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6-mm-short and 11-mm-long implants compared in the full-arch rehabilitation of the edentulous mandible: A 3-year multicenter randomized controlled trial

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Abstract

Objective: The aim of this multicenter parallel-group randomized controlled trial is to compare 6-mm-short with 11-mm-long implants in the rehabilitation of totally edentulous mandible in a completely comparable clinical situation, from anatomical, surgical, and prosthetic point of view.

Material and methods: Thirty patients were selected in three study centers to receive a fixed full-arch mandibular rehabilitation supported by five inter-foraminal implants. Patients were randomly allocated, at the time of surgery, half to the test group (6-mm-long implants) and half to the control group (11-mm-long implants). No bone augmentation procedure was performed. After 3 months, a screw-retained full-arch prosthesis with distal cantilevers was positioned (baseline). Peri-implant marginal bone level change (MBLc), implant and prosthesis survival rate, and biological/technical complications were evaluated after 1 and 3 years.

Results: Thirty subjects (150 implants) were evaluated after 1 year and 28 (140 implants) after 3 years. No implant or prosthesis loss occurred. No significant inter-group difference for biological/technical complications was registered. No statistically significant ($p > .025$) intra-group or inter-group difference in the mean MBLc values was registered. The mean MBLc was 0.01 ± 0.19 mm and −0.04 ± 0.21 mm at 1 year, and −0.10 ± 0.24 mm and 0.02 ± 0.25 mm at 3 years (test and control groups, respectively).

Conclusions: 6-mm-short implants may be a reliable option when used in the rehabilitation of total edentulous mandibles. These results need to be confirmed by longer follow-up data from well-designed randomized controlled clinical trials.

KEYWORDS

edentulous jaw, randomized controlled clinical trial, short dental implant

1 | INTRODUCTION

The clinical use of dental implants in the rehabilitation of totally and partially edentulous patients represents a well-documented long-term and highly predictable procedure (Adell, Lekholm, Rockler, & Brånemark, 1981; Ekelund, Lindquist, Carlsson, & Jemt, 2003). One of the main limitations for a correct implant placement, however, still remains the availability of a sufficient amount of bone at implant site. In case of reduced bone height, indeed, standard length fixtures can be inserted only after advanced reconstructive

surgical treatments, with a consequent increase in financial and biological costs for the patient (additional costs, longer treatment time, increased postoperative morbidity, and greater risk of complications) (Esposito et al., 2010; Heitz-Mayfield, Needleman, Salvi, & Pjetursson, 2014).

The use of short implants for the rehabilitation of atrophic sites in order to avoid the disadvantages of vertical bone augmentation procedures has greatly expanded in recent years, with promising results (Nisand & Renouard, 2014; Jung et al., 2018).

Short implants offer benefits in terms of less invasive surgery, ease of handling, and reduced risk of damaging anatomical structures, thus supporting the concept of a "stress minimizing surgery" (Nisand & Renouard, 2014). For this reason, it would be reasonable to hypothesize their use also in clinical conditions where longer fixtures can be inserted.

The efficacy of short dental implants has been a matter of debate in the recent literature. Short implants have been historically associated with higher failure rates than longer ones (Bahat, 1993; Pommer et al., 2011). More recent studies, on the other hand, have failed to find a difference in the survival rate of short versus longer implants placed in both pristine or regenerated bone, as reported by several systematic reviews (Camps-Font et al., 2016; Lemos, Ferro-Alves, Okamoto, Mendonça, & Pellizzer, 2016; Monje et al., 2014; Palacios, Garcia, Caramês, Quirynen, & Silva Marques, 2018; Sierra-Sánchez et al., 2016; Thoma, Zeltner, Hüsler, Hämmerle, & Jung, 2015; Tong, Zhang, & Yu, 2017; Toti et al., 2017; Ravidà, Wang, et al., 2019).

It must be remembered that many of these studies are not addressed to compare the performance of short and long implants in the same clinical scenario (the comparison of short implants in healed sites vs. long implants in regenerated sites is prevalent), and extended follow-up are lacking. Furthermore, the definition of "short dental implant" differs among studies (<10 mm, ≤8 mm, ≤7 mm) (Fan, Li, Deng, Wu, & Zhang, 2017; Pommer et al., 2011; Renouard & Nisand, 2006; Telleman et al., 2011). In a recent Consensus Report focused on the influence of implant length, meta-analytic data exclusively derived from studies using fixtures with an intra-bony length of ≤6 mm were included and discussed (Jung et al., 2018; Papaspyridakos et al., 2018). In this Consensus the authors highlight, on one hand, the comparable prognosis of short and long implants in terms of implant and prosthesis survival and marginal bone loss but also, on the other hand, a 30% higher failure risk for short implants over time as well as the further need for well-designed RCT with a long follow-up.

In order to have a reliable comparison of the clinical performance between short and long implants, a comparison should be made according to a similar bone quality, the same bone height (this assumes the installation of short implants in sites able to receive longer ones) and according to the resolution of the same type of edentulism by means of an identical prosthetic solution.

The aim of this randomized controlled clinical trial was to evaluate the efficacy of 6-mm-short implants compared with 11-mm-long implants supporting fixed full-arch mandibular prostheses in patients with a fully edentulous mandible with no need for bone

