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Retrospective study on the clinical outcomes of small-diameter implants supporting fixed prostheses without bone augmentation in the posterior region after 2 to 12 years

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Abstract

Background: Small-diameter implants (SDIs: diameter <3.5 mm) are often chosen as an alternative to bone augmentation in clinical practice, but the scientific evidence regarding SDI application in the posterior area remains deficient.

Purpose: To evaluate the clinical and radiographic outcomes of SDIs supporting fixed prostheses without bone augmentation in the posterior region, and to analyze the potential influencing factors related to SDI failures.

Materials and Methods: Clinical and radiographic data of 243 SDIs in 156 patients were retrospectively assembled after 2 to 12 (mean 4.75) years of follow-up. Implant and prosthesis failures, mechanical and biological complications, and radiographic marginal bone loss (MBL) were evaluated. The influence of patient/implant characteristics and prosthetic design on SDI failures was investigated.

Results: Five implants in five patients failed, contributing to 10-year cumulative survival rates of 97.9% on an implant-based analysis and 96.8% on a patient-based analysis. Biological complications and mechanical complications were detected in 22 (9.1%) and 31 (12.8%) of implants, respectively. No implant fracture was detected. Peri-implant MBL during 10 years was 0.60 ± 0.90 mm on average. The implant type (bone-level or tissue-level) was the only factor that significantly influenced SDI failures.

Conclusion: SDIs supporting fixed prostheses in the posterior region achieved predictable long-term clinical outcomes. However, tissue-level titanium SDIs should be avoided where possible.

KEYWORDS
complications, marginal bone loss, posterior region, small-diameter implants, survival rate

1 | INTRODUCTION

For decades, implant-supported prostheses have been widely accepted for replacing missing teeth for totally and partially edentulous patients, but several difficulties remain regarding regular-diameter implant placement in clinical practice. For instance, insufficient bone width in the buccal-lingual direction and narrow approximal space between adjacent teeth in the mesial-distal direction prevent patients and their dentists from choosing implants as their optimal choice for restoration. Although horizontal bone augmentation and orthodontic treatment may solve the above-mentioned problems, these extra treatments increase the cost, time, and medical risk of the process. Small-diameter implants (SDIs), which have been defined as dental implants of 3.5 mm in diameter or less,[1,2] might be

considered in such situations to minimize cost, time, and possible surgical injuries, rendering implant therapy more accessible and practical to the edentulous majority.

Since the end of the 1980s, when SDIs became commercially available in the dental field,[3] they have become commonly used in the anterior region due to their geometric advantages.[4] Recent studies have indicated their similar survival rate to regular diameter implants,[1,2] and increasing attention has been paid to their application in different types of edentulism. Papadimitriou et al.[5] conducted a virtual evaluation on the necessity of ridge augmentation when inserting implants of different diameters. The authors concluded that using 3.3-mm-diameter implants could significantly reduce the chance of bone grafting in completely edentulous patients.

However, the use of SDIs-supported restorations in the posterior region is considered aggressive because the strong biting force may increase the risk of implant fracture. Zinsli et al.[6] reported two SDI implant fractures in canine and premolar sites in a clinical follow-up of 10 years. Similarly, Yaltirik et al.[7] retrospectively evaluated 48 SDIs in 28 patients for 5 years and found that two implants had fractured in the posterior region. Although new Ti-Zr implants with high mechanical stress are currently available, SDI fractures continue to occasionally occur in clinical practice.[8]

The majority of clinical studies on SDIs in the literature have generally focused on overall implant survival regardless of the SDI installation sites and have not analyzed the factors influencing SDI failures and complications. Results regarding SDI application at molar and premolar sites remain rare.

For a comprehensive understanding of SDIs, we assembled clinical data of partially edentulous patients who accepted pure titanium SDIs to support fixed restorations in the posterior region without bone augmentation over the recent decade at our clinic. Implants and prostheses failures, mechanical and biological complications as well as radiographic marginal bone loss (MBL) were analyzed. The characteristics and distributions of patients, implants, and prosthetic design were also investigated for factorial analysis, to obtain scientific evidence on SDI applications to support fixed prostheses in the posterior region without bone augmentation in partially edentulous patients.

