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Trans-crestal dental implants in the rehabilitation of a severely atrophic maxilla: A retrospective case series

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Abstract

Purpose: To evaluate the mid-term clinical and radiographic results of immediate fixed full-arch prosthesis supported by two anterior axial and two posterior trans-crestally placed tilted implants in patients with severely atrophic posterior maxilla.

Materials and methods: Patients with posterior maxillary ridge less than 4 mm high and 3 mm wide were rehabilitated with an immediate fixed provisional prosthesis supported by two anterior axially placed and two trans-crestal posterior tilted implants within 3 h after implant surgery. The final prosthesis, consisting of a CAD-CAM titanium framework and composite teeth was delivered 6 months later. Patients were scheduled for follow-up visits every 6 months to assess clinical and radiological parameters. Patients' satisfaction was assessed by a questionnaire up to 5 years.

Results: From April 2008 to May 2017, 56 implants (28 axial and 28 tilted) were inserted in 14 subjects (eight female and six male). The average bone loss for the anterior axial implants was 0.99 ± 0.19 mm at 1 year ($n = 28$ implants), 1.37 ± 0.31 mm at 5 years ($n = 28$), and 2.05 ± 0.32 mm at 10 years ($n = 14$). Only for three implants in two subjects the marginal bone loss was higher than 2 mm after 60 months. No implant was lost, and no prosthetic failure occurred after a mean follow-up of 125 months (range 79–186 months), leading to 100% implant and prosthesis survival rates. The upper 95% confidence limit of the failure rate was 23% and 6% at patient and implant level, respectively. High level of satisfaction was reported at 5-year follow-up.

Conclusion: Wider sample sizes will be required to determine whether the presented technique is a reliable treatment option for the immediate rehabilitation of the atrophic maxilla.

KEYWORDS
atrophic maxilla, full-arch fixed prosthesis, immediate loading, tilted implants

Enrico Gherlone and Massimo Del Fabbro share the last position.

Summary Box

What is known

- A technique for full-arch implant-supported immediate fixed rehabilitation of the upper jaw with severely atrophic posterior region, based on two anterior axial and two posterior trans-crestal tilted implants is presented.
- This retrospective study provides an analysis of implant survival and peri-implant bone level changes, in 14 patients followed by 6.5–15 years.

What this study adds

- Though retrospective and with a limited sample size, this study suggests that combining axially placed and trans-crestal tilted implants is a predictable and safe technique for immediate fixed rehabilitation of posteriorly atrophic maxilla, in the medium-long term.
- This technique may represent a viable alternative to more invasive reconstruction techniques such as inlay and onlay bone grafts associated with conventional implant placement.

1 | INTRODUCTION

Full-arch implant maxillary rehabilitation in the presence of posterior ridges with reduced bone height and width is often challenging. Three-dimensional bone reconstruction can be achieved using various techniques, and sometimes two or more surgical approaches can be combined.[1] Maxillary sinus floor elevation can increase bone height from the residual ridge,[2] while bone augmentation with resorbable[3] and non-resorbable membranes,[4] onlay grafts/blocks,[5] and titanium mesh[6] have been reported for the reconstruction of the ridge volume. In spite of their predictability, all the techniques mentioned above are associated with risks, possible complications, high biological, and financial costs and often result in long treatment time, making those type of interventions poorly accepted by patients.[7,8]

Tilted implants have been introduced in partial and full arch prosthesis to avoid augmentation procedures and bypass vasculo-nervous structures such as mental foramen, resulting in increased inter-implant distance and antero-posterior spread, and shorter distal cantilever.[9] In highly pneumatized sinus cavities, tilted implants have been placed with a trans-sinus approach as an alternative to sinus augmentation and delayed axial implants placement.[10,11] In mandibles with reduced height or hour glass variant with lingual concavities in the mandibular body, a mesio-distal inclination can be associated with a linguo-buccal inclination, fully exploiting the residual bone for implant engagement.[12,13] Although tilted implants represent a viable option in case of limited bone height, in the presence of knife-edge ridges the insertion of implants with a regular platform, that is, between 3.7 and 4.1 mm in diameter, could be challenging.

The aim of this retrospective study was to present the mid-term clinical outcomes and satisfaction of patients with very thin posterior maxillary ridges, rehabilitated with immediate fixed full-arch prosthesis sustained by two axial and two posterior trans-crestal tilted implants. The null hypothesis was that no difference in survival rate would exist between trans-crestal tilted and axially placed implants after at least 6 years of function.

2 | MATERIALS AND METHODS

2.1 | Patient selection

This retrospective case series was performed following the principles indicated by the Helsinki Declaration for biomedical research involving human subjects, published in 1975 and revised in 2004.[14] the Ethical Committee of the IRCCS San Raffaele Hospital approved the clinical protocol (Reg. N. 190/INT/2021). The day of enrollment subjects were informed of the nature of the study before signing the consent form. The STROBE guidelines for observational studies were followed in the preparation of the manuscript.

All patients received an immediately loaded full-arch implant-supported fixed maxillary prosthesis between April 2008 and March 2017. All subjects were treated by a team of clinicians with expertise in advanced procedures in implant surgery and immediate restoration. Inclusion criteria were: age greater than 18 years; any race or gender; mentally and physically able to undergo surgical procedures for implant placement as well as restoration phases; motivated to preserve optimal self-administered oral hygiene throughout the follow-up, and to return for periodical maintenance; full edentulism in the maxilla or presence of maxillary teeth with compromised prognosis in the short-term[15]; sufficient bone volume in the pre-maxilla for inserting implants of at least 10-mm length and 4-mm diameter; residual bone volume in the premolar and molar areas less than 4 mm high and 3 mm wide below the sinus cavity.

