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Prognostic factors associated with implant loss, disease progression or favorable outcomes after peri-implantitis surgical therapy

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Abstract

Background: The treatment of the peri-implantitis remains complex and challenging with no consensus on which is the best treatment approach.

Purpose: To examine the key local and systemic factors associated with implant loss, disease progression, or favorable outcomes after surgical peri-implantitis therapy.

Materials and Methods: Records of patients treated for peri-implantitis were screened. Patient-, implant- and surgery-related variables on and prior to the day of the surgery were collected (T0: time of peri-implantitis treatment). If the treated implant was still in function when the data was collected, the patient invited to participate for a recall study visit (T1, longest follow-up after treatment). Impacts of the variables on the implant survival, success, and peri-implant bone change after treatment were investigated.

Results: Eighty patients with 121 implants with a mean follow-up of 42.6 ± 26.3 months were included. A total of 22 implants (18.2%) were removed during the follow-up period. When relative bone loss (%) was in range 25%–50%, risk for implant removal increased 15 times compared to lower bone loss <25% (OR = 15.2; CI: 2.06–112.7; $p = 0.008$). Similarly, relative bone loss of >50% increased 20 times the risk of implant failure compared to the <25% (OR = 20.2; CI: 2.42–169.6; $p = 0.006$). For post-treatment success rate, history of periodontitis significantly increased the risk of unsuccess treatment (OR = 3.07; $p = 0.04$) after resective surgery).

Conclusion: Severe bone loss (>50%) poses significantly higher risk of treatment failure.

KEYWORDS
dental implants, disease management, peri-implantitis

What is known

The literature presents with questionable findings on which is the best treatment protocol for peri-implantitis, as well as how patient related factors influence the treatment outcome.

What this study adds

This study is one of the few in the literature with a relevant sample size that reports outcomes for resective and regenerative treatment of peri-implantitis. This study shows that patient-related factors have an overall limited influence on the surgical outcomes than the severity of peri-implant defect, but supportive maintenance care did show high importance, especially in the regenerative approach.

1 | INTRODUCTION

Peri-implantitis is a chronic inflammatory disease of soft and hard tissues surrounding dental implants.[1,2] With its prevalence, non-linear accelerating pattern of progression, and unclear predisposing factors, peri-implantitis represents one of the unsolved challenges of contemporary implant dentistry.[3–6] Current evidence suggests an increased risk of peri-implantitis in patients with irregular and/or limited maintenance recall but this is confounded with health awareness.[7–9] To promote successful resective and regenerative surgical treatments, it is considered important to disinfect contaminated implant surfaces.[10,11] Resective therapy aims to improve access for patient's hygiene maneuvers while the goal of the regenerative approaches is to rebuild the lost supporting bone with the aid of bone grafting, membrane, and/or biologics. Despite the efforts in improving treatment modalities, outcomes after therapy are sub-optimal[10,12] with some reported recurrence rates as high as 50%.[13] Therefore, there is a need to examine the key factors affecting treatment outcomes after therapy.

Baseline bone levels at the time of peri-implantitis treatment emerged as the strongest prognostic factor for outcome after therapy.[14–16] Implant misplacement also played an important role in developing peri-implantitis.[17] So far, there is a lack of conclusive evidence about a possible link between systemic contribution and peri-implantitis. Both smoking and diabetes have been associated with peri-implantitis in longitudinal studies[18,19] but available data are heterogeneous to determine them as established risk factors. In addition, their influence on disease remission or progression, as well as their contribution to the outcome post-therapy remains undetermined.

The aim of this study was to analyze a retrospective cohort diagnosed and treated for peri-implantitis and to examine the key local and systemic factors associated with implant loss, disease progression, or favorable outcomes after surgical peri-implantitis therapy.

2 | MATERIAL AND METHODS

This retrospective investigation was performed in accordance with the Declaration of Helsinki, approved by the University of Michigan School of Dentistry Institutional Review Board (IRB) for Human Studies (ID: HUMOOI48346). Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed during the preparation of the manuscript.