2 | MATERIALS AND METHODS

2.1 | Study design and ethical approval

A retrospective cohort design was used, and the study design and clinical procedures were performed in accordance with Helsinki Declaration as revised in 2008; the study was approved by the Ethics Committee of the Stomatology Hospital, the School of Medicine, Zhejiang University, China (No. 2018-001). All patients signed an informed consent form.

2.2 | Patient selection

Patients who were consecutively treated at the Department of Oral Implantology at the Stomatology Hospital, the School of Medicine, Zhejiang University, Hangzhou, China from January 2006 to December 2016 were screened. The inclusion criteria were as follows: (a) age ≥18 years, (b) partial edentulism in the posterior region for at least 3 months, (c) received SDI (Straumann Φ3.3 pure titanium implants with SLA surfaces) placement- and implant-supported fixed prostheses without bone augmentation, (d) with a minimum follow-up of 1 years after prostheses installation, (e) systemic and local conditions were compatible with implant placement, and (f) willingness to provide informed consent.

Patients were excluded for the following reasons: (a) uncontrolled diabetes mellitus or other systemic disorders, (b) uncontrolled periodontal conditions, endodontic lesions, or other oral disorders, (c) a history of bisphosphonate therapy, (d) complete edentulism, (e) previous implant installation or bone augmentation at the surgical site, (f) received an implant-supported overdenture or a partial removable denture, (g) lack of compliance.

Smokers were not excluded but were informed that smoking is a risk factor for implant loss and biological complications.

2.3 | Treatment procedures

Φ3.3 implants with or without a polished collar (Straumann pure titanium tissue-level or bone-level implants with SLA surfaces, Institute Straumann AG, Waldenburg, Switzerland) were installed according to the surgical protocol under local anesthesia for every patient. A nonsubmerged or submerged protocol in a one-stage or two-stage procedure was performed. Oral panoramic radiographs were taken after implant placement (baseline). No provisional prosthesis was allowed during the healing period.

All patients returned for restoration 3 months after implant surgery. Oral panoramic radiographs were taken again to examine any radiolucency around the implant. Implant-supported fixed prostheses including screw-retained or cement-retained single crowns and all-ceramic and metal-ceramic fixed bridges with and without cantilever were delivered. No combined tooth-implant-supported bridges or implant-supported overdentures/partial removable dentures were applied.

The patients were recalled every 6 to 12 months. Clinical examination of the implants, prostheses, and peri-implant tissues was conducted. Oral panoramic radiographs were taken to evaluate the peri-implant bone level and radiolucency. Implant loss or other complications were recorded.

2.4 | Outcome measures

2.4.1 | Implant failure and prosthesis failure

Implant survival was determined by the method suggested by Buser et al.[9] and Cochran et al.[10]: (a) the absence of clinically detectable implant mobility, (b) the absence of pain and subjective discomfort, (c) the absence of peri-implant infection, and (d) the absence of continuous radiolucency around the implant. Implant loss, mobility, or removal in case of progressive MBL, severe peri-implant infection, or

implant fracture were considered as implant failure. The implant failures were classified into two categories: early failures (or initial failures) before loading and late failures after loading.

Prosthesis failure was defined as prosthesis loss or remake because of implant failure or other complications.

2.4.2 | Mechanical and biological complications

Implant fracture, abutment fracture, screw loosening or fracture, veneer chipping, breaking of the prosthesis framework, and loss of retention (cement-retained) were included as mechanical complications.

