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Clinical outcomes of full-arch immediate fixed prostheses supported by two axial and two tilted implants: A retrospective cohort study with 12–15 years of follow-up

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Abstract

Purpose: To retrospectively assess clinical and radiographic outcomes of immediately loaded full-arch fixed prostheses supported by axial and tilted implants up to 15 years of function.

Materials and Methods: Patients with one completely edentulous arch received an immediate full-arch fixed prosthesis supported by two anterior axial and two posterior tilted implants. Definitive prosthesis consisting of a CAD-CAM titanium framework and acrylic teeth was delivered 6 months later. Patients were regularly followed to assess clinical parameters and marginal bone level (MBL) change. Multilevel regression analysis was performed to investigate factors affecting implant failure and MBL.

Results: Six hundred ninety-two implants were placed in 72 maxillae and 101 mandibles. Seven maxillary implants (5 axial and 2 tilted) in 6 patients and 12 mandibular implants (6 axial and 6 tilted) in 5 patients failed. 15-year cumulative implant survival was 97.51% and 96.91% in maxilla and mandible, respectively ($p = .64$). After 10 years, the difference in MBL between axial and tilted implants was not significant in the maxilla ($p = .47$, 65 patients), while it was in the mandible ($p < .001$, 80 patients). Significant higher bone loss was reported in the mandible at both 5- and 10-year follow-up ($p < .001$ and $p = .004$, respectively). Mixed-effect multilevel linear regression evidenced a correlation between arch and bone loss at 5- and 10-year follow-up, while no correlation was found with age, gender, smoking, diabetes, and history of periodontal disease.

Conclusion: This long-term study suggests that the present technique can be considered a viable treatment modality for the immediate rehabilitation of both maxilla and mandible.

KEYWORDS
axial implants, full-arch fixed prosthesis, immediate loading, marginal bone loss, tilted implants

1 | INTRODUCTION

Implant fixed complete dental prostheses (IFCDPs) offer an established long-term predictability as well as a high level of satisfaction for the patient in terms of aesthetics, phonetics, and function (Gallardo et al., 2019; Gonçalves et al., 2022; Jiang et al., 2021). Over the years, significant changes have been made to the original protocol proposed by Brånemark (Brånemark et al., 1997 Reference 'Brånemark et al., 1997', Year 1977 year has been changed to 1997 to match the reference list. Please check for correctness."). The surgical technique has been improved, and new implant morphologies and prosthetic materials have been introduced. Moreover, protocols using a reduced interval between implant insertion and prosthetic loading proved successful, and immediate function of full-arch fixed prosthesis became a predictable treatment modality in both jaws (Del Fabbro et al., 2019).

Immediate fixed rehabilitations can be challenging when reduced bone volume hampers ideal implant positioning, and anatomical constrains, such as maxillary sinus and inferior alveolar nerve, prevent optimal implant distribution along the arch. Bone grafting procedures might represent a solution for facilitating implant insertion in the atrophic posterior areas of the jaws, but such interventions are poorly accepted by patients and might be associated with increased surgical risks, cost, and treatment time (Aghaloo et al., 2016; Raghoebar et al., 2019).

The surgical invasiveness and the costs related to grafting procedures and to the need of placing a high number of implants led to the development of alternative solutions (Agliardi et al., 2015; Aparicio et al., 2001). One of them is represented by tilted implants, namely, fixtures inserted with an angulation respect to the occlusal plane (Del Fabbro et al., 2012). Implant tilting provides an alternative to grafting, with the possibility of placing fixtures of greater length in the residual bone, thus achieving higher levels of primary stability because of the greater implant surface area in contact with bone (Lin & Eckert, 2018). Tilting may result in prosthetic advantages, such as shorter distal cantilever, a favorable anterior–posterior distribution of implant platforms, and a reduction of the number of fixtures down to four implants for cross-arch prosthesis (Krekmanov et al., 2000). On the other hand, with this technique, even in case of only one implant failure, a new prosthesis must be fabricated, and a new implant inserted. Furthermore, some limitations are represented by the scarce information regarding the bone remodeling pattern around tilted implants and the mechanical complications concerning the tilted abutments.

A surgical and restorative protocol, named "All-on-4" by his inventor, consisted in the placement of two anterior axial implants and two posterior implants inserted with an inclination of 30–45 degrees respect to the occlusal plane, supporting a complete arch fixed prosthesis (Maló et al., 2003). Preliminary results for the All-on-4 technique in the mandible and the maxilla have been published in 2003 and 2005, respectively (Maló et al., 2003; Maló et al., 2005). This concept has been subsequently proposed by different implant manufacturers with their own implant designs and brand names, and it has been adopted by many clinicians worldwide (Agnini et al., 2014; Pera et al., 2019; Piano et al., 2016). Short and medium term results appeared encouraging in both jaws, with similar clinical outcomes compared to the conventional *ad-modum* Brånemark prosthesis (Soto-Penaloza et al., 2017: de Araújo Nobre et al., 2020: Ayna et al., 2021; de Araújo Nobre et al., 2022). A retrospective long-term study with up to 18 years follow-up for mandibular All-on-4 reported a cumulative prosthetic survival rate of 98.8% and an implant cumulative survival and success rates of 93% and 91.7%, respectively (Maló, de Araujo Nobre, Lopes, Ferro, & Botto, 2019). In the maxilla, up to 13 years of follow-up, the prosthetic success rate was 99.2% and implant cumulative survival and success rates were 94.7% and 93.9%, respectively (Maló, de Araujo Nobre, Lopes, Ferro, & Nunes, 2019). However, despite the popularity of these treatment modalities, there is still a paucity of long-term studies on a wide number of patients.

The aim of this retrospective study was to report the long-term clinical outcomes of immediate fixed prostheses supported by two axial and two tilted implants and to examine possible risk factors related to implant failure and marginal bone loss.

2 | MATERIALS AND METHODS

The investigation was conducted according to the principles embodied in the Helsinki Declaration of 1975 for biomedical research involving human subjects, as revised in 2004 (Vanpee et al., 2004). The manuscript was prepared in compliance with the STROBE guidelines for observational studies. The study was started as a prospective study, and 3-year preliminary results were published previously (Agliardi et al., 2010). Then, since most patients continued to be followed regularly for more than 12 years, it was decided to review long-term results retrospectively. The protocol of this long-term retrospective analysis was approved by the Ethical Committee of the IRCCS San Raffaele Hospital (Reg. N. 190/INT/2021). In this single cohort study, patients were consecutively enrolled and treated in the presence of complete edentulism, compromised dentition, or teeth with a poor short-term prognosis. Clinical intervention was limited to one arch per subject. During the preliminary examination, all participants were informed on the nature of the study and on possible alternative treatments, and they signed an informed consent.

Implant placement and prosthetic phases were performed in a private practice by a group of three clinicians who have been treating patients with immediate loading prostheses for an average of 4 years (range 2–7 years) at the beginning of the study. Inclusion and exclusion criteria are listed as follows (Agliardi et al., 2010): subjects of at least 18 years old with no restriction for race or gender, physically and psychologically able to undergo implant surgery, restorative procedures, and domestic maintenance. Subjects were excluded if at least one of the following conditions was present: active infection and inflammation at the sites intended for implant installation; presence of severe or uncontrolled systemic diseases (i.e., hematological disease, uncontrolled diabetes and diseases of the immune system);

irradiation to the head or neck region within 12 months before surgery; use of intravenous bisphosphonates; severe bruxism or clenching habits; pregnancy or lactation; and poor oral hygiene and poor motivation to return for scheduled follow-up visits.

