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Marginal bone level changes around dental implants with one or two adjacent teeth – A clinical and radiographic retrospective study with a follow-up of at least 10 years

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Abstract

Aim: To compare mean bone level (mBL) changes around dental implants with one or two adjacent teeth after a function time of ≥10 years.

Materials and Methods: One hundred thirty three periodontally compromised patients (PCPs) with 551 implants enrolled in supportive periodontal care (SPC) were screened. Implants were categorized either into group TIT (tooth-implant-tooth) or into group TIG (tooth-implant-gap). MBL changes from delivery of restoration (i.e., baseline) to follow-up were calculated in millimeters and compared between implants and adjacent teeth. Survival rates and the need for surgical interventions during SPC were recorded.

Results: Eighty seven patients with 142 implants were re-evaluated after a mean observation time of 14.5 ± 3.5 years. The mBL at mesial implant sites in the TIT group increased −0.07 ± 0.92 mm and decreased in the TIG group 0.52 ± 1.34 mm, respectively (95% CI: 0.04/1.14, $p = .037$). At distal implant sites, the mBL in the TIT group increased −0.08 ± 0.84 mm and decreased 0.03 ± 0.87 in the TIG group, respectively (95% CI: −0.20/0.42, $p = .48$). The overall implant loss rate was 3.5% ($n = 5$; 2 TIT, 3 TIG), without a statistically significant difference between the two groups (95% CI: 0.18/7.07, $p = .892$). Tooth loss rates (TIT: 12.3%, TIG: 12.3%) were not statistically significantly different (OR = 1.00, $p = .989$).

Conclusion: High tooth and implant survival rates were observed in PCPs. The presence of one or two adjacent teeth seemed to have no impact on marginal bone level changes.

KEYWORDS
bone loss, clinical trial, dental implant, periodontal disease

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1 | INTRODUCTION

Dental implants have become a highly successful therapeutic choice to replace missing teeth with high long-term survival and success rates (i.e., 97% after 5 years, 95% after 10 years) (Chrcanovic et al., 2018; Duong et al., 2022; Esposito et al., 2013; Jung et al., 2012). Periodontally compromised patients (PCP), however, have been shown to be at higher risk for implant loss (Carra et al., 2022; Roccuzzo, Imber, Marruganti, et al., 2022). More specifically, moderately PCP exhibits an implant survival rate of 94.2% and severely PCP of 90% after 10 years (Roccuzzo et al., 2010). Thus, it might be tempting in some patients of teeth with a doubtful prognosis to proceed with extraction and implant placement. However, with increasing numbers of implants being placed also the likelihood of the development of peri-implant diseases is rising (Derks et al., 2016; Roccuzzo et al., 2023; Salvi et al., 2022). The 2017 World Workshop defined peri-implantitis as a plaque-associated inflammation of the implant surrounding tissues that manifests itself as bleeding on probing and/or suppuration, increased probing depth and/or recession, as well as radiographic bone loss compared to previous examinations. In cases of lack of previous examinations, the presence of probing depths ≥6 mm, bleeding on probing and ≥3 mm bone loss apical to the most coronal intra-osseous part of the implant qualifies as peri-implantitis (Berglundh et al., 2019).

Peri-implant radiographic marginal bone loss (BL) is therefore a major outcome assessed in studies, and advanced BL is a predictor for implant loss (French et al., 2019). In failing implants, a total of 30.2% presented with severe BL on the last radiograph taken before implant loss (Chrcanovic et al., 2018). In the same retrospective study over a minimum of 20 years follow-up, 11.7% or 35 implants demonstrated bone gain and another 35 implants presented at least 3 mm of bone loss. When comparing different patient groups, BL was greater in patients with a history of periodontal disease (Karoussis et al., 2003; Matarasso et al., 2010). For these groups also a higher risk for implant loss was documented (Matarasso et al., 2010). Higher bone and implant loss was also correlated with a smoking history (Aglietta et al., 2011) and with patients not adhering to supportive periodontal therapy (Roccuzzo et al., 2012). A recent cross-sectional study, however, revealed no significant difference in terms of BL around implants between smokers and non-smokers (Amerio et al., 2022).