Biological complications were defined as biological processes affecting the supporting tissues, such as postsurgical infection, nerve dysfunction, peri-implant mucositis, and peri-implantitis. Peri-implantitis was set at a probing pocket depth ≥6 mm and bleeding on probing or pus secretion.[11]

2.4.3 | Peri-implant marginal bone loss

Peri-implant marginal bone level was evaluated on digital oral panoramic radiographs taken at implant placement and follow-up visit using a software program (Clinview Software, 6.1.3.7 Version; Instrumentarium Imaging Corporation, Tuusula, Finland). The method was the same as that used in a previous study[12] (Figure 1). All measurements were adjusted to the radio of "true implant length/ implant length on radiograph" to avoid radiographic distortion. The radiographic result at the follow-up visit was compared with that at implant installation to calculate the MBL.

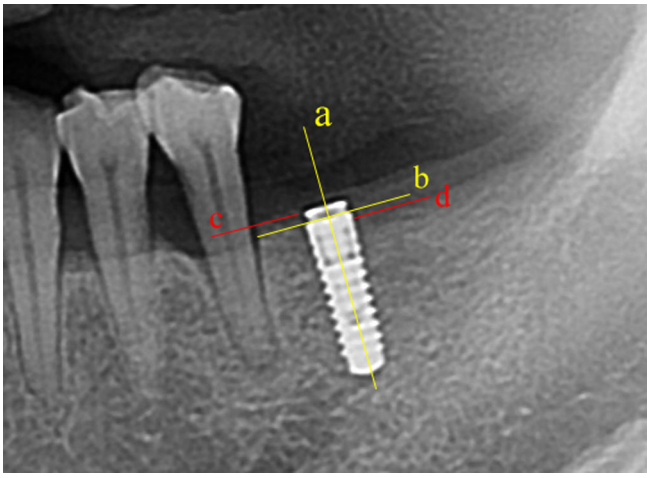

FIGURE 1 Peri-implant marginal bone level measured on radiographs. (A) Implant axis, (B) implant collar line: a line vertical to (A), and crossing the coronal point of the implant, (C) a line vertical to (A), and right cross the coronal point of the mesial bone crest, (D) the same as (C), at the implant distal site. The marginal bone level is the distance between (B) and (C) at the mesial site and the distance between (B) and (D) at the distal site which both parallel to the implant axis. Marginal bone loss was calculated by comparing the radiographic result at follow-up with that at implant installation. All measurements were adjusted to the radio of "true implant length/ implant length on radiograph" for avoid radiographic distortion

2.5 | Statistical analysis

Data collection was performed by two independent examiners (Y.Z. and J.Y.L.). SPSS Software (SPSS 17.0, SPSS, Inc, Chicago, Illinois) was applied to conduct the statistical analyses. Absolute and relative frequency distributions were calculated for qualitative variables. Means and standard deviations were calculated for quantitative variables. The normality of data was investigated using the Kolmogorov-Smirnov test. The homogeneity of variances was verified. To avoid dependencies between multiple implants within one patient, statistics at the patient level and at the implant level were analyzed, respectively. Implant and prosthesis survival were assessed as a function of the time using life-table analysis.

Potential influencing factors of implant survival were first assessed by univariate analysis using one-way ANOVA. The included factors were as follows: patients' gender, age, periodontal status, smoking status, implant length, implant type (tissue-level or bone-level), implant insertion site (premolar or molar, maxilla, or mandible), prosthesis type (single crown or splinted crown or fixed bridge with or without cantilever), prosthesis material (metal-ceramic or all-ceramic), retention type (screw-retained or cement-retained), type of opposing teeth (natural teeth or prosthesis), the reason for SDI installation (narrow approximal space or insufficient bone width), crown-root radio and occlusal force (light or normal). Light occlusal force was defined as no contact for light bites but light contacts for heavy bites, as previously described by Lundgren and Laurell.[13] Any factors showing significant difference were entered into the logistic regression based on a generalized estimating equation (GEE) for further investigation. The significance level was set at .05.

3 | RESULTS

A total of 166 patients met the inclusion criteria. Ten patients were lost of contact during the past years. Therefore, 156 patients (56 males and 100 females) aged from 21 to 82 (mean 51.5) years with 243 SDIs were enrolled in the present study. The follow-up period ranged from 17 to 144 months with an average of 57 months (4.75 years). The patient and implant distributions are shown in Table 1.