2.1 | Eligibility criteria

Physical and electronic records of patients who were treated for peri-implantitis at the University of Michigan School of Dentistry were screened by five examiners (A.G., A.R., R.S., R.D., and G.K.). Patients with treated implants still in function were contacted with an invitation to participate in the study. The data were collected from January 2019 to February 2021. The patients would only be deemed eligible if they met the following criteria: (a) received at least one dental implant that had been previously diagnosed with peri-implantitis using the 2017 World Workshop Classification[20]; (b) their files provided clinical and radiographic pre-surgical documentation; (c) the patient returned to the clinic for a follow-up visit at least 1 year after surgical therapy for peri-implantitis with either resective or regenerative therapy; and (d) the presence of opposing occlusion. Patients were excluded based on the following: (a) absence or incomplete clinical and radiographic records; (b) <1 year follow-up after surgical therapy; (c) peri-implantitis treatment occurred outside the University of Michigan; (d) patient did not return for the follow-up visit at the University of Michigan School of Dentistry ≥1 years after treatment; and (e) diagnosis of retrograde peri-implantitis.[21]

2.2 | Data collection and classification

Patient-, implant-, prosthetic-, and surgical-related variables were collected at T0 (peri-implantitis treatment). If the treated implant was still in function when the data were collected, the patient was contacted and invited to participate (T1 = follow-up after treatment for recall visits). In the event of implant failure, the date of implant removal was registered, and the implant was included in the analysis, but the patient was not contacted (no T1 appointment).

2.2.1 | Clinical variables related to patient

All relevant patient demographic information (at T0) including gender, age at the time of the treatment of peri-implantitis, diabetes status, self-reported cigarette consumption, history of periodontal disease,[22] and number of supportive peri-implant therapy (SPIT) were collected.

2.2.2 | Clinical variables related to the implant

At T0, all relevant information such as the location of the implant in the arch, length, diameter, type of connection was gathered. Furthermore, the following clinical information was collected at T0 (from patient files) and at T1 (clinical appointment)[6]: keratinized mucosa (KM) width defined as the distance measured between the free mucosal margin to the mucogingival junction at the mid-buccal aspect utilizing a North Carolina probe (Hu-Friedy), peri-implant probing depths (PPD) (using a North Carolina probe), peri-implant marginal bone loss (MBL), bleeding on probing (BoP), and suppuration (SUP) (dichotomous [1/0] scale using a North Carolina probe). MBL was defined utilizing calibrated periapical radiographs as the distance between the most coronal portion of the implant expected to present radiographic bone contact (for tissue-level implants: the interface between the polished collar and rough surface, and for bone level implants: the platform level) to the most coronal point of the implant body in contact with bone. The MBL for each radiograph was examined by two authors (A.R., R.S.) at the mesial and distal aspects of the affected implants using commercially available software (ImageJ, U.S. National Institutes of Health). MBL was measured in millimeters and as a percent of the implant's length with no presence of radiographic bone at the interproximal sites (mild <25%; moderate 25%–50%; or severe >50% bone loss). For implants with a polished collar, the length was measured from the smooth–rough interface to the apex. Repeated measurements of 15 implants were conducted to quantify mean intra- and inter-agreement measurement errors between two examiners (RS, AR): 0.29 ± 0.25 mm and 0.44 ± 0.36 mm, respectively.

2.2.3 | Clinical variables related to the prosthesis

Prosthetic-related information such as type of retention (cemented, screw, or attachment ball) and the presence of a single/splinted crowns were recorded at T0 and analyzed.

2.2.4 | Clinical variables related to the surgery

Surgical-related factors including the type of surgery (resective, regenerative), performance of non-surgical therapy prior to the surgical procedure, and implantoplasty (IP) as adjunctive therapy were collected at T0 and analyzed. Furthermore, information about the antibiotic prescription after the surgical procedure was collected.

2.3 | Surgical treatment of peri-implantitis

Resective procedures was performed when no infrabony defect was present (horizontal bone loss) and consisted in a submarginal or intrasulcular incisions aimed to maintain >2 mm of KM in the facial and in the lingual flaps. Full thickness flaps were elevated. Implant surface and peri-implant bone were degranulated from the connective tissue retained in the peri-implant defect. One or more mechanical devices were advocated to debride the implant surface including stainless steel curettes, titanium curettes, Er:YAG laser, titanium brush, air-powder device, or burs for IP. In the presence of bony ledges or shallow infrabony defects, osteoplasty was performed with diamond burs on high-speed handpiece. Flaps were approximated at the level of the bone crest with single interrupted or external mattress sutures. Regenerative approaches were performed when infrabony defect was present (vertical bone loss) and were initiated with intrasulcular incision and full thickness flap elevation. Degranulation and debridement were performed as for resective approaches. IP, when used during regenerative protocols, was performed only for the suprabony exposed surface not amenable for regeneration. Infrabony defects were grafted with particulate bone allograft and/or xenograft and covered with collagen membrane. Flaps were coronally advanced, if needed, and were approximated using single interrupted and internal mattress monofilament sutures. Prostheses were not removed before surgical treatment.