A midcrestal incision was conducted from first molar region to the contralateral side and a full thickness flap was elevated. If present, residual teeth and roots were extracted and their sockets were carefully derided. The mental foramen or the anterior sinus wall was detected in order to determine the ideal position and angulation of the posterior implants. All patients received four implants (Brånemark System® MKIV or NobelSpeedy Groovy®, Nobel Biocare AB, Göteborg, Sweden) in the interforaminal region of the mandible or in the area limited by the anterior sinus walls in the maxilla. Each patient received a single type of implants (either MKIV or NobelSpeedy implants). At first the two distal tilted implants were positioned. In the mandible, the implants were inserted at the level of the ridge in correspondence with the alveolar nerve foramen and tilted approximately between 30 and 45 degrees relative to the occlusal plane. In the maxilla, the posterior implants were placed with the same angulation and engaging the anterior sinus wall. Thereafter, the two mesial fixtures were inserted axially at the level of the lateral incisors. 30 degrees multiunit abutments (MUA®, Nobel Biocare AB), were connected to the posterior implants, while axial or 17 degrees abutments were placed over the anterior implants. Approximately 3 h after the surgery, a full acrylic fixed temporary prosthesis containing 10 denture teeth was delivered. Occlusal contacts in maximum intercuspation were limited to the intercanine region and contacts during lateral excursion were eliminated. After 4–6 months of function, a conventional method was used to fabricate a definitive prosthesis by setting Polymethyl Methacrylate (SR Vivodent PE, Ivoclar Vivadent North America, Amherst, NY) or Nano Hybrid Composite (SR Phonares II, Ivoclar Vivadent North America, Amherst, NY) teeth and processing heat acrylic to wrap around a titanium Computer-Aided Designed/Computer-Aided Manufacturing framework (Procera®, Nobel Biocare AB). A single laboratory made all the prostheses.

2.1 | Follow-up visits and recall appointments

During the first month after surgery, all patients were evaluated once a week for tissue healing and prosthesis function. Further visits were scheduled at 6 and 12 months and then every 6 months. In 2010, an individualized protocol for recall exam and hygienic maintenance was introduced. This included an alternation of routine and advanced check-ups scheduled according to patients' risk factors and compliance with the aim of proving a personalized care. The routine exam included four peri-apical x-rays taken before the patient accessed the dental chair and the following procedures done by the dentist: evaluation of the integrity of the prosthesis from mechanical complications, static and dynamic assessment of the occlusion, evaluation, and, whenever possible, probing of the peri-implant soft tissues. Subsequently, a qualified and calibrated dental hygienist cleaned the prosthesis and the abutments and reinforced the oral hygiene instructions. In the advanced check-up, in addition to the steps of the routine exam, the dentist removes and polishes the prosthesis while the hygienist assesses clinical parameters (stability of the implant-abutment system, probing depth, bleeding on probing, plaque index, soft tissue recession). Subsequently, the dentist repositions the prosthesis in the mouth of the patient and closes the access holes with Teflon tape and composite resin material. Routine and advanced examinations were alternated twice a year for most of the patients. Differently, subjects with history of periodontal disease, smoking habit with a daily consumption superior to 4 cigarettes, bruxism, and reduced manual dexterity were scheduled every 3 months, with two advanced and two conventional recall exams every other visit. Patients were considered as periodontal cases if they had at least 2 non-adjacent teeth with detectable proximal clinical attachment loss (CAL), or at least 2 teeth with buccal or oral CAL ≥ 3 mm with pocketing >3 mm (Tonetti et al., 2018).

2.2 | Outcome measures

The outcome measures evaluated in the present study were adapted from the criteria established by Maló et al. (Maló, de Araujo Nobre, Lopes, Ferro, & Botto, 2019):

1. Implant success. Implant in function as planned, no pain on percussion and absence of visible mobility when individually tested (pain and stability of individual implants were assessed using two opposing instruments' pressure after unscrewing the prosthesis), no peri-implant radiolucency on radiographs and no signs of peri-implantitis;
2. Implant survival. Implant in function, with no pain on percussion or mobility;
3. Implant failure. Implant removed for severe peri-implantitis, mobility, loss of bone integration or mechanical complications (fracture of the implant or its prosthetic connection);
4. Prosthetic survival. Prosthesis in function, with or without modifications, with absence of pain and mobility tested by means of two opposing instruments' pressure;
5. Prosthetic failure. Loss of the prostheses after major mechanical complication, the need to remove the prostheses after the explantation/loss of all the implants, the need of replacing the prosthesis after placement of zygomatic implants as consequences of implant failure, conversion to implant supported/retained overdenture based on patient request;
6. Marginal bone level (MBL): Conventional intraoral radiographs were taken and scanned at 600 dpi with a scanner. After 2011, phosphor-plate digital images were used. Radiographs were taken by multiple calibrated operators using the parallel technique, while their assessment and measurement were done by one independent blinded evaluator with experience in dental radiography. Radiographs were considered eligible for measurements based on clarity and sharpness of the most coronal threads. Calibration was

done using the implant diameter at the level of the platform, or implant length. The marginal bone level (the most coronal bone-to-implant contact) was assessed on mesial and distal aspect using an image analysis software (UTHSCSA Image Tool version X for Windows, University of Texas Health Science Center in San Antonio, TX). The interface between the implant neck and the multiunit abutment (IMU) was the reference for each measurement. Mesial and distal values were averaged in order to have one single value for each implant. Patient received periapical radiographs whenever it was considered necessary for clinical diagnosis. However, each patient received radiographs at least the day of immediate loading, after 6 months, and at 1, 3, 5, 8, 10, 12, 15-year follow-up. Peri-apical radiographs taken the day of immediate loading were used as baseline for the calculation of marginal bone level change.

Data related to plaque and bleeding index, biological and mechanical/prosthetic complications, patient satisfaction were also recorded, but the results were not reported in this study.

2.3 | Data analysis

Implant failure distribution was assessed using a time-to-event analysis. The Kaplan–Meier method was used to estimate implants and prosthesis cumulative survival rates. The cumulative survival rates of axial and tilted implants, as well as maxillary and mandibular implants, were compared using log-rank Mantel-Cox test. The implant was considered as the analysis unit. The software used for survival analysis was GraphPad Prism version 5.03 (GraphPad Software, Inc., La Jolla, CA). The normality of distributions of all data was checked using the D'Agostino and Pearson omnibus normality test. Data following a Gaussian distribution (such as patients' age at surgery) were reported using the mean values and standard deviations. For data that did not follow a Gaussian distribution (such as the MBL), the synthetic results were reported using the median and 95% confidence interval. MBL comparisons between axial and tilted implants at each follow-up were made using Wilcoxon matched pairs signed rank test. For each patient, a single value was considered for axial as well as for tilted implants at each observation time, by averaging the measurements obtained from the apical radiographs. Comparison of MBL change around MKIV versus Speedy implants at each follow-up was done using Mann–Whitney test. Proportions of events between groups were compared using Fisher's exact test or Pearson's chi square, as appropriate. The effect of different variables (age, gender, arch, smoking, type 2 diabetes, and periodontitis) on implant failure and MBL change at patient level at 5 and 10 years was analyzed using, respectively, a Cox proportional hazards regression model and a multilevel mixed-effects linear regression model. Since all patients had multiple implants, we also investigated the possibility of a cluster behavior of implant failures among the patients, assessing the effect of different factors on the occurrence of multiple failures within patients. In analogy with a previous study (Chrcanovic et al., 2017), patients experiencing at least three failures were considered as "cluster patients." A logistic regression model was initially used at patient level, to determine the effect of variables related to the patient status. At first, a univariate regression was undertaken to determine the significance of the effect of each single factor on implant failure, considering cluster versus non-cluster patients. Odds ratios were calculated, along with their 95% confidence intervals, using Wald chi-squared test with 2×2 contingency tables, to determine each factor's significance. Only factors resulting with significant ($p < .10$) odds ratio were planned to be subsequently included in the multivariate logistic regression analysis, to assess the effect of multiple failures on the cluster behavior. Computations were carried out with the software STATA 17 (StataCorp LLC, 4905 Lakeway Drive College Station, Texas 77,845). p-values less than .05 were considered statistically significant.

