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Comparison of 4- or 6-implant supported immediate full-arch fixed prostheses: A retrospective cohort study of 217 patients followed up for 3–13 years

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Abstract

Purpose: Choosing four or six implants to support immediate full-arch fixed prostheses (FAFPs) is still controversial worldwide. This study aims to analyze and compare the long-term results of All-on-4 and All-on-6.

Materials and Methods: This retrospective cohort study enrolled 217 patients rehabilitated with 1222 implants supporting 271 FAFPs, including 202 prostheses supported by 4 implants (All-on-4 group) and 69 prostheses supported by 6 implants (All-on-6 group), and followed up for 3–13 years. Implant survival, prosthesis survival, complications, and implant marginal bone loss (MBL) were evaluated and compared between two groups. Patient characteristics including age, gender, jaw, opposite dentition condition, smoking habit, bruxism, bone quantity and quality, cantilever length (CL), prosthesis material, and oral hygiene were analyzed to assess their influence on the clinical results of the two groups. Six surgeons and three prosthodontists who performed FAFPs more than 5 years were invited for questionnaires, to assess patient- and clinician-related influences on implant number.

Result: In general, All-on-4 group indicated no significant difference with All-on-6 group in the implant survival (implant-level: hazard ratio [HR] = 1.0 [95% confidence interval (CI): 0.8–1.2], $P = 0.96$; prosthesis-level: HR = 0.8 [95% CI: 0.3–1.8], $P = 0.54$), prosthesis survival (odds ratio [OR] = 0.8 [95% CI: 0.3–2.8], $P = 0.56$), biological complications (OR = 0.9 [95% CI: 0.5–1.8], $P = 0.78$), technical complications of provisional prosthesis (OR = 1.3 [95% CI: 0.7–2.3], $P = 0.42$), technical complications of definitive prosthesis (OR = 1.1 [95% CI: 0.6–2.2], $P = 0.33$) and the 1st, 5th, and 10th year MBL ($P = 0.65$, $P = 0.28$, $P = 0.14$). However, for specific covariates, including elderly patients, opposing natural/fixed dentition, smoking, bruxism, long CL, low bone density, and all acrylic provisional prostheses, All-on-6 was more predictable in some clinical measurements than All-on-4. The implant prosthodontists and the medium-experienced clinicians showed significant preference for All-on-6 ($P < 0.05$).

Conclusion: Based on this study, the long-term clinical results showed no significant difference between All-on-4 and All-on-6 groups in general. However, for some

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specific characteristics, All-on-6 seemed to be more predictable in some clinical measurements than All-on-4. For the clinicians' decision-making, medium-experienced clinicians and the implant prosthodontists showed significant preference for All-on-6.

KEYWORDS
All-on-4, All-on-6, immediate loading, implant number, implant supported full-arch fixed prostheses

Summary Box

What is known

- Both All-on-4 and All-on-6 have been suggested to be predictable methods for full-arch implant and immediate rehabilitation.
- An randomized controlled trial (RCT) study[1] in 40 patients reported comparable results between All-on-4 and All-on-6 in maxillae.
- Choosing four or six implants to support immediate full-arch fixed prostheses is still controversial worldwide.

What this study adds

- This observational study in a larger sample size confirms the results of the RCT that clinical results are comparable between All-on-4 and All-on-6 in general.
- This study reports that for specific characteristics, including opposing natural/fixed dentition, smoking, bruxism, long cantilever length, low bone density, and all acrylic provisional prostheses, All-on-6 indicates more predictable clinical results than All-on-4.

1 | INTRODUCTION

The number of implants to support full-arch fixed prostheses (FAFPs) varied from three to eight[2–14] in different studies. In 2003, Maló and colleagues[15,16] proposed the classical All-on-4 concept, which was proved by many later studies to be a reliable and effective method for full-arch immediate implant restoration. While some other studies[17,18] reported that All-on-6 was also a predictable protocol. The implant survival rate and prosthesis survival rate of All-on-4 (94.7% ~ 95.4% and 99.2% ~ 99.7%[19,20]) and All-on-6 (96% ~ 99.3% and 100%[21,22]) were comparable.

An RCT study by Tallarico and colleagues[1] in 2016 reported that, there was no significant difference in the clinical outcomes (implant failure rate, complications and marginal bone loss [MBL]) between All-on-4 and All-on-6 in maxillae. Toia and colleagues[23] also reported that in maxillae, using 4 or 6 implants to support FAFPs showed no significant difference in implant survival rate, MBL and incidence of complications. The results in these studies might challenge the necessity of All-on-6.

Choosing 4 or 6 implants to support FAFPs is still currently controversial worldwide. Many clinicians believe that some objective patient characteristics, including age, smoking habit, jaw, bone quantity and quality, bruxism, opposite dentition condition, cantilever length (CL), prosthetic material, and so forth, might have different influence on the long-term results of All-on-4 or All-on-6. And some subjective clinician- and patient-related factors, including clinicians' experience, specialty, education, training background, patients' demands and expectations might also influence the decision on the number of implants.[24] However, no studies were found that assessed these factors' influence on the long-term results and the decision-making on All-on-4 and All-on-6 protocols.

This retrospective study tried to compare and identify different factors' influences on the long-term results of All-on-4 and All-on-6. This study might also be the first to evaluate clinicians' preference for All-on-4 or All-on-6, which may provide some reference for optimizing the number of implants for FAFPs in different cases.

2 | MATERIALS AND METHODS

2.1 | Study subjects

From 2008 to 2018, a total of 257 patients received 4 or 6 implants supported immediate provisional and definitive FAFPs in Implantology Department of Peking University Hospital of Stomatology. In this retrospective cohort study, a total of 202 definitive prostheses were supported by 4 implants (All-on-4 group), whereas 69 definitive prostheses were supported by 6 implants (All-on-6 group). In particular, there were All-on-6 provisional prostheses being supported by 4 implants only, with 2 implants embedded until definitive restoration. These cases were categorized into All-on-4 group when analyzing the provisional prostheses, and were categorized into All-on-6 group when analyzing definitive prostheses.

Each patient enrolled was recalled and informed of the purpose of this study, then signed a written informed consent form for an

approval to get involved into this retrospective study and provide relative clinical data. This study was conducted according to the tenets of the Helsinki Declaration, and was approved by Ethics Committee of Peking University Health Science Center (PKUSSIRB-201839146).

The inclusion and exclusion criteria for patients were as follows:

2.2 | Inclusion criteria

1. Patients received implant-supported full-arch immediate fixed rehabilitations;
2. The number of implants was four or six;
3. The final torque of the immediate loading implant was ≥35 N cm (the implants with final torque <35 N cm were embedded till definitive prosthesis);
4. The immediate provisional FAFPs were delivered within 24 h after the implant surgery.

2.3 | Exclusion criteria

1. Patients did not have regular maintenance and complete medical records;
2. Patients refused to participate in and share related medical information in this study;
3. Patients smoked more than 20 cigarettes per day.

2.4 | Surgical procedure

Each patient received 4 or 6 implants that were placed straight or tilted in the mesial or distal direction at 30–45° relative to the alveolar ridge according to their position and the bone volume available at the placement site.

In All-on-4 group, 4 implants (Brånemark System® Mk II, Mk III; NobelSpeedy™; NobelActive™, Sweden) were placed according to standard procedures of All-on-4 protocol described in the manufacturer's guidelines and previous studies.[25,26] In most of the All-on-4 cases, two anterior implants were axially oriented perpendicular to the occlusal plane, and typically placed in the lateral incisor regions; two posterior implants were distally tilted by 30–45° relative to the occlusal plane, along the anterior maxillary sinus wall (in the maxilla) or anterior to the mental foramen (in mandible), with the emergence of the implant platform typically at the second premolar regions.

In All-on-6 group, two more implants were placed distally. In most of the All-on-6 cases, two anterior implants were axially placed typically at the lateral incisor or canine region; two more axial or tilted distal implants were placed along the anterior maxillary sinus wall (in the maxilla) or anterior to the mental foramen (in mandible); the last two distal implants were placed either axially (mostly in the mandibles), or tilted mesially along the posterior sinus wall or the pterygoid plates in the maxilla.

