

Marginal Bone Stability Around Tapered, Platform-Shifted Implants Placed with an Immediately Loaded Four-Implant–Supported Fixed Prosthetic Concept: A Cohort Study

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Purpose: To longitudinally evaluate marginal bone remodeling around tapered, platform-shifted implants placed for total arch rehabilitation with fixed hybrid prostheses. **Materials and Methods:** A retrospective cohort study was designed that evaluated radiographic data from patients undergoing implant surgical procedures with an immediately loaded four-implant–supported fixed prosthetic concept (All-on-4, Nobel Biocare) in a single clinic setting during a 36-month period. The primary outcome variable was the change in marginal bone levels during a 12- to 36-month follow-up postloading with the definitive prosthesis. All measurements were performed on matched and calibrated periapical radiographs obtained at: (1) the time of placement of the definitive prosthesis (baseline) versus (2) 12 to 36 months following definitive loading (follow-up). Other study variables, including duration of follow-up, implant position, maximum insertion torque, implant angulation, and implant diameter, were assessed for their association with changes in marginal bone levels. **Results:** One hundred sixty-nine patients ($n = 856$ implants) with a mean age of 59.5 ± 10.5 years were included in this study. Two implants failed, resulting in a 99.8% overall survival rate (mean follow-up: 15.2 ± 4.8 months, range: 12 to 36 months). The radiographic mean bone levels at baseline and follow-up were 1.16 ± 0.71 mm ($n = 805$) and 1.31 ± 0.93 mm ($n = 805$), respectively. The mean marginal bone loss from baseline to follow-up was 0.14 ± 0.59 mm ($n = 805$). The duration of follow-up had no effect on the extent of marginal bone loss ($P = .154$). **Conclusion:** Within the limitations of this large-scale retrospective cohort study, it was concluded that the use of tapered, platform-shifted implants for total arch rehabilitation with the use of the All-on-Four protocol yields very favorable radiographic outcomes, at least after a minimum of 12 months in function. *INT J ORAL MAXILLOFAC IMPLANTS* 2016;31:643–650. doi: 10.11607/jomi.4354

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Patients with total edentulism frequently seek implant rehabilitation to regain function, confidence, and esthetics. Multiple studies have shown that

implant-supported fixed restorations have a positive effect on the oral health–related quality of life (QoL) of edentulous patients as compared with conventional dentures.^{1,2} Despite the benefits that fixed full-arch restorations have over conventional dentures, factors such as the need for bone grafting and sinus elevation procedures often hinder the selection of implant-supported restorations by patients due to their invasive nature, treatment time, and associated costs.^{3–6} The immediately loaded four-implant–supported fixed prosthetic concept (All-on-4, Nobel Biocare) was introduced nearly a decade ago in response to these prohibitive patient-related factors that individuals often struggle with prior to implant rehabilitation of the total arch.⁷

This less-invasive and more affordable concept is based on the placement of two straight mesial implants and two tilted distal implants, angled by approximately 30 degrees to overcome sensitive anatomical landmarks and to maximize anterior-posterior spread.^{3,8} Tilted implants in the maxilla are placed in close proximity to the mesial

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walls of the maxillary sinus, without invasion or rupture of the sinus membrane.⁹ In the mandible, the tilted implants are placed 5 mm anterior to the mental foramen bilaterally to avoid neurosensory disturbances. Clinical studies have demonstrated that tilting of implants may be advantageous, with a reduction of cantilever length of approximately 6.5 mm in the mandible and 9.3 mm in the maxilla.^{8,10,11} The core principle of the All-on-4 treatment concept is the rehabilitation of the total arch without the need for bone augmentation utilizing a strategic combination of straight and tilted implants to obtain prosthetic^{12,13} and surgical advantages.¹⁴