Patients were excluded if they had active infection and/or inflamed tissues at the sites planned for implant placement; uncontrolled diabetes, hematological disorders or immunodepression; radiotherapy to the head and neck in the previous 60 months; therapy with intravenous bisphosphonates; severe clenching and bruxism; lactation or pregnancy; inadequate oral hygiene and poor motivation to adhere to hygiene maintenance and follow-up protocols.

2.2 | Surgical protocol

The images of one clinical case are used to document the technique. Figures 1–4 illustrate the initial situation of the patient. A single 2 g dose of prophylactic antibiotic (amoxicillin and clavulanic acid, GlaxoSmithKline, Italy) was administered 1 h before surgery and patients will continue to take 1 g of the same antibiotic twice a day for additional 6 days.[16] Patient were also instructed to use chlorhexidine mouthwash 0.2% (Curasept, Curaden Healthcare, Italy) for 1 min, twice a day, starting 2 days prior to implant placement and thereafter for 1 week. After administering local anesthesia, the surgeon made a linear incision from the first molar to the contralateral side, slightly towards the palate. Vertical release incisions were made in the corresponding disto-vestibular regions. A mucoperiosteal buccal flap was elevated exposing the underlying ridge while the palatal flap was sutured in order to have a better access and surgical visibility (Figure 5). The thickness of the posterior ridges was measured with a caliper in the entry points of the future posterior implants. Four implants (NobelSpeedy Groovy, Nobel Biocare AB, Göteborg, Sweden) were positioned in each patient. At first were placed the trans-crestal posterior tilted implants. The osteotomy started from the palatal slope of the residual ridge and was conducted with a disto-mesial and palato-buccal inclination ranging between 30° and 45° respect to the occlusal plane and engaging the anterior wall of the sinus (Figure 6). Drilling protocols and implant length were selected based on the local bone density. In case of poor density (D3–D4 as defined by the classification of Lekholm and Zarb),[17] the lateral wall of the nose was engaged to gain enough primary stability for immediate loading (insertion torque had to be at least 35 Ncm). The two medial implants were then placed at the level of lateral incisors perpendicularly to the occlusal plane (Figure 7). In seven cases (all trans-crestal implants) there was a fenestration or threads superficialization at the level of the implant body (Figure 8). Therefore, a combination of autogenous bone harvested from adjacent areas and a xenograft

FIGURE 1 Patient presented with residual anterior teeth on both arches and removable partial dentures to replace the posterior teeth. The patient was unhappy with the esthetics and with occlusal function.

FIGURE 2 The occlusal view of the maxillary arch evidenced posterior edentulous ridges covered by keratinized gingiva and apparent adequate residual width for implant placement.

FIGURE 3 Mandibular arch was restored with a fixed partial denture on the six anterior natural teeth and precision attachment for a Kennedy class 1 removable partial denture.

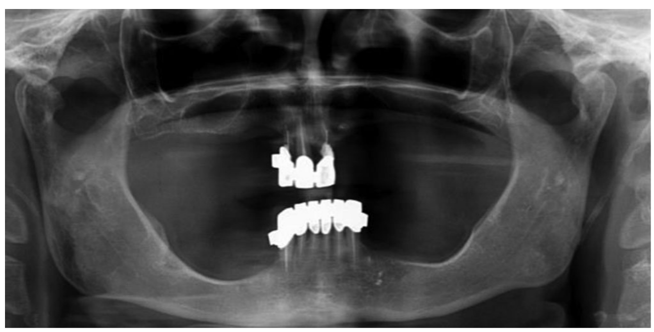

FIGURE 4 The panoramic radiograph revealed extensive sinus pneumatization and resorption of the mandibular posterior ridges.

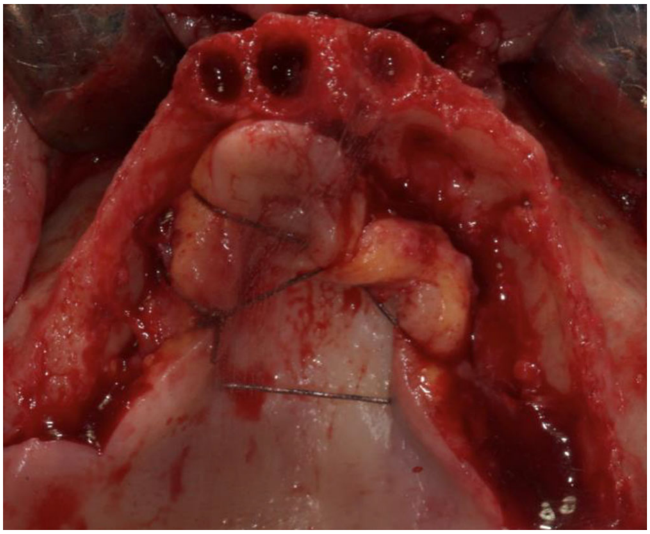

FIGURE 5 The remaining teeth were extracted and a mid-crestal incision was conducted towards the palate. Full thickness buccal and palatal flaps were raised to exposed the underline bone.