Bone augmentation (including guided bone regeneration and sinus lift), was performed when there was horizontal and/or vertical bone deficiency. If the primary stability of the implants at the augmentation sites was poor, the implants would be embedded for 6–8 months. Only the implants with a final torque ≥35 N cm would be loaded immediately.

Straight or angulated multi-unit abutments were connected to the emerged axial and tilted implants to achieve a relative parallel common insertion path so that the fixed prosthesis would seat in a passive manner. The abutments were secured with a torque of 35 and 15 N cm for straight and angulated abutments, respectively.

2.5 | Provisional and definitive prosthetic procedure

After implant surgery, open-tray impression transfer copings were fastened to the multi-unit abutments with screws and connected with self-curing composite resin materials. The impression was taken with silicone material. Vertical dimension and bite registration were taken. Provisional full-arch all-acrylic (some reinforced with metal, carbon or glass fibers[27]) prostheses were manufactured at the dental laboratory and delivered to the patients in approximately 6 h (within 24 h) after implant placement. Based on the emerging positions of the posterior implants, the provisional prostheses of All-on-4 were consisted of 10–12 crown units (up to the second premolar or the first molars), and the provisional prostheses of All-on-6 were consisted of 12–14 crown units (up to the first or the second molars). Mutually protected occlusion with minimal or no cantilever was recommended. A semisolid diet was recommended for 3 months after implant placement. Each patient was given detailed oral hygiene instructions.

After 4–6 months, the definitive prostheses were delivered to the patients. The definitive All-on-4 prostheses were consisted of 12 crown units (up to the first molars), and the definitive All-on-6 prostheses were consisted of 12–14 crown units (up to the first or the second molars). Each definitive prosthesis contained a CAM metal framework. The material of the definitive prostheses included all-acrylic resin, acrylic resin with metal occlusal-surfaces, porcelain-fused-to metal, and zirconia (with or without porcelain veneer).

The postoperative panoramic image All-on-4 and All-on-6 were shown as Figures 1 and 2, respectively.

2.6 | Outcome measurements

2.6.1 | Implant survival

The survival of an implant was identified if it fulfilled all of the following criteria based on a combination of modified Maló Clinic criteria[19] and Albrektsson criteria[28]:

1. Absence of peri-implant radiolucency.
2. No signs of persistent infection, pain, numbness or paraesthesia of lower lip or chin, or ongoing pathological processes such as fistula or abscess at the implant site.

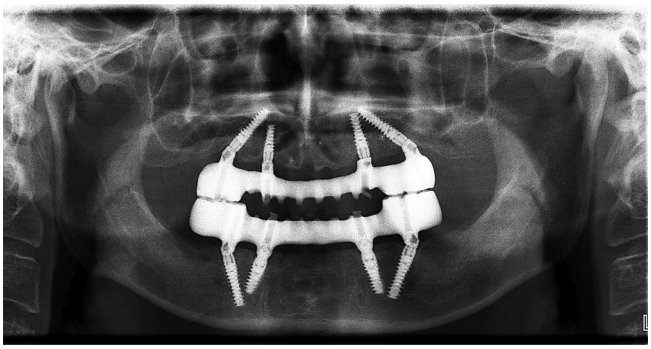

FIGURE 1 Postoperative panoramic image of All-on-4 after bimaxillary definitive rehabilitation.

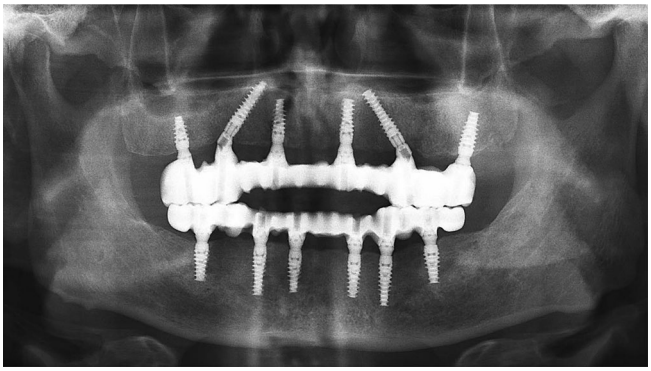

FIGURE 2 Postoperative panoramic image of All-on-6 after bimaxillary definitive rehabilitation.

3. The implant was stable when individually and manually tested with prosthesis removed after functional loading;
4. No fracture of any structure of the implant.
5. The implant fulfilled its planned function as a support for rehabilitation, which provided the patient with aesthetics, comfort, and convenient hygiene maintenance.

2.6.2 | Prosthesis survival

The survival of a definitive prosthesis was defined as the prosthesis remaining in situ and in absence of irremediable fracture, mobility, and pain. The failure of a definitive prosthesis was identified if it was removed for any reason.[26,29]

Since most of the provisional prostheses could be repaired easily, and all the provisional prostheses were replaced by definitive prostheses after 4–12 months, determining the survival rate of provisional prostheses was of limited value and was not evaluated.

2.6.3 | Complications

Complications including biological and technical complications were assessed by clinicians during the routine follow-up clinical visit. Biological complications (peri-implant mucositis and peri-implantitis) was recorded with prosthesis as unit of analysis. Technical complications (fracture of any components of the prostheses and abutment/prosthetic screw loosening) of provisional and definitive prostheses were calculated, respectively.

2.6.4 | Marginal bone loss

The implant platform (the horizontal interface between the implant and the abutment) was used as the reference for each measurement. The linear distance (in millimeters) between the platform and the most coronal bone-to-implant contact was measured. To adjust for dimensional distortion and enlargement on the orthopantomography, the actual known lengths of the implants were compared to the measured implant dimensions on the orthopantomography. Mesial and distal values were averaged so as to have a single value for each implant. The image analysis software Planmeca Romexis (Planmeca Dental Imaging Oy, Helsinki, Finland) was used for measurements with an accuracy of 0.1 mm.[21,25]

2.7 | Covariates and subgroups

Patient characteristics were analyzed as covariates. Covariates that may modify the association between two protocols and clinical outcomes were assessed in this study, including age, gender, jaw, opposite dentition condition, smoking habit, bruxism, bone quantity and quality, CL, prosthesis material, and oral hygiene. The following subgroups of the aforementioned covariates were considered:

1. Age: ① <40 years, ② 40 ~ 60 years, ③ ≥60 years;
2. Gender: ①male, ②female;
3. Jaws: ①maxilla, ②mandible;
4. Opposite dentition condition: ①natural teeth with/without fixed prostheses, ②implant supported FAFPs, ③complete or partial removable denture;
5. Smoking habit: ①nonsmoker, ②smoking 1 ~ 10 cigarettes/day, ③smoking 11 ~ 20 cigarettes/day;
6. Bruxism: ①with, ②without;
7. Posterior bone quantity: ①adequate (both the vertical bone height ≥10.5 mm and the horizontal width ≥5.5 mm), ②inadequate (either the vertical bone height <10.5 mm or the horizontal width <5.5 mm).
8. Bone density (Lekholm and Zarb classification): ①I, ②II, and III, ③IV;
9. Cantilever length: ①0 ~ 5 mm, ②5 ~ 10 mm, ③ ≥ 10 mm.
10. Provisional prosthesis material: ①all-acrylic resin, ②acrylic resin with fiber reinforcement;
11. Definitive prosthesis material (all with a metal framework): ①all-acrylic resin, ②acrylic resin with metal occlusal-surfaces, ③porcelain-fused-to metal, ④zirconia with or without porcelain veneer.

12. Oral hygiene: ①good maintenance, ②poor maintenance.

2.8 | Measurement of clinicians' subjective preference

The 217 cases enrolled in this study were performed by 15 clinicians from the Implantology Department of Peking University Hospital of Stomatology. A total of 9 clinicians, including 6 implant surgeons and 3 prosthodontists who performed at least 10 implant-supported FAFPs among the enrolled cases in this study were invited for interviews as well as the modified Likert scale questionnaires (as shown in the Appendix).