Despite the initial reservations of clinicians regarding the survival of implants placed with the All-on-4 concept, survival rates of immediately loaded fixed restorations supported by four implants have been shown to be equivalent to those of conventional implant-supported restorations.^{8,11,15–17} The concept of immediate loading of full-arch implant-supported prostheses is now considered as a viable treatment modality that demonstrates high survival rates of both implants and prostheses.^{17–22} The use of distal implants to reduce the cantilever is a key factor of the All-on-4 concept that contributes to favorable load transmission with a low risk of compressive overloads²³ without increasing stress in the fixed full-arch restorations.²⁴ Clinical and radiographic outcomes that support this concept have been extensively documented using implants with minimal taper.^{8,11,13,14,16,25–29} Recently, a tapered, platform-shifted implant design (NobelActive Implant, Nobel Biocare) has been specifically engineered with a bone-condensing capability to ensure high primary stability in demanding clinical scenarios, such as the All-on-4 concept. Clinical studies have verified the clinical survival of this implant type^{17,30–32}; however, to the authors' knowledge, no study has reported longitudinal radiographic outcomes using this implant design with the All-on-4 concept.

Thus, the aim of this retrospective cohort study was to assess the change in marginal bone levels of tapered, platform-shifted implants placed with the All-on-4 concept utilizing periapical radiographs.

MATERIALS AND METHODS

Study Design

This was a retrospective, single-center study in which patients with at least one fully edentulous arch, or a partially edentulous arch in need of extraction of the remaining compromised teeth, were rehabilitated with the All-on-4 protocol. The primary objective was to assess the change in marginal bone levels of implants placed in this patient cohort during a 36-month period. An independent review board (Independent Review Consulting; Approval no: 12152-02) approved the study protocol.

Data Collection

Dental records of patients who were treated from October 2, 2008 to September 27, 2011 were screened for inclusion. The inclusion criteria for radiographic data collection were:

1. Implants placed with the All-on-4 concept in the maxilla and/or the mandible
2. Periapical baseline radiograph (3 to 4 months after implant placement; time of delivery of definitive implant-supported restoration)
3. Periapical follow-up radiographs (12 to 36 months after implant placement)

The search included implants placed from October 2, 2008 up to and including September 27, 2011. Individual records were excluded if: (1) they only had panoramic radiographs, or (2) they did not have follow-up radiographs.

Treatment Protocol

Prior to surgical treatment, medical and dental history was reviewed, and a cone beam computed tomography scan (CBCT; I-CAT cone beam CT-scan, Imaging Science) was obtained for preoperative assessment. Following treatment plan presentation and patient consent, surgical treatment was scheduled. In the majority of cases, intravenous (conscious) sedation was administered utilizing Fentanyl citrate (Fentanyl, Hospira), Diazepam (Valium, Hospira) as well as nitrous oxide/oxygen inhalation, and local anesthesia was administered (Articaine hydrochloride 4% /epinephrine 1:100,000, Septodont). In limited cases, treatment was performed under general anesthesia.

Individuals followed an antibiotic regimen (Penicillin VK 250 mg, Dispensing Solutions) four times a day, starting two days prior to the surgical procedure in cases where teeth had to be extracted simultaneously. Postoperatively, all patients were prescribed the same antibiotic regimen over a period of 10 days. If patients were allergic to Penicillin, Clindamycin (Clindamycin HCL 150 mg, Dispensing Solutions) was prescribed four times a day. In addition, hydrocodone bitartrate and acetaminophen (7.5 mg/750 mg, Vicodin, Dispensing Solutions) was prescribed as an analgesic along with anti-inflammatory medication, Methylprednisolone, 4 mg dose pack (Medrol, Dispensing Solutions). At the end of the procedure, a long-lasting local anesthetic (Bupivacaine 0.5%/1:200,000, Epinephrine, Bupivacaine-Cook-Waite) was also administered for its analgesic sparing effect.