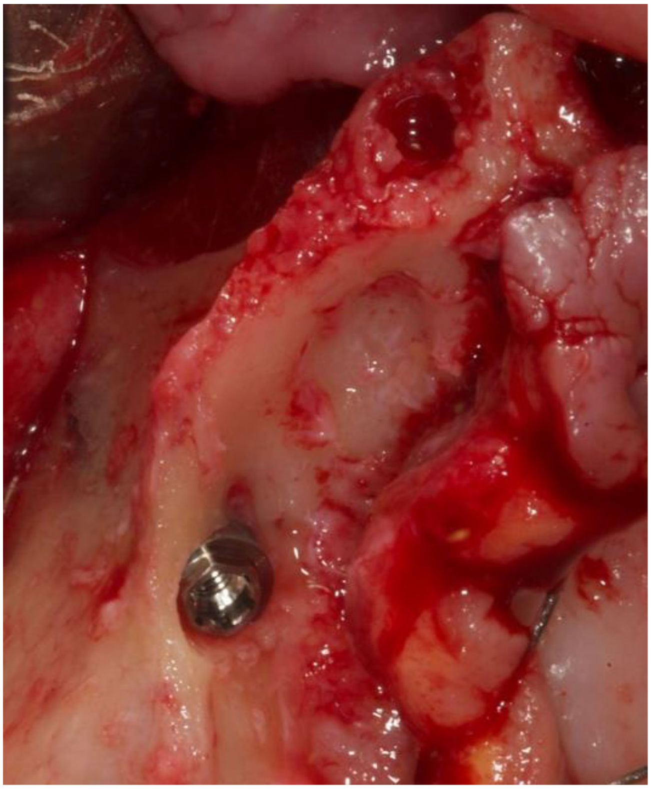

FIGURE 6 With a mesio-distal inclination of approximately 30° and starting the osteotomy on the palatal slope of the ridge, the right trans-crestal tilted implant was placed entirely in native bone.

(Creos Xenogain, Nobel Biocare AB), was used to augment the contour of the buccal bone (Figures 9 and 10). A collagen membrane (Creos Xenoprotect, Nobel Biocare AB) was then placed to cover the graft. Thirty degrees multi-unit abutments were positioned over the

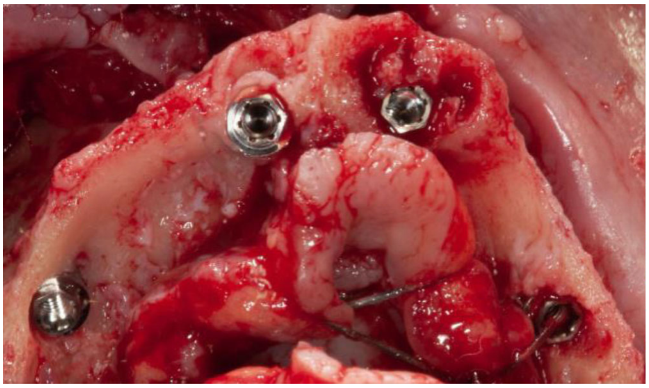

FIGURE 7 Two anterior axial implants were placed closed to the midline.

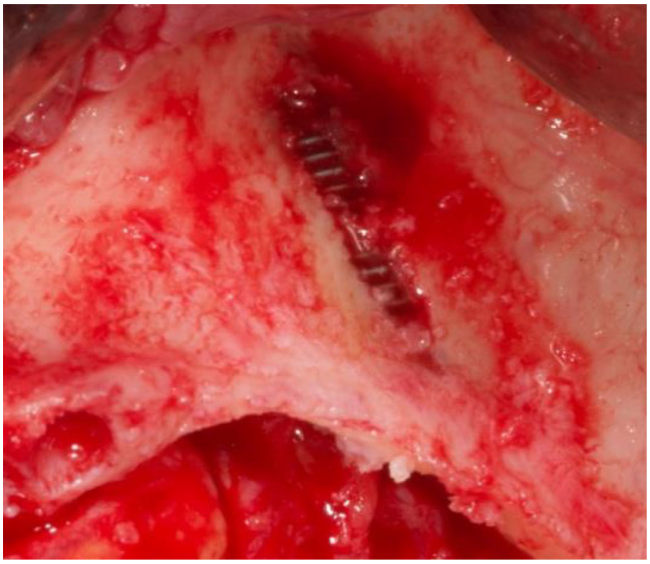

FIGURE 8 After the placement of the posterior left implant, fenestration occurred and part of the threads on the buccal side remained exposed.

tilted implants, and 17° or straight abutments were connected to the axial implants. The height of the posterior abutment was selected in order to have the interface between the abutment and the prosthetic cylinders 1 mm above the residual crest on the buccal aspect. The flap was then closed using a 4-0 resorbable or non-resorbable suture (Vicryl or Silk, Johnson & Johnson Medical, Pomezia, Italy).

2.3 | Prosthetic protocol

A silicon putty polyvinylsiloxane (Elite Implant Impression Material, Zhermack, Badia Polesine, Rovigo, Italy) was used to take an impression at abutment level. The flaps were protected by a sterile rubber dam placed around the copings for impression. Then, four healing caps were positioned on the multi-unit abutments, to support the mucosa around implants. A screw-retained interim restoration made of acrylic

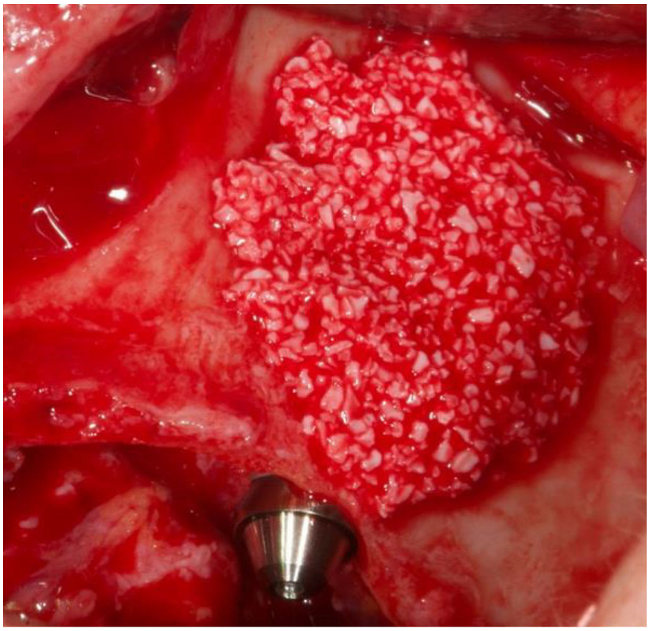

FIGURE 9 A combination of autogenous bone and xenograft was placed over the fenestration to augment the bone contour. Implant stability was higher than 35 Ncm.