When comparing implants with teeth, similarly high survival rates of 96.8% and 97% were reported for implants in molar position compared with root-resected, endodontically treated teeth after 13 years in function (Fugazzotto, 2001). Outcomes from additional studies indicated higher survival rates for natural teeth than for adjacent implants after 10 years (Rasperini et al., 2014). When considering crestal/marginal bone level changes comparing periodontally compromised teeth with implants, little long-term evidence is available. Rasperini and co-workers evaluated radiographic bone level changes of teeth and adjacent implants within the same patient. After 10 years, teeth in all patients – whether periodontally healthy or periodontally compromised – yielded more stable marginal bone levels than implants (Rasperini et al., 2014).

With respect to the present study, it was hypothesized that periodontal attachment of a tooth adjacent to a dental implant plays a beneficial role in maintaining the peri-implant marginal bone level (Roccuzzo et al., 2018).

Hence, given the paucity of data on this topic, the aim of this retrospective comparative study was to compare mean bone level (mBL) changes around dental implants with one or two adjacent teeth after at least 10 years of supportive periodontal care (SPC).

2 | MATERIALS AND METHODS

The study protocol was submitted to and approved by the Ethical Committee of the Canton of Bern, Switzerland (Kantonale Ethikkommission–KEK Nr.: 2018–01877). The investigation was conducted according to the revised principles of the Helsinki Declaration (2013; 2018), and a signed informed consent was obtained from each patient.

2.1 | Patient selection

Data for the present investigation were collected from the pool of patients attending a tailored supportive periodontal/peri-implant care (SPC) program at the Department of Periodontology, University of Bern, Switzerland. More specifically, in order to minimize missing data and loss to follow-up, a substantial effort was undertaken by one of the authors (L. W.) to screen the list of all patients undergoing periodontal therapy and consequently rehabilitated with implant-supported porcelain fused-to-gold single unit crowns (SUCs) or porcelain fused-to-gold fixed dental prostheses (FDPs) from May 1993 to September 2011. For the purpose of the present study, only patients with at least one dental implant in function for at least 10 years were invited to take part in the study.

Patients were retrospectively divided into two groups based on baseline (i.e., T0) clinical characteristics. One group included implants a mesial and distal adjacent tooth (i.e., TIT, Figure 1a), whereas a second group included an implant with only one mesial or distal adjacent tooth and a gap or free end situation (i.e., TIG, Figure 1b).

The following inclusion criteria were applied:

- patient aged ≥18 years;
- patient willing to participate in the study (informed consent);
- patients with systemic health or controlled medical conditions;
- patients with treated periodontal conditions;
- patients enrolled in regular supportive periodontal/peri-implant care (SPC) program;
- at least one dental implant with a follow-up ≥10 years;
- presence of a tooth mesially and/or distally to the implant site at baseline;