Implant Placement Protocol

Implants were placed according to the All-on-4 concept. Each individual received two distally tilted implants in

the posterior region followed by two anterior implants in either the maxilla or the mandible. In the maxilla, the tilted implants were positioned just anterior to the maxillary sinus, and in the mandible, the tilted implants were positioned anterior to the mental foramen. Implant placement was assisted by the All-on-4 surgical guide (Nobel Biocare). The guide was placed into a 2-mm osteotomy made at the midline of the mandible and/or maxilla, and the titanium band was contoured so that the occlusal centerline of the opposing arch was followed. The guide allowed for optimal positioning, alignment, parallelism, and inclination of the implants for subsequent anchorage and prosthetic support. Implants were placed at the level of the osseous crest, avoiding countersinking. A manual surgical torque wrench was utilized to assess the final torque of the implant, and the maximum insertion torque was recorded. Localized bone grafting was performed to cover exposed threads and/or other osseous defects associated with extraction sockets, as needed with demineralized allografts. Straight, 17-degree multiunit internal abutments (Nobel Biocare) and 30-degree angulated multiunit internal abutments (Nobel Biocare) were used to achieve relative parallelism of the implants so that a rigid prosthesis would seat in a passive manner. Open-tray multiunit impression copings were placed on the multiunit abutments, and an impression was made with a custom open tray using precision impression material to fabricate a master cast for the provisional restoration (Flexitime, Heraeus Kulzer). Individuals were instructed to avoid brushing and to use warm water rinses for the first postoperative week. A cold or room-temperature soft diet for the first 24 hours following surgery was recommended, followed by a semisolid diet for the next 3 months. Individuals were given antibiotics and analgesics as per standard oral surgical protocol. A CBCT scan was taken immediately postoperatively to verify the implant positions and the prosthetic components.

Restorative Protocol

A provisional denture was prefabricated with heat-cured acrylic resin (Ivoclar High Impact acrylic, Ivoclar Vivadent) prior to the surgical procedure. Immediately following surgery, the denture was modified to the master model in the laboratory. Fabrication was completed using cold curing material (Probase, Ivoclar Vivadent). This provisional all-acrylic prosthesis was seated within 3 to 4 hours of completion of the surgery. The individuals were scheduled for routine follow-up visits after surgery at 1, 2, and 4 weeks, 3 months postoperative, and on a yearly basis thereafter. At the 3-month appointment, fabrication of the definitive prosthesis was initiated and consisted of a milled titanium frame with a wrap-around heat-cured acrylic resin. Periapical digital radiographs were obtained at the 3-month appointment using a

long-cone paralleling technique and obtained thereafter on a yearly basis. The 3-month radiographs were utilized as a baseline to assess the bone levels longitudinally. Implants were assessed for plaque and bleeding on probing and signs of peri-implantitis at the follow-up intervals according to routine clinical practice.

Radiographic Assessment

Radiographic evaluation was conducted by an independent researcher who was not affiliated with the center, the investigators, or the sponsor. Radiographs were digitized in a 640 (H) × 480 (V) pixel matrix image with an 8-bit depth. The digital image was saved as a TIF extension image. The image was then exported to a software program (Photoshop CS4⁺⁺, Adobe systems). The radiographs of each patient were opened in the software, and a reference line was drawn on each image. The density and contrast were then adjusted for optimal visualization of the marginal bone, and the images were saved as TIF extension grayscale files with an 8-bit identification code. Each digitized radiographic image was corrected for magnification in the image to match the true dimensions utilizing the known implant thread distances for internal reference, as previously described.³³ For calibration and measurement, the TIF images were opened in image analysis software (Alice 3D, Perceptive Informatics). Following calibration, the bone levels were measured on the mesial and distal sides of the implant by measuring the distance from the reference line to the first bone-to-implant contact. Marginal bone loss was calculated for each side of the implant (mesial and distal) separately, and the average of mesial and distal values was then calculated for each implant site. The change from baseline to the follow-up was reported as the mean marginal bone loss.

Statistical Analysis

A multilevel approach was employed in all analyses to account for within-patient correlation due to the allocation of multiple implants per patient. For summary statistics, the grand means for demographics, immediate postoperative marginal bone levels, bone levels at follow-up, and differences in marginal bone loss were estimated from the marginal means across patients to account for the nested study design. All summary statistics were reported as mean ± SD. An actuarial life table was used to calculate the cumulative survival rate.³⁴

Repeated measures analysis of variance (ANOVA) was utilized to assess the primary outcome of this study (radiographic change in bone levels between baseline and follow-up). Due to the retrospective design of this study, a post hoc power analysis was performed to determine the effect size of the given sample size at $1 - \beta = 90\%$ to determine the threshold for statistical significance for the primary outcome of this study.

