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Radiographic evaluation of marginal bone levels around implants supporting splinted fixed bridges: A retrospective study on 412 implants

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Abstract

Objectives: The effect of the implant position within the prosthesis on bone remodeling is scarcely documented so far. Thus, the aim of the present study was to investigate whether central implants may suffer higher peri-implant marginal bone levels (MBL) compared to laterals in case of fixed splinted bridges supported by ≥ three implants.

Materials and Methods: Partially edentulous subjects rehabilitated with at least one fixed bridge supported by ≥ three dental implants were enrolled. MBL was assessed radiographically by means of intraoral radiographs acquired with phosphor plates and imported in a dedicated software. MBL was calculated as the distance between the implant platform level and the most coronal visible bone-to-implant contact. A three-level linear mixed effects model was used for investigating the fixed effect of patient-, prosthesis-, and implant-level variables on the MBL.

Results: Overall, 90 patients rehabilitated with 130 splinted fixed bridges supported by 412 implants were included. The median follow-up was 136 months. The mean peri-implant MBL resulted statistically significantly higher at central implants if compared to lateral implants ($p < .01$). The estimated MBL averages for central and external implants were 1.68 and 1.18 mm, respectively. The prosthesis-level variables suggested that a cement-retained bridge was prone to a significant 0.82 mm higher MBL than a screw-retained one. Implant surface showed an association with MBL changes, although less pronounced than implant retention.

Conclusions: In case of ≥3 adjacent implants supporting splinted bridges, central implants were more predisposed to MBL compared to laterals. At the prosthesis level, implants supporting cement-retained bridges were statistically more susceptible to MBL compared to screw-retained ones. Surface characteristics can also influence MBL stability at the implant level.

KEYWORDS
fixed partial denture, marginal bone loss, splinted bridges, dental implants, splinted position, peri-implant health, marginal bone level, marginal bone resorption

1 | INTRODUCTION

Rehabilitation of partially and fully edentulous sites with implant-supported prostheses represents a reliable treatment option in the long term (Maiorana et al., 2016, 2019). Primary stability, meticulous oral hygiene, prevention of soft tissue inflammation and maintenance of stable peri-implant bone levels are all important variables in dental implant survival (Berglundh et al., 2018). Considering the latter, the magnitude of crestal bone resorption around dental implants has been extensively debated (Beretta et al., 2021). In past decades, a marginal bone resorption of 2 mm in the first year of treatment, followed by 0.2 mm per year was considered to be acceptable (Albrektsson et al., 1986, 2012). Currently, according to the current guidelines proposed by the EFP/AAP world workshop in 2018, the diagnosis of peri-implantitis requires the presence of bleeding and/or suppuration on gentle probing, increased probing depth compared to previous examinations and the presence of bone loss beyond marginal bone level (MBL) changes resulting from initial bone remodeling. Bone loss should be reported using thresholds above the measurement error (>0.5 mm on average) (Berglundh et al., 2018).

Besides systemic and patient-related conditions, MBL can be negatively influenced by local factors related to the prosthetic design (Yi et al., 2020) the type of connection and retention (Dalago et al., 2017; Daubert et al., 2015; Derks et al., 2016), and the distribution of occlusal loads (Lima et al., 2019) amongst others.

In this matter, evidence concerning the response of MBL to splinted and non-splinted rehabilitations is largely missing and controversial (Nissan et al., 2011). A reduced overall peak stress induction around the central implant in fixed partial denture supported by three implants has been reported (Guichet et al., 2002). Similar results were obtained by comparing load transfer and stress distribution at splinted and unsplinted implant-supported fixed cemented restorations (Nissan et al., 2010). Other authors claimed that occlusal loads transferred to implants supporting fixed partial dentures were higher than those applied to implants supporting unsplinted restorations because of the development of moments (Brunski et al., 2000; Simion, 2022). Compared to other rehabilitations, fixed partial dentures supported by three implants were more prone to develop peri-implant complications, with a higher incidence at the level of the middle implant (Ravidà et al., 2019). Accordingly, other authors found that plaque index and probing pocket depths were higher in fixed partial dentures supported by three implants (Yi et al., 2013). Similarly, central implants supporting fixed splinted crowns showed a four-time higher risk of peri-implant disease. In this prosthetic design, namely three-unit splinted crowns, although the risk of mechanical complications is reduced, the middle implant of three-unit splinted crown is more susceptible to peri-implantitis (Yi et al., 2022). Apart from prosthetic factors, it is also well known that the maintenance of a good oral hygiene within the interproximal spaces is essential to preserve the health of marginal peri-implant tissues (Monje et al., 2016). This would make splinted crowns a disadvantageous option as they present a more difficult access to the interproximal spaces, particularly in patients with limited ability to clean (Renvert & Persson, 2009). An additional disadvantage of splinting implant crowns is the challenge of adapting the framework and making a correct emergence profile (Ravidà et al., 2018).