3.1 | Implant survival and failure

During the 144-month follow-up, five implants in five patients were lost. The cumulative survival rates were 97.9% on an implant basis and 96.8% on a patient basis (Table 2). Two implants were lost during the healing period (early failure); thus, the early failure rate was 0.8%. Another three implants failed after functional loading. The details of the failed implants are listed in Table 3.

3.2 | Prosthesis failure and complications

The prosthetic design distributions are listed in Table 1. A total of 10 (4.1%) prostheses failed during follow-up: three failed due to implant failures, two failed due to abutment fracture, and five were remade because of major veneer chipping. The cumulative survival rate of the prostheses was 95.9%.

TABLE 1 Patient/implant distributions and survival rates

	Gender		Age (years)			Periodontal status		Smoking status	
	Male	Female	20-34	35-54	55-73	Treated-periodontitis	Nonperiodontitis	Smokers	Nonsmokers
Patient number	56	100	25	60	71	41	115	13	143
Implant number	79	164	29	91	123	71	172	22	221
Implant survival rate	94.9%	99.4%	96.6%	96.7%	99.2%	97.2%	98.3%	90.9%	98.6%
p Value	.022*		.021*			.594		.015*	

	Implant type		Implant length			Implant insertion site (a)		Implant insertion site (b)	
	Tissue-level	Bone-level	8	10	12	Premolar	Molar	Maxillae	Mandible
Implant number	54	189	26	150	66	146	96	80	163
Implant survival rate	94.4%	98.9%	100%	97.3%	98.5%	97.9%	97.9%	96.3%	98.8%
p Value	.040*		.639			.997		.194	

	Prosthesis type				Prosthesis material	
	Single crown	Splinted crown	Rigid fixed bridge	Fixed bridge with cantilever	Metal-ceramic	All-ceramic
Implant number	89	69	50	35	132	111
Implant survival rate	96.6%	98.6%	98%	100%	97.3%	98.5%
p Value	.658				.196	

	Type of opposing teeth				Reason for SDI installation	
	Natural teeth	Implant-supported prosthesis	Tooth-supported prosthesis	Removable denture	Narrow approximal space	Insufficient bone width
Implant number	171	35	32	5	60	183
Implant survival rate	97.7%	97.1%	100%	100%	98.3%	97.8%
p Value	.815				.624	

	Prosthesis retention type		Crown-root ratio		Occlusal force	
	Screw-retained	Cement-retained	≤1	>1	Light	Normal
Implant number	119	124	109	134	98	145
Implant survival rate	96.6%	99.2%	96.%	99.3%	100%	96.6%
p Value	.162		.111		.064	

*Significant differences ($P < .05$) detected by univariate analysis using one-way ANOVA.
Abbreviation: SDI, small-diameter implant.

Biological complications were detected in 22 implants, two of which were postsurgical infections, seven of which were peri-implantitis, and thirteen of which were peri-implant mucositis. No nerve dysfunction was observed. Thirty-one implants resulted in mechanical complications, including two abutment fractures, seven cases of screw loosening, fourteen cases of veneer chipping, and eight cases of loss of retention (cement-retained prostheses). No implant fracture was detected. The total complication rate was 21.9% over the 10-year follow-up (Table 3).

3.3 | Peri-implant marginal bone loss

The overall MBL around the SDIs between implant placement and follow-up visit during 10 years was 0.60 ± 0.90 mm on average. In total, 154 implants had an MBL of 0 to 1 mm, 52 had an MBL of 1 to 2 mm, and 15 had an MBL >2 mm. Another 21 implants showed marginal bone gain according to the radiographs. Figure 2 shows that the radiographic marginal bone level around a SDI supporting a single crown prosthesis remained stable during 5 years.