Table 1 Distribution of Implant Length and Diameter

| Implant length (mm) | Diameter | | | Total |
|---------------------|----------|--------|--------|-------|
| | 3.5 mm | 4.3 mm | 5.0 mm | |
| 10.0 | 1 | 1 | 3 | 5 |
| 11.5 | 7 | 11 | 3 | 21 |
| 13.0 | 68 | 69 | 21 | 158 |
| 15.0 | 139 | 339 | 159 | 637 |
| 18.0 | 6 | 11 | 18 | 35 |
| Total | 221 | 431 | 204 | 856 |

Subsequently, a multilevel analysis was performed via linear mixed effects models to assess the relationship between changes in marginal bone levels and various predictors. Predictors such as arch (maxilla versus mandible), implant diameter, site type (extraction versus healed), insertion torque, and implant angulation (tilted versus axial implants) were considered as fixed effects. Individuals were assigned random intercepts due to the multiple implants nested in each individual. Since the range of follow-up varied from 12 to 36 months, a linear mixed model with random individual person intercepts was constructed with the extent of marginal bone loss (bone level at follow-up minus the bone level at baseline) as the dependent variable and time of loading (in months) as the explanatory variable to assess the effect of time of loading on marginal bone remodeling. All analyses were performed at $\alpha = .05$ using R statistical software (R Core Team, 2012) and package lme4.³⁵

RESULTS

Two hundred nine patients with complete records of periapical radiographs underwent implant placement with tapered platform-shifted implants during the study period. During this period, two implants failed in two patients. Implant failure was assessed at the time of definitive impressions (four months postplacement) in both cases, and implants were removed and thus excluded from the radiographic analysis but included in the cumulative survival rate estimation. After excluding patients with failed implants and those who had undergone implant placement for single crowns and fixed partial restorations, 169 individuals (66 women and 103 men) between the ages of 20 and 89 years (mean \pm SD: 59.5 \pm 10.5 years) underwent full-arch rehabilitation using the All-on-4 concept. A total of 214 arches were treated with 45 individuals undergoing rehabilitation in both arches. On an implant level, 484 tapered platform-shifted implants were placed in the maxilla ($n = 121$

Table 2 Cumulative Survival Rates for Implants

| Time period | Implants | Failed | CSR % |
|---------------------------|----------|--------|-------|
| Implant insertion to 3 mo | 856 | 2 | 99.8 |
| 3 to 6 mo | 854 | 0 | 99.8 |
| 6 to 12 mo | 854 | 0 | 99.8 |
| 12 to 24 mo | 443 | 0 | 99.8 |
| 24 to 36 mo | 16 | | |

arches), and 372 were placed in the mandible ($n = 93$ arches). The most frequently chosen lengths were 13.0 or 15.0 mm, and the most frequently chosen diameter was the 4.3-mm-diameter implant (Table 1). The majority of implants were placed in extraction sites ($n = 618$), and the remaining implants were placed in healed sites ($n = 238$). Localized bone grafting to cover exposed implant threads was performed in 463 implants using demineralized bone allograft (Dyna graft; Keystone Dental), while 35 implants underwent grafting with autogenous bone chips. All implants were placed with a single-stage, immediate loading protocol. The majority of the implants achieved optimal primary stability with a recorded maximum insertion torque (MIT) of 70 Ncm ($n = 541$) or 35 to 65 Ncm ($n = 293$), while 22 implants reached good primary implant stability according to the MIT index.³³

Implant and Prosthetic Survival Rates

The overall survival rate was 99.8% for a range of follow-up from a minimum of 12 months to a maximum of 36 months (mean follow-up: 15.2 \pm 4.8 months; Table 2). In total, two anterior implants failed in two different individuals prior to prosthetic delivery. In both patients, mobility was observed, and the implants were removed and replaced successfully. All prostheses successfully survived to follow-up.