In view of the above, it seems that, to the best of the authors' knowledge, only few studies have addressed peri-implant marginal bone level changes accounting for the position of the implants at splinted crowns. Therefore, the aim of the present retrospective study was to investigate whether central implants may suffer higher peri-implant MBL compared to lateral implants in fixed splinted crowns supported by three or more dental implants in the rehabilitation of partial edentulisms. The secondary aim was to evaluate the possible influence of several variables (age, gender, level of maintenance, surgical site, loading time, type of connection and type of retention) on MBL.

2 | MATERIALS AND METHODS

2.1 | Study design

The research protocol of the present investigation has been conducted in accordance with STROBE guidelines and has been approved as a monocentric retrospective radiographic study by the local Institutional Review Board (Ethical Committee Milano Area 2, ID 2678, study number 5997, report 26_2022). All fixtures included in the present study were bone-level type implants with internal or external connection and rough surfaces. All patients included were rehabilitated at the Implant Center for Edentulism and Jawbone Atrophies, Maxillofacial Surgery and Odontostomatology Unit, Fondazione IRCCS Ca′ Granda Ospedale Maggiore Policlinico, University of Milan. All of the procedures described herein were conducted in accordance with the ethical principles listed in the World Medical Association Declaration of Helsinki for medical research involving human subjects. All of the procedures performed in the present retrospective investigation did not differ from those regularly carried out in the normal clinical practice during periodic follow-up recalls. All patients involved provided their informed consent prior to inclusion in the study.

2.2 | Inclusion and exclusion criteria

Patients must have met all of the following inclusion criteria to be eligible for participation in this study: (1) Male or female subjects with an age ≥18 years; (2) Former partially edentulous patients; (3) Patients rehabilitated with at least one fixed bridge supported by ≥

three dental implants; (4) Patients who underwent all surgical and prosthetic procedures in the authors' Department; (5) Non-smoking patients (≤10 cigarettes/day); (6) Patients willing and able to provide written informed consent. Patients were excluded if (1) Pregnant; (2) Rehabilitated with full-arch prostheses; (3) Patients who finalized the prosthetic rehabilitation after implant insertion in a different dental clinic; (4) Patients who were followed-up with professional oral hygiene sessions in a different dental clinic.

2.3 | Procedures and visits

Medical records of all patients treated at the authors' department available in the database were screened to verify the inclusion and exclusion criteria. Patients eligible for enrolment in the present study were subsequently recalled by telephone (M.M. & F.R.) for a follow-up examination. An appointment was then scheduled for each patient who accepted to be included in the investigation. Just before the visit, a signed informed consent was obtained. Follow-up recalls were carried out between January 2022 and June 2022. Patients not contactable by phone after several attempts, or who answered and refused to come to the visit, or who died, were considered as drop-outs.

The visit consisted of clinical and radiographic evaluations of the rehabilitated site. The following clinical and patient-related data were collected (M.M., F.R., & P.P.P.): (1) age; (2) gender; (3) position of the rehabilitation (anterior/posterior maxilla/mandible). In this respect, bridges supported by implants positioned in canine–canine sites (sextants/segments 2 and 5) were considered anterior, while bridges supported by implants placed in premolar–molar sites (remaining sextants/segments) were considered posterior. In case of bridges supported by implants inserted in both canine–canine and premolar–molar regions, the position of the bridge was defined according to the higher number of implants within one of the two sectors, being that anterior or posterior; (4) loading time (time in months from the connection of the prosthesis); (5) type of connection (internal or external); (6) type of retention (screw-retained or cement-retained); (7) frequency of professional oral hygiene sessions (≥1/year).