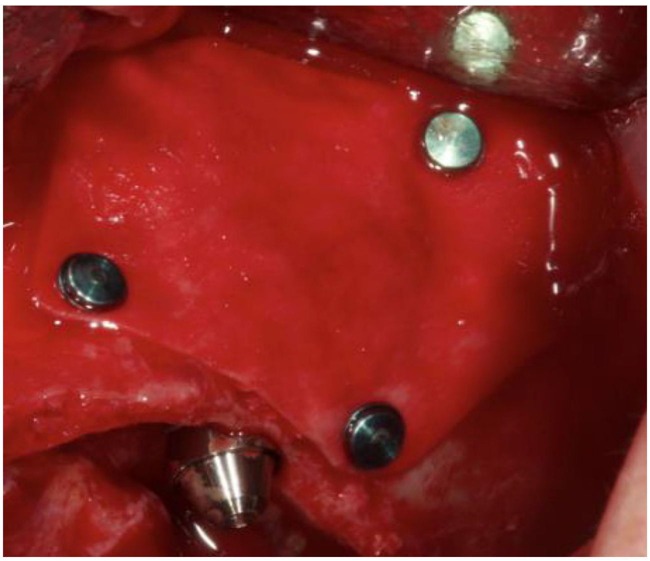

FIGURE 10 A collagen membrane was placed over the graft and stabilized with metallic pins.

resin, containing 10 teeth and no distal cantilever, was delivered within 3 h from the surgery (Figures 11–13). All the lateral and centric contacts were checked with an articulating paper until uniformly distributed light occlusal contacts were obtained.

After 5–6-month of loading, in the absence of inflammatory signs and pain, a final CAD/CAM (computer-aided designed/computer-aided manufactured) screw-retained full-arch restoration with composite teeth (SR Phonares II, Ivoclar Vivadent North America, Amherst, NY) or with individually cemented lithium disilicate crowns

FIGURE 11 Three hours after the surgery, a full acrylic fixed prosthesis with 10 teeth was delivered.

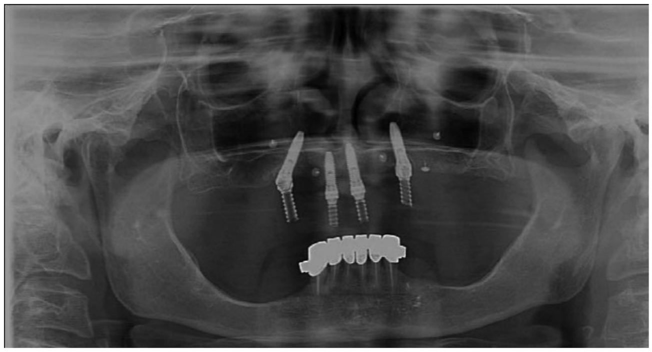

FIGURE 12 Panoramic radiograph showing the distribution of the maxillary implant along the arch.

was provided (Procera Implant Bridge/Ti, Nobel Biocare AB) (Figures 14–16). At each scheduled follow-up visit of the patients were evaluated radiologically and clinically. Based on their risk factors and compliance, the patients were included in an individual maintenance program.[18]

2.4 | Follow-up and outcome measures

In the first month after surgery the patients returned every week for checking prosthesis function and healing of soft tissues. Subsequent follow-ups were scheduled at 6 and 12 months after surgery, and every 6 months thereafter.

The outcome measures were based on those suggested by Maló and colleagues[19]:

- *Implant success*. The implant maintains its function, without signs of pain on percussion nor visible mobility once tested individually (stability and pain of each implant was evaluated after the prosthesis was unscrewed, by using two opposing instruments' pressure). There is no sign of peri-implantitis, nor peri-implant radiolucency;
- *Implant survival*. Implant maintains its function, with no mobility nor pain upon percussion;

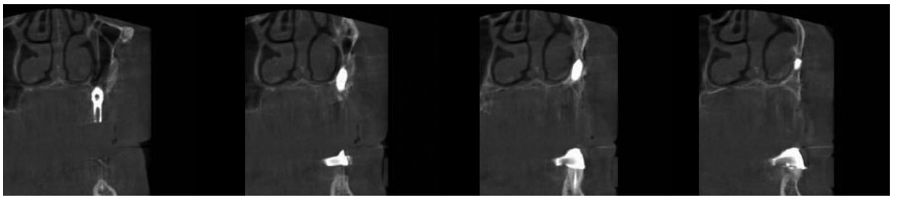

FIGURE 13 The CBCT at the level of the right trans-crestal tilted implant showed that the implant is placed entirely in the residual bone.

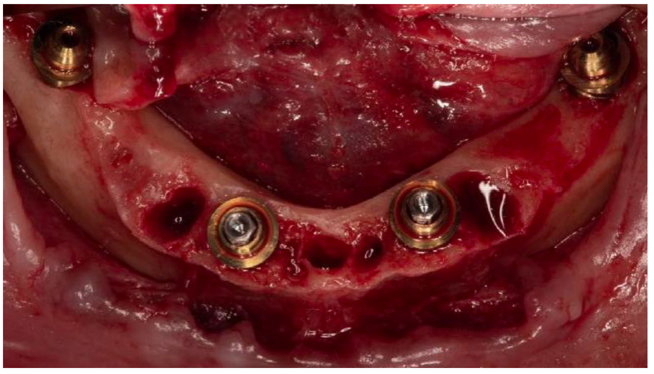

FIGURE 14 Four years after the maxillary rehabilitation, the patient decided to have a fixed implant-retained prosthesis in the mandible.