Bone Levels

For bone-level assessment, 51 implants were excluded due to incomplete bone-level measurements (missing either a mesial or a distal measurement at one or both of the time points) for a final sample size of 805 implants. Based on this sample size, post hoc power analysis using a paired test of means at $\alpha = .05$ and 90% power revealed that the present study was powered to detect a difference of 0.11 \pm 1 mm as being statistically significant.

The mean marginal bone loss noted from baseline to the follow-up was 0.14 \pm 0.59 mm ($P = .001$). The duration of follow-up had no effect on the degree of

Fig 1 (right) Graphic representation of mean marginal bone loss for all implants at each observation time point. Statistical analysis found no difference in mean marginal bone loss among the different follow-up time points ($P = .154$).

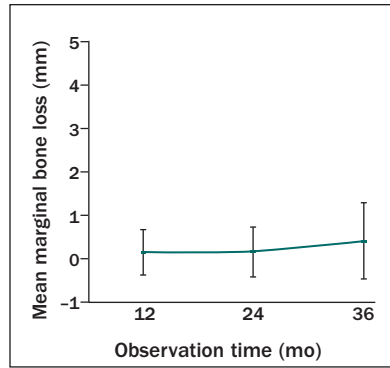


Fig 2 (far right) Change in bone level per arch (mandible or maxilla).

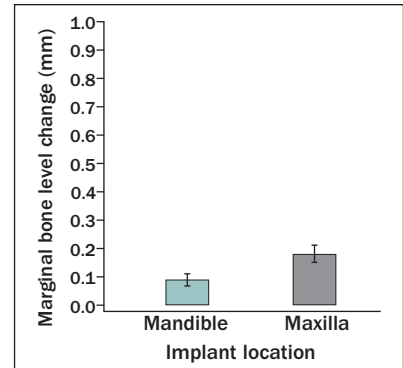


Fig 3 (right) Change in bone level by implant diameter (3.5, 4.3, or 5.0 mm).

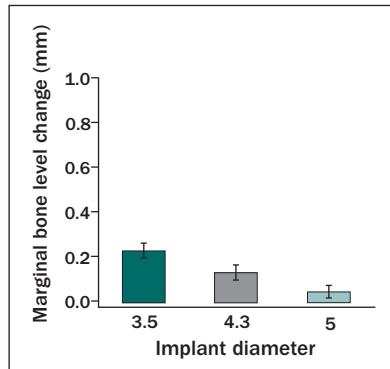


Fig 4 (far right) Change in bone level by extraction or healed site (at time of placement).

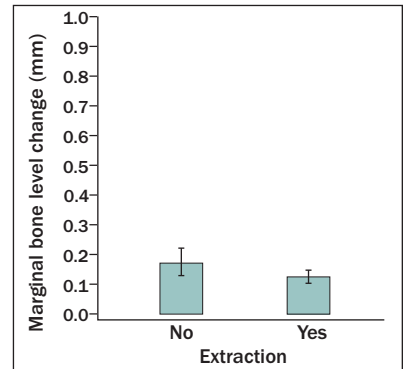


Fig 5 (right) Change in bone level by insertion torque. Note the smoother line for bone-level change that is almost parallel to the x-axis.

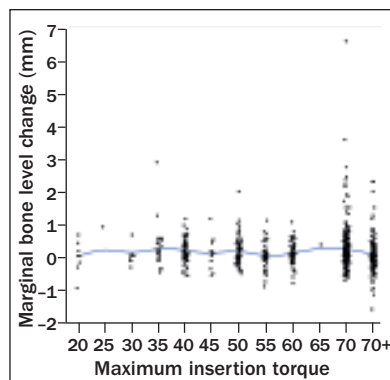


Fig 6 (far right) Change in bone level by angulation (tilted versus axial implants).