2.4 | Implant survival, treatment success, and bone change

Implant failure was defined as a removed, lost, mobile, or fractured implant.[23] The treatment success criteria based on the study of Berglundh and colleagues[24] was utilized. In their investigation, they used three separate parameters (PPD ≤5 mm, BoP-negative, and bone loss ≤0.5 mm) to construct different combinations of outcome variables making up to seven criteria, all used to identify treatment success. The one utilized in the current study was the more rigorous combination of all three, negative BoP, no bone loss ≥0.5 mm, and PPD ≤5 mm.[24] At T1, treatment was recorded as successful if the implant showed no BoP, no further bone loss (≥0.5 mm) during the post-surgical follow-up, and PPD ≤5 mm. Treatment was considered unsuccessful if the implant scored positive BoP and/or longitudinal bone loss ≥0.5 mm and/or PPD > 5 mm.

Finally, the impact of all the studied variables on bone change (considering a 0.5 mm of radiographic error) after resective surgery (bone loss vs stability) and regenerative surgery (showed bone loss or stability vs bone gain) was analyzed.

2.5 | Statistical analysis

Descriptive of categorical variables (absolute and relative frequencies) and continuous (mean, standard deviation, range, and median) were

utilized for the total sample and differentiating by failure event and success criteria.

At implant-level, the outcome implant failure (yes/no) was related to all independent variables using multi-level binary logistic regression with generalized estimation equations. The utilized correlation structure was robust estimator (sandwich) with independent working correlation matrix. Other specified structures did not achieve the convergence. The utilized procedure was GENLIN (SPSS). Raw odds ratio and 95% confidence intervals were obtained from the Wald's χ^2 statistic. Multiple models were estimated to

TABLE 1 Demographic and systemic factors of patients at T0

	Overall	Resective	Regenerative
No. of patients	80	46	35
Age (years)	67.9 ± 9.8	69.8 ± 8.8	65.2 ± 10.6
Gender			
Male	35 (43.8)	16 (34.8)	19 (54.3)
Female	45 (56.3)	30 (65.2)	16 (45.7)
Smoking			
No	66 (82.5)	38 (82.6)	29 (82.9)
Yes	14 (17.5)	8 (17.4)	6 (17.1)
Diabetes			
No	67 (83.8)	39 (84.8)	29 (82.9)
Yes	13 (16.3)	7 (15.2)	6 (17.1)
History of periodontal disease			
No	27 (33.8)	13 (28.3)	15 (42.9)
Yes	53 (66.3)	33 (71.7)	20 (57.1)

Note: Number of patients (%) or mean ± standard deviation. Please note that one patient received both resective and regenerative procedure in two different implants.

TABLE 2 Impact of clinical variables related to patient on implants failure rate

	Total	Failure rate	OR	95% CI	*p*
No. of implants	121	22 (18.2)			
Age (years)	67.8 ± 9.8		0.96	0.90–1.03	0.286
Gender					
Male	53 (43.8)	12 (22.6)	1		
Female	68 (56.2)	10 (14.7)	0.59	0.13–2.64	0.489
Smoking					
No	100 (82.6)	14 (14.0)	1		
Yes	21 (17.4)	8 (38.1)	3.78	0.69–20.7	0.125
Diabetes					
No	103 (85.1)	21 (20.4)	1		
Yes	18 (14.9)	1 (5.6)	0.23	0.03–1.65	0.144
History of periodontal disease					
No	40 (33.1)	9 (22.5)	1		
Yes	81 (66.9)	13 (16.0)	0.66	0.14–3.13	0.658
Follow-up (months)	42.6 ± 26.3		0.97	0.94–0.99	**0.049***
Maintenance					0.696
Never	11 (9.1)	1 (9.1)	1		
Sporadically (<2 time/year)	46 (38.0)	8 (17.4)	2.11	0.17–26.6	0.565
Twice per year	30 (24.8)	8 (26.7)	3.64	0.31–42.5	0.304
Ideal (more than three times/year)	34 (28.1)	5 (14.7)	1.72	0.16–18.2	0.650

Note: Number of implants (%) or mean ± standard deviation. Failure rate: number of failed (%), results of simple binary logistic regression using GEE (OR, 95% confidence interval, and *p* value of Wald's test).
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

adjust by potential confounding factors (age, maintenance, time since IP, bone loss at T1). The goodness of fit of different estimations (for different matrix correlations) was assessed by QIC statistics. The same methodology was conducted to analyze the outcome success criteria (success/failure).