All of the nine clinicians enrolled had received DMD degrees and were proficient dental implantologists practicing in the Implantology Department of Peking University Hospital of Stomatology for 10 ~ 36 years. Each of them had performed average 32.2 (for surgeons) and 60.3 (for prosthodontists) implant-supported FAFP cases (ranging from 16 to 158) by the time of the interview. The 6 implant surgeons received specialty training in oral maxillofacial surgery and 3 implant prosthodontists received specialty training in prosthodontics.

In the questionnaire, the objective patient characteristics influencing the clinicians' choices were as the same as the characteristics listed in the above covariates. The subjective patients' demands of rehabilitation were categorized as follows: ①up to the second molars, ②up to the first molars.

The clinician characteristics, including clinicians' experience and specialties were categorized as follows: Experience (by the time of the interview, years of performing implant-supported FAFP cases): ①medium-experienced (5 ~ 10 years), ②well-experienced (≥10 years); Specialty: ①implant surgeon, ②implant prosthodontist.

2.9 | Statistical analysis

Descriptive statistics were computed to provide a general distribution of covariates and compared between All-on-4 and All-on-6 groups using chi-square tests.

The implant survival rate was calculated using Kaplan–Meier method both at implant level (each implant failure was considered as the event of interest) and prosthesis level (the first implant failure in a prosthesis unit was considered as the event of interest). The implant survival was further compared between the All-on-4 and All-on-6 groups using Cox proportion hazards models. Additionally, a separate analysis was conducted adjusting for potential confounders, including age, bruxism and jaw, in the Cox model. Robust variance estimators were used in the implant-level analyses to account for within-patient correlation. Hazard ratios (HRs) and corresponding 95% confidence intervals (CIs) were reported.

The prosthesis survival rate and the incidence of complications were compared between two groups by the chi-square test, and the odds ratios (ORs) and corresponding 95% CIs were reported. In addition, the risk of prosthesis failure and complications were also assessed using logistic regression models adjusting for age, bruxism, and jaw.

TABLE 1 Distribution of patients' characteristics and clinical characteristics.

Group	All-on-4	All-on-6	*P*-value
Age			
Mean age	57.0 (1.2)	57.1 (1.3)	0.96
<40	12	2	0.62
40 ~ 60	105	37	
≥60	85	30	
Gender			
Male	109	46	0.07
Female	93	23	
Smoking habit			
Nonsmoker	149	49	0.89
1 ~ 10 cigarettes/day	33	12	
11 ~ 20 cigarettes/day	20	8	
Bruxism			
With	26	23	<0.001*
Without	176	46	
Jaw			
Maxilla	77	37	0.02*
Mandible	125	32	
Opposite dentition			
Natural teeth/fixed prostheses	54	24	0.06
Full-arch rehabilitation	119	42	
Removable denture	29	3	
Bone quality (Lekholm and Zarb classification)			
I	20	8	0.92
II ~ III	160	54	
IV	22	7	
Posterior bone quantity			
Adequate	94	50	0.001*
Inadequate	108	19	
Cantilever length (mm)			
0 ~ 5	45	19	0.67
5 ~ 10	130	41	
>10	27	9	
Oral hygiene			
Good maintenance	123	50	0.08
Poor maintenance	79	19	
Definitive prosthesis material			
All-acrylic resin	75	20	0.48
Acrylic resin with metal occlusal -surfaces	45	15	
Porcelain-fused-to metal	30	10	
Zirconia	52	24	
Provisional prosthesis material			
All-acrylic resin	137	37	0.64
Reinforced with fiber	74	23	

*$P < 0.05$ was taken as the statistical significance level.

The MBL and clinicians' preference scores were compared between two groups using two-sample *t* tests.

Subgroup analyses were conducted using the aforementioned methods within each pre-specified subgroup of covariates listed previously.

$P < 0.05$ was taken as the statistical significance level, and all tests were 2-tailed. All statistical analyses were conducted using Stata 16 (StataCorp LP, USA) and SPSS 24.0 for Windows (IBM, USA).

3 | RESULTS

3.1 | Characteristics of enrolled patients

The distribution of characteristics and descriptive statistics of the study population were given in Table 1. According to the inclusion and exclusion criteria, 40 patients were excluded. Thus, this study consecutively enrolled 217 patients (119 males and 98 females; average age of 57.5(11.0) years), rehabilitated with 1222 implants supporting 271 FAFPs. Since 9 immediate provisional prostheses were supported by 4 implants only, on account of low primary stability especially after bone augmentation, All-on-4 group contained 211 provisional and 202 definitive prostheses, and All-on-6 group contained 60 provisional, and 69 definitive prostheses.

3.2 | Implant survival

A total of 27 prostheses lost 48 implants, rendering an implant survival rate of 96.1% and 90.0% at implant level and prosthesis level, respectively. As given in Table 2, the implant survival showed no significant difference between All-on-4 and All-on-6 groups at implant level (HR = 1.0 [95% CI: 0.8–1.2], $P = 0.96$) and prosthesis level (HR = 0.8 [95% CI: 0.3–1.8], $P = 0.54$) in general.

Results of subgroup analyses regarding influences of covariates on the implant survival at implant level of two groups were given in Table 3. No significant differences were observed between All-on-4 and All-on-6 groups in all subgroups assessed except for age and smoking habit.

For elderly (≥60 years) patients, the risk of implant failure was 1.7 times higher in All-on-4 than in All-on-6 (HR = 1.7 [95% CI: 1.1–2.7], $P = 0.03$).

For patients smoking 11 ~ 20 cigarettes/day, the risk of implant failure at implant level was 1.7 times higher in All-on-4 than in All-on-6 (HR = 1.7 [95% CI: 1.0–2.8], $P = 0.048$), and it was 3.2 times higher at prosthesis level (HR = 3.2 [95% CI: 1.5–7.0], $P = 0.04$) (Table S1).

3.3 | Prosthesis survival

As given in Table 2, the prosthesis survival rate showed no significant difference between two groups in general (OR = 0.8 [95% CI: 0.3–2.8], $P = 0.56$). Results of subgroup analyses regarding influences of covariates on the prosthesis survival rate of two groups were given in Table 4. There were no significant associations of implant number with prosthesis survival rate within all subgroups ($P > 0.05$).

3.4 | Incidence of complications

As given in Table 2, in general, there was no significant difference between two groups in biological complications (OR = 0.9 [95% CI: 0.5–1.8], $P = 0.78$), provisional prosthesis technical complications (OR = 1.3 [95% CI: 0.7–2.3], $P = 0.42$) and definitive prosthesis technical complications (OR = 1.1 [95% CI: 0.6–2.2], $P = 0.33$). Results of subgroup analyses regarding influences of covariates on the complications of two groups were given in Tables 5 and 6.

3.4.1 | Incidence of biological complications

For patients with poor oral hygiene maintenance, the odds of biological complications in All-on-4 was 70% lower than in All-on-6 (22.8% vs. 47.4%, OR = 0.3 [95% CI: 0.1–0.9], $P = 0.03$).

There were no significant associations of implant number with the incidence of biological complications within other subgroups ($P > 0.05$).

TABLE 2 General comparison of outcome measurements between two groups.

Groups variant	All-on-4	All-on-6	OR/HR (95% CI)	*P*-value
Implant survival at implant level	95.9%	96.4%	1.0 (0.8, 1.2)	0.96
Implant survival at prosthesis level	90.6%	88.4%	0.8 (0.3, 1.8)	0.54
Prosthesis survival	95.1% (192/202)	94.2% (65/69)	0.8 (0.3, 2.8)	0.56
Technical complications of provisional prostheses	40.8% (86/211)	35.0% (21/60)	1.3 (0.7, 2.3)	0.42
Technical complications of definitive prostheses	27.2% (54/202)	24.6% (17/69)	1.1 (0.6, 2.2)	0.33
Biological complications	17.3% (35/202)	18.8% (13/69)	0.9 (0.5, 1.8)	0.78
1st year MBL (mm)	0.4 (0.7)	0.4 (0.6)	—	0.65
5th year MBL (mm)	0.6 (0.9)	0.6 (0.8)	—	0.28
10th year MBL (mm)	0.9 (1.4)	0.8 (0.8)	—	0.14

Abbreviation: MBL, marginal bone loss.