TABLE 1 Distribution of patients and implants according to the year of enrollment.

Year of enrollment	N° of patients	N° of implants
2004	5	20
2005	23	92
2006	31	124
2007	55	220
2008	50	200
2009	9	36
TOTAL	173	692

3 | RESULTS

3.1 | Patient demographics and implants

From April 2004 to January 2009, 173 patients (80 males and 93 females; mean age 57.3 ± 8.5 years; median 58 years, range 42–74 years) received two axial and two tilted implants in the maxilla or in the mandible (Table 1). At the time of surgery, 48 of the included patients (27.8%) were smokers, with 30 of them smoking less or equal than 10 cigarettes per day and no patient smoking more than 20 cigarettes per day. Within the first year, 12 subjects quit smoking. All participants received an immediate fixed temporary prosthesis and the definitive prosthesis as planned. Changes in the opposing dentition during the follow-up period are reported in Table 2. A total of 42 patient (24.3%) was lost to follow-up: 8 patients deceased for causes not related to the study, 14 subjects moved to another city or country, 4 patients retired in a nursing, and 16 subjects could not be contacted (Table 3).

A total of 692 implants (92 Brånemark System MKIV and 600 Nobel Speedy Groovy, all with TiUnite surface) were placed in 72 maxillary arches and 101 mandibles. All implants could be seated with a minimum torque of at least 30 Ncm. Tables 4 and 5 report implant distribution according to type and length.

TABLE 2 Changes in the patient opposing dentition during the follow-up period.

Type of opposing dentition	Subjects treated in the maxilla				Subjects treated in the mandible			
	Enrollment	At 1 year follow-up	At 5 years follow-up	At 10 years follow-up	Enrollment	At 1 year follow-up	At 5 years follow-up	At 10 years follow-up
Complete denture	22 patients	22 patients	16 patients	7 patients	50 patients	50 patients	39 patients	18 patients
Natural teeth	9 patients	9 patients	9 patients	5 patients	15 patients	15 patients	14 patients	3 patients
Natural teeth and FPD on natural teeth	none	none	none	none	12 patients	12 patients	11 patients	9 patients
Full-arch FPD on natural teeth	5 patients	5 patients	5 patients	3 patients	3 patients	3 patients	3 patients	2 patients
Natural teeth and FPDs on implants	none	none	none	3 patients	4 patients	4 patients	4 patients	5 patients
IFCDPs on axial implants	25 patients	25 patients	25 patients	24 patients	9 patients	9 patients	8 patients	12 patients
Implant retained overdenture	11 patients	11 patients	11 patients	8 patients	8 patients	8 patients	8 patients	8 patients
IFCDPs (All-on-4)	none	none	6 patients	15 patients	none	none	13 patients	23 patients
TOTAL	72	72	72	65	101	101	100	80

Abbreviations: FPD, fixed partial denture; IFCDP, implant fixed complete dental prosthesis.

TABLE 3 Distribution of withdrawn patients with regard to time and reason.

Year of withdrawal	Deceased	Moved	Health issues	Unable to contact	Total
First–Fifth	0	0	0	0	0
Sixth	1	0	0	0	1
Seventh	1	2	0	1	4
Eighth	1	1	0	2	4
Ninth	2	4	0	2	8
Tenth	3	1	2	3	9
Eleventh	0	1	1	4	6
Twelfth	0	3	0	1	4
Thirteenth	0	2	0	3	5
Fourteenth	0	0	0	0	0
Fifteenth	0	0	1	0	1
Sixteenth	0	0	0	0	0
Total	8	14	4	16	42

TABLE 4 Implant distribution according to the implant type.

	Maxilla	Mandible	Total
MKIV	44	48	92
Speedy Groovy	244	356	600
Total	288	404	692

3.2 | Prosthetic and implant survival rates

Two patients lost their mandibular prosthesis after all the implants were extracted due to a severe peri-implantitis after 4 and 6 years of loading, resulting in a prosthetic cumulative survival rate of 98.01% in the mandible, up to 16 years of follow-up. All the maxillary prostheses remained in function throughout the study with a 100% prosthetic survival rate up to 17 years of function. There was no statistically significant difference in the prosthetic survival between the arches ($p = .34$).

In the maxilla, 7 implants (5 axial and 2 tilted) failed in 6 patients (Table 6), while none of the remaining implants showed persistent infection and marginal bone loss greater than 50% of their length. Up to 17 years of function, implant survival rates were 91.67% and 97.51% at patient and implant level, respectively (Tables 7 and 8). Four of the 7 implants (3 axial and 1 tilted) failed in four subjects within 6 months of loading, when patients were still using the immediate prosthesis. In these four subjects, a new implant was placed and loaded the same day and the temporary prosthesis was modified to include this new implant. One patient, heavy smoker and with an

TABLE 5 Distribution of the implants according to the length.

	18mm	15mm	13mm	11.5mm	10mm	8.5mm	Total
Number of implants (%) maxilla	18 (6.25)	164 (56.94)	49 (17.01)	40 (13.88)	17 (5.91)	0	288 (100)
Number of implants (%) mandible	0	210 (51.98)	101 (25)	53 (13.11)	28 (6.93)	12 (2.98)	404 (100)
Number of implants (%) total	18 (2.6)	374 (54.05)	150 (21.68)	93 (13.44)	45 (6.5)	12 (1.73)	692 (100)

history of periodontal disease, lost one axial implants after 8 years due to advanced peri-implantitis. The definitive prosthesis was left on three implants and bone grafting was done. After 6 months the same patient lost the other axial implant. The same day, two narrow connection implants were placed and loaded together with the surviving tilted implants. One subject lost a tilted implant after 8 years, the area was grafted, and the definitive prosthesis was temporary left on three implants. After 6 months, a new implant was placed and loaded.

In the mandible, 12 implants (6 axial and 6 tilted) failed in 5 patients (Table 9), while no other implant showed persistent infection and marginal bone loss greater than 50% of their length. Up to 16 years of function, implant survival rates were 94.92% and 96.91% at patient and implant level, respectively (Tables 10 and 11). One tilted implant was lost in a diabetic patient after 2 months and a new implant was placed the same day and loaded. Two subjects lost all the implants due to severe peri-implantitis after 60 and 73 months of loading. Patients spent 6 months with a complete denture before new implants and immediate prostheses were placed. One subject lost a tilted implant after 74 months; the area was grafted, patient stayed 8 months with three implants, and then a new tilted implant was placed and loaded. One diabetic patient lost the two axial implants after 10 years due to peri-implant disease. The area was grafted and one narrow implant was placed to support the prosthesis. 6 months later, the narrow implant was removed due to mobility and two implants were placed and loaded. Implants and prosthesis remained stable over time. Overall, 14 out of 19 implants were lost in 6 patients because of peri-implantitis (3 in the maxilla and 11 in the mandible), representing the 2.02% of the total number of implants placed (3.47% of the patients).