FIGURE 15 Frontal view of the definitive implant supported prostheses.

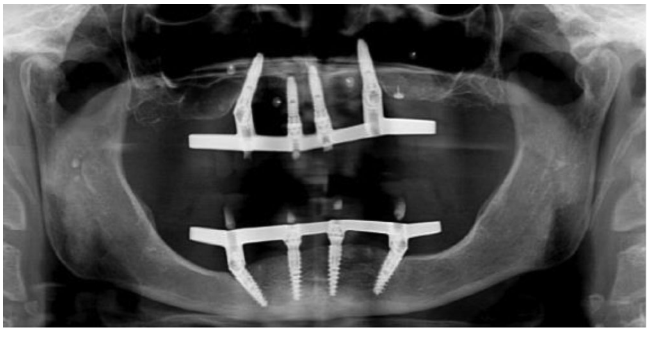

FIGURE 16 The panoramic radiograph showing the stability of the bone level 4 years after the rehabilitation of the maxillary arch.

- *Implant failure*. The implant is removed due to loss of bone integration, excess of mobility, severe peri-implantitis, or mechanical complications such as fracture of the prosthetic connection or the implant;
- *Prosthetic survival*. The prosthesis is in function, and there are no signs of pain nor mobility upon testing with two opposing instruments' pressure;
- *Prosthetic failure*. The prosthesis is removed due to severe mechanical complication; the prosthesis has to be removed after the loss or explantation of all the implants; the prosthesis needs to be replaced due to the insertion of zygomatic implants in substitution of failed conventional implants; the patient requests a conversion to an implant-retained overdenture;
- *Plaque Index (PI) and Bleeding Index (BI) (at implant level)*. Implants were individually examined at four sides (distal, mesial, palatal, and facial) and the ratio of sites in which plaque was found (independent of its amount), over the total sites assessed, was recorded. The BI was assessed similarly: it was calculated as the ratio of sites showing bleeding on probing over total sites evaluated.[20] PI and BI were assessed at 6 months, 1 year, and 5 years.
- *Patient satisfaction*. Upon enrollment every patient filled a questionnaire evaluating masticatory function, phonetics, and esthetics. Items were scored as excellent, very good, good, sufficient or poor. The questionnaire was filled on the day of delivering the definitive prosthesis and during the 1-year and 5-years recall exam.
- *Marginal bone level (MBL)*. Phosphor-plate periapical radiographs using the parallel technique were taken by two calibrated experienced operators. The bone level measurements were assessed by an independent evaluator with experience in dental radiology. Only radiographs showing clear and sharp coronal threads were used for measurements. The implant length or the diameter at platform level was used for calibration. The most coronal implant-bone contact was detected at both distal and mesial aspect, through an image analysis software (UTHSCSA Image Tool for Windows, version X, University of Texas Health Science Center, San Antonio, TX, USA) only for the anterior axial implants. The interface between the multi-unit abutment (IMU) and the implant neck was taken as reference for measurement. Distal and mesial values were averaged to provide a single value for each implant. The MBL values of the two implants were averaged for patient-based analysis. X-rays were taken at loading, at 6 months, 1 year, 3 years, 5 years, and every 2 years thereafter. Because of the palatal entrance of the posterior angulated implants and the overlapping with the facial residual crest in the periapical radiograph, measurement of the bone loss for the posterior implants was not done, as the results would be affected by measurement bias.

Biological complications as well as mechanical/prosthetic ones were also registered when they occurred, but we planned to report the results in a separate study.

2.5 | Data analysis

Descriptive statistics was performed. For continuous variables normally distributed, data were summarized using mean value ± one standard deviation (SD), and using median with 95% confidence intervals (CI) for variables not following a normal distribution. Normality was assessed by means of the D'Agostino and Pearson omnibus normality test. Qualitative variables were summarized using absolute or relative frequency. Comparisons of clinical and radiographic outcomes between consecutive time frames were made using appropriate non-parametric or parametric tests (Wilcoxon matched-pairs signed rank test or paired *t*-test, respectively). Analysis of the differences in MBL among consecutive time frames, and between subgroups (smokers and non-smokers, patients with and without type I diabetes, patients with and without a history of periodontitis, edentulous patients, and patients with failing dentition) at the different time frames, was made on a patient basis. The confidence limits for failure at patient and implant level were calculated using the Clopper–Pearson exact method for binomial data, based on the beta distribution. A *p*-value equal to 0.05 was considered as the significance level. The statistical software used was SPSS for Windows release 28 (SPSS Inc., Chicago, IL, USA).

3 | RESULTS

From April 2008 to May 2017, 14 patients (six males and eight females; mean age 64.4 ± 2.4 years; range 61–69 years) were rehabilitated through a fixed maxillary full prosthesis supported by four implants and immediately loaded. Table 1 presents the main medical status and smoking habits of the patients included in the study. The opposing dentition at surgery differed among patients: natural teeth (four subjects), natural teeth and implant-supported fixed partial denture (one subject), natural teeth and removable partial denture (one subject), two implant-supported removable prostheses (overdenture, two subjects), implant-supported complete fixed dental prosthesis (four subjects), complete denture (two subjects). The average width of the residual posterior ridges was 2.4 ± 0.35 mm (range 1.5–2.9 mm). Bone regeneration to augment the buccal bone contour was carried out on seven posterior implants in four patients.