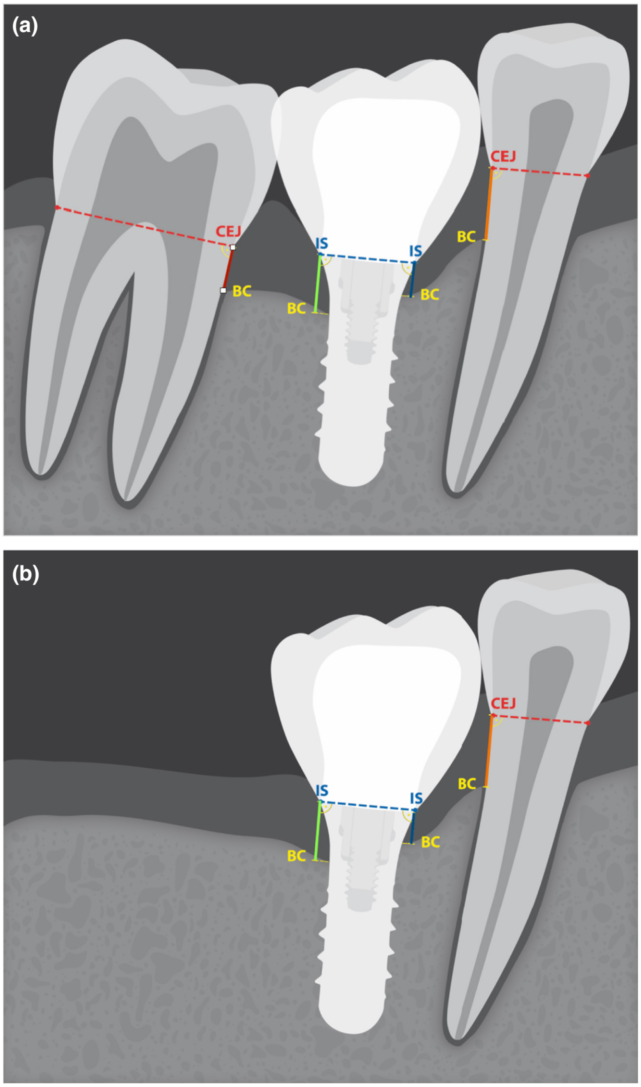

FIGURE 1 (a) Schematic illustration of the group TIT (tooth-implant-tooth). (b) Schematic illustration of the group TIG (tooth-implant-gap).

- availability of a periapical radiograph at baseline (T0) (i.e., at the time point of FDP delivery or at the immediately following recall appointment) and at a follow-up of ≥10 years after baseline radiograph (T1) obtained with the parallel long-cone technique;
- tissue/bone level solid-screw implants with a sand-blasted and acid-etched (SLA) surface (Straumann® Dental Implant System, Institut Straumann AG).

All patients not fulfilling the inclusion criteria listed above were excluded from the present study.

2.2 | Clinical examination at follow-up

All patients underwent a comprehensive clinical and radiographic examination, including an update of the medical history, soft tissue examination and assessment of the periodontal conditions. Cigarette smokers were not excluded. With respect to the radiographic evaluation, a periapical radiograph was obtained by means of the parallel long-cone technique (Updegrave, 1951) ≥10 years following baseline (i.e., FDP delivery). Moreover, full-mouth bleeding score (FMBS; Lang et al., 1986; i.e., percentage of tooth/implants sites revealing the presence of bleeding on probing) at the most recent SPC recall appointment was recorded. Finally, implant survival rate, defined as the presence of the implant in the oral cavity at follow-up, as well the additional surgical interventions during SPC both at implants and at the adjacent teeth, were recorded. All clinical measurements and radiographs were taken during regular SPC by experienced dental hygienists.

2.3 | Radiographic examination at follow-up

As previously described and validated by Schmid et al. (2020), Schmid et al. (2021), the radiographic examination analog radiographs from intraoral dental films (Kodak Ultraspeed DF 58 – Eastman Kodak Company) were scanned and digitized using Microtek TMA 1600 and Microtek ScanPotter (settings on Mac OS X: 1600 dpi, Diafilm, Format.tif). Subsequently, each radiographic image was calibrated and evaluated by means of the software ImageJ (National Institutes of Health).

Based on the fact that all patients were rehabilitated with Straumann® implants, the known distance between two implant threads (e.g., 1.25 mm for a tissue level implant, four threads visible: 3 × 1.25 mm = 3.75 mm) was used to calibrate the radiographs. A line was drawn between the mesial and distal edge of the implant shoulder (IS) and used as landmark (Figure 1a,b). Measurements of the mesial and distal bone levels (BL) were taken from these 2 points perpendicular to the connecting line to the first bone to implant contact (Figure 1a,b). In order to accurately identify the true radiographic linear distance BL, the height of the supracrestal machined neck (i.e., 2.8 mm for standard implants and 1.8 mm for standard plus implants) was subtracted from the measured values. For bone level implants, the methodology proposed and validated by Roccuzzo, Imber, Lempert, et al. (2022) was applied. With respect to assessment of marginal bone levels at teeth, a line connecting both the mesial and distal CEJs was drawn. Thereafter, linear measurements along the tooth surface facing the implant were taken from the CEJ to the bone crest (CEJ-BC; Figure 1a,b).

Following the calculation of the linear measurements, four different comparisons were performed:

- mBL change on the mesial implant surface in TIT group and mesial implant surface without adjacent tooth in TIG group (blue line);
- mBL change on the distal implant surface in the TIT and distal implant surface without adjacent tooth in TIG group (green line);
- mBL change at tooth site facing the mesial implant surface in TIT group and facing the mesial implant surface in TIG group (orange line);
- mBL change at tooth site facing the distal implant surface in TIT group and facing the distal implant surface in TIG group (red line).