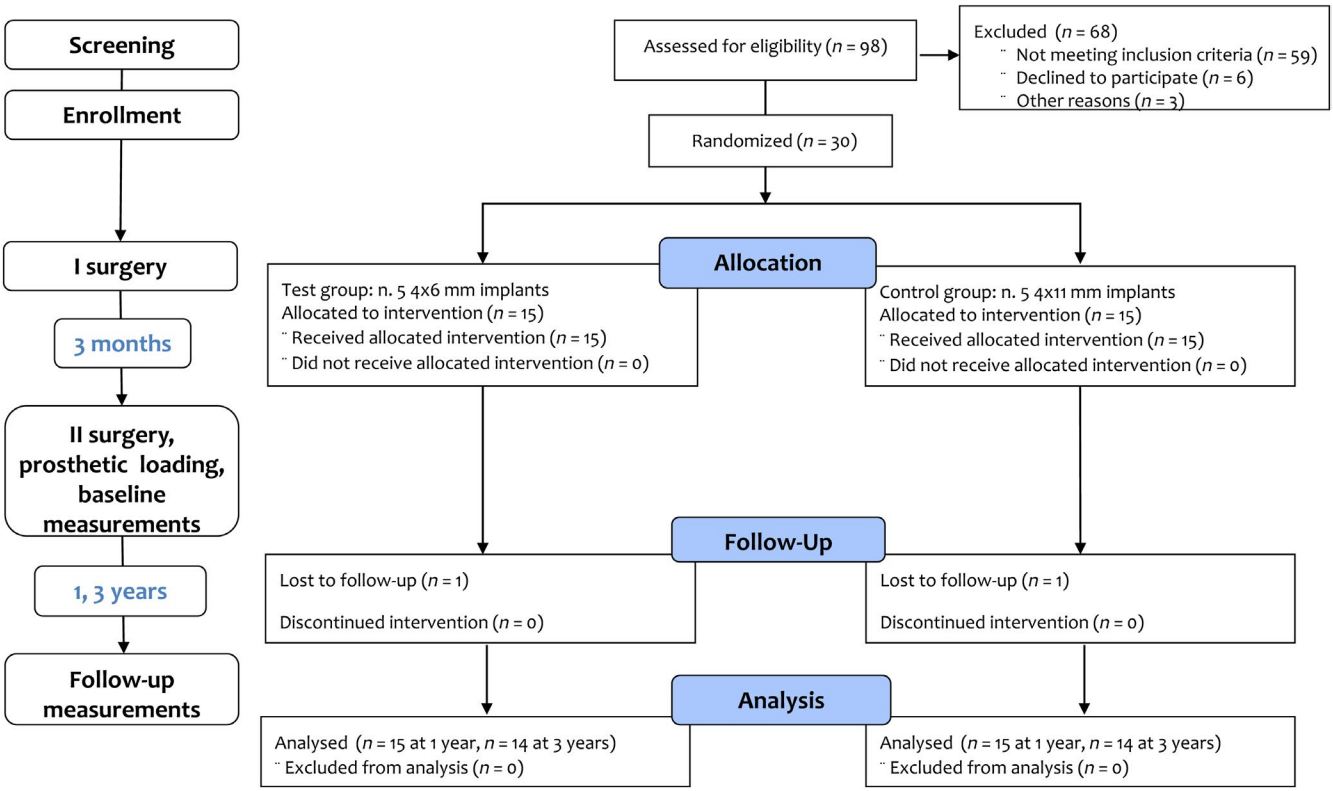

FIGURE 1 CONSORT flow diagram of the research protocol

augmentation procedures. In particular, the null hypothesis was that there was no difference in terms of marginal bone level change between short and longer implants from prosthetic installation to 1 and 3 years of follow-up.

2 | MATERIAL AND METHODS

2.1 | Study design and general information

This study was designed as a multicenter parallel-group randomized controlled clinical trial (RCT) with a 1:1 allocation ratio. It was reported according to the CONSORT statement (http://www.consort-statement.org/). Three Italian centers participated in the study: the Department of Dentistry of the University Hospital "Luigi Vanvitelli," Naples (leading center), the Hospital "A. Cardarelli" of Naples, and a private office in Catania (Dr. Paolo Torrisi's office). The principles outlined in the Declaration of Helsinki on clinical research involving human subjects were followed. All patients received thorough explanations and signed a written informed consent form prior to being enrolled in the trial. The research protocol was approved by the ethical committee of the University of Campania "Luigi Vanvitelli" (Aut. N. 13/2010) and registered on a public RCT database (clinicaltrials.gov NCT03509402). The CONSORT flow diagram of the research protocol is shown in Figure 1.

2.2 | Primary and secondary outcomes

The primary outcome of the study was the radiographic marginal bone level change (MBLc) around 6-mm-short and 11-mm-long implants, evaluated from prosthetic installation to 1 and 3 years of follow-up.

The secondary outcomes included (a) implant survival rate, (b) prosthesis survival rate, and (c) biological or technical complications.

Surviving implant or prosthesis were those still in function at the last follow-up. Biological complications were considered peri-implant mucositis and peri-implantitis (Renvert, Persson, Pirih, & Camargo, 2018). Technical complications were considered prosthesis fracture, screw loosening or fracture, implant fracture, veneer fracture.

2.3 | Sample size calculation

Sample size calculation revealed that group sample sizes of 13 per group achieved 80% power to detect non-inferiority using a two-sample, one-sided test. The margin of non-inferiority (δ), that is the threshold value judged as clinically relevant, was 1.0 mm. The true difference between the means was assumed to be 0.0. In consideration of the one-tail nature of the non-inferiority test, the significance level (alpha) was set at 0.025. The data were drawn from populations with standard deviations of 0.9 and 0.9. Such a value was based on the long-term marginal bone loss data from the population of mandibular edentulous patients rehabilitated with Toronto bridges supported by conventionally loaded inter-foraminal long implants (Ekelund et al., 2003). Fifteen patients per group were recruited to compensate for possible drop-outs.

2.4 | Patient enrollment

Patients were enrolled at the three involved centers. Inclusion criteria were age between 18 and 75 years, total mandibular edentulism for at least 8 months, sufficient amount of native bone (no previous bone augmentation procedures) in the recipient sites to allow the installation of five implants with length ≥11 mm and width 4 mm being circumferentially surrounded by ≥1 mm of peri-implant bone, systemic health, compliance with good oral hygiene. Exclusion criteria were any disease, medication or drug that could jeopardize healing, osseointegration or treatment outcome, severe bruxism or other parafunctional habits, unrealistic aesthetic demands. Smokers were not excluded, however, the smoking habit was registered as heavy smoker (≥10 sig./day), light smoker (<10 sig./day), non-smoker, or former smoker. Patient eligibility in terms of bone dimensions was determined on computer tomography (CT) scans, with the aid of an implant planning software (Simplant, Dentsply Sirona Implants, Mölndal, Sweden).

2.5 | Preparing and planning phase

Eligible patients received a complete anamnestic and clinical examination; hopeless teeth were extracted; caries and periodontal lesions on the remaining teeth were treated. The prosthetic project was accurately planned on cast models mounted in an articulator. When possible, the previous denture was used as a reference.

2.6 | Randomization and allocation concealment

The randomization and the allocation concealment were carried out using sealed opaque envelopes created following a computer-generated randomization list by a person not otherwise involved in the study (C.N.). Such envelopes were consecutively opened at the leading center and communicated to the surgeon at the moment of the first surgery.