3.4 | Factors influencing SDI failure

The univariate analysis results are described in Table 1. There were no significant differences in SDI survival based on periodontal status, implant length, implant insertion site, prosthesis type, prosthesis material, retention type, type of the opposing teeth, reason for SDI installation, occlusion force, or crown-root radio. In contrast, patients' gender, age, smoking status, and implant type showed statistical correlations with SDI failure. These four factors were entered into a further investigation by GEE logistic regression (Table 4). Only one factor

TABLE 2 Ten-year life table analysis of small-diameter implants

Time interval	Implant numbers	Failure numbers	Survival rate on interval (%)	Cumulative survival rate (%)	Patient number	Failure number	Survival rate on interval (%)	Cumulative survival rate (%)
0–1	243	2	99.2	99.2	156	2	98.7	98.7
1–2	241	0	100	99.2	154	0	100	98.7
2–3	233	0	100	99.2	148	0	100	98.7
3–4	225	1	99.6	98.8	143	1	99.3	98.1
4–5	158	0	100	98.8	101	0	100	98.1
5-6	114	0	100	98.8	73	0	100	98.1
6–7	78	0	100	98.8	56	0	100	98.1
7–8	51	2	96.1	97.9	35	2	94.3	96.8
8–9	26	0	100	97.9	20	0	100	96.8
9-10	18	0	100	97.9	13	0	100	96.8
>10	4	0	100	97.9	2	0	100	96.8

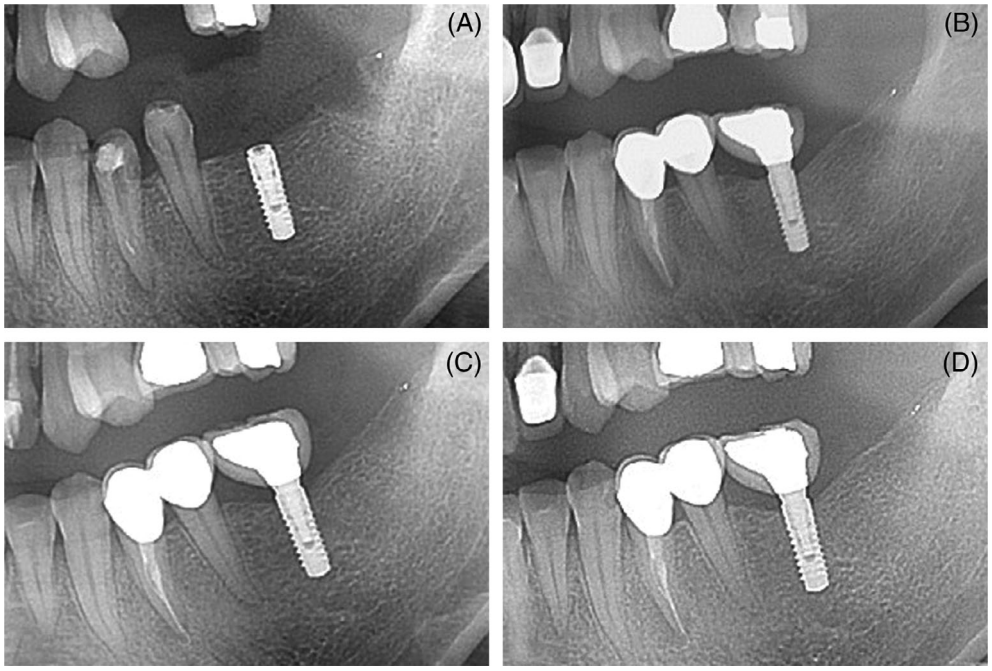

FIGURE 2 Radiographic marginal bone level around a small-diameter implant supporting a single crown prosthesis. A, Implant installation, B, 6 months after loading, C, 2 years after loading, and D, 5 years after loading. The marginal bone loss after 5 years in this case was 0.75 mm at the mesial site and 1.0 mm at the distal site

(implant type) exhibited statistical significance after this. The SDI survival rates were 98.9% and 94.4% in bone-level and tissue-level implants, respectively. The mean peri-implant MBL of bone-level implants (0.53 ± 0.86) was much less than that of tissue-level implants (0.86 ± 1.00, $P = .019$), while the complication rates between two types of implants showed no significant differences (Table 5).

