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Computer-Guided Flapless Immediate Function Dental Implants for Full-Arch Rehabilitations Using the All-on-4 Concept: A 12-Year Clinical and 10-Year Radiographic Retrospective Study

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Abstract

Background/Objectives: Implant-supported rehabilitations using the All-on-4 concept represent a viable treatment option for completely edentulous patients. The guided surgery software allows for the performance of a flapless computer-guided surgery with similar results to those achieved through a flap surgery. This study aimed to evaluate the long-term outcomes of complete edentulous implant-supported rehabilitations using an All-on-4 arrangement, following a computer-guided protocol. Methods: A total of 111 patients (68 females, 43 males) with an average age of 60.9 years ± 9.67 years were treated. The primary outcome measures were implant and prosthetic survival. Secondary outcome measures were marginal bone loss (MBL) and the incidence of mechanical and biological complications. Results: Thirty-nine patients were lost to follow-up. Thirty-seven implants and five prostheses failed, rendering a 92.5% implant cumulative survival rate and a 96.2% prosthetic survival rate at 12 years. The average MBL per implant was 1.19 ± 1.16 mm, with 1.26 ± 1.33 mm for axial implants and 1.12 ± 0.95 mm for tilted implants at 10 years. The incidence rate of mechanical complications at the patient level was 90.1% for provisional prostheses and 55.9% for definitive prostheses. The rate of biological complications was 14.3% at the implant level. Conclusions: Full-arch rehabilitations following an All-on-4 implant arrangement and assisted by a computer-guided protocol may be a viable alternative for patients with edentulism/hopeless teeth in the long term.

Keywords: computer-assisted surgery; digital dentistry; immediate loading; All-on-4; flapless procedure; implant-supported rehabilitation; dental implants; full arch

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1. Introduction

Complete edentulism is a public health problem, with an estimated average rate of 6.82% globally [1]. Implant-supported full-arch fixed prosthetic rehabilitations with immediate function represent a viable treatment option for completely edentulous patients, allowing fast, safe, and satisfactory results for both jaws in the long term [2,3].

Treatment with dental implants was first described in the 1960s by Brånemark, in a two-stage procedure, with implant loading occurring 3 to 6 months post-surgery [4]. However, to provide patients with a simpler and more efficient treatment, a one-stage implant

placement protocol was implemented in the 1990s with similar results [5,6], followed by immediate function protocols [2,3]. The All-on-4 treatment concept (Nobel Biocare AB, Gothenburg, Sweden) consists of a full-arch immediate function protocol allowing the rehabilitation of an edentulous jaw with minimum bone volume, where four implants are placed strategically (with at least 30 Ncm)—two anterior implants are inserted in an axial position and two posterior implants are tilted distally [2,3]. The All-on-4 protocol is a valid rehabilitation alternative with a registered 94.7% implant survival rate for the maxilla (13 years of follow-up) [3] and 93% for the mandible (18 years of follow-up) [2].

An additional advancement in implant dentistry was the adoption of digital planning and computer-guided surgical protocols alongside immediate loading, which ultimately led to the development of flapless computer-guided implant surgery [7]. One example of this software is the NobelGuide® (Nobel Biocare AB) concept. Computer-guided surgery is performed using data from computed tomography scans (CT) or cone beam CT (CBCT), which are converted into 3D images using surgical guide software, allowing one to virtually plan the exact position and direction in which the implants will be inserted [8]. A surgical template and an immediate acrylic prosthesis are then produced prior to surgery. The implant insertion is performed with flapless surgery through the surgical template, followed by a connection with an immediate temporary prosthesis, providing similar success rates to those achieved through flap surgery [9,10]. This minimally invasive and simpler procedure is beneficial for patients, decreasing the treatment time and discomfort [11–13].

The outcome of computer-guided flapless surgery for full-arch rehabilitation with immediate function has previously been reported, with several systematic reviews demonstrating its stability in shorter follow-ups [14–16]. Good outcomes were reported for this treatment modality, with implant survival rates ranging between 94.5% and 100% in follow-ups between 1 and 5 years, drawing the general conclusion that computer-guided flapless surgery was comparable with flap surgery in full-arch rehabilitations. A previous study with a larger sample reported a 94.5% implant cumulative survival rate after 7 years of follow-up [17]. Despite these results, studies evaluating the long-term outcome of full-arch computer-guided flapless surgery with immediate function are lacking.

The aim of this study was to evaluate the 12-year clinical and 10-year radiographic outcomes of full-arch fixed prosthetic rehabilitations supported by implants with immediate function according to the All-on-4 concept following a computer-guided surgical protocol.

2. Materials and Methods

This retrospective clinical study was conducted in a private practice setting (MALO CLINIC, Lisbon, Portugal). The full-arch rehabilitations were performed between February 2005 and November 2010. The present study was approved by an independent ethical committee (Ethical Committee for Health, authorization nº 001/2015), carried out in accordance with the Declaration of Helsinki, and written according to the STROBE guidelines [18]. Informed consent for participation was obtained from all subjects involved in the study.

- **Inclusion and Exclusion Criteria**

Eligible participants were patients treated with implant-supported full-arch fixed rehabilitations with immediate function, following the All-on-4 concept with a surgery guided protocol. The exclusion criteria included patients unable to understand and sign the informed consent, those with contraindications for implant-supported full-arch rehabilitations, including insufficient bone volume or active radiotherapy or chemotherapy treatment, or those with contraindicated conditions for guided surgery, such as the existence of natural teeth interfering with implant insertion, mouth opening $\leq$ 50 mm to accommodate surgical instruments, or the requirement for bone reduction associated with

a high maxillary smile line and an irregular or thin bone crest. A minimum age of 18 years was required to participate in this study.

- **Surgical, Prosthetic, and Maintenance Protocols**

Implants were inserted following a flapless surgical procedure, and the immediate prostheses were manufactured before implant surgery [7].

All patients underwent a presurgical intraoral clinical examination, panoramic radiography, and CT/CBCT imaging (Figures 1 and 2). The anatomical inclusion criteria included a residual ridge crest ≥4 mm in buccolingual width and >8 mm in height in the mandibular interforaminal region. In the edentulous maxilla, the ridge crest was required to have sufficient width for the placement of a 4.0 mm diameter implant and a minimum height of 10 mm between the canines. When the ridge width was limited to 4 mm, bone expansion was performed to enable the placement of 4.0 mm diameter implants, taking advantage of the implant design characteristics (NobelSpeedy, Nobel Biocare AB).