All radiographic measurements were taken in duplicate by two pairs of experienced and previously calibrated examiners (A.S. + L.S. and L.W. + A.St.) not involved in any part of the treatment and follow-up examination.

2.4 | Data analysis

Data analysis was performed considering as "unit of analysis" the patient and as "unit of observation" the implants and the sites. Consequently, data were preliminary analyzed at a 3-levels design (i.e. site, implant and patient). The primary outcome variable was mean BL change. After verifying that there were no differences at implant-site, BL was calculated as a mean and expressed in mm as mean BL (mBL) ± standard deviation (SD). All negative values were defined as bone gain while bone loss was defined by positive values. The secondary outcome variable was implant and tooth-survival rates reported in %. At implant-level, multi-level logistic and linear regression using generalized estimation equations (GEE) were conducted to assess homogeneity between groups through demographic, clinical and implant characteristics, and follow-up duration. Changes at mBL and loss event rates were compared between groups using the same models (i.e., linear and logit respectively). Adjustment by confounding factors (i.e. implant location and lateral bone augmentation) was performed. Odds ratio for logit and beta coefficients for linear regression models and 95% confidence intervals were obtained from the Wald's Chi square statistic. McNemar's test was used to compare need of additional treatment at implants at teeth.

The calculated inter-examiner agreement of all the radiographic measurements allowed an intra-class correlation coefficient (ICC) in the range of 0.94–0.99 (IC 95% 0.92–0.99) providing a very high level of reproducibility of the performed measurements. All the tests were two-tailed and the level of significance was set at 5%. The statistical analysis was performed with a commercially available dedicated software (SPSS 15.0).

3 | RESULTS

3.1 | Patients flow chart

Data from 133 patients who underwent implant placement up to September 2011 at the Department of Periodontology, University of Bern, Switzerland, were pooled. After initial screening, 46 patients with 196 implants not fulfilling the inclusion criteria were excluded. From the remaining 87 patients with 355 implants, 213 implants not meeting the inclusion criteria were excluded. Data on the remaining 142 implants available at baseline (i.e., delivery of restoration, T0) and at follow-up (i.e., ≥10-years follow-up, T1) were extracted from the patient's charts and used to stratify them into two groups. Sixty-one implants (43%) were categorized as group tooth-implant-tooth (TIT) and 81 implants (57%) as group tooth-implant-gap (TIG). Details of the patients' flow chart are provided in Figure 2.

3.2 | Patient characteristics

Eighty-seven patients (40 males and 47 females) with a mean age of 72.7 ± 9.8 years at T1 rehabilitated with at least one dental implant at the Department of Periodontology, University of Bern, Switzerland, between May 1993 and September 2011, were included. Sixty-four patients (73.6%) were non-smokers while 23 (26.4%) were smokers (i.e., ≥5 cigarettes/day). Five patients (5.7%) were diagnosed with diabetes mellitus. Overall mean FMBS was 9.0 ± 7.6. Details of the patient characteristics are summarized in Table 1.

3.3 | Implant and FDP characteristics

The baseline characteristics of the implants and FDPs are summarized in Table 2. The mean follow-up was 14.5 ± 3.5 years with a range from 10 to 25 years. Thirteen implants (9.2%) were bone level implants while 129 implants (90.8%) were tissue level implants. All implants had a diameter of 3.3 mm, 4.1 mm or 4.8 mm and a length between 6 and 12 mm. Concomitant with implant placement, 45 lateral bone augmentation procedures (i.e., contour guided bone regeneration) (Buser et al., 2009; Roccuzzo et al., 2021) were performed. One-hundred seventeen FDPs (82.4%) were cemented while 25 (17.6%) were screw-retained. Sixty-one implants with 122 adjacent teeth belonged to the TIT group, while 81 implants with 81 adjacent teeth were included in the TIG group (Figure 2).