TABLE 3 Subgroup analyses of implant survival at implant level.

Variables	All-on-4 (%)	All-on-6 (%)	*P*-value	HR (95% CI)
Age				
<40 years	100	100	—	—
40 ~ 60 years	96.3	94.6	0.18	0.8 (0.6, 1.1)
≥60 years	95.4	99.3	0.03*	1.7 (1.1, 2.7)
Gender				
Male	93.8	95.2	0.82	1.1 (0.8, 1.3)
Female	98.5	98.6	0.99	1.0 (0.6, 1.7)
Jaw				
Maxilla	91.5	94.1	0.46	1.1 (0.9, 1.4)
Mandible	98.6	99.0	0.49	0.9 (0.5, 1.3)
Opposite dentition				
Natural teeth/fixed prostheses	92.9	94.1	0.88	1.0 (0.6, 1.8)
Full-arch rehabilitation	97.1	96.2	0.42	0.9 (0.7, 1.2)
Removable denture	96.7	100	—	—
Smoking habit				
Nonsmoker	97.8	96.7	0.50	0.9 (0.7, 1.2)
1 ~ 10 cigarettes/day	93.9	92.6	0.72	0.9 (0.6, 1.4)
11 ~ 20 cigarettes/day	85.7	93.7	0.048*	1.7 (1.0, 2.8)
Bruxism				
With	91.7	93.5	0.63	1.1 (0.7,1.7)
Without	96.9	97.4	0.89	0.9 (0.7, 1.3)
Bone quality				
I	95.0	94.3	0.55	0.9 (0.5, 1.4)
II ~ III	97.5	98.1	0.55	0.9 (0.7, 1.2)
IV	91.5	95.7	0.56	1.2 (0.7, 2.0)
Posterior bone quantity				
Adequate	96.7	97.1	0.76	1.0 (0.8, 1.4)
Inadequate	94.2	94.4	0.61	0.9 (0.6, 1.3)
Cantilever length (mm)				
0 ~ 5	96.7	97.2	0.80	1.0 (0.6, 1.3)
5 ~ 10	95.3	95.8	0.55	0.8 (0.5, 1.8)
>10	93.1	94.5	0.21	1.1 (0.4, 4.0)
Definitive prosthesis material				
All-acrylic resin	95.6	96.7	0.61	1.0 (0.6, 1.3)
Acrylic resin with metal occlusal -surfaces	95.2	94.8	0.81	1.0 (0.8, 1.4)
Porcelain-fused-to metal	96.5	96.0	0.70	1.0 (0.7, 1.2)
Zirconia	94.0	94.2	0.87	0.9 (0.7, 1.3)
Oral hygiene				
Good maintenance	97.2	98.7	0.52	1.1 (0.8, 1.5)
Poor maintenance	94.4	94.3	0.17	1.0 (0.6, 1.1)

*$P < 0.05$ was taken as the statistical significance level.

3.4.2 | Incidence of technical complications

For patients with bruxism, the risk of technical complications of provisional prostheses in All-on-4 was 3.5 times higher than in All-on-6 (69.2% vs. 39.1%, OR = 3.5 [95% CI: 1.1–11.4], $P = 0.04$).

When the CL of the provisional prostheses was >10 mm, the risk of technical complications of provisional prostheses in All-on-4 was 5.7 times higher than in All-on-6 (74.1% vs. 33.3%, OR = 5.7 [95% CI: 1.1–29.2], $P = 0.03$).

For all-acrylic provisional prostheses without fiber reinforcement, the risk of fracture in All-on-4 was 2.2 times higher than in All-on-6 (43.8% vs. 26%, OR = 2.2 [95% CI: 1.1–4.5], $P = 0.03$).

There were no significant associations of implant number with the incidence of technical complications of provisional prostheses within other subgroups ($P > 0.05$).

There were no significant associations of implant number with the incidence of technical complications definitive prostheses within all subgroups (Table S7) ($P > 0.05$).

3.5 | Marginal bone loss

As given in Table 2, the 1st, 5th, and 10th year MBLs showed no significant difference between two groups in general ($P = 0.65$, $P = 0.28$, and $P = 0.14$). Results of subgroup analyses regarding influences of various covariates on the MBL at the 1st, 5th, and 10th year of two groups were given in Table 7. There were no significant associations of implant number with the 1st year MBL within all subgroups ($P > 0.05$).

When the opposite dentition was natural teeth (or fixed prostheses), the MBL at the 5th and 10th year were significantly higher in All-on-4 than All-on-6 (0.8 [1.0] mm, 1.0 [1.0] mm versus 0.7 [0.9] mm, 0.7 [0.8] mm; $P = 0.03$, $P = 0.02$).

For patients smoking 1 ~ 10 and 11 ~ 20 cigarettes/day, the MBL at 10th year was significantly higher in All-on-4 than All-on-6 (1.1 [0.9] mm, 1.3 [1.2] mm versus 0.8 [0.5] mm, 0.9 [1.1] mm; $P = 0.03$, $P = 0.02$).

For patients with low bone density (class IV), the MBL at 5th and 10th year were significantly higher in All-on-4 than All-on-6 (1.1 [1.0] mm, 1.1 [1.2] mm versus 0.7 [1.0] mm, 0.8 [1.0] mm; $P = 0.04$, $P = 0.04$).

There were no significant associations of implant number with the 5th and 10th year MBL within other subgroups ($P > 0.05$).

3.6 | Factors affecting clinicians' decision making on implant number

The interviewed clinicians showed significant preference for All-on-6 when the patients had adequate posterior bone quantity, long cantilever, bruxism, opposing natural/fixed dentition, maxilla

TABLE 4 Subgroup analyses of prosthesis survival.

Variables	All-on-4% (*n*)	All-on-6% (*n*)	OR (95% CI)	*P*-value
Age				
<40	100 (12)	100 (2)	—	1.0
40 ∼ 60 years	94.3 (99)	94.5 (35)	1.1 (0.2, 5.5)	1.0
≥60 years	95.3 (81)	93.3 (28)	0.7 (0.1, 4.0)	0.65
Gender				
Male	92.6 (101)	93.5 (43)	1.1 (0.3, 4.5)	1.0
Female	96.8 (91)	95.7 (22)	0.7 (0.1, 7.4)	1.0
Jaw				
Maxilla	92.2 (71)	91.9 (34)	1.0 (0.2, 4.1)	1.0
Mandible	96.8 (121)	96.9 (31)	1.0 (0.1, 9.5)	1.0
Opposite dentition				
Natural teeth/fixed prostheses	92.6 (51)	95.8 (23)	1.4 (0.1, 13.7)	1.0
Full-arch rehabilitation	95.8 (114)	95.2 (40)	0.9 (0.2, 4.7)	1.0
Removable denture	93.1 (27)	100 (3)	—	1.0
Smoking habit				
Nonsmoker	96.6 (144)	100 (49)	—	0.34
1 ∼ 10 cigarettes/day	93.9 (31)	83.3 (10)	0.3 (0.1, 2.6)	1.0
11 ∼ 20 cigarettes/day	85.0 (17)	75.0 (6)	0.5 (0.1, 4.0)	0.61
Bruxism				
With	88.5 (23)	91.3 (21)	1.4 (0.2, 9.0)	1.0
Without	96.0 (169)	95.7 (44)	0.9 (0.2, 4.5)	1.0
Bone quality				
I	100 (20)	100 (8)	—	1.0
II ∼ III	95.6 (153)	94.4 (51)	0.8 (0.2, 3.1)	0.72
IV	86.3 (19)	85.7 (6)	1.0 (0.1, 10.9)	1.0
Posterior bone quantity				
Adequate	95.7 (90)	94.0 (47)	0.7 (0.2, 3.2)	0.64
Inadequate	94.4 (98)	94.7 (18)	1.1 (0.1, 9.7)	1.0
Cantilever length (mm)				
0 ∼ 5	97.8 (44)	100 (19)	—	1.0
5 ∼ 10	94.6 (123)	92.7 (38)	0.7 (0.2, 2.9)	0.70
>10	92.6 (25)	88.9 (8)	0.6 (0.1, 8.0)	1.0
Definitive prosthesis material				
All-acrylic resin	96.0 (72)	95.0 (19)	0.8 (0.1, 8.1)	1.0
Acrylic resin with metal occlusal -surfaces	95.6 (43)	93.3 (14)	0.7 (0.1, 7.7)	1.0
Porcelain-fused-to metal	96.7 (29)	100 (10)	—	1.0
Zirconia	92.3 (48)	91.7 (22)	0.9 (0.2, 5.4)	1.0
Oral hygiene				
Good maintenance	95.1 (117)	94.0 (47)	0.9 (0.2, 3.4)	1.0
Poor maintenance	94.9 (75)	94.7 (18)	1.0 (0.1, 9.1)	1.0

to restore and demand to rehabilitate up to the second molars. Besides, the implant prosthodontists and the medium-experienced clinicians showed significant preference for All-on-6 than implant surgeons and well-experienced clinicians (Table S7) ($P < 0.05$).