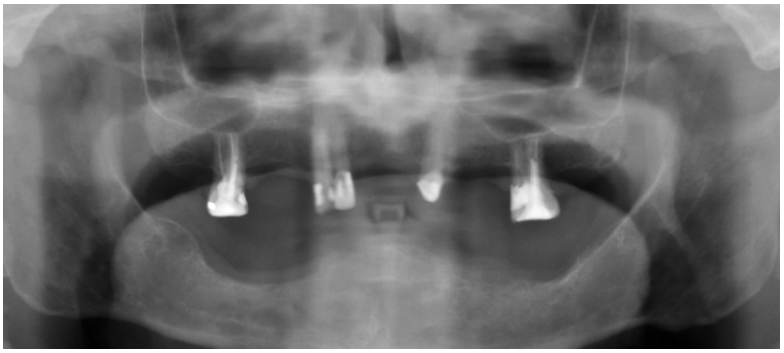


Figure 1. Pre-treatment orthopantomography.



Figure 2. Intraoral pre-operative view.

A removable prosthesis served as a radiographic guide for the CT/CBCT imaging; when feasible, an existing prosthesis was used. Radiopaque markers (gutta-percha; SDI, Bayswater, Victoria, Australia) were placed in three palatal and six buccal holes, and a silicone interocclusal record (Zhermack Spa, Badia Polesine, Italy) was used for stabilization. Imaging followed a double-scan protocol, and DICOM data were imported into planning software (NobelGuide®, versions 1.0 and 2.0; Nobel Biocare) for three-dimensional virtual implant planning and fabrication of the surgical template (Figure 3) [8].



Figure 3. Mandibular surgical template.

The surgical template was incorporated into the laboratory workflow to generate a working cast, which was articulated using the radiographic guide and index. The removable prosthesis was then converted into a fixed full-arch prosthesis, fabricated entirely in acrylic resin (Figure 4).

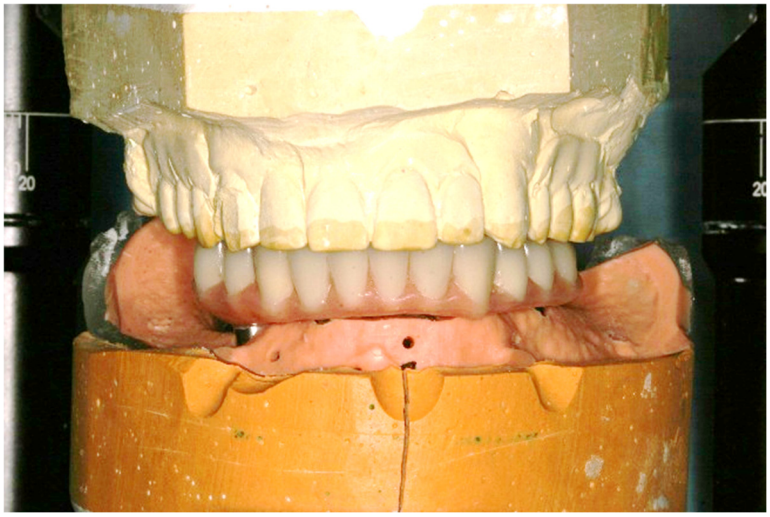


Figure 4. Provisional acrylic resin fixed prosthesis in the articulator before surgery.

All surgical procedures were performed under local anesthesia, with patients receiving a standardized medication protocol, as previously described [8]. The surgical template was positioned and stabilized intraorally with anchor pins following verification with a surgical index on the opposing arch. The flapless implant placement was performed according to the protocol [8] (Figures 5 and 6).

After the surgical template removal, straight or 17 degree MultiUnit abutments and 30 degree Multiunit abutments (Nobel Biocare AB) were connected to the anterior and posterior implants, respectively, using a custom laboratory-fabricated jig (Figure 7).

The prefabricated fixed prosthesis was delivered immediately to achieve immediate function, with occlusal adjustments performed when required (Figures 8–10).



Figure 5. The use of anchor pins to stabilize the surgical template in the mandible.

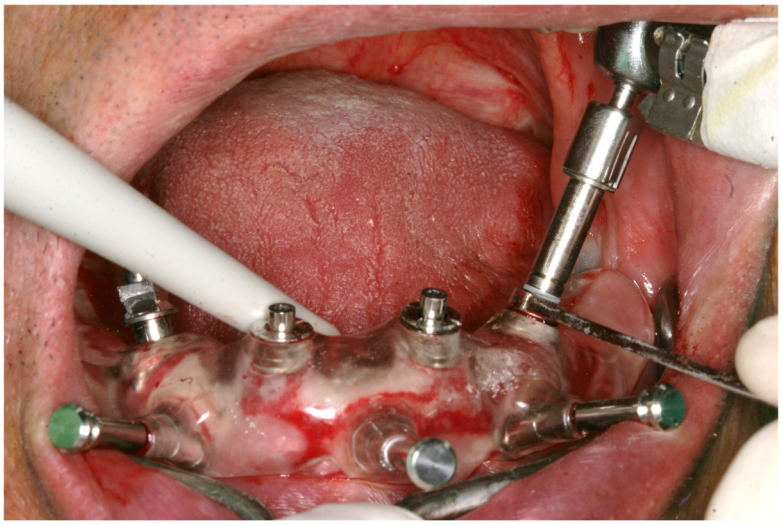


Figure 6. Posterior implant placement.

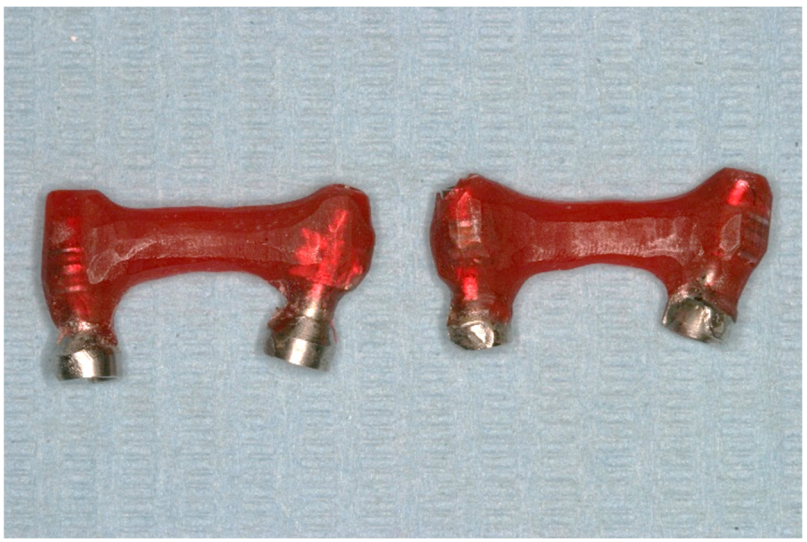


Figure 7. Nonengaging abutment jig (Patent No. U.S. 8,142,192 B2).