3.4 | Changes in radiographic marginal bone levels

At T0 there were no statistically different bone level measurements between the two groups for the mesial and distal implant sites (mesial: 95% CI: −0.40/0.84, $p = .477$; distal: 95% CI: −0.33/0.27, $p = .831$). Regarding T1 at the mesial implant site group TIT had a mBL of 0.13 ± 1.07 mm and the TIG group of 0.99 ± 1.86 mm with a statistically significant difference between the two groups (95% CI: 0.16/1.56, $p = .016$). While the mBL increased in group TIT (T1–T0: −0.07 ± 0.92 mm), it decreased in group TIG (T1–T0: 0.52 ± 1.34 mm) with a statistically significant difference (95% CI: 0.04/1.14, $p = .037$). The comparison at the distal implant site did not reveal any statistical differences over time between the two groups (T1–T0: 95% CI: −0.20/0.42, $p = .482$). The mBL increased minimally in group TIT (T1–T0: −0.08 ± 0.84 mm) and decreased minimally in group TIG (T1–T0: 0.03 ± 0.87 mm). Teeth adjacent to the mesial implant site showed in the TIT group a slight decrease from 3.7 ± 1.63 mm to 3.94 ± 1.5 mm (T1–T0: 0.24 ± 1.29 mm) and in the TIG group a decrease from 3.81 ± 1.63 mm to 4.21 ± 1.69 mm (T1–T0: 0.48 ± 1.15 mm) with no statistically significant difference between the two groups (95% CI: −0.20/0.68, $p = .285$). Comparing the teeth adjacent to the distal site of the implant a statistically significant difference between TIT and TIG group at T0 was calculated (95% CI: −1.37/−0.01, $p = .049$), whereas at T1 no statistically significant difference between the groups could be measured (95% CI: −0.79/0.72, $p = .926$). The mBL of

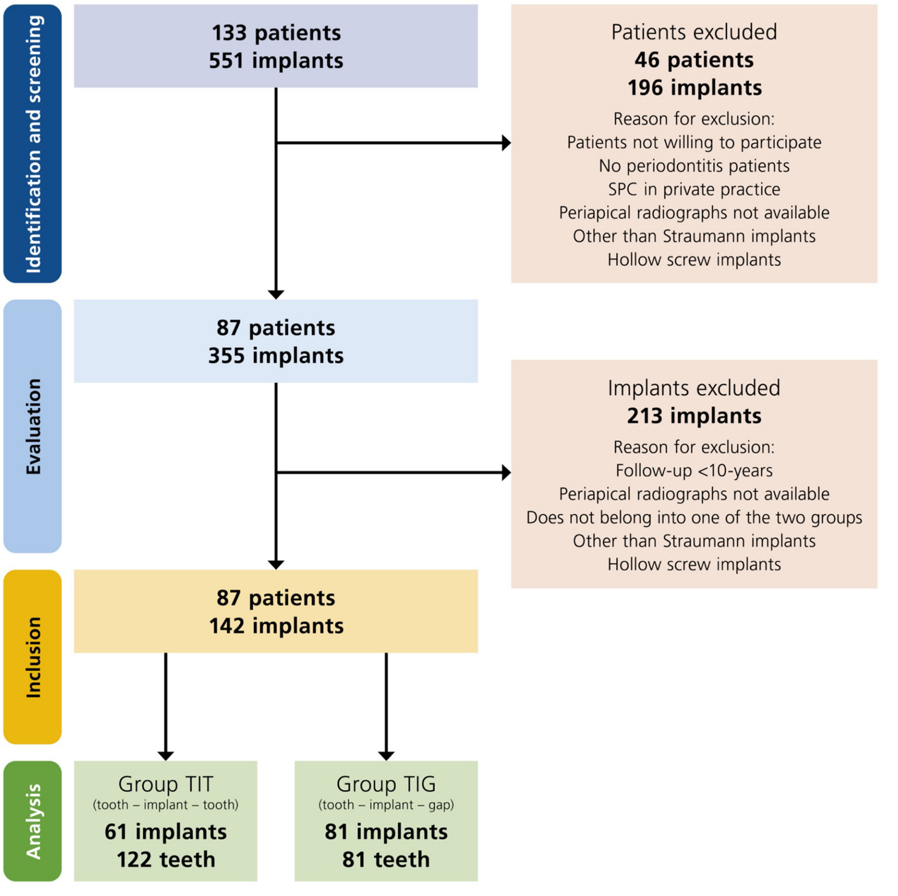

FIGURE 2 Flow-chart for study patients and implants.