2.7 | First surgical step

Surgeries were performed by expert clinicians (one per center: L.G., U.E., P.T.). Surgical protocol was shared among all three centers. The implant positioning was carried out with the help of a computer-aided bone-supported surgical guide (Simplant, Dentsply Sirona Implants, Mölndal, Sweden). All patients were treated under local anesthesia using mepivacaine or articaine with adrenaline 1:100,000. A full-arch crestal incision, with distal releasing incisions if needed, was performed and full thickness flaps were raised. The mental nerves were visualized and isolated, five parallel implant sites were prepared by calibrated burs and five 4-mm wide implants (OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants) were installed anterior to the mental foramens following the outline described by the

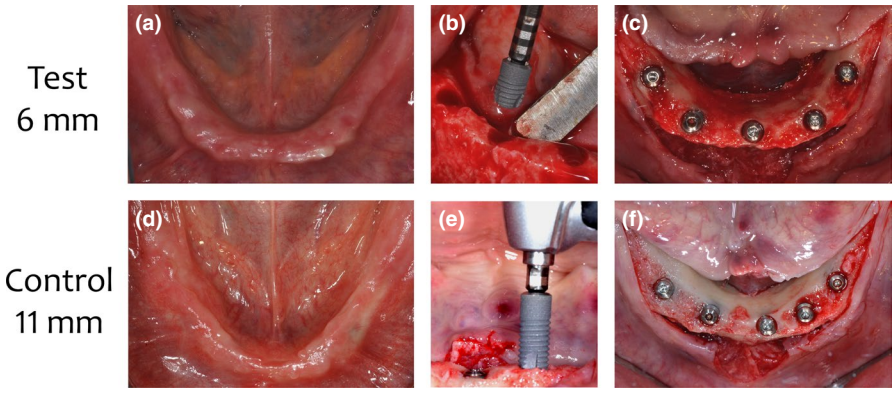

FIGURE 2 Example clinical images of the first surgical stage. Edentulous arch (a and d), test (6 mm), and control (11 mm) implants (b and e), and the five implants positioned (c and f), in the test (6 mm-length implants), and control (11 mm-length implants) group, respectively

manufacturer. In the test group, 5 short (6 mm length) implants were placed, while in the control group 5 long (11 mm length) implants were used. A minimum of 3 mm of inter-implant distance and 1 mm of bone at the buccal and lingual aspects were required, with no need for augmentation procedures (if augmentation was required, the patient would have been excluded from the study). If needed, an osteoplasty of the alveolar ridge was done by means of a carbide-cutting bur mounted on a straight surgical handpiece. The implant head was placed flash to the bone (Figure 2). At the end of the surgical procedure cover screws were positioned and a careful adaption of the flaps by means of an accurate suture was assured in order to obtain primary closure and full periosteal coverage.

2.8 | Postoperative care

The patients were instructed to rinse with a chlorhexidine 0.12% mouthwash twice a day for 2 weeks and to avoid using the denture. Liquid and semisolid food was prescribed for the first postoperative week, after which the sutures were removed. Two weeks after the surgery, the denture was properly relined avoiding direct contact with the fixture until the second-stage surgery. Patients were controlled at 4, 8, and 12 weeks.

2.9 | Second surgical phase and prosthetic procedures

After 3 months of healing all implants were exposed by separated linear incisions, cover screws were removed and replaced by healing abutments. After 1 week, the final abutment (Uni-abutment, Astra Tech Implant System, Dentsply Sirona Implants, Mölndal, Sweden) was screwed on each implant and an abutment-level impression was registered. Expert clinicians (M.A., M.S., and P.T.) followed all the prosthetic phases. All patients received a fixed screw-retained full-arch prosthesis with distal cantilevers (Figure 3a,d). It consisted of a cobalt-chrome framework, fabricated according to the Cresco method (Dentsply Sirona Implants, Mölndal, Sweden) covered by an acrylic veneer. The length of the bridge cantilevers was duly calculated to minimize implant overloading (Mericske-Stern, Taylor, & Belser, 2000). All prosthetic procedures were made according to the Astra Tech Implant System procedures and products manuals.

2.10 | Supportive peri-implant therapy

Patients were instructed in proper hygiene measures, suitably designed on individual needs, including tooth brushing, interdental brushing, flossing, and rinses with a chlorhexidine 0.12% mouthwash. Patients were recalled every 6 months for professional supragingival infection control, including ultrasonic debridement and polishing.

2.11 | Postoperative examinations

Radiographs and clinical examinations of the restored segments were performed at baseline (permanent restoration placement), and after 1 and 3 years of loading. Marginal bone level change (primary outcome), implant survival rate, prosthesis survival rate, and biological/technical complications (secondary outcomes) were registered.

For MBLc measurements, peri-apical radiographs were taken at the baseline (Figure 3b,e) and after 1 and 3 years (Figure 3c,f) of loading. Radiographs were taken with an X-ray apparatus supplied with a long cone and digital radiograms. At all examinations, a Rinn Universal Collimator (Dentsply RINN, York, PA, USA) to limit exposure levels and Rinn film holders (XPC Extension Cone Paralleling System, Dentsply RINN, York, PA, USA) for accurate positioning were used. Film-holder's position was noted down for each implant site to increase reproducibility. The level of the marginal bone at implants was determined using a software program (ImageJ 1.48a, National Institutes of Health, Bethesda, MD, USA). The distance between consecutive threads was used for the calibration of MBL measurements. Reference points for the radiographic measurements were the top of the microthread implant region and the most coronal level of the bone-to-implant contact. MBL was measured at the mesial and distal aspect of each fixture and a mean value was calculated at the implant level, patient level, and group level. The MBLc from the baseline was expressed as negative numbers in cases of bone loss. All the radiographic measurements were performed by one experienced examiner (A.P.) not otherwise involved in the study, who was blinded to the group allocation since all radiograms were duly masked so that the implant length could not be identified.