Additionally, time to event "implant failure" was analyzed using Kaplan–Meier survival methodology (procedure SURVIT from SURVIVAL package). Cumulative survival functions were plotted and compared between baseline bone loss levels, using log-rank test. In order to consider dependence between observations (implant-level data clustered

TABLE 3 Impact of clinical variables related to implant, prosthesis, and treatment characteristics on the implant failure rate

	Total	Failure rate	OR	95% CI	*p*
No. of implants	121	22 (18.2)			
Sector					
Anterior	29 (24.0)	11 (37.9)	1		
Posterior	92 (76.0)	11 (12.0)	0.22	0.06–0.77	**0.017***
Arch					
Maxilla	52 (43.0)	9 (17.3)	1		
Mandible	69 (57.0)	13 (18.8)	1.11	0.28–4.36	0.882
Time since IP to TX (months)	83.7 ± 53.4		1.00	0.99–1.01	0.477
Implant length					0.214
≤10 mm	29 (25.2)	2 (6.9)	1		
10.5–12 mm	40 (34.8)	11 (27.5)	5.12	0.82–32.0	0.081
>12 mm	46 (40.0)	7 (15.2)	2.42	0.30–19.7	0.407
Implant diameter					0.097
<4 mm	26 (22.6)	2 (7.7)	1		
4–4.5 mm	52 (45.2)	15 (28.8)	4.87	0.78–30.3	0.090
>4.5 mm	37 (32.2)	3 (8.1)	1.06	0.16–7.04	0.953
Connection					
Internal	85 (71.4)	14 (16.5)	1		
External	31 (26.1)	7 (22.6)	1.48	0.26–8.57	0.662
Self-retentive	3 (2.5)	0 (0.0)	–	–	
Retention					0.874
Cemented	84 (69.4)	17 (20.2)	1		
Screwed	24 (19.9)	3 (15.0)	0.70	0.15–3.14	0.637
Attachment	13 (10.7)	2 (15.4)	0.72	0.11–4.62	0.726
Splinted					
No	58 (47.9)	11 (19.0)	1		
Yes	63 (52.1)	11 (17.5)	0.90	0.20–4.00	0.894
Non-surgical TX					
No	66 (54.5)	7 (10.6)	1		
Yes	55 (45.5)	15 (27.3)	3.16	0.86–11.7	0.084
TX type					
Resective	77 (63.6)	12 (15.6)	1		
Regenerative	44 (36.4)	10 (22.7)	1.59	0.49–5.19	0.440
Antibiotics					
No	30 (24.8)	1 (3.3)	1		
Yes	91 (75.2)	21 (23.1)	8.70	1.00–75.5	0.050
Implantoplasty					
No	66 (54.5)	15 (22.7)	1		
Yes	55 (45.5)	7 (12.7)	0.50	0.13–1.85	0.297

Note: Number of implants (%) or mean ± standard deviation. Failure rate: number of failed (%), results of simple binary logistic regression using GEE (OR, 95% confidence interval, and *p* value of Wald's test).
Abbreviations: IP, implantoplasty; TX, treatment.