TABLE 1 Demographic and clinical characteristics at patient level: Number of patients (%) or mean ± standard deviation.

	N (%) or mean ± SD (range)
N patients	87
Gender	
Male	40 (46.0)
Female	47 (54.0)
Age (years)	72.7 ± 9.8 (42–93)
Diabetes	
No	82 (94.3)
Yes	5 (5.7)
Smoking	
No	64 (73.6)
Yes	23 (26.4)
FMBS (%)	9.0 ± 7.6 (0–37)

Abbreviation: FMBS, full-mouth bleeding score.

group TIT decreased minimally from 3.7 ± 1.64 mm to 3.7 ± 1.43 mm (T1–T0: 0.15 ± 1.06 mm) while mBL in group TIG decreased from 3.02 ± 1.46 mm to 3.67 ± 1.6 mm (T1–T0: 0.5 ± 1.21 mm) with no statistically significant difference between the two groups (95% CI: −0.23/0.93, $p = .234$). All details of the mBL changes are displayed in Table 3.

3.5 | Implant and tooth survival

The overall implant loss rate was 3.5% ($n = 5$; 2 TIT, 3 TIG), without a statistically significant difference between the two groups (95% CI: 0.18/7.07, $p = .892$). The reason for implant loss was peri-implantitis ($n = 3$), implant fracture ($n = 1$) and aseptic loosening ($n = 1$).

In the TIT group, 13 patients (15 implants) lost one adjacent tooth (24.6%), while in the TIG group 10 patients (10 implants) lost one adjacent tooth (12.3%). With respect to the total number of adjacent teeth, the rate of tooth loss (i.e., 12.3%) was not statistically significantly different between TIT and TIG (OR = 1.00, $p = .989$). The recorded reason for tooth loss was periodontitis ($n = 9$), caries ($n = 5$), root fracture ($n = 4$) and endodontic lesion ($n = 2$). In five cases, the reason for tooth loss was unknown.

3.6 | Additional surgical interventions

Overall, 11 implants required at least one additional surgical intervention (i.e. open flap procedure without bone recontouring) during the follow-up period (7.7%; $n = 9$ implants were treated once; $n = 2$ implants were treated more than once). In the TIT group, 2 implants (3.3%) required additional surgical treatment, while in the TIG group surgery was performed around nine implants (11.1%). This difference did not reach statistical significance (95% CI: 0.73/18.6, $p = .114$). When focusing on teeth, 1 tooth in the TIG group was additionally

TABLE 2 Characteristics of the implants and FDPs by group at baseline: Number of implants (%) or mean ± standard deviation.

		GROUP				
		TIT	TIG	OR/Beta	95% CI	*p*-value
N implants	142 (100)	61 (42.9)	81 (57.0)			
Area						.419
Anterior (ref.)	33 (23.2)	17 (51.5)	16 (48.5)	1		
Premolar	48 (33.8)	17 (35.4)	31 (64.6)	1.94	0.71/5.29	.196
Molar	61 (43.0)	27 (44.3)	34 (55.7)	1.34	0.53/3.36	.535
Arch						
Maxilla (ref.)	82 (57.7)	36 (43.9)	46 (56.1)	1		
Mandible	60 (42.3)	25 (41.7)	35 (58.3)	1.10	0.58/2.08	.780
Implant type						
BL (ref.)	13 (9.2)	5 (38.5)	8 (61.5)	1		
TL	129 (90.8)	56 (43.4)	73 (56.6)	0.82	0.24/2.83	.747
Lateral augmentation						
No (ref.)	97 (68.3)	45 (46.4)	52 (53.6)	1		
Yes	45 (31.7)	16 (35.6)	29 (64.4)	1.57	0.84/2.93	.159
Type of retention						
Screw-retained (ref.)	25 (17.6)	11 (44.0)	14 (56.0)	1		
Cemented	117 (82.4)	50 (42.7)	67 (57.3)	1.05	0.43/2.59	.911
Mean follow up (years)	14.5 ± 3.5	15.1 ± 3.8	14.0 ± 3.2	B = −1.12	−2.39/0.15	.084

Note: Results of binary logistic regression (odds ratio OR and 95% CI) for the outcome GROUP and characteristics as exposure or linear regression (beta coefficients and 95% CI) using GEE model.

surgically treated with an access flap procedure. Overall, additional surgical interventions were statistically significantly more frequent at implant than at tooth sites ($\chi^2 = 7.68$; $p = .006$).