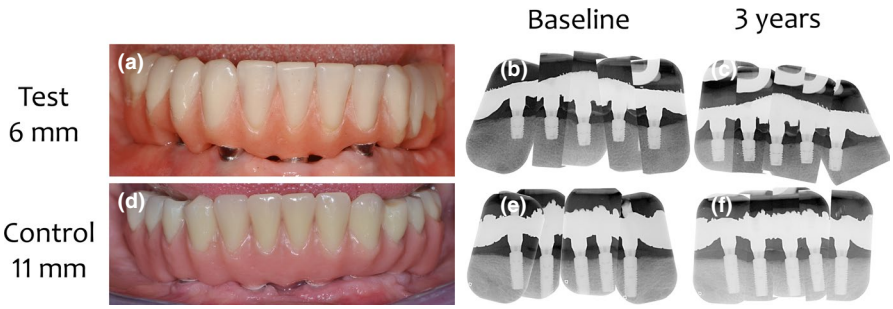

FIGURE 3 Example clinical images (a and d) of the full-arch cantilever bridge and peri-apical radiographs at the baseline (b and e) and at the 3-year follow-up (c and f) of the test (6 mm-length implants) and control (11 mm-length implants) group

TABLE 1 Baseline patient characteristics

	Test	Control	Total	*p*
Number of patients (implants)	15 (75)	15 (75)	30 (150)	1.00
Center 1	5 (25)	3 (15)	8 (40)	.68
Center 2	5 (25)	5 (25)	10 (50)	1.00
Center 3	5 (25)	7 (35)	12 (60)	.71
Mean Age (*SD*)	63 (6.3)	61 (8.6)	63 (7.5)	.31
Gender (Male:Female)	5:10	12:3	17:13	**.02**
Smoking habit				
Heavy smokers (≥10 sig./day)	3	4	7	1.00
Light smokers (<10 sig./day)	0	0	0	1.00
Nonsmokers	10	9	19	1.00
Former smokers	2	2	4	1.00

Note: p = Mann–Whitney *U* test or Fisher exact test *p*-value.
Alpha level = 0.05 (significant values in bold).

Early or late (before and after prosthetic loading, respectively) implant losses were registered, as well as any other biological or technical complications which occurred during the study period.

2.12 | Statistical analysis

Descriptive statistics (means, standard deviations [SDs], medians, and inter-quartile ranges [IQRs]) of continuous variables and relative frequencies of discrete variables were computed for each group separately using a statistical software program (OpenStat, http://openstat.info). Data were analyzed by an examiner (M.A.) blinded to the experimental groups using both patient and implant as the statistical unit. Intention-to-treat (ITT) analysis and the Fisher exact test were applied to evaluate differences of discrete variables between the groups; the one-sided Mann–Whitney *U* test was applied for differences of MBL values due to the not normal distribution of data. For primary outcome, statistical significance was set at the alpha level of 0.025 using a one-sided test, while for two-sided tests statistical significance was set at the alpha level of 0.05.

3 | RESULTS

Thirty patients were enrolled from July 2011 to July 2015, and allocated 15 to the test and 15 to the control group. The demographic characteristics of the enrolled patients are listed in Table 1. More female patients were enrolled in the test group ($p = .02$, Fisher exact test), no inter-group differences at the baseline for any other of the considered variables were found.

A total of 150 implants (5 per patient, 75 per group) were inserted. All patients were re-evaluated at 1 and 3 years of follow-up, from December 2012 (the first 1-year follow-up visit) to March 2019 (the last 3-year follow-up visit). Between the 1- and 3-year follow-up, one patient (control) did not attend control visits and another one (test) died, so that 14 test patients and 14 control patients were able to be evaluated at the 3-year follow-up. No implant or prosthesis failure was registered (100% survival rate in both the test and control group). In one patient (control), there was a wound dehiscence within the first 2 weeks of healing and the placement of healing screws on three exposed implants was anticipated. In two patients (one test and one control), two implants per patient suffered, during the first year of function, from peri-implant mucositis, resolved by professional cleaning and 1% chlorehexidine gel application every week for 1 month. No other biological complications that required additional chair-time were observed. In three patients (test), a fracture of the acrylic veneer was registered and repaired. Three cantilever fractures happened in two control patients (after 2 years of function) and one test patient (after 1 year of function) and were repaired by laser welding after prosthesis removal. Two of them had natural teeth and one had a removable denture at the opposite arch. No other complications that might require chair-time were observed. No significant inter-group difference for any of the registered complications was found (Fisher exact test).

No statistically significant difference ($p > .025$) in terms of MBLc between baseline and 1- and 3-year follow-up visits in both groups, as well as between test and control group at all follow-up visits was observed (Table 2). The 1-year MBLc mean ± *SD* values were 0.01 ± 0.19 mm for the test group and −0.04 ± 0.21 mm for the control group. The 3-year MBLc mean ± *SD* values were −0.10 ± 0.24 mm for the test group and 0.02 ± 0.25 mm for the control group. Figure 4 shows box-plots reporting median MBLc values (minimum, first quartile, third quartile, maximum) for the test group

TABLE 2 Marginal bone level values and changes at 1 year and 3 years of follow-up

	N	Baseline	*N*	1 year	Δ 0–1	*p*	*N*	3 years	Δ 0–3	*P*
Test	15	0.26 ± 0.23	15	0.27 ± 0.29	**0.01 ± 0.19**	.755	14	0.36 ± 0.35	**−0.10 ± 0.24**	.471
Control	15	0.31 ± 0.30	15	0.28 ± 0.31	**−0.04 ± 0.21**	.647	14	0.25 ± 0.19	**0.02 ± 0.25**	.810
p		.803		.724	.494			.565	.270	

Note: Alpha level = 0.025. There are no significant *p*-values.
Data expressed in millimeters as mean ± standard deviation (patient level). Statistical difference calculated by Mann–Whitney *U* test.
N: number of patients; *p*: Mann–Whitney *U* test *p*-value; Δ 0–1: marginal bone level change between baseline (prosthetic installation) and 1-year follow-up; Δ 0–3: marginal bone level change between baseline (prosthetic installation) and 3-year follow-up.