TABLE 4 Impact of clinical and radiographic parameters on the implant failure rate

	Total	Failure rate	OR	95% CI	*p*
Follow up (months)	42.6 ± 26.3		0.99	0.96–1.01	0.331
Maintenance					
Bad (<2)	57 (47.1)	9 (15.8)	1		
Good (≥2)	64 (52.9)	13 (20.3)	2.28	0.49–10.7	0.297
PPD (mm)	5.59 ± 1.67		0.71	0.47–1.08	0.113
Suppuration					
No	54 (45.8)	7 (13.0)	1		
Yes	64 (54.2)	14 (21.9)	1.53	0.37–6.35	0.555
Bone loss					**0.016***
<25%	49 (40.8)	1 (2.0)	1		
25–50%	43 (35.8)	10 (23.3)	15.2	2.06–112.7	**0.008****
>50%	28 (23.3)	11 (39.3)	20.2	2.42–169.6	**0.006****
Keratinized mucosa					
>2 mm	55 (48.7)	4 (7.3)	1		
≤2 mm	58 (51.3)	18 (31.0)	2.85	0.84–9.74	0.094

Note: Number of implants (%) or mean ± standard deviation. Failure rate: number of failed (%), results of multiple binary logistic regression using GEE (OR, 95% confidence interval, and *p* value of Wald's test). Abbreviation: PPD, probing pocket depth.

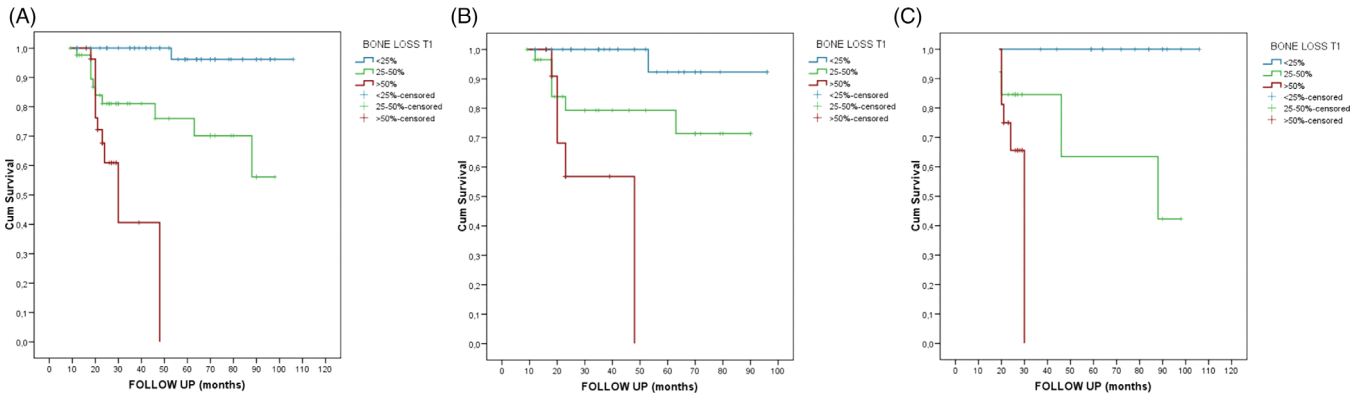

FIGURE 1 Survival rate of all the implants (A), implants treated with resective surgery (B), or regenerative surgery (C) after surgical treatment of peri-implantitis according to initial % of bone loss

by patients), univariate Cox regression frailty models were also performed. Procedure COXPH including clustered observations (by patient) from SURVIVAL package (R software 3.5.1) was utilized. Hazard ratio estimations and corresponding 95% CI were obtained. Wald test was used to consider the within-patient correlation. Significance level used in analysis has been 5% ($\alpha = 0.05$).

Regarding the power analysis, a post-hoc estimation was obtained. A sample size of 121 independent implants provides 93.3% power at confidence 95% to detect OR = 4.0 as significant using logistic regression model.

3 | RESULTS

The sample included 80 patients comprising 35 men (43.8%) and 45 women (56.3%) who underwent treatment for peri-implantitis. They received 121 implants which were treated either with regenerative ($n = 44$) or with resective ($n = 77$) approaches. The mean follow-up (T0–T1) was 42.6 ± 26.3 months, with a range of 12–106 months. Patient's demographics are described in Table 1.