3.7 | Systemic and local risk factors

No statistically significant differences with respect to bone level changes at implants of diabetic or non-diabetic patients (95% CI: −0.36/0.06, $p = .154$), nor at the adjacent teeth (95% CI: −0.85/0.09, $p = .109$) were observed. The diabetes diagnosis did not statistically significantly influence tooth loss rate (OR = 0.66, 95% CI: 0.17–2.48 $p = .533$). The bone level changes at implants and adjacent teeth of both smokers and non-smokers did not show any significant differences (mBL implant: 95% CI: −0.08/0.64, $p = .124$; mBL adjacent teeth: 95% CI: −0.28/0.64, $p = .439$). No association was observed for the impact of smoking on implant or tooth loss rate (implant loss: OR = 0.61, $p = .663$; tooth loss: OR = 1.85, $p = .199$).

4 | DISCUSSION

The aim of the present study was to investigate peri-implant marginal bone level changes at implant sites with one or two adjacent teeth after a follow-up of at least 10 years. The results of the present study indicated that both teeth (i.e., 87.7%) and implants (i.e., 96.5%) yielded high survival rates after a mean follow-up 14.5 years, corroborating outcomes of a previous publication by Rasperini et al., 2014 reporting a 100% survival rate of periodontally treated teeth and an implant survival rate ranging from 80% to 95% after a mean follow-up of 10-year (Rasperini et al., 2014).

In the present study, implants with two adjacent teeth (i.e., 96.7%) and implants with one adjacent tooth (i.e., 96.3%) showed comparable survival rates, confirming that implant-supported FDPs represent a long-term reliable treatment option even in patients previously affected by periodontal diseases (Roccuzzo et al., 2010; Roccuzzo et al., 2012). This was confirmed in a long-term prospective study reporting an implant survival rate of 93% after 20 years (Roccuzzo, Imber, Marruganti, et al., 2022).

Despite the fact that all patients of the present study had a history of periodontal disease, which has been documented as a risk factor for the development of peri-implant diseases (Carra et al., 2022; Ramanauskaite et al., 2014; Roccuzzo et al., 2014; Sgolastra et al., 2015), only 7.7% of implants underwent surgical interventions for the treatment of peri-implantitis. One plausible explanation is that all patients complied with a tailored SPC program with recall intervals from 3 to 4 months as demonstrated by the low mean values of FMBS (i.e., 9.0%) reflecting the overall low level of residual periodontal inflammation.

Similar considerations can be drawn with respect to the number and reasons for tooth loss. In the present cohort, only 25 teeth were extracted during a mean follow-up of 14.5 years, most of them

TABLE 3 BL at baseline (T0), follow up (T1) and BL changes T1–T0 (MBL) by Group: Number of implants/teeth (%) or mean ± standard deviation.