4 | DISCUSSION

In the past, SDIs were considered inappropriate to support fixed prostheses in the posterior region due to the reduced strength and osseointegration surface.[14] However, in some circumstances, SDIs can be an effective alternative to regular-diameter implants in the posterior area. As shown in the present study, 60 SDIs (98.3% of 243 in total) were placed in the posterior region due to narrow interdental spaces, and the other 183 (97.8%) were placed due to insufficient bone width to avoid an augmentation procedure. This indicates that SDIs are demanded for expanded indications in clinical practice. The present study provided results that are indispensable for a comprehensive understanding of this treatment option.

Some evidence has been found that SDIs might have a higher failure risk because of their reduced surface area for osseointegration.[6,15] However, the results of the present study reveal a high survival rate (97.9% on an implant basis and 96.8% on a patient basis) for SDIs supporting fixed prostheses in the posterior region after 144 months of follow up. These results are comparable to the overall long-term survival rate for implant-supported fixed prostheses reported in previous studies.[16-18] Shi et al.[19] also indicated a similar high survival rate (96.9%) for SDIs in posterior jaws after 10 years.

TABLE 3 Implant failures and complications

Implant failure analysis											
	Gender	Age (years)	Site	Implant length (mm)	Implant type	Periodontal status	Smoking status	Time of failure	Cause of failure	Failure type
#1	Male	35	25	10	Bone-level	Treated-periodontitis	Smoker	3 months after surgery	Postsurgical infection	Early
#2	Male	43	14	12	Tissue-level	Nonperiodontitis	Smoker	3 months after surgery	Implant mobility	Early
#3	Female	63	45	10	Bone-level	Treated-periodontitis	Nonsmoker	34 months after loading	Peri-implantitis	Late
#4	Male	30	46	10	Tissue-level	Nonperiodontitis	Nonsmoker	78 months after loading	Implant mobility	Late
#5	Male	50	27	10	Tissue-level	Nonperiodontitis	Nonsmoker	81 months after loading	Implant mobility	Late
Complications										
Biological complications (9.1% in total)							**Mechanical complications (12.8% in total)**			
	Postsurgical infection	**Nerve dysfunction**	**Peri-implantitis**		**Peri-implant mucositis**	**Implant fracture**	**Abutment fracture**	**Screw loosening or fracture**	**Veneer chipping**	**Prosthesis framework broken**	**Loss of retention (cement-retained)**
	2 (0.8%)	0 (0%)	7 (2.9%)		13 (5.3%)	0 (0%)	2 (0.8%)	7 (2.9%)	14 (5.8%)	0 (0%)	8 (3.3%)

In addition, some studies suggested that SDIs might present more MBL due to increased stress around the implant neck.[20-22] The present study failed to find this unfavorable tendency. The total peri-implant MBL around the SDIs at the follow-up visit after 10 years was 0.60 mm on average, a value that is comparable to the overall peri-implant bone loss reported in previous reviews.[23,24] These results were also much lower than those revealed in a similar previous study. Shi et al.[19] investigated the long-term outcome of tissue-level narrow-diameter implants in posterior jaws and reported an average MBL of 1.19 mm after 10 years. This difference might be explained by the different implant types included in the present study. The statistical comparison also showed that the MBL around the tissue-level implants was significantly greater than that around the bone-level implants (Table 5).

Although SDIs demonstrated a high survival rate with minimal MBL, a series of complications were observed. The biological complication rate was 9.1% in total, including peri-implant mucositis (5.3%) and peri-implantitis (2.9%). The most frequent mechanical complication was veneer chipping (5.8%). Two cases of abutment fracture occurred in bone-level implants (0.8%), resulting in a cumulative prosthesis survival rate of 95.9%. When compared to implant-supported prosthesis data in the literature, regardless of implant diameter, it is comforting to find that the complication rate was similar or slightly lower in the present study.[16,17]