3.1 | Clinical variables related to survival rate

A total of 22 implants (18.2%) were removed during the follow-up period. The overall failure rate was 15.6% (12 implants) for resective surgery and 22.9% (10 implants) after regenerative surgery. Clinical variables related to patient, implant, prosthesis, and surgery were correlated to implant removal after treatment of peri-implantitis (Tables 2–4). Overall, posterior implants significantly reduced the likelihood of failure at 78% (OR = 0.22; CI 0.06–0.77; $p = 0.017$) as juxtaposed to anterior implants (Table 3). Furthermore, percentage of bone loss at T0 (prior to surgical treatment) influenced

TABLE 5 Impact of clinical variables related to the patient on the bone stability after regenerative procedure

	Total	Loss + stable rate	OR	95% CI	*p*
No. of implants	44	32 (72.7)			
Age (years)	65.2 ± 10.6		0.93	0.87–1.00	0.050
Gender					
Male	24 (54.5)	17 (70.8)	1		
Female	20 (45.5)	15 (75.0)	1.24	0.28–5.55	0.783
Smoking					
No	38 (86.4)	29 (76.3)	1		
Yes	6 (13.6)	3 (50.0)	0.31	0.05–1.91	0.207
Diabetes					
No	37 (84.1)	27 (73.0)	1		
Yes	7 (15.9)	5 (71.4)	0.93	0.14–6.33	0.937
History of periodontal disease					
No	20 (45.5)	14 (70.0)	1		
Yes	24 (54.5)	18 (75.0)	1.29	0.28–5.85	0.745
Follow up (months)	46.7 ± 29.0		1.02	0.99–1.05	0.183
Maintenance					0.127
Never	1 (2.3)	0 (0.0)	–		
Sporadically (<2)	25 (56.8)	21 (84.0)	1		
Twice per year	11 (25.0)	8 (72.7)	0.51	0.09–2.97	0.452
Frequent (≥3)	7 (15.9)	3 (42.9)	0.14	0.02–0.93	**0.042***

Note: Number of implants (%) or mean ± standard deviation. Bone loss assessment: number of loss + stable (%), results of simple binary logistic regression using GEE (OR, 95% confidence interval, and *p* value of Wald's test). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

significantly on risk of implant failure (Table 3; Figure 1A). When relative bone loss (%) was in range 25%–50%, risk failure increased 15 times compared to lower level <25% (OR = 15.2; CI: 2.06–112.7; $p = 0.008$). Similarly, relative bone loss (%) of >50%, increased 20 times the risk of implant failure compared to the <25% (OR = 20.2; CI 2.42–169.6; $p = 0.006$).

When only clinical variables of implants treated with resective surgery were analyzed, again only the % relative bone loss was significantly related with implant failure (Figure 1B; Table S1). When only implants treated with regeneration were considered (Figure 1C; Table S2), in addition to the bone loss at T0 (Figure 1C), reduced KM width (≤2 mm) was also identified to be a significant factor influencing the final outcomes of the treatment (OR = 13.9; $p = 0.020$).

3.2 | Clinical variables related to bone loss versus stability (resective surgery) and bone loss or stability versus bone gain (regenerative surgery)

After resective surgery, 41 implants (53.2%) displayed progressive bone loss while 36 (46.8%) showed bone stability during the follow-up period. None of the examined variables significantly increased the stability of these implants (Table S3).

After regenerative treatment, 32 implants (72.7%) showed bone loss/stability while bone gain was achieved in12 implants (27.3%). Frequent maintenance (≥3 maintenance/year) had a positive effect on the final outcomes by reducing the likelihood of bone loss (OR = 0.14; $p = 0.042$) (Table 5). Furthermore, implants placed in the mandible showed higher chance of bone gain after surgery than those placed in the maxilla (OR = 0.07; $p = 0.021$) (Table S4). All the other variables related to the patient, implant, prosthesis, and surgery did not significantly impact the success of the surgery.

3.3 | Clinical variables related to success rate

When all the implants were analyzed, 87 (71.9%) implants were classified as unsuccessful according to the utilized criteria. None of the analyzed variables led to increased chance of success after treatment (Table S5). After resective surgery, 53 (68.8%) implants were classified as failures according to the utilized treatment success criteria. Among the studied clinical variables (Table S6), history of periodontal disease significantly increased risk of treatment unsuccess (OR = 3.07; $p = 0.043$). For the regenerative procedure, failure rate was 77.3% ($n = 34$ failed). Among the studied variables (Table S7), statistically significant difference was only found between implants that underwent frequent maintenance (>3 visits/year) compared to sporadically visits (<2 times/year) (OR = 0.14; $p = 0.042$).

4 | DISCUSSION

4.1 | Summary of main findings

The overall findings of this study revealed that 22 out of 121 implants followed an average time of 42.6 months, were lost. Implant failure

was associated with location (anterior implants failed more than posterior), and percentage of bone loss present before surgical treatment. The number of maintenance visits (≥3 times/per year) was associated with positive regenerative outcomes after surgery.