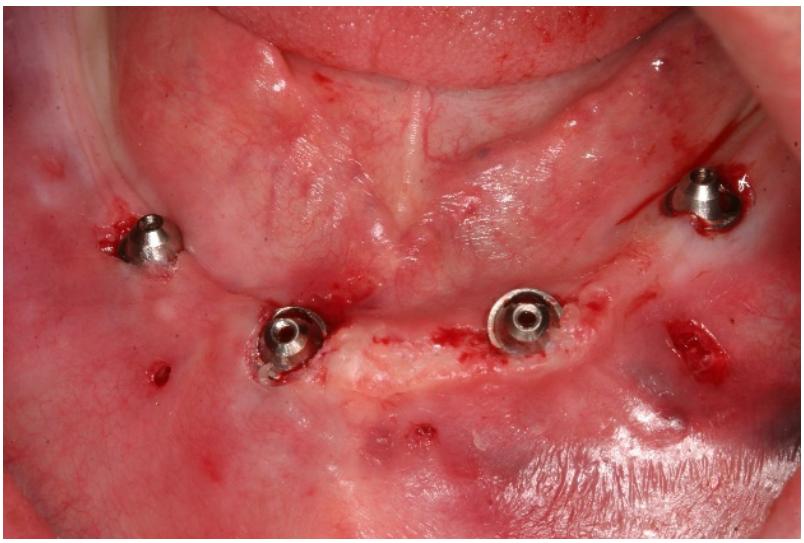


Figure 8. Mandibular intraoral postoperative view.



Figure 9. Immediate provisional prosthesis placed in the mandible.



Figure 10. Patient's smile after placement of the immediate provisional mandibular prosthesis.

The occlusion privileged maximum contacts in intercuspation, incisal guidance in protrusion, canine guidance in lateral movements, and adequate overbite and overjet (allowing a horizontal component in excursive movements). No particular occlusal scheme was designed for patients with bruxism habits other than the mandatory use of a nightguard.

The patients were enrolled in an implant maintenance program and instructed to stay on a soft diet for 2 months. After 4 months, if the implants were judged stable, the patient had the option of replacing the fixed acrylic resin prosthesis with a hybrid metal–acrylic prosthesis (Maló Clinic Acrylic Bridge) featuring acrylic resin teeth (Heraeus Kulzer GmbH, Hanau, Germany) and a titanium infrastructure (Procera® framework, Nobel Biocare) or a hybrid metal–ceramic prosthesis (Maló Clinic Ceramic Bridge) featuring Zirconia crowns (Procera crowns, and NobelRondo Ceramics; Nobel Biocare AB) and a titanium infrastructure (Procera titanium framework, Nobel Biocare AB) (Figures 11–14).



Figure 11. Frontal view of the patient with the definitive mandibular prosthesis in place.



Figure 12. Occlusal view of the definitive final prosthesis placed in the mandible.



Figure 13. Patient smiling with definitive prosthesis in place.

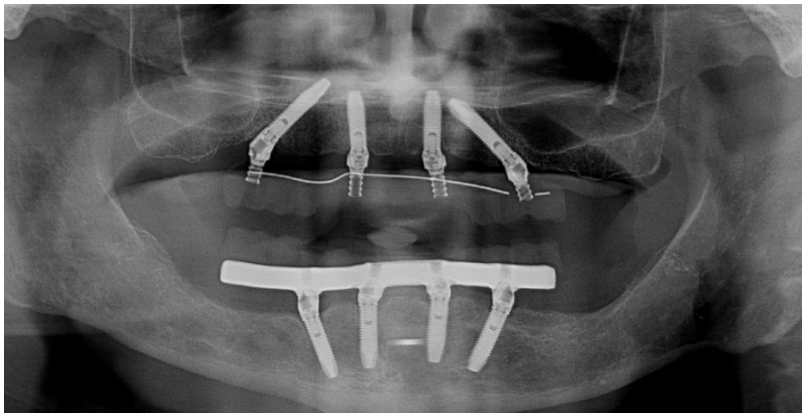


Figure 14. Orthopantomography with 10 years of follow-up of the mandibular rehabilitation (at this time, the patient decided to also perform the full-arch maxillary rehabilitation).

- **Outcome Measures**

The primary outcomes were implant and prosthetic survival. Implant survival required that the implants achieved the following: (a) supported the prosthesis without "sleeping"; (b) were stable on manual testing; (c) showed no radiolucency; (d) achieved good aesthetics with no complaints from the prosthodontist or patient; (e) allowed the connection of a fixed prosthesis, providing patient comfort and hygiene. Stability was assessed at each maintenance visit by removing the prosthesis and manually testing each implant. Prosthetic survival was defined as continued function, with prosthesis removal considered a failure.

Secondary outcomes included marginal bone loss (MBL) for axial and tilted implants, as well as the incidence of biological and mechanical complications. The MBL was assessed using periapical radiographs obtained at implant placement and at 5- and 10-year follow-ups, acquired with the parallel technique and a film holder (Super-bite; Hawe Neos, Bioggio, Switzerland), manually adjusted to approximate an orthogonal orientation. The assessment was performed by a calibrated blinded assessor using image analysis software (iRYS, version 13.0; MyRay, Imola, Italy). The implant platform (horizontal interface between implant and abutment) served as the reference point, and MBL was defined as the change in the marginal bone level relative to surgery. Radiographs were included for analysis only if the implant threads were clearly visible, ensuring both image sharpness and

proper beam orientation. The measurements were calibrated based on the known distance between the implant threads. The intra-examiner measurement reliability was 0.85 (Cohen's Kappa). The mechanical complications evaluated in this study were fracture or loosening of any prosthetic components. The biological complications assessed included suppuration, fistulae formation, and peri-implant disease (peri-implant pockets ≥5 mm, bleeding on probing, and concurrent presence of marginal bone loss and clinical attachment loss).