The Kaplan–Meier analysis in Figure 1 illustrated implant survival in maxilla and mandible up to 16 years of follow-up, showing no significant difference ($p = .64$) between the arches. No significant differences were also found with respect to implant position and inclination (Figure 2). The differences between maxillary and mandibular survival rates, estimated by log-rank (Mantel-Cox) test resulted in $p = .98$ and $p = .36$ for axial and tilted implants, respectively. The p-values for axial versus tilted implant survival rates were $p = .25$ and $p = .99$ for maxilla and mandible, respectively.

Implant cumulative survival analysis was conducted using the patient as level of analysis with respect to age at surgery ($p = .38$), gender ($p = .25$), arch ($p = .13$), smoking habits ($p = .52$), type 2 diabetes ($p = .42$), and history of periodontal disease ($p = .55$) (Table 12). None of those factors significantly affected implant survival. The Cox proportional hazards regression model used to analyze the relationship between implant failure and potential risk indicators found the following hazard ratios (HR): age at surgery (HR = 0.946), gender (HR = 0.862), arch (HR = 0.582), smoking (HR = 0.551), type 2 diabetes (HR = 8.651), and history of periodontal disease (HR = 0.717) (Table 13). Among these factors, only type 2 diabetes resulted very close to significance ($p = .052$), indicating that implants tend to fail in type 2-diabetic patients more frequently than in non-diabetic ones.

Regarding the cluster analysis, only two patients exhibited cluster failure. Therefore, no further analyses were performed.

3.3 | Marginal bone loss

Since not all MBL distributions were Gaussian, the patient-based data were expressed using the median along with 95% confidence interval. Starting from the first year, a general trend evidenced significant higher marginal bone loss in the mandible compared to the maxilla. At 5 years MBL was 1.20 mm (1.15, 1.23 mm) in the maxilla and 1.40 mm (1.39, 1.59 mm) in the mandible ($p < .001$). At 10 years, it was 1.70 mm (1.64, 1.79 mm) and 1.80 mm (1.79, 1.99 mm) in the maxilla and mandible, respectively ($p = .004$). The proportion of implants not eligible for marginal bone level assessment at 10 years was 10.2% and 10.5% in the maxilla and in the mandible, respectively.

In the maxilla, the MBL change for axial implants was 1.20 mm (1.15, 1,24 mm) ($n = 72$ patients) at 5 years and 1.7 mm (1.61, 1.78 mm) ($n = 65$) at 10 years, while for tilted implants it was 1.10 mm (1.00, 1.15 mm) ($n = 72$) at 5 years and 1.70 (1.47, 1.70 mm) ($n = 65$) at 10 years (Table 14). No difference was found between axial and tilted implants in all intervals considered. No difference was found between MKIV and NobelSpeedy implants as well, both for axial and tilted implants (Table 14).

In the mandible, the MBL change for axial implants was 1.4 mm (1.42, 1.61 mm) ($n = 100$ patients) at 5 years and 1.8 mm (1.79, 2.07 mm) ($n = 80$) at 10 years, while tilted implants showed a marginal bone loss of 1.4 mm (1.23, 1.48 mm) ($n = 100$) at 5 years and 1.8 mm (1.65, 1.80 mm) ($n = 80$) at 10 years (Table 15). No significant differences were found between MKIV and NobelSpeedy implants in both arches, at any follow-up. No difference was found in MBL between axial and tilted implants in the maxilla, while a significantly less marginal bone loss around tilted implants respect to axial ones was found in the mandible, for most of the intervals considered (Table 15). Mixed-effect multilevel linear regression evidenced a correlation between the arch and bone loss at 5 and 10 years,

TABLE 6 Failed implants in the maxilla during the study period.

Subject	Gender (age at surgery)	Time of loss (months after placement)	Implant type and dimension	Site (axial/tilted)	Reason for failure	Replacing implant	Note
1	F (52)	5	MKIV 4 × 11.5 mm	12 (Axial)	Loosening	NobelSpeedy 4 × 13 mm (same day)	Smoker (5 cigarettes/day)
2	F (54)	107	Speedy 4 × 13 mm	22 (Axial)	Peri-implantitis	After the first failure the prostheses was left on 3 implants and bone grafting was done. After the second failure, 2 NobelSpeedy 3.3 × 11.5 mm were placed the same day in place of the lost ones	Heavy smoker (15 cigarettes/day), history of periodontal disease
		113	Speedy 4 × 13 mm	12 (Axial)	Peri-implantitis		
3	F (51)	4	Speedy 4 × 10 mm	22 (Axial)	Loosening	NobelSpeedy 4 × 10 mm (same day)	Long-term use of steroids
4	F (52)	4	Speedy 4 × 10 mm	22 (Axial)	Loosening	NobelSpeedy 4 × 10 mm (same day)	Moderate osteoporosis
5	F (62)	102	Speedy 4 × 13 mm	15 (Tilted)	Peri-implantitis	NobelSpeedy 4 × 15 mm (6 months later in grafted bone)	Smoker (5 cigarettes/day)
6	F (49)	3	Speedy 4 × 11.5 mm	25 (Tilted)	Loosening	NobelSpeedy 4 × 11.5 mm (same day)	Long-term use of steroids

confirming a greater risk of bone loss associated with the mandible. No correlation was found with age at surgery, gender, smoking, type 2 diabetes, and history of periodontal disease (Table 16).

4 | DISCUSSION

Full-arch fixed prosthesis supported by axial and tilted implants represents today a well-accepted option for the treatment of edentulous jaws (Fürhauser et al., 2016; Lin & Eckert, 2018; Pommer et al., 2014). The evidence given by clinical studies and the development of surgical and prosthetic solutions by leading dental industries have contributed to their rapid diffusion among clinicians in a global scale. The use of the residual bone of the patient, avoiding bone regeneration procedures, and the reduction of treatment times are key factors responsible for the diffusion of this treatment modality. Such technique is especially indicated for elderly patients, where local factors and systemic conditions might reduce implant success rates or even represent a contraindication for bone grafting (Baj et al., 2016; Schimmel et al., 2018).

This clinical study presented the long-term outcomes of IFCDPs supported by two anterior axial and two posterior tilted implants. Preliminary results on the same cohort of patients have been published in 2010 (Agliardi et al., 2010). It is important to underline that patients were enrolled irrespective of their age, smoking habits, or systemic conditions (as long as pharmacologically controlled) and that a decade ago there were limited data on protocols involving the use of tilted implant and immediate loading for full-arch prosthesis. After 10 years, implant and prosthetic survival rates were 97.51% and 100% for the maxilla and 96.91% and 98.01% for the mandible, respectively. This is in line with the results of other large retrospective studies by Maló and coworkers, reporting a cumulative implant success rate of 95.2% in the maxilla (Maló, de Araujo Nobre, Lopes, Ferro, & Nunes, 2019) and 94.9% in the mandible during the same follow-up period (Maló, de Araujo Nobre, Lopes, Ferro, & Botto, 2019). Francetti et al. also showed a similar cumulative success rate of 96.11% up to 9 years for maxillary and mandibular implants combined (Francetti et al., 2019).