In total, 56 NobelSpeedy Groovy implants (28 axial and 28 tilted) were positioned with an insertion torque of at least 35 Ncm. The diameter of all implants was 4 mm. Table 2 reports the distribution of implants according to the length. Ten subjects received a metal-

TABLE 1 Medical and habit status of the subjects enrolled in the study.

Patient no.	Gender (M/F)	Age at surgery (years)	Smoker (no. of cigarettes/day)	Type I diabetes	History of periodontal disease	Already edentulous	Follow-up at the time of analysis (months)
1	M	64	N	N	Y	Y	186.5
2	F	61	Y (5)	N	N	Y	174.1
3	F	62	N	Y	Y	Y	151.9
4	M	65	N	N	N	N	144.3
5	F	67	N	N	N	Y	133.3
6	F	64	Y (10)	N	N	Y	129.5
7	M	65	N	N	N	N	125.3
8	M	68	N	N	N	N	120.0
9	M	64	N	Y	N	Y	115.7
10	F	61	Y (5)	N	Y	Y	105.9
11	M	65	Y (5)	N	N	Y	104.1
12	F	65	N	N	Y	N	100.9
13	F	69	Y (5)	N	Y	Y	93.0
14	F	62	N	N	N	Y	79.3

TABLE 2 Distribution of the implants according to fixture length.

	18 mm	15 mm	13 mm	11.5 mm	10 mm	8.5 mm	Total
No. of axial implants	0	0	0	6	18	4	28
No. of tilted implants	8	12	6	2	0	0	28
Total number of implants	8	12	6	8	18	4	56

TABLE 3 Results of the patient-based subgroup analysis for possible factors affecting marginal bone loss.

	6 months	12 months	36 months	60 months
Smokers ($n = 5$)	0.67 ± 0.12	0.96 ± 0.24	1.11 ± 0.23	1.25 ± 0.25
Non-smokers ($n = 9$)	0.69 ± 0.21	1.01 ± 0.17	1.21 ± 0.19	1.44 ± 0.34
p-Value[a]	0.82	0.65	0.39	0.29
History of PD ($n = 5$)	0.69 ± 0.13	0.97 ± 0.22	1.18 ± 0.28	1.33 ± 0.36
No history of PD ($n = 9$)	0.68 ± 0.21	1.01 ± 0.18	1.17 ± 0.17	1.40 ± 0.31
p-Value[a]	0.95	0.75	0.95	0.71
Failing dentition ($n = 4$)	0.79 ± 0.29	1.08 ± 0.21	1.30 ± 0.24	1.68 ± 0.43
Edentulous ($n = 10$)	0.65 ± 0.11	0.96 ± 0.18	1.13 ± 0.17	1.26 ± 0.17
p-Value[a]	0.19	0.33	0.15	0.02[b]

Note: Data are presented as mean values ± standard deviations in mm at the different follow-ups.
Abbreviation: PD, periodontal disease.
[a]Unpaired *t*-test.
[b]Statistically significant.

composite prosthesis and four subjects were treated with a titanium-ceramic prosthesis.

At the 1-year and 5-year visits, all implants resulted stable. The mean follow-up duration was 125.2 ± 30.3 months (range 78.5–185.7 months). Since all patients achieved 5 years follow-up, the results of clinical and radiographic variables are presented for such follow-up, while for implant survival the longest follow-up is considered. No implant failure, nor prosthetic failure occurred, leading to a 100% implant and prosthetic survival rate. Given 14 patients with 0 failures the 95% upper bound on the failure rate of the described approach is 23%. On an implant basis, considering 0 failures out of 56 implants, the upper 95% confidence of the failure rate is 6%. Three patients (21%) experienced fracture of the immediate prosthesis at the level of the interface with the temporary cylinder. When the prosthesis was removed, in one of these patients mobility of the angulated posterior abutment was noted. Both immediate prostheses were repaired chair-side. No fracture of the definitive prostheses has been reported. Minor wear of the posterior composite teeth was noted in all patients and in three prosthesis posterior teeth delimitation occurred after 5 years of function. Minor chipping of the ceramic material was registered in one patient.

Plaque Index score averaged 28.13 ± 6.82% at 6 months, 25.89 ± 7.30% at 1 year and 29.02 ± 6.76% at 5 years, respectively ($n = 14$ patients) (Table 3). Bleeding Index score averaged 6.70 ± 5.73% at 6 months, 6.25 ± 5.48% at 1 year and 7.14 ± 5.93% at 5 years, respectively ($n = 14$ patients) (Table S1).

The average MBL for the anterior axial implants was 0.99 ± 0.20 mm at 1 year ($n = 28$ implants), 1.18 ± 0.21 mm at 3 years ($n = 28$), 1.38 ± 0.32 mm at 5 years ($n = 28$), and 2.05 ± 0.30 mm at 10 years ($n = 14$). In Table S2 are reported the MBL values of the anterior implants for all patients up to 120 months. The observed changes were in line with conventional values, and only three axial implants in two subjects reported a marginal bone loss higher than 2 mm after 60 months. The change in bone level at each follow-up, as compared to the previous control, resulted significant (paired *t*-test, $p < 0.001$ in all cases). On a patient basis, there was no significant difference in MBL at each follow-up between smokers ($n = 5$ patients) and non-smokers, between patients with ($n = 5$) and without a history of periodontal disease, and between edentulous patients ($n = 10$) respect to patients with failing dentition. Only in the last case, a significantly higher bone loss was recorded at the 60-month follow-up in the patients with failing dentition at inclusion, as compared to edentulous patients (1.68 ± 0.43 mm vs. 1.26 ± 0.17 mm, respectively; unpaired *t*-test, $p = 0.02$). The results of the above between-subgroup analysis are reported in Table 3. No comparison was made between patients with and without diabetes mellitus, due to the small number of diabetic patients ($n = 2$) in our sample.