4.2 | Comparison with previous data on resective approach

This study includes one of the largest sample sizes in the literature concerning the surgical treatment of peri-implantitis. Previous publication reported high survival rates (>80%) for implants submitted to a resective approach.[13,16,21,24] Likewise, implant survival rate was high (84%) in the present research. Forty-one implants (53.2%) displayed progressive bone loss while 36 (46.8%) showed bone stability during the follow-up period. Carcuac and colleagues[13] have shown similar outcomes over a 5-year follow-up period after resective approach. The authors showed a disease recurrence rate of 44% (57 implants) and indicated that among other relevant clinical parameters, radiographic bone level at 1 year was positively correlated with the odds for further deterioration of peri-implant condition (OR 1.4; 95% CI 1.1–1.7; $p = 0.01$). Likewise, this study revealed a negative influence of marginal bone levels on surgical outcomes. Implants with >50% of bone loss had 23.6 times greater risk of implant failure compared to the implants with <25% of bone loss (OR = 23.6.; $p = 0.014$).

A long-term retrospective study with an observation period of up to 11 years (2–11 years) showed 64% of patients and 71% of implants presenting with absence of bone loss or even bone gain after resective therapy for peri-implantitis.[24] The positive outcomes reported might be related to two aspects.[24] First, the outcomes were better at implants with non-modified surfaces compared to implants with modified surfaces. This is in accordance with the previous publications that demonstrated peri-implantitis tends to advance at a faster rate and with more residual inflammation on rough coated surfaces than the machined implant surfaces.[25,26] None of the implants included in our analyses were machined, therefore comparison between different implant surfaces could not be made. Second, screw-retained reconstructions were removed and reconnected to the implants only after flaps were adjusted, sutured, and compressed to the crestal bone. Prosthesis removal can have a positive effect on gaining access for implant surface decontamination and osseous recontouring.[27] No prosthesis was removed for surgical treatment in the present study, and this might have had a negative impact on access for mechanical debridement.

Implant surface modification by means of IP is one of the most controversial topics in the peri-implantitis treatment literature. Results from a previous clinical trial reported smaller peri-implant MBL changes following IP compared with those observed in the control group (resection approach only), after 3-year follow-up.[28] A case series study indicated that combining IP to a bone resection procedure resulted in stable marginal bone levels after a mean follow-up of 3.4 years.[29] On the other hand, a retrospective study showed that IP was not able to improve implant survival rate when compared to implants that received a resective therapy without IP.[16] A recent RCT also challenged the clinical benefits of IP in peri-implantitis management since the authors found no difference between implants treated with IP or glycine air polishing.[30] Likewise, implantoplasty failed to promote an additional benefit in the surgical outcomes of our cohort ($p = 0.297$). The question of whether implant surface modification using this method should be indicated seems to remain open.

4.3 | Comparison with previous data on regenerative approach

Positive outcomes in terms of PPD, BoP reduction, and radiographic bone fill are presented in the literature for reconstructive therapy of peri-implant bone defects.[31–34] A systematic review demonstrated a statistically significant larger marginal bone gain (1.7 mm) and defect fill (57%) for regenerative treatment but found no differences for clinical measures (PPD reduction, BoP reduction).[35] A limitation of this finding is that only three randomized controlled trials were available.

For this study, bone gain was attained around only 12 implants (27.3%). An important aspect on the regenerative potential of peri-implant bony defects is related to defect configuration.[36] Although defect configuration could not be assessed in this study, the amount of bone loss before surgery had a detrimental impact on surgical outcomes. MBL after surgical treatment was on average 4.43 ± 2.41 mm, contributing significantly to implant failure ($p = 0.04$). With more bone loss, the less likely the peri-implant defect is to be completely self-containing and thus yielding poor regeneration outcome.[34,36] Another detrimental factor for a positive regenerative outcome is the different postoperative healing phases (i.e., submerged vs non-submerged). It has shown positive outcomes for peri-implant defects regeneration that were submitted to a submerged healing.[34] Wen and colleagues in three case reports also showed favorable outcomes for submerged healing.[37] Submerged post-operative wound closure healing is recommended to allow a protected physiological healing and respect the principles for bone regeneration.[27,38] In this study, the implants crowns were not removed at the time of treatment, therefore, a non-submerged healing was applied to the regenerative surgical procedures. This could partially explain the inferior outcomes obtained in our study.