MBL was assessed radiographically by means of intraoral radiographs using the long cone paralleling technique with the same apparatus and setting for all patients. The radiographic images acquired using phosphor plates positioned with conventional film holders were saved in an archiving software. The saved images were then imported in a dedicated software (ImageJ v 1.49, NIH, Bethesda, MA, USA) with the highest resolution in order to measure the apical repositioning of the marginal bone levels. In this respect, MBL was calculated as the distance between the implant platform level and the most coronal bone-to-implant contact visible in the digital radiograph. Measurements were performed at the mesial and distal aspect of each implant, parallel with the long axis of the assessed implant. Calibration of the pixel/mm ratio was based on a known distance, namely the length of the assessed implant (Figure 1). The radiographic examinations were performed by two investigators (M.M. & F.R.). A third investigator was involved if the results were not congruent (P.P.P.). The cut-off was set at ±0.5 mm. All three examiners were calibrated in identifying the most coronal position of the bone-to-implant contact in relation to the implant platform. A set of 30 randomly chosen digitalized radiograph was used to measure the mesial MBL and determine the investigators agreement levels. Each investigator measured the mesial MBL twice on consecutive days. Intra-class correlation coefficient (ICC) and Kendall coefficient of concordance (Kendall's W) were estimated to assess the intra- and inter-observer agreement of the radiographic assessments between the three examiners. Estimated values close to 1 stated that the correlation was strong. A *p* value ≤.05 was set as the significance level. The concordance between the radiographic measurements of each examiner at the two different timepoints was excellent as estimated from the intraclass correlation coefficient (ICC = 0.96, 0.95 and 0.95 for examiners 1, 2, and 3, respectively, *p* < *.001*) and the Kendall coefficient (Kendall's W = 0.95, 0.96, 0.96 for examiners 1, 2, and 3, respectively, *p* = *.002*). The inter-observer reliability was similar, considering both the intraclass correlation coefficient (ICC = 0.97, *p* < *.001*) and the Kendall coefficient (Kendall's W = 0.94, *p* < *.001*) between the three examiners. According to these results, following the start of the study, the two examiners conducted the measurements on all the radiographs included in this investigation independently, blinded to each other. Finally, the MBL at each implant surface (mesial and distal) was calculated as a mean value for all observers' measurements.

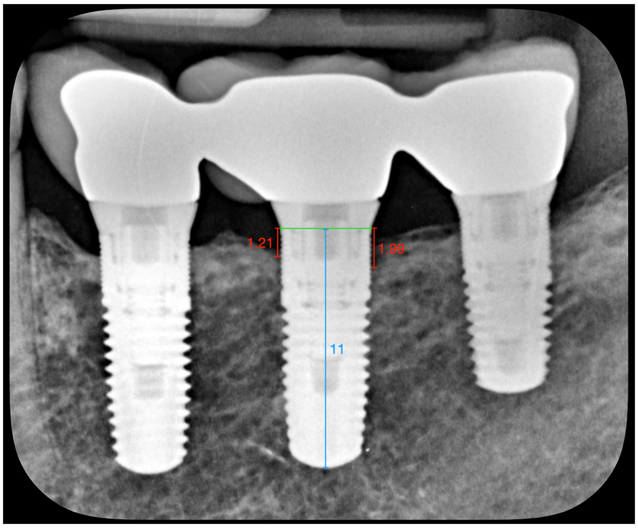

FIGURE 1 Radiographic evaluation of the peri-implant marginal bone levels defined as the distance between the implant platform and the most coronal visible bone-to-implant contact.

2.4 | Sample size calculation

A dedicate software (G*Power 3.1, Heinrich-Heine University, Dusseldorf, Germany) was used to calculate the sample using the two-tailed Wilcoxon sign ranks test. An estimated marginal bone level of 1.09 mm was assumed for the lateral implant and 2.13 mm for the intermediate implant according to previous literature results (Yi et al., 2020). Assuming a standard deviation of ±2 mm, with a significance level of 5%, and an effect size of .52, a sample of 79 patients with 79 bridges on ≥ three implants with at least one mesial/distal implant and one intermediate central implant was required to obtain a statistical power (1-β) of 90%. Considering a drop-out rate of 10%, a total of 90 patients should be enrolled. To meet the sample size calculation, 90 patients were included in the present study, providing a total of 130 fixed partial dentures supported by at least three dental implants each.

2.5 | Statistical analysis

Patients' data were collected in dedicated data collection forms. The source documents were the medical records where data concerning the surgery and follow-up visits were located. Study data were collected and managed using REDCap electronic data capture tools hosted at the authors' institution and exported into electronic spreadsheets (Excel version 16.19, Microsoft corp., Redmond, WA, USA). Once data collection was completed, the files were imported and processed with statistical software as described below.

Data were reported, both at the patient and prosthesis level, as median and interquartile range (IQR) for continuous variables and as absolute and relative frequency for categorical variables. Since the outcome, that is, MBL, was measured at the implant level, nested within prosthesis within patient, data were prone to lead to correlated responses (Lesaffre, 2009). Indeed, observations (implants) within the same cluster (patient or prosthesis) tended to be more similar than observations from different clusters. It was, therefore, necessary to acknowledge multiple sources of variability and then attribute the variation to the appropriate level. For this purpose, a linear mixed effects model (LMM) was able to more accurately and precisely estimate the effects of all variables included in the model, if compared, for example, to a naïve linear regression model.