All the 14 patients filled the questionnaires to evaluate satisfaction on the day of enrollment and during the scheduled follow-ups. After 5 years the aesthetic aspect (teeth and smile) was scored as excellent/very good by 86.0% of patients; phonetics and masticatory function were judged excellent/very good by 71.5% and 78.5% of the subjects, respectively (Table 4).

4 | DISCUSSION

The medium to long-term clinical results of this study have shown that maxillary fixed rehabilitations based on a combination of axial and trans-crestal tilted implants have a favorable prognosis, and the null hypothesis can be retained.

The rationale of this technique was to place the posterior tilted implants into the residual bone between the canine eminence and the anterior sinus wall. Due to the reduced ridge thickness, the implant body of seven posterior implants in seven patients remained partially exposed on the vestibular surface of the maxillary bone, and grafting materials in combination with a covering collagen membrane were placed over that fenestration. To reduce the risk of fenestration, dedicated drills manufactured by Versah (Jackson, MI, USA) and used for the osseodensification technique might be considered.[21]

In this clinical study, the residual bone height over the thin posterior ridges was less than 4 mm due to alveolar resorption and sinus

TABLE 4 Results of the satisfaction questionnaires completed by all the patients.

	Baseline (day of enrollment)	6 months (delivery of final prosthesis)	1 year follow-up	5-year follow-up
Esthetics				
Excellent	0	3 (21.5%)	7 (50%)	7 (50%)
Very good	3 (21.5%)	6 (43%)	5 (36%)	5 (36%)
Good	3 (21.5%)	4 (28.5%)	2 (14%)	2 (14%)
Sufficient	4 (28.5%)	1 (7%)	0	0
Poor	4 (28.5%)	0	0	0
Phonetics				
Excellent	1 (7%)	1 (7%)	2 (14%)	2 (14%)
Very good	10 (71.5%)	10 (72%)	8 (57.5%)	8 (57.5%)
Good	3 (21.5%)	2 (14%)	3 (21.5%)	3 (21.5%)
Sufficient	0	1 (7%)	1 (7%)	1 (7%)
Poor	0	0	0	0
Function				
Excellent	0	4 (28.5%)	7 (50%)	7 (50%)
Very good	3 (21.5%)	5 (36%)	4 (28.5%)	4 (28.5%)
Good	3 (21.5%)	4 (28.5%)	3 (21.5%)	3 (21.5%)
Sufficient	2 (14%)	0	0	0
Poor	6 (43%)	1 (7%)	0	0

pneumatization. If axial implants were to be placed, the three-dimensional ridge reconstruction should be associated with maxillary sinus augmentation, or in alternative, to the insertion of short and ultra-short implants.[22–24] The use of tilted implants may allow to avoid demanding augmentation procedures, reducing cost and discomfort for the patient.

Another treatment alternative for the graftless rehabilitation of patients with extreme atrophy of the maxillary bone is the placement of zygomatic implants.[25] However, such treatment requires considerable surgical skills, and is associated with high morbidity and incidence of biological complications.[26] Conversely, in the present study no biological complications have been reported during the follow-up, even if one has to consider that the cohort of patients was small.

The regenerative treatment of the knife-edge ridge may involve the use of covering membranes and particulate bone substitute,[3] intraoral,[27] and extra-oral bone blocks (autologous, allogeneic, and xenogeneic)[28] or titanium mesh/grid.[29] Despite the validity of each technique, all of them could be considered operator-dependent and, moreover, are associated with high biological and financial costs, and long treatment duration.[30–32] Moreover, the amount of regenerated bone may vary significantly based on the surgical technique that has been used.

A systematic review from Wessing in 2018 summarized data on bone augmentation using resorbable collagen membrane and particulate graft material, estimating an overall mean bone gain of 2.27 ± 1.68 and 3.05 ± 1.02 mm in the horizontal and vertical dimension, respectively.[3] No significant difference in implant survival rate resulted between simultaneous (99.75%) and delayed (98.30%) implant placement. Although only few publications reported data on the survival of implants placed subsequently to guided bone regeneration, and the statement of no differences should be considered with caution. In fact, in only half of the studies the follow-up went beyond the implant surgical procedure: as a consequence, the effect of the occlusal load on implant survival was not taken into consideration.[3] Early exposure of the membrane occurred with a rate of 20.74% for non-cross-linked and 28.62% for cross-linked ones, but no data were reported about a possible influence of membrane exposure on bone gain.[3] Systematic reviews by Sanz-Sánchez[33] and Garcia,[34] on the other hand, evidenced that the amount of regenerated bone was significantly higher in non-exposed sites.