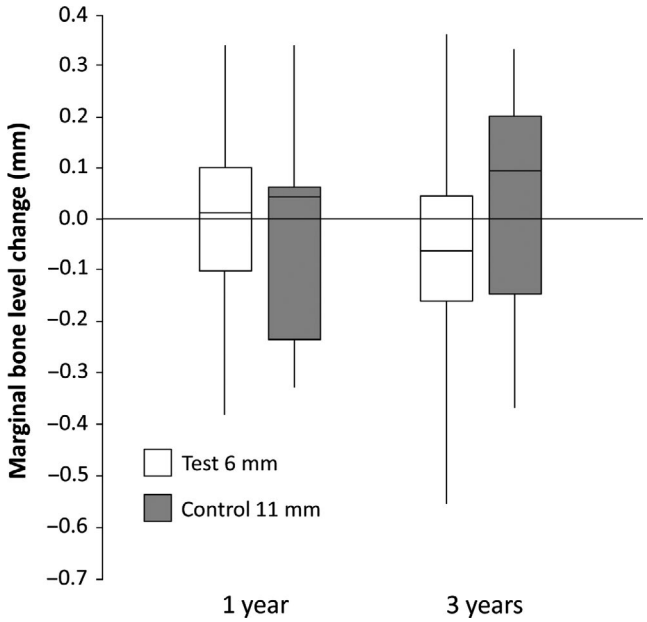

FIGURE 4 Box Plot of the 1- and 3-year values of marginal bone level change of the test (6 mm-length implants) and control (11 mm-length implants) group reporting minimum, first quartile, median, third quartile, and maximum values (patient level)

and for the control group at 1 and 3 years. All the results were reported at patient level, however the same trend was observed also at implant level. There were no significant correlations between MBLc and any of the patients' demographic variables (center, age, gender, and smoking habit) at any time point when each arm was analyzed separately and when data from both arms were pooled together.

4 | DISCUSSION

This study compared two groups of patients: one group (test) receiving a full-arch mandibular-fixed prosthesis with distal cantilevers supported by 5 short (6 mm) implants positioned in the inter-foraminal region, and another group (control) receiving the same type of prosthetic rehabilitation supported by 5 long (11 mm) implants. Due to the randomized nature of the study, all enrolled patients had mandibles able to host five inter-foraminal 11-mm-long and 4-mm-wide implants, with at least 1 mm of peri-implant bone circumferentially, without requiring augmentation procedures. Such restrictive inclusion criteria represent the main reason for the prolonged enrolment phase experienced in this study. All implants were positioned in native healed bone and left submerged for 3 months. Afterward, they were exposed and connected to the final prosthesis. After 3 years of follow-up, we found excellent clinical and radiographic conditions in both groups and no inter-group differences in terms of marginal bone level change, implant/prosthetic survival rate, and complications.

The placement of both short and longer implants in non-atrophic sites avoiding any augmentation procedure represents a specific characteristic of our protocol. The majority of published studies, indeed, have only considered short implants in conditions of atrophic bone compared with longer implants in augmented sites (Palacios et al., 2018; Tong et al., 2017; Toti et al., 2017). Only a few other studies have compared short and long implants both positioned in non-atrophic sites. Most of them focused on partial edentulism in the posterior segment of the jaws rehabilitated by single crowns or 2–3 splinted crowns (Gulje et al., 2013; Esposito et al., 2015; Romeo, Storelli, Casano, Scanferla, & Botticelli, 2014; Felice et al., 2016; Rossi et al., 2016; Storelli, Abbà, Scanferla, Botticelli, & Romeo, 2018). Only one study (Cannizzaro et al., 2015) focused on total edentulism rehabilitated by full-arch prostheses. In this latter work, 4 inter-foraminal implants were placed and immediately loaded, although several deviations from the original protocol were reported (e.g., implants placed distally to the mental foramina, post-extraction implants, and implants with different diameters).

Our study is the first, at the best of our knowledge, that compares short versus long implants for the rehabilitation of total edentulism in fully comparable clinical conditions, from both an anatomical and prosthetic point of view. In both test and control patients, indeed, five implants were positioned in the inter-foraminal area of edentulous mandibles, with a type IV surgical timing (Chen, Wilson, & Hammerle, 2004; Hammerle, Chen, & Wilson, 2004) and with a conventional loading (Weber et al., 2009), supporting a full-arch bridge with distal cantilevers. Our choice fell on such a prudential surgical/prosthetic protocol, in consideration of its long-lasting validation in the literature among all the types of implant-supported rehabilitations (Adell et al., 1981; Brånemark et al., 1977; Bryant, MacDonald-Jankowski, & Kim, 2007; Ekelund et al., 2003).

In the present study, no implant had been lost at the 3-year observation period. Lower implant survival rates, especially at higher

follow-up, have been reported in the recent literature in those studies where a similar comparative protocol was used (short and long implants placed in non-atrophic sites). In particular, 1-year implant survival rates for short implants ranged from 90.1% (Romeo et al., 2014) to 93.3% (Cannizzaro et al., 2015), 96.7% (Rossi et al., 2016), 97% (Gulje et al., 2013), and 97.6% (Felice et al., 2016). 5-year values ranged from 86.7% (Rossi et al., 2016) to 90.1% (Romeo et al., 2014). In all these studies, higher implant survival rates for the long implant group were reported.

In all these studies, implant failures in the group of short implants were reported as early, before, or immediately after loading and occurred when short implants were inserted in low-quality bone and/or with low insertion torque values or (e.g., Felice et al., 2016) with an immediate post-extraction protocol. In the present study, the insertion torque was not systematically measured, but all implants were placed in non-augmented sites in the inter-foraminal area, which is usually characterized by high bone quality, and the primary stability was always obtained.

In this study, the marginal bone level change registered after 3 years of prosthetic loading in the test and control groups was very limited, in line with the most recent literature data on this specific implant system (Laurell & Lundgren, 2011).

Our findings also fit well with the results reported by other similar studies in terms of MBLc.

In particular, 1-year MBLc for short implants ranged from −0.06 ± 0.27 mm (Gulje et al., 2013) to −0.08 ± 0.03 mm (Cannizzaro et al., 2015), −0.13 mm (Rossi et al., 2016), −0.18 mm (Romeo et al. 2014), and −0.3 mm (Felice et al., 2016). The 3-year value was −0.18 mm in the study of Rossi et al. (2016. The 5-year MBLc value in the study of Romeo et al. (2014) was −0.49 mm. In all these studies, MBLc values were comparable between short and long implants. Only in the study of Cannizzaro et al. (2015), MBLc was significantly less pronounced in the short implant group with a mean inter-group difference of 0.44 mm ± 0.11. As noted above, any comparison between these studies is very difficult in consideration of the significant differences in the study protocol.