- **Statistical Analysis**

Post hoc sample size analysis determined the necessity of 83 pairs to detect a 37% increase in marginal bone loss (>0.35 mm) between axial and tilted implants with $\alpha = 0.05$ and $\beta = 0.8$. The survival of implants and prostheses was calculated through life table analysis (actuarial method) using the implant (not adjusted for clustering), patient, and prosthesis as the units of analysis, respectively, to assess the cumulative survival rate (CSR). Descriptive statistics were used for the variables of interest (marginal bone loss and incidence of biological and mechanical complications). Inferential analysis (log-rank test) was computed to compare the difference in implant survival curves between healthy patients, patients with systemic conditions, patients with smoking habits, and patients with systemic conditions and smoking habits simultaneously (considering the inclusion of high-risk patients). The Wilcoxon Signed Rank test was computed to assess the differences in marginal bone loss between axial and tilted implants. The comparison between patients lost to follow-up and patients with completed follow-up was performed for the variables of age (Student's *T*-test), sex (Chi-square test), systemic conditions (Chi-square test), and smoking habits (Chi-square test). The level of significance was set at 5%. The data were analyzed with the software SPSS for Windows (IBM SPSS Statistics, New York, NY, USA) version 26.

3. Results

A total of 111 patients with 133 full-arch fixed prostheses supported by 532 implants (NobelSpeedy® Groovy; Nobel Biocare) were included in this study and followed for 12 years. In total, 68 patients were female and 43 were male, with an average age of 60.9 ± 9.67 years. A total of 61 patients (55%) presented systemic conditions, including cardiovascular conditions ($n = 46$), a history of oncologic conditions ($n = 12$), diabetes ($n = 11$), rheumatologic conditions ($n = 5$), hepatitis ($n = 3$), neurologic conditions ($n = 1$), and HIV under medication ($n = 1$). Fifteen patients (13.5%) presented more than one condition. A total of 21 patients (18.9%) presented with smoking habits, and 56 patients (50.5%) were bruxers.

A total of 39 patients (35.1%) with 186 implants (35.0%) and 48 prostheses (36.1%) were lost to follow-up. Eight patients (37 implants) died due to causes unrelated to the implant treatment, one patient (with 8 implants) moved abroad, and thirty patients (141 implants) became unreachable (Table 1). A flowchart representing the number of patients and implants at each point of follow-up is displayed in Figure 15. The comparison between patients lost to follow-up and patients with completed follow-up registered no significant differences in the distribution for age ($p = 0.485$, Student's *T*-test), sex ($p = 0.716$, Chi-square test), systemic conditions ($p = 0.235$, Chi-square test), or smoking habits ($p = 0.752$, Chi-square test).

After 12 years, 37 implants failed in 17 patients (22 in the maxillae and 15 in the mandible), giving a CSR of 92.5% and 83.7%, using the implant and patient as units of analysis, respectively (Tables 2 and 3; Figures 16 and 17). Of the 17 patients who lost implants, 10 (58.8%) were bruxers, 9 (52.9%) presented with smoking habits, and 12 (70.6%) had at least one systemic condition. Regarding opposing dentition, of the 37 lost implants, 25 (67.6%) had implant-supported prostheses as opposing dentition, 4 implants (10.8%) had

a removable prosthesis, and 8 implants (21.6%) had natural teeth. A significant difference was registered for implant survival considering the systemic condition of the patient, with a lower cumulative survival for patients with a simultaneous systemic condition and smoking habits (44.5% CSR; $p = 0.008$, log-rank test; Figure 18).

Table 1. Patients lost to follow-up during this study.

Follow-Up Period (Years)	Patients Deceased	Patients Unreachable	Patients Moved Abroad	Total
0–1	1	3	1	5
1–2	0	0	0	0
2–3	0	2	0	2
3–4	1	1	0	2
4–5	1	0	0	1
5–6	0	5	0	5
6–7	0	2	0	2
7–8	0	1	0	1
8–9	0	1	0	1
9–10	0	1	0	1
10–11	4	8	0	12
11–12	1	6	0	7

Table 2. Cumulative survival rate of implants in this study during the 12-year follow-up.

Time (Years)	Number of Implants	Lost	Lost to Follow-Up	Survival (%)	Cumulative Survival (%)
0–1	532	19	28	96.3	96.3
1–2	485	3	0	99.4	95.7
2–3	482	2	8	99.6	95.3
3–4	472	4	8	99.2	94.5
4–5	460	0	4	100	94.5
5–6	456	0	28	100	94.5
6–7	428	0	8	100	94.5
7–8	420	5	4	98.8	96.4
8–9	411	1	4	99.8	93.2
9–10	406	2	8	99.5	92.7
10–11	396	1	56	99.7	92.5
11–12	339	0	30	100	92.5

Table 3. Cumulative implant survival rate using the patient as unit of analysis.

Time (Years)	Number of Patients	Lost Implant	Lost to Follow-Up	Survival (%)	Cumulative Survival (%)
0	111	10	5	90.8	90.8
1	96	1	0	99.0	89.8
2	95	1	2	98.9	88.9
3	92	2	2	97.8	86.9
4	88	0	1	100	86.9
5	87	0	4	100	86.9
6	83	0	2	100	89.9
7	81	2	1	97.5	84.8
8	78	1	1	98.7	83.7
9	76	0	1	100	83.7
10	75	0	9	100	83.7
11	66	0	6	100	83.7
12	60	0	0	100	83.7