Sánchez-Sánchez reported the volumetric changes of horizontal ridge augmentation achieved using two different and novel surgical approaches[35]: the Khoury technique (consisting of autogenous split bone blocks without membrane), and the Urban technique (also named "Sausage technique", which uses biomaterials covered by a membrane). The clinical horizontal bone gain assessed with CBCT or the use of caliper at the time of implant placement ranged between 1.41 ± 0.08 and 5.68 ± 1.42 mm in four studies using the Urban technique, and between 3.93 ± 0.9 and 5.02 ± 0.8 mm in two studies using the Khoury technique.[35]

A recent systematic review by Aloy-Prósper reported the clinical outcomes of intraoral onlay block and cortical tenting technique.[36] The onlay graft allowed a horizontal bone gain of 4.29 mm, corresponding to a resorption of 10.28%, while the cortical tenting technique resulted in 5.55 mm of horizontal bone augmentation (6.12% of resorption). Despite the lack of RCTs and the limited follow-up, both techniques offer predictable bone reconstruction, even if the cortical tenting technique apparently provides greater bone augmentation and less superficial resorption.[36]

Clinical outcomes from xenogeneic and autogenous block grafts were assessed by Sánchez-Labrador and colleagues.[5] Xenogeneic blocks reported similar bone gain and failure rate (around 6%) than autogenous block, but implant survival rate was slightly lower. Differently, greater bone formation and a lesser amount of residual bone substitute were found for autogenous blocks. Although autogenous bone is considered the gold standard, factors such as patient morbidity due to the need of a donor site, and the limited volume of grafting material must be considered when choosing the surgical technique or the type of graft material.[37]

Regardless of the material and technique used for the bone augmentation, various degrees of resorption will occur on the regenerated bone due to tissue remodeling and structural reorganization.[38] A systematic review on 17 RCTs estimated that the final bone gain was 4.03 ± 0.49 mm for blocks and 2.59 ± 0.23 mm for guided bone regeneration, with the block graft experiencing almost no resorption.[33] The GBR technique resulted in significant volume reduction, in particular if autologous bone was used; thus, horizontal defects should undergo overcorrection.[33]

Bone augmentation procedures have been proven to be effective, but a key aspect that needs to be considered is if the dimensional increase in bone volume allows the placement of the desired implant platform. Furthermore, different amount of graft shrinkage may occur over time, with different grafting materials.[39] Supplementary grafting at the time of implant insertion (for delayed approach) or ridge splitting might be needed to achieve the desired clinical outcomes. The use of narrow platform implants might also be considered as alternative.

A further therapeutic option for knife-edge ridges could be represented by the split crest technique, which in some cases can allows the simultaneous placement of implants.[40–42] Despite the high implant survival reported by several studies,[40,41] because of the risk of vestibular cortical fracture, expansion techniques may not be implemented in the presence of a bone crest thickness of less than three millimeters with no trabecular component between the two cortical bone layers.[42]

Implant success/survival in the long-term is the most relevant outcome to be considered for implant treatment. A 2021 systematic review by Donkiewicz and colleagues[43] reported implant survival rates with autogenous and allogenic blocks. Implant survival was significantly higher with the use of intraoral blocks, in younger individual with partial edentulism, with cortical blocks and delayed implant insertion.[43] Clementini and colleagues in 2013 summarized implant success after guided bone regeneration or grafting alone with delayed implant placement, reporting that the success rate for implants placed using a staged approach ranged between 75% and 98% and for a simultaneous approach it ranged between 61.5% and 100%.[44] They concluded that delayed implant insertion could lead to more predictable outcomes than immediate placement, but the downside is that the overall treatment time increases.[44] However, they found a limited number of controlled studies, and the criteria to define success and failure were not standardized. For instance, a high implant survival rate might not imply that the regenerative technique was successful, considering that an implant can be stable and integrated even if all the regenerated bone has been resorbed because of the support provided by the residual bone.[44] In the present study, the implants were inserted entirely in native bone and no implants were lost, leading to 100% survival rate. Anterior axial implants reported bone loss in line with similar studies on immediate loaded prosthesis on four implants.[18,45,46]

In our study all patients received a fixed prosthesis on the same day of surgery. By contrast, in cases of advanced bone regeneration procedure extended to the maxillary posterior segments, patients usually cannot wear a removable prosthesis for several weeks, in order not to jeopardize the survival of the graft, resulting in compromised esthetics, reduced function and patient comfort.

Minor mechanical complications have been recorded and their frequency is in line with similar clinical studies.[46–49]

The main limitations of this study are the absence of a control group, the retrospective design, and the reduced sample size, that prevents a generalization of the results. Based on the upper 95% confidence limit estimated with the results of the described approach, one might conclude that less than 23% of patients (about one out of four) are expected to experience a failure, or less than 6% of implants (1 out of 16) are expected to fail. Clearly, even with zero failures, the theoretical failure risk with a small sample size is not negligible. Another limitation is that the marginal bone level was measured only on anterior implants. In fact, a bi-dimensional image would not provide a true representation of the hard tissue levels around tilted implants, and measurements could be unreliable. Exposing the patients to multiple consecutive cone-beam computed tomographies only for assessing marginal bone level was not ethical according to the current guidelines for the use of X-rays in dentistry. Furthermore, the use of grafting technique in the posterior sites in combination with tilted implant placement, when necessary, makes unfeasible any comparison of bone levels among patients. Further studies, possibly comparative and prospective, and with a larger sample size, are needed to confirm the promising results of this minimally invasive and cost-effective alternative to more demanding reconstruction techniques for the rehabilitation of patients with atrophic edentulous maxilla.

AUTHOR CONTRIBUTIONS

E.L.A., M.D.F., E.G. and D.R. conceived and designed the analysis. Data were collected by E.L.A., D.R., S.P., B.D.O., J.A. and E.G. Surgical interventions were performed by E.L.A. All the authors contributed on interpretation of data for the work. Data analysis was performed by M.D.F. and D.R. D.R. and M.D.F. drafted the manuscript with input from all authors. M.D.F., D.R., E.G. and E.L.A. revised the work critically for intellectual content. Integrity of the work was appropriately investigated and resolved by all authors. All authors contributed and approved equally to the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

Enrico Luigi Agliardi is currently consultant for Nobel Biocare Services AG. No further conflicts of interest are declared for the remaining authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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