceramic (IPS e.max ZirCAD, Ivoclar Vivadent), a hot isostatically pressed (HIP) Y-TZP ceramic (DC-Zirkon, DCS Dental), and an HIP Y-TZP ceramic with 25% aluminum oxide (Ziraldent, Metoxit). After 24 hours, bioflim surface coverage and bioflim thickness were determined using a confocal laser scanning microscope. One-way analysis of variance was used to determine the influence of the different materials on surface coverage and biofilm thickness. Results showed that the lowest surface coverage was found on DC-Zirkon (19.0%), followed by Imagine Reflex (19.2%), IPS e.max ZirCAD (27.0%), Ziraldent (28.0%), and IPS e.max Press (46.8%). The lowest biofilm thickness was found on DC-Zirkon (1.9 µm), followed by Ziraldent
(4.0 µm), Imagine Reflex (4.6 µm), IPS e.max ZirCAD (6.9 µm), and IPS e.max Press (12.6 µm). The authors concluded that significantly lower amounts of biofilm formation on zirconia ceramics was advantageous compared to lithium disilicate glass-ceramics with respect to bacterial adhesion. However, further studies over longer periods with more participants would confirm these results and help gain greater understanding of biofilm formation on dental ceramics.

Bremer F, Grade S, Kohorst F, Stiesch M. *Quitessence Int* 2011;42:565–574. **References:** 39. **Reprints:** Dr Philipp Kohorst, Department of Prosthetic Dentistry and Biomedical Materials Science, Hannover, Germany. Email: Kohorst.Philipp@mh-hannover.de—*Teo Juin Wei, Singapore*