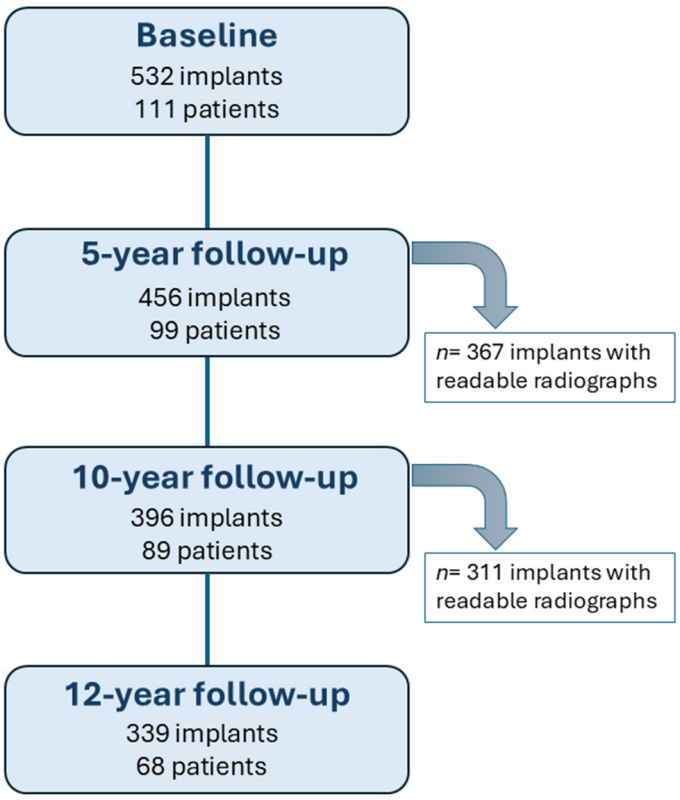


Figure 15. Flowchart representing the number of patients and implants at each point of follow-up.

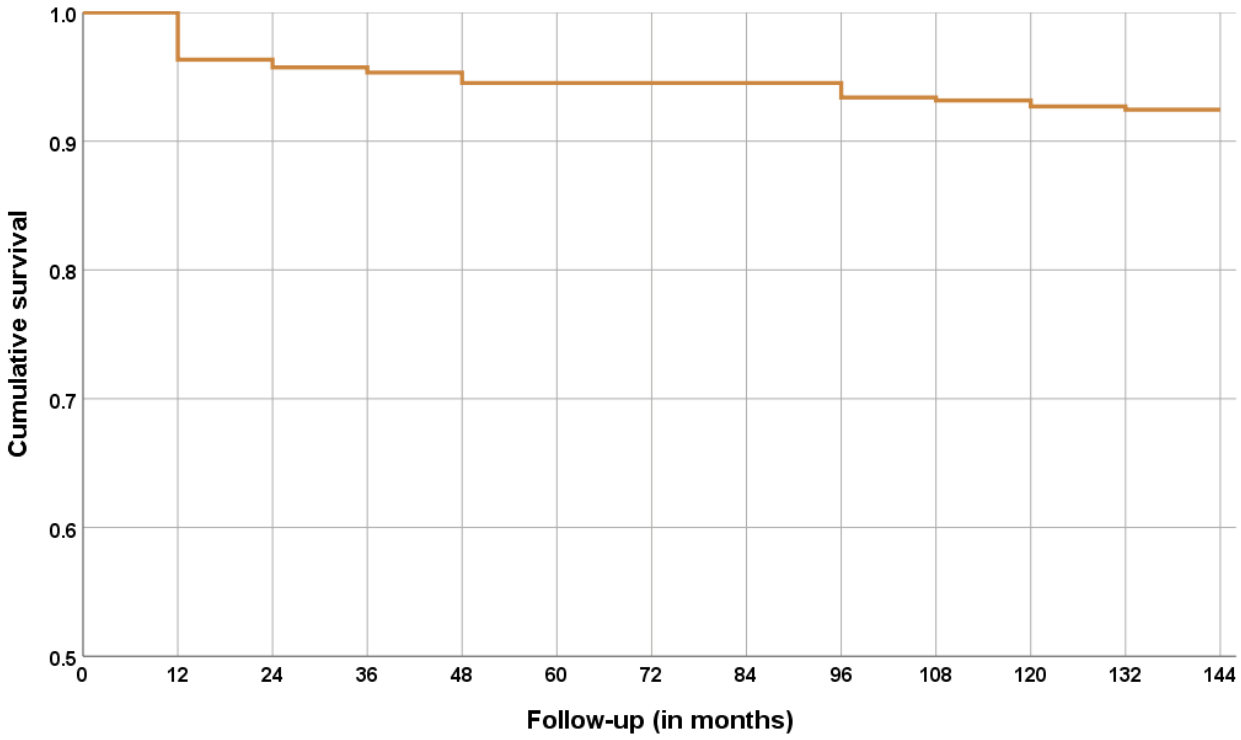


Figure 16. Graphical representation of the 12-year cumulative survival rate of implants placed in this study.

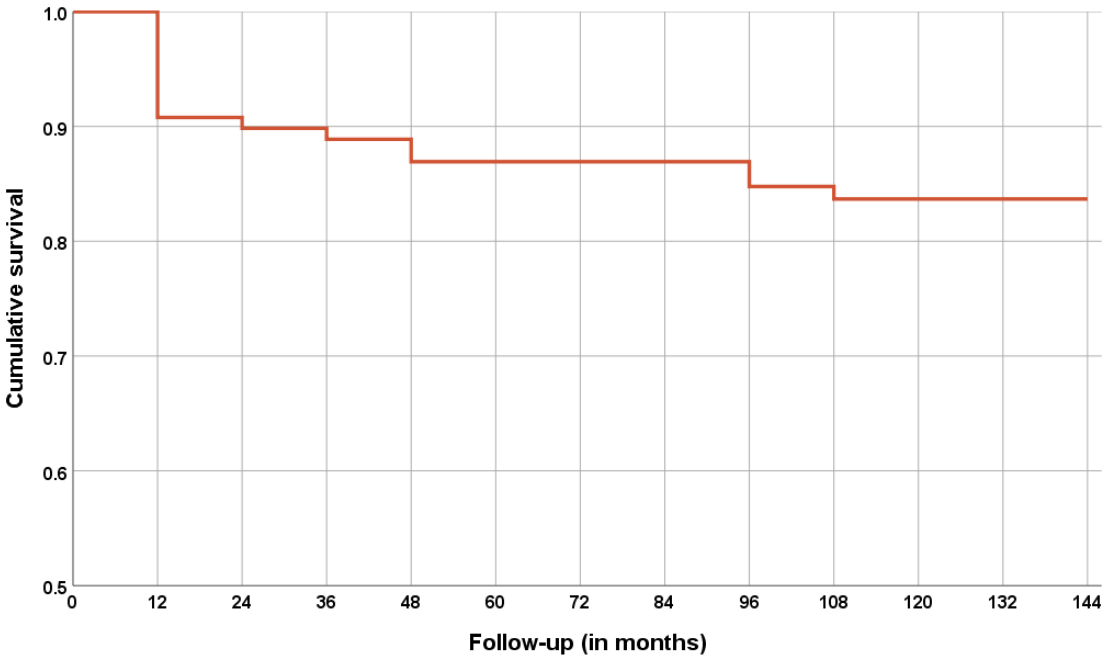


Figure 17. Graphical illustration of the cumulative implant survival rate using the patient as unit of analysis.