Reduced KM width (≤2 mm) was also a significant factor influencing on the final outcomes of implants treated with regeneration. A retrospective study found that surgical outcome in treating peri-implantitis was mainly influenced by the severity of bone loss present at the time of treatment and not by the presence of KM.[15]

Literature have shown the importance of SPIT on peri-implant health.[8,39,40] Generally, a SPIT interval of 5–6 months has been recommended, and can be modified based on the individual's specific needs.[40,41] In line with above findings, the number of SPIT (≥3 time/year) was associated with positive regenerative outcomes, denoting higher chance of bone gain. This is in agreement with another study that reported clinical improvement after surgery for treating peri-implantitis was highly dependent on the number of SPIT visits.[16]

Other patient- (smoking, diabetes, history of periodontitis, etc.) and implant-related factors (diameter, connection, surface modification, etc.) failed to demonstrate a significant association with the obtained outcomes after regenerative therapy.

4.4 | Comparison with previous data on success outcomes criteria

Assessment of peri-implantitis therapy outcome should ideally include clinical measures of inflammation and radiographic assessments of bone-level alterations.[35] A composite success criterion including combination of BoP negative, no bone loss ≥0.5 mm and PPD ≤5 mm was utilized in this investigation.[24] Based on this rigorous criterion, 87 (71.9%) implants were classified as unsuccessful. A previous investigation reported residual PPD ≥ 6 mm as the strongest risk factor for recurrence/progression of peri-implantitis after surgical therapy.[13] This previous finding might partially explain the low success rate obtained in our investigation, where a fair number of sites with remaining deep PPD (mean PPD = 5.23 ± 1.48 mm for resection approach, and mean PPD = 6.20 ± 1.82 mm for regenerative approach) and a great number of sites with BoP positive were encountered. Although BoP is a classically proposed clinical sign of peri-implantitis, incidence of BoP with the bleeding scale may not be able to help diagnose peri-implantitis.[42] There is an increasing body of evidence questioning the extent to which BoP is capable of identifying peri-implantitis.[43] It is important to be mindful that the dichotomous nature (presence or absence) of BoP reporting could potentially consider bleeding induced by traumatic probing.[44,45] So far, the index by French and colleagues[46] seems to be the best validated, incorporating the presence and extensiveness of BoP. This is the reason why in a recent classification of peri-implant status after peri-implantitis surgical treatment, BoP caused by traumatic probing is compatible with success after treatment since it may be present in the clinical scenario of healthy peri-implant tissue.[44]

4.5 | Limitations

A limitation of this study is that implant surface decontamination was accomplished by using different tools (e.g., titanium curettes, power-driven instruments such as ultrasonic, IP, and/or lasers). Nonetheless, there is lack of evidence supporting superior effectiveness of one method over another regarding decontaminating implant surfaces.[13,16,47] Another limitation that should be noted is that the surgical interventions and clinical measurements (excluded MBL) were carried out by different operators which were not calibrated. The impact of prosthesis characteristics on peri-implant tissues has gained increase attention in the last few years. Overcontoured prosthesis can create uncleanable niche and have been associated with diagnosis of peri-implantitis and increased marginal bone loss.[48,49] Due to the nature of this study and different types of prosthesis design included, authors could not make further analysis with regards to this variable. Finally, patients were not following a standardized maintenance schedule.

5 | CONCLUSION

Severe bone loss (>50%) poses significantly higher risk of failure after treatment. Patient-related factors have an overall limited influence on the surgical outcomes than the severity of peri-implant defect, but frequency of supportive maintenance care showing high importance, especially in the regenerative approach.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

AUTHOR CONTRIBUTIONS

Andrea Ravidà, Rafael Siqueira, Riccardo Di Gianfilippo, and Hom-Lay Wang. contributed to the conception and design of the work. Andrea Ravidà, Rafael Siqueira, Riccardo Di Gianfilippo, Anthony Giannobile, and Gurpreet Kaur collected and analyzed the data. Andrea Ravidà, Rafael Siqueira, Riccardo Di Gianfilippo, Chin-Wei Wang, and Hom-Lay Wang led the writing.

DATA AVAILABILITY STATEMENT

Data are available upon request from the authors.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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