The clinical and radiographic outcomes from the present study demonstrate that short implants are a reliable option after one and 3 years of loading and are comparable to those of longer (11 mm) implants for the rehabilitation of total mandibular edentulism, in a completely comparable clinical situation, from both an anatomical and prosthetic point of view. The benefits of using short implants, instead of long implants associated with bone augmentation procedures, are evident and include the use of a simple and minimally invasive surgical procedure, with a reduced risk of damaging anatomical structures, as well as the reduction of treatment time, costs, and patient discomfort. All these aspects contribute to enlarge the number of subjects in need of a prosthetic dental rehabilitation willing to undergo implant therapy. Furthermore, the potential use of short implants also in sites able to host longer fixtures, as described in our study, might offer adjunctive benefits also compared to their standard use in atrophic sites. Such a rehabilitative approach, indeed, does not imply the aesthetic, technical, and biological drawbacks commonly described in the case of increased inter-arch distance and increased crown-to-implant ratio. Furthermore, in the case of severe complications requiring fixture removal, short implants would require a simplified removal procedure, minimizing bone loss and would simplify the possible use of the same site for a new implant rehabilitation.

Different factors may have contributed to the satisfactory clinical performance of short implants, as observed in the present study.

First of all, the use of a modified implant surface must be considered. The role of moderately rough surfaces compared with smooth ones in promoting osseointegration has been widely demonstrated (for a review see Lang & Jepsen, 2009; Wennerberg & Albrektsson, 2009). In particular, the positive effect of rough surfaces on the prognosis of short implants has been pointed out in several papers (for a review see Nisand & Renouard, 2014) where the increasing performance of short implants observed in recent years has been correlated to the extensive worldwide diffusion of roughened implants with respect to the smooth machine surfaces used in the past.

Other factors have probably played a central role in determining the favorable results of this study limiting, however, the applicability of our findings to other clinical conditions as well. Among these factors, implant location, that is inter-foraminal mandibular area and related bone quality, must be cited. Higher survival rates, indeed, are usually reported using short implants in the mandible instead of the maxilla (Pommer et al., 2011; Srinivasan et al., 2014). A lower bone quality is usually present in the maxilla, and this aspect may impose caution in using such a type of implant in these areas (ten Bruggenkate, Asikainen, Foitzik, Krekeler, & Sutter, 1998; Nisand & Renouard, 2014; Renouard & Nisand, 2006).

The strict respect of the scheduled visits for supportive peri-implant therapy must be also underlined, probably playing a detrimental role in the low rate of biological complications registered (Mombelli, 2019).

Biomechanical factors should also be considered to correctly interpret the results obtained. Despite the presence of distal cantilevers proper of the prosthetic design adopted in the present study, the splinting of 5 inter-foraminal implants probably played a protective role in preventing possible complications. Splinting of implants, indeed, has been recommended to more uniformly distribute forces among implants under loading (Guichet, Yoshinobu, & Caputo, 2002; Ravidà, Barootchi, et al., 2019), but there is no consensus in the literature on this aspect. There are studies, for instance, which failed to find a difference between splinted and non-splinted implants in terms of marginal bone level change (e.g., Guarnieri, Nardo, Gaimari, Miccoli, & Testarelli, 2019; Vigolo & Zaccaria, 2010) or they even found a gain in marginal bone level for non-splinted implants (Clelland, Chaudhry, Rashid, & McGlumphy, 2016).

Among the possible limitations of the present study, the absence of standardized radiographs must be cited. Although care was taken to correctly position the film-holder and the x-ray tube, inaccuracies in the radiographic measurements cannot be

excluded and this aspect must be considered in data reading and interpreting.

The short follow-up (3-year) must be considered another limit of this study, although all patients will be followed over time and longer follow-up data will be available thereafter.

In conclusion, it has been shown that short (6 mm) implants may be a reliable option when used in the rehabilitation of a total edentulous mandible, with clinical and radiographic outcomes, up to 3 years of loading, comparable to those of long implants (11 mm). Although further data with a longer follow-up and a larger sample size from well-designed RCT are needed to provide clear evidence and sound clinical recommendations, these preliminary results support a very promising hypothesis of a standard and routine use of short implants, even in the case of non-atrophic sites. Therefore, it supports the concept of a minimally invasive, low-stress, simplified implant therapy, with absolute benefits for both patients and clinicians.

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CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

Guida, L: principal investigator; conceived the idea; contributed to conception and design; coordinated the research; performed implant surgery; contributed to data interpretation; drafted the manuscript, gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy. Annunziata M: contributed to conception and design; performed prosthesis treatment; contributed to data acquisition, analysis and interpretation; drafted the manuscript, gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy. Esposito, U: performed implant surgery; contributed to data interpretation; critically revised the manuscript; gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy. Sirignano M: performed prosthesis treatment; contributed to data acquisition and interpretation; critically revised the manuscript, gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy. Torrisi P: performed implant surgery and prosthesis treatment; contributed to data acquisition and interpretation; critically revised the manuscript; gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy. Cecchinato D: supervised the research; contributed to conception and design; contributed to data interpretation; critically revised the manuscript; gave final approval; and agreed to be accountable for all aspects of work ensuring integrity and accuracy.

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REFERENCES

Adell, R., Lekholm, U., Rockler, B., & Brånemark, P. I. (1981). A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *International Journal of Oral Surgery*, *10*, 387–416. https://doi.org/10.1016/S0300-9785(81)80077-4

Bahat, O. (1993). Treatment planning and placement of implants in the posterior maxillae: Report of 732 consecutive Nobelpharma implants. *International Journal of Oral and Maxillofacial Implants*, *8*(2), 151–161.

Brånemark, P. I., Hansson, B. O., Adell, R., Breine, U., Lindström, J., Hallén, O., & Ohman, A. (1977). Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scandinavian Journal of Plastic and Reconstructive Surgery. Supplementum*, *16*, 1–132.

Bryant, S. R., MacDonald-Jankowski, D., & Kim, K. (2007). Does the type of implant prosthesis affect outcomes for the completely edentulous arch? *International Journal of Oral and Maxillofacial Implants*, *22*(Suppl), 117–139.

Camps-Font, O., Burgueño-Barris, G., Figueiredo, R., Jung, R. E., Gay-Escoda, C., & Valmaseda-Castellón, E.. (2016). Interventions for dental implant placement in atrophic edentulous mandibles: Vertical bone augmentation and alternative treatments. A Meta-Analysis of Randomized Clinical Trials. *Journal of Periodontology*. *87*(12), 1444–1457.