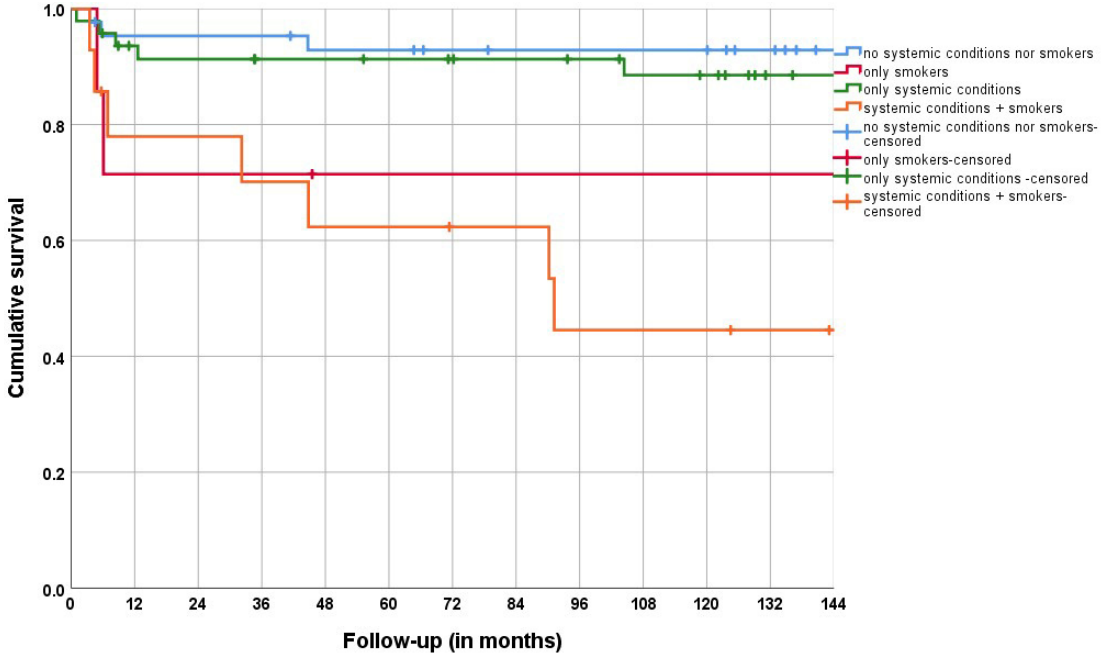


Figure 18. Cumulative implant survival rate using the patient as unit of analysis and according to health status. Patients with no systemic conditions registered the highest implant CSR with 92.8%, followed by patients with systemic conditions (CSR = 88.5%), patients with smoking habits (CSR = 71.4%), and patients with simultaneous systemic conditions and smoking habits (CSR = 44.5%).

Five prostheses failed in five patients, rendering a CSR of 96.2%. All five prosthetic failures were secondary to implant failures: four patients lost all four implants; one patient lost three of the four implants; nevertheless, all five patients lost at least three implants in a short amount of time, deeming it impossible to sustain prosthetic support.

The distributions of the MBL at 5 and 10 years are presented in Table 4. At the 5-year follow-up, a total of 367 (70%) implants in 87 patients (78.4%) had readable radiographs.

The average (standard deviation) marginal bone loss per implant at 5 years was 1.30 mm (1.06 mm), with 1.34 mm (1.10 mm) for axial implants and 1.27 mm (1.02 mm) for tilted implants ($p < 0.001$). A total of 311 (58.5%) implants in 74 (66.7%) patients had readable radiographs at the 10-year follow-up. The average (standard deviation) marginal bone loss per implant at 10 years was 1.19 mm (1.16 mm). Regarding tilted implants, the marginal bone loss was 1.12 mm (0.95 mm), and for axial implants this value increased to 1.26 mm (1.33 mm) (Table 3). The Wilcoxon Signed Rank test result showed no significant difference between marginal bone loss in axial and tilted implants ($p = 0.795$).

Table 4. Marginal bone loss (MBL) distribution at 10 years of follow-up: overall, axial, and tilted specifically.

5-Year Follow-Up	**Overall Marginal Bone Loss**			
Average (mm)	1.30			
SD (mm)	1.06			
Number (%) of readable radiographs	367 (70)			
Frequencies	*n*		%	
0 mm	37		7.0	
0.1–1 mm	122		22.9	
1.1–2 mm	138		25.9	
2.1–3 mm	44		8.3	
>3 mm	26		4.9	
5-Year Follow-Up	Bone Loss: Axial Implants		Bone Loss: Tilted Implants	
Average (mm)	1.34		1.27	
SD (mm)	1.10		1.02	
Number (%) of readable radiographs	177		190	
Frequencies	*n*	%	*n*	%
0 mm	21	11.9	16	8.4
0.1–1 mm	51	28.8	71	37.4
1.1–2 mm	71	40.1	67	35.3
2.1–3 mm	20	11.3	24	12.6
>3 mm	14	7.9	12	6.3
10-Year Follow-Up	**Overall Marginal Bone Loss**			
Average (mm)	1.19			
SD (mm)	1.16			
Number (%) of readable radiographs	311 (72.2)			
Frequencies	*n*		%	
0 mm	26		8.4	
0.1–1 mm	139		44.7	
1.1–2 mm	106		34.1	
2.1–3 mm	22		7.1	
>3 mm	18		5.8	
10-Year Follow-Up	Bone Loss: Axial Implants		Bone Loss: Tilted Implants	
Average (mm)	1.26		1.12	
SD (mm)	1.33		0.95	
Number (%) of readable radiographs	152 (78)		159 (80.7)	
Frequencies	*n*	%	*n*	%
0 mm	15	9.9	11	6.9
0.1–1 mm	65	42.8	74	46.5
1.1–2 mm	53	34.9	53	33.3
2.1–3 mm	7	4.6	15	9.4
>3 mm	12	7.9	6	3.8

A total of 105 patients (94.6%) experienced mechanical complications. One hundred patients (90.1%) experienced mechanical complications in the provisional prosthesis (Table 5). Of these patients, 53 (53%) were bruxers and 61 (61.6%) had implant-supported rehabilitations as opposing dentition. Nine patients presented more than one mechanical complication in the provisional prosthesis. These mechanical complications were solved by either the prosthodontist or by the technicians in the laboratory repairing the prostheses, by retightening the abutment and prosthetic screws, by adjusting the occlusion, and by reinforcing the importance of using a nightguard in cases of patients presenting heavy bruxism.