4 | DISCUSSION

Many clinicians are confronted with the dilemma of choosing 4 or 6 implants to support full-arch immediate fixed prostheses, since the long-term clinical results of both protocols have been proved by many

TABLE 5 Subgroup analyses of biological complications (at prosthesis level).

Variables	All-on-4% (*n*)	All-on-6% (*n*)	OR (95% CI)	*P*-value
Age				
<40	16.7 (2)	0	—	1.0
40 ~ 60 years	20.9 (22)	21.6 (8)	1.0 (0.4, 2.4)	0.93
≥60 years	12.9 (11)	16.7 (5)	0.7 (0.2, 2.4)	0.76
Gender				
Male	18.3(20)	19.6(9)	0.9 (0.4, 2.2)	0.86
Female	16.1(15)	17.4(4)	0.9 (0.3, 3.1)	1.0
Jaw				
Maxilla	18.2(14)	21.6(8)	0.8 (0.3, 2.1)	0.67
Mandible	16.8(21)	15.6(5)	1.1 (0.4, 3.2)	0.87
Opposite dentition				
Natural teeth/fixed prostheses	16.7(9)	16.7(4)	1.0 (0.3, 3.6)	1.0
Full-arch rehabilitation	19.3(23)	21.4(9)	0.9 (0.4, 2.1)	0.77
Removable denture	10.3(3)	0	—	1.0
Smoking habit				
Nonsmoker	12.8(19)	12.2(6)	1.1 (0.4, 2.8)	0.93
1 ~ 10 cigarettes/day	27.3(9)	33.3(4)	0.8 (0.2, 3.1)	0.72
11 ~ 20 cigarettes/day	35(7)	37.5(3)	0.9 (0.2, 4.9)	1.0
Bruxism				
With	19.2(5)	21.7(5)	0.9 (0.2, 3.4)	0.44
Without	17.0(30)	17.4(8)	1.0 (0.4, 2.3)	0.97
Bone quality				
I	15(3)	12.5(1)	1.2 (0.1, 14.0)	1.0
II ~ III	17.5(28)	18.5(10)	0.9 (0.4, 2.1)	0.87
IV	18.1(4)	28.6(2)	0.6 (0.1, 4.0)	1.0
Posterior bone quantity				
Adequate	14.9(14)	16(8)	0.9 (0.4, 2.4)	0.86
Inadequate	19.4(21)	26.3(5)	0.7 (0.2, 2.1)	0.49
Definitive prosthesis material				
All-acrylic resin	18.6(14)	25(5)	0.7 (0.2, 2.3)	0.54
Acrylic resin with metal occlusal -surfaces	13.3(6)	13.3(2)	1.0 (0.2, 5.6)	1.0
Porcelain-fused-to metal	16.7(5)	20(2)	0.8 (0.1, 5.0)	1.0
Zirconia	19.2(10)	16.7(4)	1.2 (0.3, 4.3)	1.0
Oral hygiene				
Good maintenance	13.8 (17)	8 (4)	1.8 (0.6, 2.8)	0.30
Poor maintenance	22.8 (18)	47.4 (9)	0.3 (0.1, 0.9)	0.03*

*$P < 0.05$ was taken as the statistical significance level.

studies to be predictable.[19–22] Although two studies showed that the clinical outcomes were comparable between the 2 protocols in maxillae, and All-on-4 seems to be more cost- and time-effective and less invasive, some clinicians still choose All-on-6 in consideration of some patient- and clinician-related influential factors. Many clinicians make subjective treatment decision due to the lack of relevant scientific evidence on treatment effect among patients with certain characteristics. Specifically, there is a knowledge gap in studies assessing the modification effect of various patient and clinician characteristics on the implant number-clinical outcome association. In addition, factors affecting clinicians' choices of implant number in FAFP cases were less known.

In order to provide some reference for this yet to be explored 4 versus 6 issue concerned by implant clinicians worldwide this retrospective study analyzed and compared influences of covariates on the long-term results of All-on-4 and All-on-6 protocols.

TABLE 6 Subgroup analyses of technical complications of provisional prostheses (at prosthesis level).

Variables	All-on-4% (*n*)	All-on-6% (*n*)	OR (95% CI)	*P*-value
Age				
<40	33.3 (4)	50.0 (1)	0.5 (0.0, 10.3)	1.0
40 ~ 60 years	48.6 (53)	33.3 (11)	1.9 (0.8, 4.3)	0.12
≥60 years	32.2 (29)	36.0 (9)	0.9 (0.3, 2.1)	0.72
Gender				
Male	44.3 (51)	32.5 (13)	1.7 (0.8, 3.5)	0.19
Female	36.5 (35)	40.0 (8)	0.9 (0.3, 2.3)	0.77
Jaw				
Maxilla	36.0 (31)	32.1 (9)	1.2 (0.5, 3.0)	0.71
Mandible	44.0 (55)	37.5 (12)	1.3 (0.6, 2.9)	0.51
Opposite dentition				
Natural teeth/fixed prostheses	52.5 (31)	52.6 (10)	1.0 (0.4, 2.8)	0.10
Full-arch rehabilitation	40.7 (50)	26.3 (10)	1.9 (0.9, 4.3)	0.11
Removable denture	17.2 (5)	33.3 (1)	0.4 (0.0, 5.5)	0.48
Smoking habit				
Nonsmoker	41.3 (60)	32.6 (14)	1.5 (0.7, 3.0)	0.30
1 ~ 10 cigarettes/day	45.7 (16)	40.0 (4)	1.3 (0.3, 5.3)	1.0
11 ~ 20 cigarettes/day	47.6 (10)	42.9 (3)	1.2 (0.2, 6.8)	1.0
Bruxism				
With	69.2 (18)	39.1 (9)	3.5 (1.1, 11.4)	0.04*
Without	36.8 (68)	27.0 (12)	1.2 (0.6, 2.6)	0.62
Bone quality				
I	45.0 (9)	25.0 (2)	2.5 (0.4, 15.3)	0.42
II ~ III	41.3 (69)	38.3 (18)	1.1 (0.6, 2.0)	0.71
IV	33.3 (8)	20.0 (1)	2.0 (0.2, 21.0)	1.0
Posterior bone quantity				
Adequate	34.0 (32)	32.0 (16)	1.1 (0.5, 2.3)	0.80
Inadequate	46.1 (54)	50.0 (5)	0.9 (0.2, 3.1)	1.0
Cantilever length (mm)				
0 ~ 5	20.0 (10)	32.0 (8)	0.5 (0.2, 1.6)	0.25
5 ~ 10	41.8 (56)	38.5 (10)	1.2 (0.5, 2.7)	0.75
>10	74.1 (20)	33.3 (3)	5.7 (1.1, 29.2)	0.03*
Material				
All-acrylic resin	54.0 (74)	38.0 (19)	1.9 (0.1, 3.7)	0.05
Reinforced with fiber	16.2 (12)	20.0 (2)	0.8 (0.1, 4.1)	0.76
Incidence of fracture				
Material				
All-acrylic resin	43.8 (60)	26.0 (13)	2.2 (1.1, 4.5)	0.03*
Reinforced with fiber	10.8 (8)	20.0 (2)	0.5 (0.1, 2.7)	0.34

*$P < 0.05$ was taken as the statistical significance level.