Cannizzaro, G., Felice, P., Buti, J., Leone, M., Ferri, V., & Esposito, M. (2015). Immediate loading of fixed cross- arch prostheses supported by flapless- placed supershort or long implants: 1- year results from a randomised controlled trial. *European Journal of Oral Implantology*, *8*, 27–36.

Chen, S. T., Wilson, T. G. Jr, & Hammerle, C. H. (2004). Immediate or early placement of implants following tooth extraction: Review of biologic basis, clinical procedures, and outcomes. *The International Journal of Oral & Maxillofacial Implants*, *19*, 12–25.

Clelland, N., Chaudhry, J., Rashid, R. G., & McGlumphy, E. (2016). Split-mouth comparison of splinted and nonsplinted prostheses on short implants: 3-year results. *The International Journal of Oral and Maxillofacial Implants*, *31*(5), 1135–1141. https://doi.org/10.11607/jomi.4565

Ekelund, J. A., Lindquist, L. W., Carlsson, G. E., & Jemt, T. (2003). Implant treatment in the edentulous mandible: A prospective study on Brånemark system implants over more than 20 years. *International Journal of Prosthodontics*, *16*, 602–608.

Esposito, M., Barausse, C., Pistilli, R., Checchi, V., Diazzi, M., Gatto, M. R., & Felice, P. (2015). Posterior jaws rehabilitated with partial prostheses supported by 4.0×4.0 mm or by longer implants: Four-month

post-loading data from a randomised controlled trial. *European Journal of Oral Implantology*, *8*(3), 221–230.

Esposito, M., Grusovin, M. G., Rees, J., Karasopoulos, D., Felice, P., Alissa, R., … Coulthard, P. (2010). Interventions for replacing missing teeth: Augmentation procedures of the maxillary sinus. *Cochrane Database of Systematic Reviews*, *3*, CD008397.

Fan, T., Li, Y., Deng, W. W., Wu, T., & Zhang, W. (2017). Short implants (5 to 8 mm) versus longer implants (>8 mm) with sinus lifting in atrophic posterior maxilla: A meta-analysis of RCTs. *Clinical Implant Dentistry and Related Research*, *19*, 207–215. https://doi.org/10.1111/cid.12432

Felice, P., Checchi, L., Barausse, C., Pistilli, R., Sammartino, G., Masi, I., … Esposito, M. (2016). Posterior jaws rehabilitated with partial prostheses supported by 4.0 x 4.0 mm or by longer implants: One-year post-loading results from a multicenter randomised controlled trial. *European Journal of Oral Implantogyl*. *9*(1), 35–45.

Guarnieri, R., Di Nardo, D., Gaimari, G., Miccoli, G., & Testarelli, L. (2019). Short vs. standard laser-microgrooved implants supporting single and splinted crowns: A prospective study with 3 years follow-up. *Journal of Prosthodontics*, *28*, e771–e779. https://doi.org/10.1111/jopr.12959

Guichet, D. L., Yoshinobu, D., & Caputo, A. A. (2002). Effect of splinting and interproximal contact tightness on load transfer by implant restorations. *Journal of Prosthetic Dentistry*, *5*, 528–535. https://doi.org/10.1067/mpr.2002.124589

Gulje, F., Abrahamsson, I., Chen, S., Stanford, C., Zadeh, H., & Palmer, R. (2013). Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible: A 1-year multicenter randomized controlled trial. *Clinical Oral Implants Research*, *24*, 1325–1331. https://doi.org/10.1111/clr.12001

Hammerle, C. H., Chen, S. T., & Wilson, T. G. (2004). Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. *The International Journal of Oral and Maxillofacial Implants*, *19*(Suppl.), 26–28.

Heitz-Mayfield, L. J., Needleman, I., Salvi, G. E., & Pjetursson, B. E. (2014). Consensus statements and clinical recommendations for prevention and management of biologic and technical implant complications. *The International Journal of Oral and Maxillofacial Implants*, *29*(Suppl), 346–350. https://doi.org/10.11607/jomi.2013.g5

Jung, R. E., Al-Nawas, B., Araujo, M., Avila-Ortiz, G., Barter, S., Brodala, N., … Windisch, P. (2018). Group 1 ITI Consensus Report: The influence of implant length and design and medications on clinical and patient-reported outcomes. *Clinical Oral Implants Research*, *16*, 69–77. https://doi.org/10.1111/clr.13342

Lang, N. P., & Jepsen, S. (2009). Implant surfaces and design (Working Group 4). *Clinical Oral Implants Research*, *20*(Suppl. 4), 228–231. https://doi.org/10.1111/j.1600-0501.2009.01771.x

Laurell, L., & Lundgren, D. (2011). Marginal bone level changes at dental implants after 5 years in function: A meta-analysis. *Clinical Implant Dentistry and Related Research*, *13*(1), 19–28. https://doi.org/10.1111/j.1708-8208.2009.00182.x

Lemos, C. A., Ferro-Alves, M. L., Okamoto, R., Mendonça, M. R., & Pellizzer, E. P. (2016). Short dental implants versus standard dental implants placed in the posterior jaws: A systematic review and meta-analysis. *Journal of Dentistry*, *47*, 8–17. https://doi.org/10.1016/j.jdent.2016.01.005

Mericske-Stern, R. D., Taylor, T. D., & Belser, U. (2000). Management of the edentulous patient. *Clinical Oral Implants Research*, *11*(Suppl 1), 108–125. https://doi.org/10.1034/j.1600-0501.2000.011S1108.x

Mombelli, A. (2019). Maintenance therapy for teeth and implants. *Periodontology 2000*, *79*(1), 190–199. https://doi.org/10.1111/prd.12255

Monje, A., Suarez, F., Galindo-Moreno, P., García-Nogales, A., Fu, J. H., & Wang, H. L. (2014). A systematic review on marginal bone loss around short dental implants (<10 mm) for implant-supported fixed prostheses. *Clinical Oral Implants Research*, *25*(10), 1119–1924. https://doi.org/10.1111/clr.12236

Nisand, D., & Renouard, F. (2014). Short implant in limited bone volume. *Periodontology 2000*, *66*(1), 72–96. https://doi.org/10.1111/prd.12053