Table 5. Number of mechanical complications registered in this study by patient.

Complications	Number	Percentage
Provisional prostheses		
Prosthesis fracture	45	41.3
Loosening of abutment screw	61	56.0
Loosening of prosthetic screw	2	1.8
Fracture of prosthesis screw	1	0.9
Definitive prostheses		
Prosthesis fracture	1	1.5
Crown fracture	41	64.1
Loosening of abutment screw	12	18.8
Loosening of prosthetic screw	1	1.5
Milled abutment	4	6.3
Fracture of abutment screw	2	3.1
Fracture of prosthetic screw	3	4.7

Sixty-two patients (55.9%) experienced mechanical complications in the definitive prosthesis (Table 5). Of these patients, 41 (66.1%) were bruxers and 43 (65.2%) had implant-supported rehabilitations as opposing dentition. Two patients presented more than one mechanical complication in the definitive prosthesis. These mechanical complications were solved by repairing the prostheses chairside or in the dental laboratory, by retightening the abutments, by replacing the fractured abutments and prosthetic screws, by adjusting the occlusion, and by reinforcing the importance of using a nightguard in cases of patients presenting heavy bruxism. Fifty-eight patients (52.3%) accumulated mechanical complications in both the provisional and definitive prosthesis.

A total of 40 patients (36%) registered biological complications in 76 implants (14.3%). These complications occurred in 14 (35%) patients with smoking habits and consisted of early biological complications occurring during the first year of follow-up: pocket depths > 4 mm (n = 15 implants), suppuration with pocket depths > 4 mm (n = 2 implants), ulcer (n = 2 implants), and fistula with suppuration (n = 1 implant). There were also late biological complications occurring after the first year of follow-up: peri-implant pathology (n = 56 implants).

A total of 57 implants were treated using non-surgical methods (removal of bacterial plaque and irrigation with 0.2% chlorhexidine gel), while 19 implants were treated non-surgically and surgically (flap reflection, mechanical cleansing, and decontamination of the implant surface with 0.2% chlorhexidine and removal of granulation tissue). Forty-one implant complications were resolved through non-surgical therapy, and nine implant complications were resolved through surgical therapy. A total of twenty-six biological complications were unresolved: four implants failed, eighteen implants survived, one implant was lost to follow-up, and one patient with two implants was deceased.

4. Discussion

The findings of this study suggest that implant-supported full-arch rehabilitation following the All-on-4 concept with computer-guided surgery can be a predictable long-term treatment, showing an overall cumulative implant survival rate of 92.5% (using the implant as unit of analysis) and 83.7% (using the patient as unit of analysis) at 12 years, even in a cohort with a high prevalence of bruxism and systemic conditions. It has already been demonstrated that flapless and computer-guided surgery guarantees a minimal invasiveness regarding implant placement [19] and leads to high percentages of implant survival [15]. However, the number of studies reporting the outcome of implant-supported full-arch fixed prosthetic rehabilitations with a similar follow-up to the present study is low [19]. A retrospective study by La Monaca et al. [20] evaluated the outcome of the immediate flapless full-arch rehabilitation of edentulous jaws with guided surgery and a follow-up of up to 10 years. Regarding All-on-4 rehabilitations, they reported an 89.7% cumulative survival rate for implants and 88.2% for prostheses [20]. Another study by Kaneda et al. [21] using computer-guided surgery reported a 10-year cumulative implant survival rate of 93.9% and a prosthesis survival rate of 100%. These results are comparable with those registered in the present study, with a cumulative survival rate of 92.5% and 96.2% for implants and prostheses, respectively, although we extended the clinical follow-up to 12 years. Studies using the same rehabilitation concept with a free-hand surgical protocol registered similar implant survival rates, with 95.9% and 96.4% implant survival rates in the mandible [2] and in the maxilla [3], respectively, at 10 years, although they reported fewer mechanical and biological complications than the present study. A systematic review and meta-analysis by Yogui et al. [22] stated that free-hand and computer-guided surgery yield similar results for mechanical and biological complications, as well as marginal bone loss and implant survival rates, which was only partially confirmed in the present study. The main difference reported between free-hand and fully guided implant surgery is the accuracy, since computer-guided surgery significantly improves the angular deviation, apical deviation, and 3D deviation [23,24]. This partially contrasting outcome could be explained by differences in patient characteristics. From the 17 patients who lost implants in this study, 10 patients (58.8%) were bruxers and 9 patients (52.9%) presented with smoking habits. Smoking habits had a dramatic effect on implant survival, especially in patients with systemic conditions, with an almost 50% decrease in implant cumulative survival rates compared with healthy patients. In a retrospective study by Chrcanovic et al. [25] with 2670 patients with 10,096 implants, it was concluded that the presence of bruxism significantly increased the risk of implant failure. In addition, several systematic reviews and meta-analysis concluded that implants placed in bruxers are at a higher risk of failure than implants placed in non-bruxers [26–28]. Regarding the presence of smoking habits, Mustapha et al. [29] reported that implants placed in smokers present a 140.2% risk of implant failing compared with implants placed in non-smokers. Additionally, in a meta-analysis by Chen et al. [30], smoking was also associated with an increased risk of dental implant failure. Moreover, systematic reviews and meta-analyses reported that an increase in the number of cigarettes smoked per day correlated positively with an increased risk of implant failure, and that smoking was significantly associated with early dental implant failure, particularly when placed in the maxilla [31,32]. Taking these results into consideration, careful evaluation is advisable when planning on placing dental implants in bruxers and smokers. These studies show the importance of recommending the use of a nightguard and other preventive measures in heavy bruxers, as well as advising smoking cessation for patients with implant-supported prostheses.