No significant difference was found in the survival rates between axial and tilted implants nor between implants placed in the maxilla and in the mandible, in agreement with the most recent long-term trials (Hopp et al., 2017; Testori et al., 2017) and systematic reviews (Del Fabbro et al., 2012; Chrcanovic et al., 2015a Reference 'Chrcanovic et al., 2015' year has been changed to 2015a to match the reference list. Please check for correctness."; Lin & Eckert, 2018; Gaonkar et al., 2021, Del Fabbro et al., 2022). In our study, a similar failure rate was found for axial and tilted implants in the mandible, while axial implants failed with slightly higher frequency in the maxilla. With respect to the time of failure, half of the maxillary failed implants were lost within the first 6 months (early failure), while in the mandible, most of the failed implants were lost or removed for peri-implant disease starting from 5 years of loading (late failure). Late implant failure due to peri-implant disease has

TABLE 7 Life table of maxillary implants (patient as unit of analysis).

Interval in years	Patients at risk	Dropouts/lost to follow-up	Patients with failures	Interval survival rate	Cumulative survival rate
0–1	72	0	4	94.44%	94.44%
1–2	72	0	0	100.00%	94.44%
2–3	72	0	0	100.00%	94.44%
3–4	72	0	0	100.00%	94.44%
4–5	72	0	0	100.00%	94.44%
5–6	72	0	0	100.00%	94.44%
6–7	72	0	0	100.00%	94.44%
7–8	72	3	0	100.00%	94.44%
8–9	69	3	1	98.55%	93.08%
9–10	66	1	1	98.48%	91.67%
10–11	65	2	0	100.00%	91.67%
11–12	63	1	0	100.00%	91.67%
12–13	61	1	0	100.00%	91.67%
13–14	47	0	0	100.00%	91.67%
14–15	27	1	0	100.00%	91.67%
15–16	15	0	0	100.00%	91.67%
16–17	9	0	0	100.00%	91.67%
17–18	1	0	0	100.00%	91.67%
Total		12	6		

TABLE 8 Life table of maxillary implants (implant as unit of analysis).

Interval in years	Implants at risk	Dropouts/lost to follow-up	Implants failed	Interval survival rate	Cumulative survival rate
0–1	288	0	4	98.61%	98.61%
1–2	284	0	0	100.00%	98.61%
2–3	284	0	0	100.00%	98.61%
3–4	284	0	0	100.00%	98.61%
4–5	284	0	0	100.00%	98.61%
5–6	284	0	0	100.00%	98.61%
6–7	284	0	0	100.00%	98.61%
7–8	284	12	0	100.00%	98.61%
8–9	272	12	2	98.55%	97.89%
9–10	258	4	1	98.48%	97.51%
10–11	253	8	0	100.00%	97.51%
11–12	245	4	0	100.00%	97.51%
12–13	237	4	0	100.00%	97.51%
13–14	181	0	0	100.00%	97.51%
14–15	101	4	0	100.00%	97.51%
15–16	57	0	0	100.00%	97.51%
16–17	36	0	0	100.00%	97.51%
17–18	4	0	0	100.00%	97.51%
Total		48	7		

been reported by a review of Lee, who stated that the prevalence of peri-implantitis increases after 3 years of loading (Lee et al., 2017), and with the analysis of Tonetti, who claimed peri-implantitis as a major indicator for late implant failure (Tonetti, 1999). In our study 1.04% of the maxillary implants (placed in 2.78% of the patients) and 2.72% of the mandibular implants (placed in 4.95% of the patients) failed because of peri-implant disease. These results are in line with Testori and coworkers, who using a similar protocol with

TABLE 9 Failed implants in the mandible during the study period.

Subject	Sex (age at surgery)	Time of loss (months after placement)	Implant type and dimension	Site (axial/tilted)	Reason for failure	Replaced implant	Note
1	F (49)	74	MKIV 4×13 mm	35 (Tilted)	Peri-implantitis	NobelSpeedy 4×13 mm (8 months later)	No smoker, no history of periodontal disease or diabetes
2	M (35)	73	Speedy 4×15 mm	35 and 45 (Tilted)	Peri-implantitis	2 NobelSpeedy 4×15 mm (6 months later)	Developed HIV, smoker (5 cigarettes/day)
			Speedy 4×13 mm	32 and 42 (Axial)		2 NobelSpeedy 4×13 mm (6 months later)	
3	M (66)	120	Speedy 4×13 mm	32 and 42 (Axial)	Peri-implantitis	NobelSpeedy 3.3×13 mm (6 months later in grafted bone)	Smoker (5 cigarettes/day), history of periodontal disease, type 2 diabetes
4	F (64)	60	Speedy 4×13 mm	35 and 45 (Tilted)	Peri-implantitis	4 NobelSpeedy 4×13 mm (6 months later in grafted bone)	Type 2 diabetes
			Speedy 4×13 mm	32 and 42 (Axial)			
5	M (73)	2	Speedy 4×15 mm	35 (Tilted)	Loosening	NobelSpeedy 4×15 mm (same day)	Type 2 diabetes

Abbreviations: F, female; M, male.

TABLE 10 Life table of mandibular implants (patient as unit of analysis).

Interval in years	Patients at risk	Dropouts/lost to follow-up	Patients with failures	Interval survival rate	Cumulative survival rate
0–1	101	0	1	99.01%	99.01%
1–2	101	0	0	100.00%	99.01%
2–3	101	0	0	100.00%	99.01%
3–4	101	0	0	100.00%	99.01%
4–5	101	0	1	99.01%	98.03%
5–6	101	0	0	100.00%	98.03%
6–7	101	0	2	98.2%	96.09%
7–8	96	3	0	100.00%	96.09%
8–9	91	3	0	100.00%	96.09%
9–10	88	1	0	100.00%	96.09%
10–11	82	2	1	98.78%	94.92%
11–12	79	1	0	100.00%	94.92%
12–13	74	1	0	100.00%	94.92%
13–14	58	0	0	100.00%	94.92%
14–15	35	1	0	100.00%	94.92%
15–16	14	0	0	100.00%	94.92%
16–17	3	0	0	100.00%	94.92%
Total		28	5		

four axial and two tilted implants reported 1.3% of total maxillary implant failure in 8.3% of the patients after 10 years of function, because of peri-implantitis (Testori et al., 2017). In our study, all implants removed or failed for peri-implant disease were treated with non-surgical scaling when the implant evidenced up to 5 mm of bone loss. Eventually, when bone loss exceeded 50% of the implant length, patients generally preferred extraction and replacement with a new implant instead of a surgical intervention aimed to treat the peri-implant bone defect. In most of the patients with failure for peri-implantitis, one or more systemic conditions (HIV, type 2

TABLE 11 Life table of mandibular implants (implant as unit of analysis).