4.1 | The clinical results were comparable between two groups

Generally speaking, the clinical results were comparable between two groups. The implant survival, prosthesis survival, complications, and MBL showed no significant difference between two groups in general ($P > 0.05$).

These results were in accord with the previous studies by Tallarico and colleagues and Toia and colleagues[1,23] Although the studies showed comparable outcomes between All-on-4 and All-on-6, Tallarico and colleagues stated that patient demand, compliance, dexterity, financial capability, skeletal maxillomandibular relationship, and residual bone anatomy had to be taken into consideration to customize the proper implant number, position,

TABLE 7 Subgroup analyses of MBL at the 1st, 5th, and 10th year.

MBL (mm) Variables	The 1st year			The 5th year			The 10th year		
	All-on-4	All-on-6	*P*-value	All-on-4	All-on-6	*P*-value	All-on-4	All-on-6	*P*-value
Age									
<40	0.3 (0.0)	0.3 (0.1)	0.49	0.5 (0.7)	0.6 (0.6)	0.20	0.6 (0.7)	0.6 (0.7)	0.50
40 ~ 60 years	0.4 (0.5)	0.4 (0.5)	0.43	0.6 (0.6)	0.7 (0.8)	0.85	0.8 (0.7)	0.7 (0.8)	0.91
≥60 years	0.4 (0.6)	0.4 (0.5)	0.38	0.7 (0.8)	0.6 (0.8)	0.57	1.0 (1.0)	0.4 (0.2)	0.11
Gender									
Male	0.4 (0.7)	0.4 (0.6)	0.08	0.5 (0.7)	0.6 (0.8)	0.06	0.7 (0.6)	0.6 (0.5)	0.28
Female	0.4 (0.4)	0.4 (0.4)	0.39	0.7 (0.8)	0.7 (0.7)	0.55	0.9 (0.9)	0.8 (0.8)	0.58
Jaw									
Maxilla	0.5 (0.7)	0.5 (0.8)	0.69	0.8 (1.0)	0.7 (0.9)	0.13	0.9 (0.6)	0.7 (0.7)	0.70
Mandible	0.4 (0.0)	0.4 (0.0)	0.69	0.6 (0.7)	0.5 (0.5)	0.27	0.8 (0.7)	1.0 (0.9)	0.26
Opposite dentition									
Natural teeth/ fixed prosthesis	0.5 (0.7)	0.5 (0.6)	0.34	0.8 (1.0)	0.7 (0.9)	0.03*	1.0 (1.0)	0.7 (0.8)	0.02*
Full-arch rehabilitation	0.3 (0.5)	0.3 (0.5)	0.96	0.5 (0.7)	0.6 (0.7)	0.82	0.9 (1.1)	0.8 (0.9)	0.39
Removable denture	0.4 (0.5)	0.4 (0.5)	0.40	0.6 (0.7)	0.4 (0.5)	0.23	0.7 (0.9)	0.6 (0.6)	0.70
Smoking habit									
Nonsmoker	0.4 (0.8)	0.5 (0.6)	0.29	0.6 (0.9)	0.6 (0.8)	0.86	0.6 (0.8)	0.6 (0.9)	0.77
1 ~ 10 cigarettes/day	0.5 (0.8)	0.4 (1.0)	0.30	0.7 (1.1)	0.8 (1.3)	0.46	1.1 (0.9)	0.8 (0.5)	0.03*
11 ~ 20 cigarettes/day	0.7 (1.0)	0.5 (0.9)	0.41	0.9 (1.1)	0.8 (0.7)	0.12	1.3 (1.2)	0.9 (1.1)	0.02*
Bruxism									
With	0.6 (0.6)	0.4 (0.6)	0.22	0.7 (1.0)	0.8 (0.9)	0.77	1.0 (1.1)	0.9 (0.8)	0.11
Without	0.4 (0.5)	0.4 (0.5)	0.39	0.6 (1.0)	0.6 (0.8)	0.43	0.8 (0.9)	0.7 (0.8)	0.36
Bone quality (Lekholm and Zarb classification)									
I	0.3 (0.0)	0.3 (0.1)	0.48	0.5 (0.4)	0.5 (0.3)	0.47	0.7 (0.2)	0.6 (0.4)	0.82
II ~ III	0.3 (0.4)	0.3 (0.6)	0.95	0.7 (0.7)	0.6 (0.8)	0.55	0.8 (0.9)	0.8 (1.0)	0.20
IV	0.6 (0.4)	0.6 (0.5)	0.62	1.1 (1.0)	0.7 (1.0)	0.04*	1.1 (1.2)	0.8 (1.0)	0.04*
Posterior bone quantity									
Adequate	0.4 (0.6)	0.4 (0.4)	0.19	0.6 (0.8)	0.5 (0.8)	0.27	0.6 (0.8)	0.6 (0.7)	0.29
Inadequate	0.4 (0.5)	0.4 (0.3)	0.36	0.7 (0.8)	0.7 (0.9)	0.58	0.9 (0.7)	0.9 (0.9)	0.48
Definitive prosthesis material									
All-acrylic resin	0.4 (0.6)	0.4 (0.7)	0.27	0.7 (0.8)	0.7 (0.7)	0.48	1.0 (0.9)	0.8 (0.8)	0.45
Acrylic resin with metal occlusal-surfaces	0.5 (0.3)	0.6 (0.2)	0.58	0.6 (0.7)	0.7 (0.4)	0.47	0.9 (0.6)	0.8 (0.7)	0.39
Porcelain-fused-to metal	0.4 (0.4)	0.4 (0.2)	0.57	0.6 (0.7)	0.6 (0.8)	0.36	0.7 (0.9)	0.7 (0.8)	0.49
Zirconia	0.4 (0.4)	0.5 (0.6)	0.60	0.7 (0.7)	0.7 (0.9)	0.77	—	—	—
Oral hygiene									
Good maintenance	0.4 (0.1)	0.4 (0.0)	0.45	0.6 (0.8)	0.6 (0.9)	0.58	0.8 (0.7)	0.7 (0.9)	0.48
Poor maintenance	0.4 (0.4)	0.5 (0.2)	0.50	0.6 (0.7)	0.7 (0.8)	0.36	1.0 (0.9)	0.9 (0.8)	0.49

Abbreviation: MBL, marginal bone loss.
*$P < 0.05$ was taken as the statistical significance level.

and dental prostheses. Toia and colleagues also proposed that convenience of hygienic maintenance, financial exposure, extra bone regeneration procedure (surgical invasiveness), and cost of repairing should be taken into consideration. Thus, analysis on these characteristics is in urgent demand.

4.2 | Elderly patients had lower risk of implant failure in All-on-6 group

According to this study, for elderly (≥60 years) patients, the risk of implant failure was significantly higher in All-on-4 than All-on-6 ($P = 0.03$).

The age-related differentiation in implant survival may be related to bone density and short vertical dimension of elderly patients. The finite element analysis of Sugiura and colleagues[30] in 2018 found that the density of cancellous bone had a significant impact on the micro motion of implant, reducing the cantilever during healing can effectively reduce the maximum micro motion of implant. Zhu and colleagues[31] reported that, the prevalence of osteoporosis in the elderly people (≥60 years) was 37.7% in China, (60–69 years: 32.2%; 70–79 years: 41.9%; ≥80 years: 51.8%). Using 6 implant to support the immediate loading FAFPs could effectively reduce the cantilever and micro motion of implant at the early stage of healing, thus reducing the risk of implant failure.

Meanwhile, the elderly patients' vertical dimension is mostly decreased for atrophy of jaws or occlusion loss. Sometimes the vertical dimension is not reconstructed properly. Patients with compromised vertical dimension tend to have excessive occlusal force, thus increasing the risk of implant failure. Six-implant supported FAFPs has a better distribution and support for the increased centric and lateral occlusal force, thus reducing the risk of implant failure.