			GROUP				
			TIT	TIG	Beta	95% CI	*p*-value
Mesial implant site (Blue line)	*N* implants (T0)	86	61	25[a]			
	T0	0.29 ± 1.05	0.23 ± 0.87	0.45 ± 1.41	0.23	−0.40/0.84	.477
	T1	0.37 ± 1.38	0.13 ± 1.07	0.99 ± 1.86	0.86	0.16/1.56	**.016***
	T1–T0	0.10 ± 1.08	−0.07 ± 0.92	0.52 ± 1.34	0.59	0.04/1.14	**.037***
Distal implant site (Green line)	*N* implants (T0)	117	61	56[b]			
	T0	0.34 ± 0.83	0.35 ± 0.84	0.32 ± 0.82	−0.03	−0.33/0.27	.831
	T1	0.29 ± 1.06	0.25 ± 1.12	0.32 ± 1.00	0.07	−0.30/0.44	.713
	T1–T0	−0.03 ± 0.85	−0.08 ± 0.84	0.03 ± 0.87	0.11	−0.20/0.42	.482
Tooth surface facing mesial implant site (Orange line)	*N* teeth (T0)	117	61	56[c]			
	T0	3.75 ± 1.63	3.70 ± 1.63	3.81 ± 1.64	0.12	−0.49/0.72	.710
	T1	4.06 ± 1.59	3.94 ± 1.50	4.21 ± 1.69	0.27	−0.35/0.90	.391
	T1–T0	0.34 ± 1.23	0.24 ± 1.29	0.48 ± 1.15	0.24	−0.20/0.68	.285
	95% CI T1–T0		−0.06 to 0.54				
	p-value		*p* = .123				
Tooth surface facing distal implant site (Red line)	*N* teeth (T0)	86	61	25[d]			
	T0	3.51 ± 1.61	3.70 ± 1.64	3.02 ± 1.46	−0.68	−1.37/−0.01	**.049***
	T1	3.69 ± 1.48	3.70 ± 1.43	3.67 ± 1.60	−0.04	−0.79/0.72	.926
	T1–T0	0.26 ± 1.11	0.15 ± 1.06	0.50 ± 1.21	0.35	−0.23/0.93	.234
	95% CI T1–T0		−0.25 to 0.54				
	p-value		*p* = .888				

Note: Results of linear regression (beta coefficients and 95% CI) using the GEE model.

Bold values show statistically significant differences.

*$p < .05$; **$p < .01$; ***$p < .001$.

[a]Number of implants without neighboring tooth by the mesial site.

[b]Number of implants without neighboring tooth by the distal site.

[c]Number of teeth adjacent to the implant mesial site.

[d]Number of teeth adjacent to the implant distal site.

due to periodontitis ($n=9$), followed by caries ($n=5$), root fracture ($n=4$), endodontic reason ($n=2$) and unknown reason ($n=5$). These results are comparable to those of other studies reporting very low tooth mortality rates in patients adherent to a strict SPC program (Axelsson et al., 2004; Roccuzzo, Imber, Marruganti, et al., 2022). Consequently, in light of the low number of teeth lost, the approach for strategic tooth extractions and replacement with dental implants, based on the assumption that dental implants perform better than teeth, does not find scientific support even in the long-term (Rasperini et al., 2014).

The present investigation was based on the scientific hypothesis that periodontal attachment of a tooth adjacent to a dental implant plays a beneficial role in maintaining the peri-implant marginal bone level (Roccuzzo et al., 2018). The obtained results led to the rejection of the hypothesis of the present study, since comparable peri-implant marginal bone level changes were observed at both the implant sites with and without adjacent teeth.

Several limitations, however, must be disclosed. First, the retrospective design of the present study represents a limitation, and thus, the findings must be interpreted with caution. Second, the limited sample size may have affected the obtained outcomes. Third, since only one implant surface was evaluated and due to the lack of a tri-dimensional radiographic analysis of the bucco-oral bone changes, the obtained data present limited generalizability. Finally, it has to be kept in mind that periapical radiographs were not obtained with acrylic bite blocks, thus influencing the angulation and the measurement error (Walton & Layton, 2018).

In conclusion, high tooth and implant survival rates were observed in periodontally compromised patients enrolled in regular SPC after a mean follow-up of at least 10 years. Furthermore, the presence of one or two adjacent teeth seemed to have no impact on peri-implant marginal bone level changes.

AUTHOR CONTRIBUTIONS

G.E.S. conceived the idea and critically revised the manuscript; L.W., A.S., L.S., A.St. collected the data; L.W., A.St., J.C.I. performed data analysis and interpretation and contributed to the writing; A.R. performed data analysis and interpretation and lead to the writing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflict of interest with respect to this study. A.R. was the recipient of a 3-year scholarship from the Clinical Research Foundation (CFR) for the Promotion of Oral Health, Brienz, Switzerland. A.R. is the recipient of a 1-year scholarship from the International Team of Implantology (ITI). J.C.I was the recipient of a 1-year scholarship from the Osteology Foundation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding authors. The data are not publicly available due to privacy or ethical restrictions.

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