Interval in years	Implants at risk	Dropouts/lost to follow-up	Implants failed	Interval survival rate	Cumulative survival rate
0–1	404	0	1	99.75%	99.75%
1–2	403	0	0	100.00%	99.75%
2–3	403	0	0	100.00%	99.75%
3–4	403	0	0	100.00%	99.75%
4–5	403	0	4	99.01%	98.76%
5–6	399	0	0	100.00%	97.52%
6–7	399	20	5	98.75%	97.52%
7–8	374	20	0	100.00%	97.52%
8–9	354	12	0	100.00%	97.52%
9–10	342	24	0	100.00%	97.52%
10–11	318	12	2	99.37%	96.91%
11–12	304	20	0	100.00%	96.91%
12–13	284	0	0	100.00%	96.91%
13–14	220	4	0	100.00%	96.91%
14–15	128	0	0	100.00%	96.91%
15–16	44	0	0	100.00%	96.91%
16–17	12	0	0	100.00%	96.91%
Total		112	12		

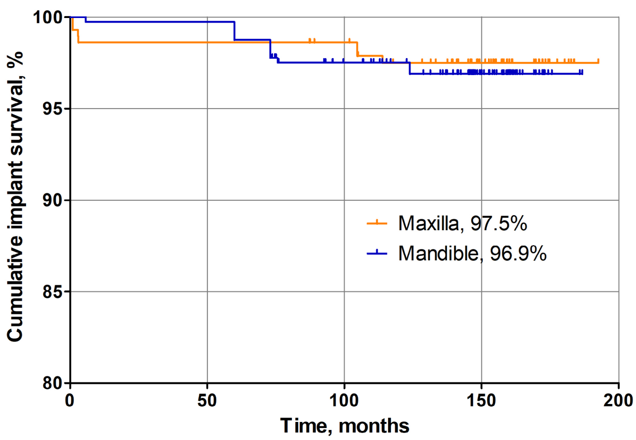

FIGURE 1 Kaplan–Meier analysis on implant basis for mandible and maxilla. The difference in cumulative implant survival rate between maxilla and mandible up to 16-year follow-up, estimated by log-rank (Mantel–Cox) test, was not significant ($p = .64$), with a slight tendency for higher survival rate in the maxilla (97.51% vs 96.91%).

diabetes, and history of periodontal disease) and smoking habits were present (Chrcanovic et al., 2015b). On the other side, early implant loss occurred mainly in the maxillary arch between 3 and 5 months after loading. Poor bone density and the relatively low insertion torque (slightly higher than 30 Ncm) might be responsible for the failure. Additionally, three of the four patients experiencing early implant failure had a medical history of moderate osteoporosis or chronic use of steroids. Cox proportional hazards regression model showed that factors such as age, gender, arch, smoking habits, and history of periodontal disease were not significantly associated with implant failure, while type 2 diabetes showed an increased hazard ratio (HR = 2.36), close to statistical significance (0.052). Malò reported an increased hazard for implant failure of 1.73 for male gender and 1.94 for smokers in the maxillary arch (Maló, de Araujo Nobre, Lopes, Ferro, & Nunes, 2019), while Francetti et al. claimed that neither smoking habit nor history of periodontal disease significantly contributed to implant loss (Francetti et al., 2019). On the other hand, in an 8-year study, Busenlechner and coworkers found that smoking habits increased the risk of implant failure by 3 folds and a history of periodontal disease doubled the failure risk (Busenlechner et al., 2014). A recent meta-analysis, based on 292 publications, confirmed a higher implant failure risk for smokers (an odds ratio of 2.91 and 2.67 in the maxilla and mandible, respectively), but did not find a significant effect of smoking in marginal bone loss (Mustapha et al., 2021).

Since all patients had multiple implants, we also tried to investigate whether a combination of factors could represent a risk for multiple failures in some patients, evaluating the clustering pattern in analogy with a statistical model previously reported (Chrcanovic et al., 2017). In our dataset, however, there were only two patients who lost all (four) implants and could be defined "cluster patient" (see Table 9 for details). According to the univariate binary logistic regression at patient level, none of the factors evaluated (gender, smoking habit, type 2 diabetes, history of periodontitis, arch, and implant type) resulted in a significant risk for cluster failures. Therefore, mainly due to the very low incidence of the cluster failures phenomenon in the present group of patients, the subsequent multivariate analysis was not performed since no factor could be included. However, we cannot exclude that such type of analysis could be successfully implemented with a wider sample size. In fact, the study taken as a model

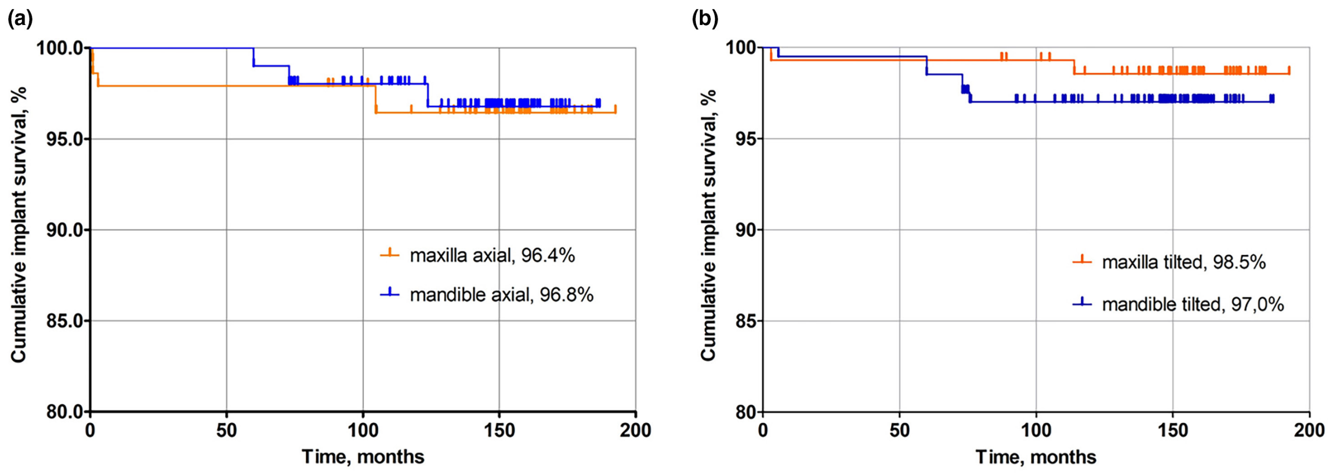

FIGURE 2 Cumulative survival for axial (a) and tilted (b) implants placed in maxilla and mandible up to 16 years of follow-up, estimated by Kaplan–Meier statistics. The differences estimated by log-rank (Mantel-Cox) test resulted in $p = .98$ and $p = .36$ for axial and tilted implants, respectively.

TABLE 12 Cumulative survival according to the different features of the sample.

Factor	N° of patients	Patients w failure (%)	N° of implants	Failed implants (%)	Kaplan–Meier cumulative 15-y survival	Log-rank mantel-cox test *p*-value
Age at surgery ≤58 years	88	7 (7.95)	352	11 (3.38)	91.93%	.38
Age at surgery >58 years	85	4 (4.71)	340	8 (2.35)	94.81%	
Males	92	4 (4.35)	368	8 (2.17)	95.38%	.25
Females	81	7 (8.64)	324	11 (3.40)	91.00%	
Maxilla	72	6 (8.33)	288	7 (2.43)	90.05%	.13
Mandible	101	5 (4.95)	404	12 (2.97)	95.76%	
Smokers	62	3 (4.84)	248	4 (1.61)	94.80%	.52
Non-smokers	111	8 (7.21)	444	15 (3.38)	92.57%	
Diabetics	19	2 (10.53)	76	5 (6.58)	89.47%	.42
Non-diabetics	154	9 (5.84)	616	14 (2.27)	93.83%	
Periodontitis history	76	4 (5.26)	304	12 (3.95)	75.82%	.55
Non-perio history	97	7 (7.22)	388	7 (1.80)	92.56%	

Note: The patient was the unit of analysis. The cutoff for age was 58 years (median value).

TABLE 13 Cox proportional hazards regression model aiming at determining the hazard ratios of various factors for implant failure ($n = 173$).

Factor	Hazard ratio	Standard error	z	$p > \|z\|$	95% confidence interval
Age at surgery	0.946	0.043	−1.21	.227	0.864, 1.035
Gender (male/female)	0.862	0.591	−0.22	.828	0.224, 3.309
Arch (maxilla/mandible	0.582	0.397	−0.79	.428	0.152, 2.219
Smoking (yes/no)	0.551	0.429	−0.77	.444	0.120, 2.536
Type 2 diabetes (yes/no)	8.651	9.594	1.95	.052	0.984, 76.061
Periodontitis (yes/no)	0.717	0.481	−0.50	.620	0.193, 2.668

Note: None of the independent variables resulted a significant factor in determining failure.