Palacios, J. A. V., Garcia, J. J., Caramês, J. M. M., Quirynen, M., & da Silva Marques, D. N. (2018). Short implants versus bone grafting and standard-length implants placement: A systematic review. *Clinical Oral Investigation*, *22*(1), 69–80. https://doi.org/10.1007/s00784-017-2205-0

Papaspyridakos, P., De Souza, A., Vazouras, K., Gholami, H., Pagni, S., & Weber, H. P. (2018). Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: A meta-analysis. *Clinical Oral Implants Research*, *29*(Suppl 16), 8–20. https://doi.org/10.1111/clr.13289

Pommer, B., Frantal, S., Willer, J., Posch, M., Watzek, G., & Tepper, G. (2011). Impact of dental implant length on early failure rates: A meta-analysis of observational studies. *Journal of Clinical Periodontology*, *38*, 856–863. https://doi.org/10.1111/j.1600-051X.2011.01750.x

Ravidà, A., Barootchi, S., Askar, H., Suárez-López del Amo, F., Tavelli, L., & Wang, H.-L. (2019). Long-term effectiveness of extra-short (≤ 6 mm) dental implants: A systematic review. *The International Journal of Oral and Maxillofacial Implants*, *34*, 68–84. https://doi.org/10.11607/jomi.6893

Ravidà, A., Wang, I. C., Barootchi, S., Askar, H., Tavelli, L., Gargallo-Albiol, J., & Wang, H. L. (2019). Meta-analysis of randomized clinical trials comparing clinical and patient-reported outcomes between extra-short (≤6 mm) and longer (≥10 mm) implants. *Journal of Clinical Periodontology*. *46*(1), 118–142. https://doi.org/10.1111/jcpe.13026

Renouard, F., & Nisand, D. (2006). Impact of implant length and diameter on survival rates. *Clinical Oral Implants Research*, *17*(Suppl. 2), 35–51. https://doi.org/10.1111/j.1600-0501.2006.01349.x

Renvert, S., Persson, G. R., Pirih, F. Q., & Camargo, P. M. (2018). Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. *Journal of Clinical Periodontology*, *45*(Suppl 20), S278–S285. https://doi.org/10.1111/jcpe.12956

Romeo, E., Storelli, S., Casano, G., Scanferla, M., & Botticelli, D. (2014). Six-mm versus 10-mm long implants in the rehabilitation of posterior edentulous jaws: A 5-year follow-up of a randomised controlled trial. *European Journal of Oral Implantology*, *7*(4), 371–381.

Rossi, F., Botticelli, D., Cesaretti, G., De Santis, E., Storelli, S., & Lang, N. P. (2016). Use of short implants (6 mm) in a single-tooth replacement: a 5-year follow-up prospective randomized controlled multicenter clinical study. *Clinical Oral Implants Research*, *27*, 458–464. https://doi.org/10.1111/clr.12564

Sierra-Sánchez, J. L., García-Sala-Bonmatí, F., Martínez-González, A., García-Dalmau, C., Mañes-Ferrer, J. F., & Brotons-Oliver, A. (2016). Predictability of short implants (<10 mm) as a treatment option for the rehabilitation of atrophic maxillae. A systematic review. *Medicina Oral, Patologia Oral Y Cirugia Bucal*, *21*(3), e392–402.

Srinivasan, M., Vazquez, L., Rieder, P., Moraguez, O., Bernard, J. P., & Belser, U. C. (2014). Survival rates of short (6 mm) micro-rough surface implants: A review of literature and meta-analysis. *Clinical Oral Implants Research*, *25*, 539–545. https://doi.org/10.1111/clr.12125

Storelli, S., Abbà, A., Scanferla, M., Botticelli, D., & Romeo, E. (2018). 6 mm vs 10 mm-long implants in the rehabilitation of posterior jaws: A 10-year follow-up of a randomised controlled trial. *European Journal of Oral Implantology*, *11*, 283–292.

Telleman, G., Raghoebar, G. M., Vissink, A., den Hartog, L., Huddleston Slater, J. J., & Meijer, H. J. (2011). A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. *Journal of Clinical Periodontology*, *38*, 667–676. https://doi.org/10.1111/j.1600-051X.2011.01736.x

ten Bruggenkate, C. M., Asikainen, P., Foitzik, C., Krekeler, G., & Sutter, F. (1998). Short (6-mm) nonsubmerged dental implants: Results of a multicenter clinical trial of 1 to 7 years. *The International Journal Oral Maxillofacial Implants*, *13*, 791–798.

Thoma, D. S., Zeltner, M., Hüsler, J., Hämmerle, C. H., & Jung, R. E. (2015) EAO Supplement Working Group 4 - EAO CC 2015 Short implants versus sinus lifting with longer implants to restore the posterior maxilla: a systematic review. *Clinical Oral Implants Research*, *11*(Suppl 11), 154–169. https://doi.org/10.1111/clr.12615

Tong, Q., Zhang, X., & Yu, L. (2017). Meta-analysis of randomized controlled trials comparing clinical outcomes between short implants and long implants with bone augmentation procedure. *International Journal of Oral and Maxillofacial Implants*, *32*, e25–e34. https://doi.org/10.11607/jomi.4793

Toti, P., Marchionni, S., Menchini-Fabris, G. B., Marconcini, S., Covani, U., & Barone, A. (2017). Surgical techniques used in the rehabilitation of partially edentulous patients with atrophic posterior mandibles: A systematic review and meta-analysis of randomized controlled clinical trials. *Journal of Craniomaxillofacial Surgery*. *45*(8), 1236–1245. https://doi.org/10.1016/j.jcms.2017.04.011

Vigolo, P., & Zaccaria, M. (2010). Clinical evaluation of marginal bone level change of multiple adjacent implants restored with splinted and nonsplinted restorations: A 5-year prospective study. *International Journal of Oral and Maxillofacial Implants*, *6*, 1189–1194.

Weber, H. P., Morton, D., Gallucci, G. O., Roccuzzo, M., Cordaro, L., & Grutter, L. (2009). Consensus statements and recommended clinical procedures regarding loading protocols. *Internation Journal and Oral Maxillofacial Implants*, *24*(suppl), 180–183.

Wennerberg, A., & Albrektsson, T. (2009). Effects of titanium surface topography on bone integration: A systematic review. *Clinical Oral Implants Research*, *20*(Suppl 4), 172–184. https://doi.org/10.1111/j.1600-0501.2009.01775.x

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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