4.3 | Smokers had lower risk of implant failure and MBL in All-on-6 group

For patients smoking 11 ∼ 20 cigarettes/day, the risk of implant failure was significantly higher in All-on-4 than All-on-6 ($P = 0.02$). For patients smoking 1 ∼ 10 and 11 ∼ 20 cigarettes/day, the MBL at the 10th year was significantly higher in All-on-4 than All-on-6 ($P = 0.03$, $P = 0.02$).

Smoking has been proved to be a risk factor for implant failure and MBL by researchers.[32–36] Yang and colleagues[37] demonstrated that the cigarette smoke extract exposure changed the micromorphology and elemental composition of titanium surface of the implants due to the carbon-containing compounds adsorption, which in turn influenced the osteoblast-titanium interactions, thus inhibiting the implant osseointegration. Moreover, Javed and colleagues[38] hypothesized that nicotine and other chemicals in tobacco smoke induced a state of oxidative stress in peri-implant tissues (gingiva and alveolar bone), with raised levels of proinflammatory cytokines identified in the gingival crevicular fluid of smokers, consequently increasing the likelihood of peri-implant disease development via an inflammatory response. If the peri-implant disease left uncontrolled, implant failure/loss will happen.

For smokers and nonsmokers, the difference of MBL between two groups may be related to the different micromotion and elemental stress distribution of the implants in resistance to the cigarette's bone remodeling effect. Implant deosseointegration caused by chemicals contained in cigarettes would increase the micromotion of the implant.[39] And micromotion of the implants would conversely induce more MBL. In All-on-6 group, since the cantilever was shorter, and the implants were more rigidly and stably connected, the occlusal force was better distributed and conducted. In consequence, the micromotion of the implants may be reduced to some extent. Hence, for smokers, using six implants in FAFPs may have a protective and preventive effect on the marginal bone level of implants.

4.4 | Patients with poor oral hygiene had more biological complications in All-on-6 group

For patients with poor oral hygiene maintenance, the incidence of biological complications was significantly lower in All-on-4 than All-on-6 ($P = 0.03$).

Poor hygienic maintenance would cause plaque accumulation around implants and on the interface of prostheses. Meanwhile, Serino and colleagues[40] and Lindhe and colleagues[40] demonstrated that bacteria was the initial factor for peri-implant mucositis and peri-implantitis.

Toia and colleagues[23] stated that the hygienic maintenance of All-on-6 was more complicated than All-on-4 owing to the reduced inter-implant space. The more implant number and the more distal position of the posterior implants in All-on-6 also increased the difficulty and time to clean each implant carefully and thoroughly. Especially for patients with poor oral hygiene habits, and not compliant for regular professional cleaning and maintenance, all the supporting implants may have peri-implant mucositis. As a consequence, the incidence of biological complications was higher in All-on-6 than All-on-4. For special patients including the elderly, the handicapped, patients with Parkinson's and patients with some mental disease, it would be even more difficult to maintain the oral hygiene by themselves as well as their care-takers.

4.5 | Patients with bruxism had less technical complications in All-on-6 group

For patients with bruxism, the incidence of technical complications of provisional prostheses was significantly higher in All-on-4 than All-on-6 ($P = 0.04$). Meanwhile, for patients with bruxism, clinicians showed significant preference for All-on-6 ($P < 0.05$).

Bruxism means an oral habit consisting of involuntary rhythmic or spasmodic parafunctional gnashing, grinding, or clenching of teeth, in nonchewing movements of the mandible, that can lead to occlusal trauma.[41] Bruxism has been proved to be related to technical complications by many studies.[42–44] Maló and colleagues[45] reported that bruxism was a risk factor for technical complications with an OR of 60.95. Ji and colleagues[46] reported that the implant failure rate was significantly higher in patients with bruxism (29.3%), than in patients without bruxism (4.6%).

Lobbezoo and colleagues[47] stated that bruxism may cause excessive occlusal load on dental implants and their suprastructures, which may ultimately result in implant MBL or even implant failure.

With the long-term accumulation of the excessive occlusal load, tooth wear, prosthesis material fatigue, and technical complications (including fracture and screw loosening) may occur.

Six-implant supported FAFPs had a better distribution and support for the increased centric and lateral occlusal force, thus reducing the risk of technical complications.

4.6 | Provisional prostheses with long cantilever had less technical complications in All-on-6 group

When the CL of the provisional prostheses was >10 mm, the incidence of technical complication of provisional prostheses was significantly higher in All-on-4 than All-on-6 ($P = 0.03$). Meanwhile, for patients with excessive expected cantilever, clinicians showed significant preference for All-on-6 ($P < 0.05$).

Long CL was reported as a risk factor of prostheses fracture and screw loosening in previous studies.[48,49] Walter and colleagues[49] stated that long CL without sufficient support could result in stress on a prosthesis, which could cause screw loosening, screw breakage, prosthesis fracture, implant fracture, and implant deosseointegration. The CL is suggested to be minimized for biomechanical considerations.

Studies indicated that the CL could be determined by anterior–posterior (A–P) spread,[50–52] and the CL/A-P ratio was suggested in a range of 0.4–1. Drago[53] evaluated the CL/A-P ratios and complications in full-arch interim all-acrylic resin prostheses, and found that CL/A-P ratios in the range of 0.5–0.6 generally resulted in successful interim prostheses. Walter and colleagues[49] proposed that CL was not solely based on AP spread, other characteristics (such as maxillae or mandible, bone quality, implant distribution, rehabilitation design, prosthesis materials, etc.) should also be taken into consideration.

According to the measurements in this study, if the anterior 2 implants were at the same sites, the last two distal implants of All-on-6 would extend AP for 5 mm averagely (ranging from 2 to 7 mm) and reduce the CL. In consequence, the prostheses would be allowed to get longer cantilever with extended AP.

4.7 | All-acrylic (without reinforcement) provisional prostheses had lower fracture rate in All-on-6 group

For all-acrylic (without fiber reinforcement) provisional prostheses, the incidence of fracture was significantly higher in All-on-4 than All-on-6 ($P = 0.03$).

The CL/AP ratio of All-on-4 is usually higher than All-on-6. Walter and colleagues[49] reported that long CL without sufficient support could result in stress on a prosthesis especially at the cantilever site, and the prosthesis material was one of the influential factor. Skalak[54] stated that the distribution of load caused by means of a cantilever depended on the strength of the material used to fabricate the restorative framework. Walter and colleagues[49] concluded that the more rigid the prosthesis was, the more evenly the forces were distributed, so that the cantilever was more resistant to deformation and could be longer.

Polyzois and colleagues[55] showed that the fracture and flexural strength of acrylic resin reinforced with metal wire were significantly higher than all-acrylic resin. Li and colleagues[27] reported that the fracture rate of the provisional prostheses was significantly lower in carbon fiber reinforced group than the all-acrylic group ($P = 0.001$). The rate of fracture at the cantilever was 29.0% for all-acrylic provisional prostheses, and 2.5% for fiber-reinforced provisional prostheses. Minami and colleagues[56] also showed increased strength of denture base with the use of metal wires (stainless steel or Co-Cr-Ni wire). Heidari and colleagues[57] reported that heat cure acrylic resin reinforced with glass fiber showed the highest flexural strength compared with other reinforcement materials including polyethylene fibers, and metal wire.

Therefore, all-acrylic material without reinforcement is more vulnerable to technical complications. Reinforcing provisional prostheses with metal, carbon or glass fibers is a cost-effective way to enhance the strength of the acrylic prostheses and to reduce the fracture, especially for 4-implant supported immediate provisional FAFPs.

4.8 | Patients with opposing natural/fixed dentition had lower MBL in All-on-6 group

For patients with opposing natural/fixed dentition, the MBL at the 5th and 10th year were significantly higher in All-on-4 than All-on-6 ($P = 0.03$, $P = 0.02$). Meanwhile, for patients with opposing natural/fixed dentition, clinicians showed significant preference for All-on-6 ($P < 0.05$).