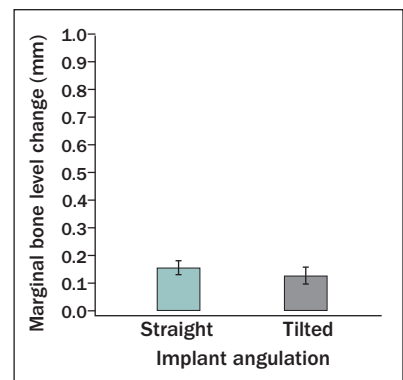
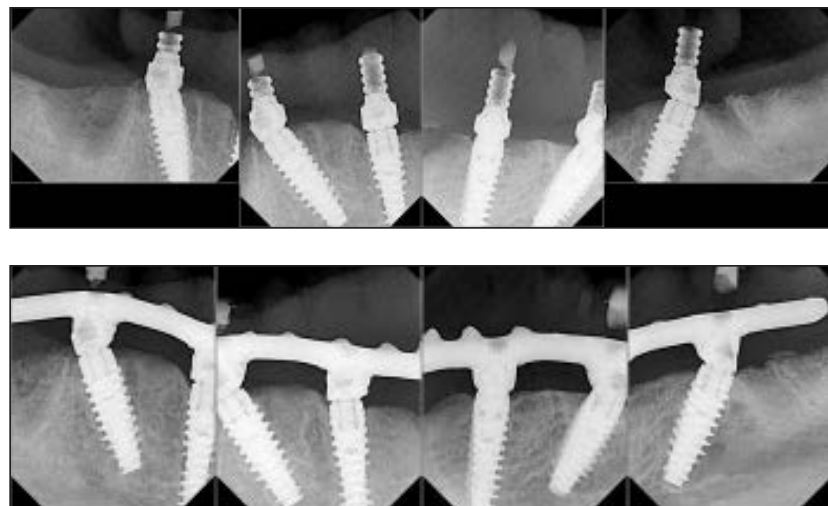


Fig 7 Representative case of mandibular rehabilitation. Periapical radiographs showing excellent bone levels at baseline and after the 12-month follow-up for both straight and tilted implants.



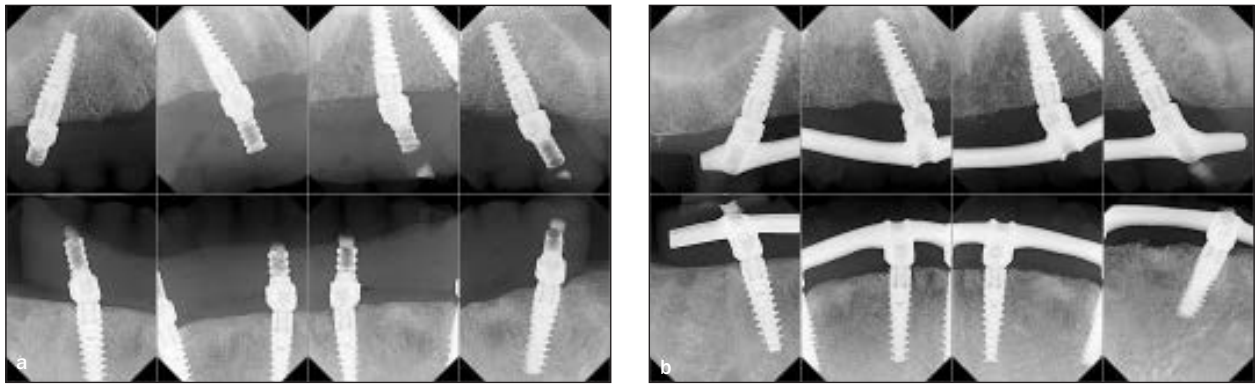


Fig 8 Periapical radiographs from a patient who was treated for complete maxillary and mandibular edentulism showing excellent bone stability at the 30-month follow-up.

marginal bone loss ($P = .154$; Fig 1). The recorded mean marginal bone loss was 0.09 ± 0.38 mm significantly greater in the maxilla than in the mandible ($P = .04$; Fig 2). In terms of implant diameter, the mean change in bone loss was 0.23 ± 0.51 mm for the 3.5-mm-diameter implants, 0.14 ± 0.14 mm for the 4.3-mm-diameter implants, and 0.05 ± 0.39 mm for the 5-mm-diameter implants (Fig 3). No significant effect from the type of site (healed versus extraction sites; $P = .62$), insertion torque ($P = .72$), or tilted versus axial implants ($P = .39$) on mean marginal bone loss was noted (Figs 4 to 6). Two representative cases are shown in Figs 7 and 8.