Regarding the marginal bone loss, in the present study, a mean overall value of 1.19 mm was obtained after 10 years, which compares favorably with studies using guided

surgery (2.09 mm [20]) and free-hand surgery [2,3]. In the present study, the difference in marginal bone loss observed between axial and tilted implants was significantly different at 5 years (although clinically non-significant) and non-significant (clinically and statistically) at 10 years. A recent umbrella review with a meta-analysis reported a significant difference in marginal bone loss between axial and tilted implants in the long-term [33]. However, the difference was 0.18 mm, which was considered negligible from the clinical point of view, and consequently was not reflected in the implant survival outcome [33]. Other clinical studies of immediate flapless full-arch rehabilitation and guided implant surgery reported similar results with no significant differences for the mean marginal bone loss [20] and peri-implant disease [34] distributions between axial and tilted implants, a pattern that was also registered in the present study (implants with peri-implant disease: n = 30 axial implants, n = 26 tilted implants).

The incidence rate of biological complications in our study (36% at patient level) was higher compared with other publications using the same protocol with freehand surgery and long-term follow-up and studies using the same protocol with guided surgery and a shorter follow-up. Previous publications of the All-on-4 concept reported 18.9% and 25.5% biological complications for the maxilla and mandible, respectively [2,3]. The difference could be partly explained by the different patient characteristics across samples, with 55% being systemically compromised patients, 18.5% being smokers, and 50.5% being heavy bruxers in the present study, compared with ranges of 28.2–35.1%, 22.5–24.5%, and 1.1–3.7% for the same parameters for the referenced studies [2,3]. Compared with a study of full-arch rehabilitation using the same protocol with guided surgery [20], despite the comparable incidence rate of biological complications when considering the implant as the unit of analysis (13.6% at 12 years for the present study compared with 10.3% at 10 years), a 23% increase in the present study was observed (36% vs. 13.3%) when using the patient as the unit of analysis. Again, the difference in sample characteristics might partly explain the difference, with a prevalence of only 10.7% of patients with systemic compromised status, 3.6% being smokers, and the absence of heavy bruxers [20]. Nevertheless, differences in oral hygiene levels could also play an important role, but, given that this variable was not collected and its effect could not be measured, the question remains open, representing a limitation of the present study.

A high rate of mechanical complications (94.6%) was registered in the present study, particularly regarding the provisional prosthesis. However, this rate decreased once the provisional prostheses were replaced by the definitive prostheses. Compared with a study using the same guided surgery protocol [20], a 41.7% mechanical complication rate was reported, with mechanical complications only occurring in the definitive prosthesis. This difference may be attributed to the high percentage of patients presenting bruxism that were included in the present study (50.5%), contrasting with no heavy bruxers included in the La Monaca et al. study [20]. Furthermore, most patients who experienced mechanical complications in the present study had an implant-supported prosthesis as the opposing dentition. A previous study [35] investigating the effect of altering the vertical dimension of occlusion registered an increased incidence of mechanical complications for patients presenting implant-supported prostheses as the opposing dentition. This result could be the consequence of an absence of shock absorption elements during occlusion, although not affecting implant survival.

The protocol used in this study combines computer-guided surgery with the All-on-4 concept (a graftless immediate-function solution for total edentulism) and does not appear to compromise treatment outcomes [17]. Although similar results were reported regarding implant failure [16], minimally invasive flapless surgery could lead to less marginal bone loss [36,37] and less pain [37] reported by patients compared with flap procedures, while

representing a less difficult procedure, which is beneficial for patients and clinicians [38]; these variables were not evaluated in the present study. Several factors should be considered before selecting this procedure, as insufficient bone volume, interfering teeth, limited mouth opening for surgical instruments, and the need for bone reduction are considered contraindications for flapless surgery [8]. Additionally, the accuracy of computer-guided surgeries depends on minimizing errors during the different stages of this procedure, since several studies reported inaccuracies when computer-guided surgery was used [39], particularly between the planned implant position and the position at which the implant was inserted [13].

The status of guided surgery has evolved in recent years. To further improve the accuracy of implant placement and maximize the efficacy outcomes, the concept of dynamic navigation surgery was developed, involving a combination of office-based imaging and planning software that enables real-time surgical navigation [40,41]. The general trend for this concept has been depicted in recent systematic reviews and meta-analytic studies [16,40,41], with non-significant differences between static guided and navigated surgery for dental implant placement regarding implant survival rates [16] but diverging results when judging the accuracy. No differences were registered between both modalities [16] regarding a highly accurate implant placement, decreased angular deviation [40], and minimal implant placement errors [41]. These results require further research to be performed to measure the clinical effect and impact on the dental implants' outcomes.

The present study has several limitations, including its retrospective design, which may result in unmeasured or missing data, the absence of a control group, limiting comparisons with other surgical protocols, its single-center nature, reducing external validity, and a high rate of patients lost to follow-up. These factors warrant caution in interpreting the results, as they may lead to an overestimation of implant survival and an underestimation of marginal bone loss and complications. To address this, a comparison between patients lost to follow-up and those with complete data was performed for age, sex, systemic conditions, and smoking. No significant differences were observed, indicating similar demographics and health profiles between the groups, and ruling out survivorship bias. Nevertheless, this high lost-to-follow-up rate possibility indicates that survival and complication rates in the retained cohort may not fully reflect the experience of all baseline patients. A further limitation was the absence of data collection for plaque levels, which prevented evaluating its potential effect on biological complications. Future studies should evaluate the long-term outcomes for implant-supported full-arch prosthetic rehabilitation through computer-guided surgery, using passive control groups (freehand) and active control groups (navigated surgery), allowing for a more robust validation of the concepts.

5. Conclusions

Considering the limitations of this study, implant-supported full-arch rehabilitation using the All-on-4 concept with computer-guided surgery appears to be a safe and effective long-term treatment for fully edentulous jaws, with high implant and prosthesis survival rates. However, a high mechanical complication rate was registered, particularly in the provisional prosthesis. This warrants a careful recall plan, particularly in heavy bruxers and patients who present with an implant-supported prosthesis as opposing dentition. In addition, patients with smoking habits experienced an increased number of implant failures, warranting a smoking cessation plan.

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Data Availability Statement: The data are available at the following public repository link: https://osf.io/4g37f/overview (accessed on 12 December 2025).

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