Shetty and colleagues[58] demonstrated that natural teeth were sensitive to even a very small occlusal force and could recognize the discrimination of its direction and magnitude, wherein the enamel-dentine-pulp complex and the mechanoreceptors on the periodontal ligament of the natural teeth formed the peripheral feedback system, which the implants lacked. The overload on the implants was usually not easily and timely perceived, thus becoming a common risk factor for implant's MBL.[59]

Bakke[60] stated that the maximum bite force of the natural teeth of healthy adults in the molar area is between 300 and 600 N. Gross MD[61] suggested that when the opposite dentition is natural teeth (or fixed prostheses), the occlusion pattern is usually mutual protection occlusion and anterior disocclusion for eccentric guidance.

Tanaka and colleagues[62] stated that the average maximum occlusal force of removable denture is reported to be 97.1 N (ranging from 28.2 to 166.5 N), which is significantly lower than natural teeth. Tarazi and colleagues[63] suggested that when the opposite dentition is removable denture, the occlusion pattern is mainly bilateral balanced occlusion in order to attain stability of the dentures when bilateral contacts exist throughout all dynamic and static states.

Thus, FAFPs bears higher and more concentrated occlusal force when the opposite dentition is natural teeth (or fixed prostheses). Using six implants can better distribute the occlusal force and reduce the force on each implant and reduce the flexural force on the cantilever and thus the distal implant.

However, the influences of opposite dentition on clinical results of FAFPs varied in different studies. Karasan and colleagues[64] reported that the opposite dentition was not related to implant failure.

4.9 | Patient with class IV bone had lower MBL in All-on-6 group

For patients with low bone density (class IV), the MBL at the 5th and 10th year was significantly higher in All-on-4 than All-on-6 ($P = 0.04, 0.04$).

These results were in accord with the previous studies. Pisulkar and colleagues[65] stated that implant success was dependent on implant stability, which had a direct relationship with the regional bone quality. The finite element analysis of Sugiura and colleagues[30] in 2018 found that the density of cancellous bone had a significant impact on the micro motion of implant, reducing the cantilever can effectively reduce the maximum micro motion of implant. And 6-implant supported FAFPs can effectively reduce the cantilever and micromotion of the implants, thus reducing the risk of bone resorption.

4.10 | Both patient- and clinician-related factors influenced the decision making on implant number

Clinicians showed significant preference for All-on-6 with the influence of multiple factors.

For patients with the demand of rehabilitation up to the second molars, clinicians showed significant preference for All-on-6 ($P < 0.05$). Naka and colleagues[66] revealed that chewing ability was closely related to the number and distribution of the remaining teeth. Steele and colleagues[67] reported a significant linear relationship between the number of missing occlusal units and adverse effects on oral-health related quality of life. Nam and colleagues[68] reported an objective increase in load-bearing contact area and a satisfaction improvement after the restoration of 1 s molar supported by implant. In clinical practice, patients who still retained the second molars in opposite dentition would have the demand of rehabilitation up to the second molars. In this case, the occlusal force and prosthesis length would likely to exceed the recommended criteria of All-on-4, thus All-on-6 was recommended.

For maxillary full-arch rehabilitation, clinicians showed significant preference for All-on-6 ($P < 0.05$). This tendency was in accord with the fact that All-on-6 were mostly conducted in the maxillae according to the present literature.[1,69–71] The clinicians chose to place six implants in the maxillae in the fear of the possible implant loss especially for low bone density condition, and in order to reduce the cantilever and undesirable occlusal force conducted to the implants. Toia and colleagues[23] stated that when choosing the protocol of a reduced number of implants, one common concern was that losing an implant may require an extra surgical procedure in order to substitute it, which was often considered unnecessary for All-on-6. As for All-on-4, only 1 implant loss may cause the inability of using the complete fixed prosthesis. While for All-on-6, even if 1 or 2 implant loss occurs, the other 4 or 5 implants can still well support the fixed prostheses, with little modification, which was also more acceptable for the patients.

Clinicians showed significant preference for All-on-6 when the posterior bone was adequate ($P < 0.05$). Chan and colleagues[72] reviewed that in staged surgical procedure, many clinicians performed traditional grafting procedure when there was bone deficiency prior to implant placement, and utilization of the "All-on-4" concept had overcome some of these anatomic restrictions. When the posterior bone was adequate, many clinicians would choose All-on-6 without extra invasive surgery, in order to utilize the good bone quantity to the maximum, rehabilitate the function optimally, and better deal with the influential factors discussed in this study.

In spite of the anatomic limitations at the posterior areas of the maxillae due to atrophy or innate low-set maxillary sinus, clinicians sometimes still choose All-on-6 for a more reliable long-term result, in consideration of the multiple characteristics such as excessive CL and low-density bone. In this case, bone augmentation is often inevitable, and the implants at the bone augmentation sites usually have a final torque less than 35 N cm and can only be delayed loaded. In this study, among All-on-6 group, there was 14 out of 37 patients (37.8%) received bone augmentation (12 sinus lift and 2 guided bone regeneration) in the maxillae, and there were 9 cases with embedded implants until definitive restoration, which was common in clinical practice.

Compared with well-experienced (>10 years), medium-experienced clinicians (5 ∼ 10 years), had a significant preference for All-on-6 ($P < 0.05$). The loss of even 1 implant in the All-on-4 may cause inability to support the prosthesis. Since the supplementary implant is not able to have exactly same position and axis as the original failed implant, meanwhile precise and passive fit is the basic principle for fixed prosthesis, a new prosthesis must be re-manufactured. It was both cost- and time-consuming for the patients as well as clinicians. Medium-experienced clinicians usually showed less confidence in the long-term survival of the implants, so that to choose All-on-6 just in case of implant failure.

The implant prosthodontists showed a significant preference for All-on-6 ($P < 0.05$). From the perspective of implant surgeons, All-on-4 could minimize the invasion and avoid some complicated bone augmentation by tilting the distal implant when the bone volume was insufficient in the posterior areas. Some advanced bone augmentation techniques especially lateral wall sinus elevation and vertical guided bone regeneration would increase the difficulty, risk, duration of the operation, postoperative reactions (swelling and pain) and surgical complications (infection), healing process, whole treatment duration, as well as the financial cost for the patients. The sophisticated bone augmentation procedures also had high technical sensitivity and demand for the implant surgeons. From the perspective of the implant prosthodontists, All-on-6 was able to minimize the cantilever[49] and to rehabilitate up to the second molars, so as to reduce the possible technical complications and the potential time and cost for the repair.

Based on the discussion above, the decision on the number of implants should not be made by one person, but by a team approach,

including the implant surgeon, the implant prosthodontist, the dental technician, and the patient. All the patient- and clinician-related factors should be assessed carefully, and a multidisciplinary and comprehensive plan needs to be made after a thorough communication and discussion. Balance and compromise have to be made when different perspectives or conflicts exist based on mutual respect and understanding. The final success of the whole treatment protocol is based on a good collaboration and joint efforts of all the team members, which can never be overemphasized.

5 | CONCLUSION

Based on this study, the long-term clinical results showed no significant difference between All-on-4 and All-on-6 groups in general. However, for some specific characteristics, All-on-6 seemed to be more predictable in some clinical measurements than All-on-4. For the clinicians' decision-making, medium-experienced clinicians and the implant prosthodontists showed significant preference for All-on-6.

In the future, more RCTs and multi-center prospective studies, with larger sample size and longer follow-up, as well as more comprehensive patient- and clinician-related factor analyses are still needed to provide a stronger evidence for deciding the number of implants to support FAFPs.

AUTHOR CONTRIBUTIONS

Yan Zhang: Data collection, questionnaire design, preparation of the manuscript, detailed analysis of the results, revision of the manuscript. Sha Li: Design of the study, research performing, drafting of the manuscript, discussion and interpretation of the results, critical revision of the manuscript. Ping Di: Data providing, critical revision and approval of the manuscript. Yu Zhang: Data providing, critical revision and approval of the manuscript. Aozhou Wu: Statistical analysis and revision of the manuscript. Ye Lin: Conception of the study, data providing, research performing, idea refining, constructive discussion and analysis, critical revision and finalizing of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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SUPPORTING INFORMATION

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

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