DISCUSSION

The purpose of this study was to evaluate radiographic outcomes of platform-shifted implants placed with the All-on-4 concept utilizing an immediate loading protocol. The authors found a 0.14-mm loss of marginal bone within the first 12 to 36 months following loading of the full-arch definitive restorations. This difference, although statistically significant due to the large sample size, is far from being clinically significant. Marginal bone stability in the present study is superior to that recorded in previous studies that evaluated slightly tapered implant systems with external connections (Brånemark MkIV and NobelSpeedy groovy, Nobel Biocare) placed using the All-on-4 protocol.^{8,11,14,16,36,37} In a retrospective study with a similar design to the present study, Agliardi et al reported bone-level changes of 0.9 mm in the maxilla and 1.2 mm in the mandible for up to 4 years of follow-up with the use of slightly tapered, external-connection implants placed with the All-on-4 protocol in 173 patients.³⁸ In the same study, the authors did not note a significant difference in marginal bone loss between axial and tilted implants. The

finding of no effect of implant angulation on marginal bone stability is in agreement with the results of the present study that showed no significant change in bone levels between axial and tilted implants ($P = .39$). These findings are in consensus with numerous previous reports that have found immediately loaded tilted implants to be a reliable treatment option in the case of full-arch rehabilitation.^{13,39–41} In a summary of these reports, Del Fabbro and Ceresoli found a range of 0.43 to 1.13 mm for axial implants and 0.34 to 1.14 mm for tilted implants without a significant change in bone level between the two groups.⁴²

A reasonable explanation for the favorable outcomes observed in the present study may be the positive effect of platform-shifting on marginal bone stability.^{43,44} Pozzi et al assessed the differences in marginal bone stability between the platform-shifted implant that was utilized in the present study, as compared to an external-connection tapered implant.⁴⁴ Their study recorded a 0.6-mm significant difference favoring the platform-shifted implant design. Nonetheless, it should be noted that the authors of the present study considered the time of definitive impressions (3 months postloading with the provisional prosthesis) as the baseline. Therefore, the results of the present study exclude the initial bone remodeling that is expected during the first months following exposure of the implants in the oral environment from the bone loss measurements.⁴⁵

The overall survival rate reported in this study was 99.8% with a 100% prosthesis survival rate. Numerous studies have reported comparable survival rates using the All-on-4 concept.^{11,14,16,38,46,47} However, the vast majority of previously published studies utilized slightly tapered implants in comparison to the tapered implant with a self-cutting design and bone-condensing potential that was used in the present study. Only a few

previous publications have reported survival outcomes using the All-on-4 procedure while placing the implant design utilized in the present study.^{17,30,48} Nonetheless, the present study is the first to report longitudinal radiographic outcomes from the use of these implants. Collectively, the excellent radiographic outcomes reported in this study further support the clinical application of the All-on-4 concept, when indicated. The favorable results observed in the present study can be substantiated based on the features of the selected implant type that include: (1) the platform-shift concept of this implant, which has been shown to be conducive to marginal bone level stability⁴⁹; and (2) the bone-condensing properties that ensure adequate maximum insertion torque that contributes to implant success during immediate loading protocols.³²

The presented findings should be viewed under the prism of the limitations posed by the retrospective design of this study, such as potential for selection bias and lack of standardized examinations as compared with a prospective study. Nonetheless, significant effort was made to minimize any bias associated with this study design with (1) the use of a robust method for internal calibration of the periapical radiographs and (2) the use of broad inclusion criteria to enhance the external validity of this study. The significance of the current findings is underlined by the fact that, to the authors' knowledge, this is the first large-scale, pragmatic investigation using periapical radiographs to longitudinally assess bone-level changes around platform-shifted implants placed with the All-on-4 concept.

CONCLUSIONS

Within the limitations of this large-scale retrospective cohort study, the authors concluded that the use of tapered, platform-shifted implants for the rehabilitation of the total arch with the use of the All-on-4 protocol yields very favorable radiographic outcomes, at least after a minimum of 12 months in function.

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