(Chrcanovic et al., 2017) included a sample of 1406 patients, which is almost an order of magnitude larger than ours.

The average data for marginal bone loss measured in our study are in line with similar long-term publications. Maló reported a marginal bone loss of 1.67 mm for the maxilla (129 patients) (Maló, de Araujo Nobre, Lopes, Ferro, & Nunes, 2019) and 1.7 mm for the mandible (281 patients) after 10 years of function (Maló, de Araujo Nobre, Lopes, Ferro, & Botto, 2019), Ayna and coworkers, in a 7-year

TABLE 14 Marginal bone loss for axial and tilted implants in the maxilla on a patient basis. Data are expressed in mm as median and 95% confidence intervals.

		6 months	1 year	3 years	5 years	8 years	10 years	12 years	14 years	15 years
Axial	MKIV	0.5 (0.36, 0.56) (12)	0.9 (0.81, 0.95) (12)	0.85 (0.77, 0.97) (12)	1.2 (1.12, 1.27) (12)	1.65 (1.41, 1.77) (12)	1.75 (1.46, 1.83) (10)	2 (1.62, 2.28) (8)	2 (1.80, 2.45) (9)	2.1 (1.85, 2.72) (7)
	Speedy	0.5 (0.49, 0.56) (60)	0.8 (0.80, 0.92) (60)	0.9 (0.83, 0.95) (60)	1.2 (1.15, 1.25) (60)	1.7 (1.59, 1.84) (57)	1.7 (1.61, 1.80) (55)	1.9 (1.76, 1.98) (53)	1.95 (1.77, 2.05) (29)	1.9 (1.73, 2.18) (18)
	p-value*	.267	.592	.665	.945	.431	.504	.760	.293	.152
	Total	0.5 (0.48, 0.54) (72)	0.9 (0.81, 0.92) (72)	0.9 (0.83, 0.94) (72)	1.2 (1.15, 1.24) (72)	1.7 (1.59, 1.80) (69)	1.7 (1.61, 1.78) (65)	1.9 (1.78, 1.98) (61)	2 (1.83, 2.09) (38)	2.05 (1.86, 2.25) (25)
Tilted	MKIV	0.5 (0.34, 0.54) (12)	0.9 (0.64, 1.02) (12)	0.9 (0.78, 1.02) (12)	1.1 (0.83, 1.27) (12)	1.6 (1.37, 1.77) (12)	1.65 (1.22, 1.85) (10)	1.75 (1.39, 2.24) (8)	1.9 (1.56, 2.28) (9)	2.2 (1.89, 2.60) (7)
	Speedy	0.5 (0.44, 0.51) (60)	0.85 (0.76, 0.88) (60)	0.9 (0.79, 0.91) (60)	1.1 (0.99, 1.16) (60)	1.7 (1.53, 1.76) (57)	1.7 (1.46, 1.72) (55)	1.8 (1.64, 2.12) (53)	1.9 (1.74, 2.07) (29)	1.95 (1.75, 2.30) (18)
	p-value*	.664	.641	.587	.616	.324	.635	.992	.796	.248
	Total	0.5 (0.44, 0.50) (72)	0.9 (0.76, 0.88) (72)	0.9 (0.80, 0.91) (72)	1.1 (1.00, 1.15) (72)	1.7 (1.53, 1.73) (69)	1.7 (1.47, 1.70) (65)	1.8 (1.66, 2.09) (61)	1.9 (1.76, 2.05) (38)	2.0 (1.87, 2.30) (25)
Tilted vs axial	*p*-value**	.154	.214	.356	.024	.825	.264	.597	.569	.850
Total maxilla		0.5 (0.48, 0.53) (72)	0.9 (0.82, 0.91) (72)	0.9 (0.84, 0.93) (72)	1.2 (1.15, 1.23) (72)	1.7 (1.58, 1.76) (69)	1.7 (1.64, 1.79) (65)	1.9 (1.81, 2.06) (61)	1.9 (1.82, 2.07) (38)	2.1 (1.88, 2.29) (25)

Note: Patients number with parentheses.* comparison between MKIV and Speedy implants (Mann Whitney test); ** comparison between tilted and axial implants (Wilcoxon matched pair test).

TABLE 15 Marginal bone loss for axial and tilted implants in the mandible on a patient basis. Data are expressed in mm as median and 95% confidence intervals. Patients number with parentheses.

		6 months	1 year	3 years	5 years	8 years	10 years	12 years	14 years	15 years
Axial	MKIV	0.5 (0.48, 0.62) (11)	0.9 (0.76, 0.99) (11)	1.2 (0.96, 1.27) (11)	1.4 (1.30, 1.55) (11)	1.7 (1.50, 1.81) (10)	1.9 (1.57, 2.13) (6)	1.95 (1.32, 2.59) (2)	2.05 (1.42, 2.69) (2)	2.15 (1.52, 2.79) (2)
	Speedy	0.5 (0.49, 0.52) (90)	1 (0.94, 1.05) (90)	1.2 (1.17, 1.40) (90)	1.4 (1.42, 1.63) (89)	1.6 (1.62, 1.69) (80)	1.8 (1.79, 2.09) (74)	2 (1.97, 2.09) (71)	2.2 (2.14, 2.25) (29)	2.2 (2.14, 2.30) (11)
	p-value*	.237	.051	.256	.355	.952	.993	.737	.138	.535
	Total	0.5 (0.49, 0.53) (101)	1.0 (0.95, 1.04) (101)	1.2 (1.16, 1.37) (101)	1.4 (1.42, 1.61) (100)	1.6 (1.62, 1.69) (90)	1.8 (1.79, 2.07) (80)	2 (1.97, 2.08) (73)	2.2 (2.14, 2.24) (31)	2.2 (2.14, 2.28) (13)
Tilted	MKIV	0.5 (0.40, 0.60) (11)	0.9 (0.69, 1.05) (11)	1.2 (0.89, 1.27) (11)	1.2 (1.06, 1.34) (11)	1.6 (1.18, 1.70) (10)	1.8 (1.02, 2.05) (6)	1.5 (−4.85, 7.85) (2)	1.6 (−6.02, 9.22) (2)	1.65 (−6.61, 9.91) (2)
	Speedy	0.5 (0.40, 0.46) (90)	1 (0.86, 0.97) (90)	1.2 (1.14, 1.36) (90)	1.4 (1.23, 1.51) (89)	1.6 (1.36, 1.53) (80)	1.8 (1.67, 1.82) (74)	2 (1.88, 2.07) (71)	2.2 (2.04, 2.40) (29)	2.2 (1.93, 2.39) (11)
	p-value*	.182	.724	.247	.041	.824	.470	.289	.217	.545
	Total	0.5 (0.41, 0.47) (101)	1 (0.86, 0.97) (101)	1.2 (1.13, 1.33) (101)	1.4 (1.23, 1.48) (100)	1.6 (1.36, 1.52) (90)	1.8 (1.65, 1.80) (80)	2 (1.87, 2.06) (73)	2.2 (2.00, 2.37) (31)	2.2 (1.81, 2.36) (13)
Tilted vs axial	*p*-value**	.001	.001	.427	<.001	<.001	<.001	.028	.806	1.00
Total mandible		0.5 (0.47, 0.5) (101)	1.0 (0.94, 1.03) (101)	1.2 (1.16, 1.35) (101)	1.4 (1.39, 1.59) (100)	1.6 (1.60, 1.67) (90)	1.8 (1.79, 1.99) (80)	2.0 (1.97, 2.11) (73)	2.2 (2.12, 2.39) (32)	2.2 (2.14, 2.30) (13)

Note: * comparison between MKIV and Speedy implants (Mann Whitney test); ** comparison between tilted and axial implants (Wilcoxon matched pair test).