Furthermore, it is worth mentioning that the most alarming complication of SDIs, implant fracture, was not detected. This result is consistent with those obtained in previous studies of SDIs,[19,25] despite the fact that the overall implant fracture rate in the literature was approximately 0.5% for fixed restorations.[26] This may be attributed to the restricted prosthesis design and occlusal adjustment. In the present study, 98 of the 243 (40.3%) SDIs received light occlusal force after occlusal adjustment at prosthesis delivery. Only 35 of the 243 (14.4%) SDIs were designed to support a fixed bridge with cantilever, and no crown-root ratio >2 or immediate loading protocol was applied. In certain situations involving high occlusal demand, new Ti-Zr implants with high mechanical stress resistance are strongly recommended to avoid this complication.[27-30]

The present study also analyzed the factors influencing SDI failures by univariate and multivariate analysis. The results indicated that none of the studied prosthetic factors (prosthesis type, prosthesis material, retention type, type of opposing teeth, occlusion force, and crown-root ratio) were significantly related to SDI failures. The only factor that contributed to implant failure was the implant type. Bone-level implants achieved a survival rate of 98.9%, significantly higher than that of the tissue-level implants (94.4%). Further assessment also showed a significant more MBL around tissue-level SDIs, which could be the reason of their lower survival rate. This new finding might explain the long-lasting concern about SDIs, which was actually a concern about the outdated tissue-level titanium SDIs. With the development of bone-level implants and Ti-Zr alloy implants, SDIs could be and might have already been a standard and promising treatment alternative at premolar and molar sites.

TABLE 4 GEE logistic regression for detecting factors influencing SDI survival

Parameters	Survival	Failure	OR	95% CI	Sig.
Intercept			0.052	(−0.194, 0.299)	.350
Factors					
Gender					
Male	75 (94.9%)	4 (5.1%)	0.364	(0.028, 4.722)	.440
Female	163 (99.4%)	1 (0.6%)	1		
Age					
20–34	28 (96.6%)	1 (3.4%)	0.116	(0.005, 2.573)	.173
35–54	88 (96.7%)	3 (3.3%)	0.246	(0.014, 4.323)	.338
>55	122 (99.2%)	1 (0.8%)	1		
Smoking status					
Nonsmokers	218 (98.6%)	3 (1.4%)	1.129	(0.047, 26.934)	.940
Smokers	20 (90.9%)	2 (9.1%)	1		
Implant type					
Bone-level	187 (98.9%)	2 (1.1%)	71.006	(1.634, 3086.075)	.027*
Tissue level	51 (94.4%)	3 (5.6%)	1		

−2 Log likelihood of GEE regression model: 31.313.
Abbreviations: CI, confidence interval; GEE, generalized estimating equation; OR, odds ratio; SDR, small-diameter implant.
*Significant *P*-value <.05.

TABLE 5 SDIs survival and complication rates in different implant types

	Implant survival rate		Mechanical complications (%)		Biological complications (%)		Marginal bone loss	
Bone-level	98.9%		11.6		7.9		0.53 ± 0.86	
Tissue-level	94.4%	*P* = .040*	16.7	*P* = .331	13	*P* = .258	0.86 ± 1.00	*P* = .019*

Abbreviation: SDI, small-diameter implant.
*Significant differences detected by one-way ANOVA (*P* < .05).

5 | CONCLUSIONS

In conclusion, subject to the limitations of the present study, the results suggested that pure titanium SDIs supporting fixed dental prostheses in the posterior region without bone augmentation yield promising long-term clinical outcomes with high implant and prosthesis survival rates, minimal MBL and a relatively low incidence of complications. This predictable prognosis of SDI application in the posterior area might increase patients' acceptance of implant therapy and expand the clinical indications for dentists. However, tissue-level titanium SDIs should be avoided where possible due to their lower survival rates and higher MBL. The potential of SDIs for use in fundamentally replacing bone augmentation in the posterior area remains unknown. Further effort should be made to provide high-level evidence to fill this gap.

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CONFLICT OF INTEREST

The authors declare that no conflict of interest exists in relation to this project.

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