TABLE 16 Mixed-effect multilevel linear regression analysis at 5y follow-up ($n=172$) (a), and 10y follow-up ($n=145$) (b). The patient was the unit of analysis. The arch resulted a significant factor in determining marginal bone loss at both 5 and 10 years.

a					
Factor	**Coefficient**	**Robust std.err.**	**Z**	***p*_value**	**95% CI**
Age at surgery	−0.008	0.010	−0.87	.382	−0.027, 0.104
Gender (male/female)	0.094	0.079	1.19	.235	−0.061, 0.248
Arch (maxilla/mandible	0.300	0.056	5.34	.000	0.190, 0.410
Smoking (yes/no)	−0.030	0.063	−0.47	.635	−0.153, 0.094
Type 2 diabetes (yes/no)	0.091	0.095	0.95	.341	−0.096, 0.278
Patient with periodontitis (yes/no)	0.053	0.075	0.70	.484	−0.095, 0.200

b					
Factor	**Coefficient**	**Robust std.err.**	**Z**	***p*_value**	**95% CI**
Age at surgery	0.008	0.004	2.02	.053	0.000, 0.016
Gender (male/female)	0.080	0.072	1.11	.268	−0.061, 0.221
Arch (maxilla/mandible	0.155	0.057	2.70	.007	0.043, 0.267
Smoking (yes/no)	0.002	0.068	0.02	.980	−0.132, 0.135
Type 2 diabetes (yes/no)	−0.070	0.125	−0.56	.578	−0.315, 0.176
Patient with periodontitis (yes/no)	0.078	0.069	1.12	.263	−0.058, 0.213

prospective study on 16 patients, evidenced an average bone loss of 1.03 mm for mandibular implants (Ayna et al., 2018), while Li et al., also in a 7-year prospective study, reported bone loss of 1.2 mm for both axial and tilted implants (32 implants were assessed in both jaws) (Li et al., 2017). In this study, the implant type seemed to play no major role, as there was no significant difference in MBL between MKIV and NobelSpeedy implants along time. However, especially at longer follow-ups, very few patients with MKIV implants were available, and the results of the comparison with NobelSpeedy should be interpreted cautiously. No consistent differences in MBL were found between axial and tilted implants, in agreement with the most recent systematic reviews (Del Fabbro et al., 2012; Del Fabbro & Ceresoli, 2014; Gaonkar et al., 2021; Lin & Eckert, 2018). However, there was a tendency for a greater bone resorption around axial as compared to tilted implant in the mandible. The major finding in our study is related to a significant higher bone loss in the lower jaw, both for axial and tilted implants. A similar trend was reported by Francetti and coworkers in a prospective study with up to 5 years of follow-up (Francetti et al., 2012). Even though they did not report significant differences, a trend for a higher bone loss in the lower jaw was noted, mainly around axial implants, like our study, finding a possible explanation in the reduced blood supply of the anterior atrophic mandibles composed mainly by cortical bone. From the results of our study, it is an opinion of the authors that early implant failure occurred in the maxilla because of its poor bone quality, while the higher bone density of the mandibular jawbone resulted in high level of fixation and insertion torque. Differently, late implant failure due to peri-implantitis and higher level of marginal bone loss around mandibular implants, especially in atrophic jaws, might be due to the reduced blood supply and difficulties in cleaning under the prosthesis reported by the patients. Moreover, the significantly higher bone loss reported in the mandible compared to the maxilla might be justified because the morphology of the latter, with its dome shape, the higher elasticity of the cancellous maxillary bone with reduced cortical component, might better dissipate the trauma of the occlusion.

In our study, the high implant survival rates and the relatively small marginal bone remodeling might be related to different factors. Among them, the authors want to emphasize the attempt to create a collar of keratinized gingiva all around the abutments (Maló et al., 2013), a prosthesis design that allows easy access to hygiene instruments and a customized recall protocol. Establishing a personalized maintenance hygiene program tailored to patient's compliance and individual risk factors has been proved to be effective for the long-term success of implant therapy (Del Fabbro et al., 2018). This is particularly important for elderly individuals that often have functional impairment, multimorbidity, and daily intake of multiple medications (polypharmacy) affecting salivary flow (Lin et al., 2019). A systematic review by Monje underlined the role of the peri-implant maintenance therapy with a minimum recall of 5 to 6 months (Monje et al., 2016). The authors also point out that despite the establishment of a personalized maintenance regime, biological complications can always occur due to their multifactorial nature where the individuality of the patients, implant characteristics, prosthetic factors, and materials play an active role. For example, Ayna reported a significantly more pronounced marginal bone loss around implants supporting maxillary acrylic prostheses compared to ceramic prostheses, starting from the fifth year of follow-up (Ayna et al., 2021). This underlines the importance of polishing the surface of the IFCDP to reduce plaque accumulation in acrylic prostheses (Ayna et al., 2021). It is authors' opinion that the long-term success of full arch fixed rehabilitations supported by only four implants relies on the strict adhesion to established clinical protocols (Maló et al., 2003, 2005). Immediate loading on just four fixtures can be more challenging and riskier as compared to having a higher number of implants, particularly in soft bone, and where high occlusal forces are present. If one or two implants fail, the entire prosthesis fails. Nevertheless, once the four implants are successfully integrated, the higher inter-implant distance, the shorter cantilevers, and the reduced number of abutments can be advantageous in terms of implant maintenance and reduced mechanical distress, as compared to prostheses supported by a higher number of implants.

The limitations of the present study include treatment being rendered in a single center by a group of clinicians with experience in implant dentistry, the lost-to-follow-up rate of 24% at 15 years (potentially resulting in overestimation of implant success rate), and a 10% of non-readable radiographs at 10 years, suggesting caution in the interpretation of the results. The long-term follow-up represents the main strength of this study.

5 | CONCLUSIONS

Despite the limitations of the present study, immediate implant-fixed complete dental prostheses supported by to axial and two tilted implants might be considered a viable treatment modality in the long term for both jaws.

AUTHOR CONTRIBUTIONS

Enrico Luigi Agliardi: Conceptualization (equal); data curation (equal); investigation (equal); methodology (equal); resources (equal); supervision (equal); validation (equal); writing – review and editing (equal). **Alessandro Pozzi:** Conceptualization (equal); data curation (equal); investigation (equal); methodology (equal); resources (equal); validation (equal); writing – review and editing (equal). **Davide Romeo:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); software (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

Enrico Luigi Agliardi and Alessandro Pozzi are currently consultants for Nobel Biocare AB. There are no further conflicts of interest for the remaining authors.

DATA AVAILABILITY STATEMENT

Authors elect not to share data

ETHICS APPROVAL STATEMENT AND PATIENT CONSENT

The protocol of this long-term retrospective analysis was approved by the Ethical Committee of the IRCCS San Raffaele Hospital (Reg. N. 190/INT/2021). All the subjects signed an informed consent form, for having their data used for scientific purpose. The study was in compliance with the principles laid down in the Declaration of Helsinki for biomedical research involving human subjects, as revised in 2004.

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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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