2.6 | Model definition and fitting

A three-level LMM was used for investigating the fixed effect of patient-, prosthesis-, and implant-level variables on the MBL, allowing to account for the correlation among responses. The model included a random intercept only, which represents the subjects or prosthesis tendency to have the same MBL over all implants. The considered patient-level covariates were the baseline characteristics of subjects, that is, age, biological sex and maintenance. At prosthesis-level, site, loading time, and prosthetic variables, that is, type of connection, retention, and surface variables, were considered. Although data on two additional prosthesis-level variables, specifically the brand and model of the fixture, were available; these were not incorporated into the model but are instead described in the Supplementary Materials (Table S1). Finally, the variable of main interest was the position of the implant within the prosthesis, which was summarized as external or central. The model under consideration incorporated retention type as a key variable while excluding loading time as a covariate. This decision was guided by our clinical interest in understanding the effects of prosthesis variables and a potential collinearity between retention type and loading time. This potential collinearity could be attributed to a trend over time towards an increased preference for screw-retained crowns rather than cement-retained crowns. Given the risk that such collinearity could influence the reliability of the estimates, these variables were not included concurrently in the model, which in the following is referred to as main model. To assure comprehensive consideration of the effects of loading time, we conducted a sensitivity analysis where loading time replaced retention type. In addition, aiming at investigating the robustness of the results obtained from the main model, a sensitivity analysis on a subset of the data only including bridges composed by three splinted crowns was implied. This allowed us to evaluate the influence of bridges composed by a varying number of splinted crowns on the overall outcome. An analogous sensitivity analysis was conducted, wherein the surface was included instead of the connection type, as it has been associated with peri-implant bone loss in the literature (Abuhussein et al., 2010).

2.7 | Model estimates

The model estimated the overall mean of the MBL in the subjects' population, the associational effect of covariates, the variance between subjects, the variance between crowns within subjects and the classical residual variance. Once the model was defined and the parameters estimated, a residual analysis (not shown) was performed for testing the initial model assumption and searching for potential outliers. The estimated parameters were equipped with 95% confidence intervals (CI), standard errors, and *p*-values (the considered significance level was $\alpha < .05$). Moreover, the intra-class correlation coefficient (ICC) was also considered. The ICC is a statistic describing the extent to which outcomes within each group (i.e., patient or prostheses within patient) are likely to be similar relatively to outcomes from other groups (Monsalves et al., 2020). An ICC close to 0 suggests that little variation in the outcome is attributable to variation among upper level units, so most of the variation in the outcome is among lower level units and thus there is little correlation among them. However, an ICC close to 1 suggests that most of the variation in the outcome is attributable to variation among upper level units, so little variation is to be found among the lower level units; thus, there is high correlation among them. In particular, $\text{ICC}_{\text{patient}}$ quantifies the correlation among all the values between and within prostheses nested within patients; while $\text{ICC}_{\text{prostheses within patient}}$ quantifies the correlation among implant's measurements within prostheses nested within patients. In both cases, the ICC is calculated as the proportion of the estimated variance of interest with respect to the estimated total variance. From the model the estimated marginal means (EMMs) were retrieved, both overall and by splinting position. EMMs are averaged over the variables in the model and allows to take into account the differences in the dental implants among patients. All the analyses were obtained using R (R Core Team, 2021), version 4.1.2 (2021-11-01). The linear mixed effects model estimates were obtained through *lmerTest* package (version 3.1.3) (Kuznetsova et al., 2017), while EMMs were calculated through *emmeans* package (version 1.7.5) (Lenth, 2022).

3 | RESULTS

A total of 412 dental implants supporting 130 fixed partial bridges in 90 patients fulfilling the selection criteria were examined (Figure 2). Table 1 reports characteristics of patients and prostheses, while Table S1 in the Supplementary materials reports the summary characteristics for the variables excluded from the models. The median age of patients was 68 (IQR [63, 74]) years; most of the subjects were female (58.9% of patients), and 37 out of 90 patients followed the maintenance therapy with at least 1 professional oral hygiene sessions per year (40.0% of subjects). Subjects mainly had only one implant-supported prosthetic rehabilitation in the mouth (67.8% of patients), and in most cases the bridge included three splinted crowns (83.8% of implants). The majority of the rehabilitations was located in the posterior sectors and the median loading time for a bridge was 136 (IQR [69, 190]) months. The bridges were mainly cemented (76.2%), and an internal connection was the most commonly used type (80.8%). In the present study, only 2 patients experienced implant loss at three-unit bridges supported by three implants. In the first patient, a 67-year-old male patient with a loading time of 63 months, the central implant was lost due to peri-implantitis, while the remaining two external implants remained in situ, still supporting the bridge. In the second case, a 46-year-old female patient with a loading time of 76 months, the bridge was lost as all three implants failed due to peri-implantitis. In both patients, implants were placed in the posterior mandible. The implants were internal connection fixtures with an SLA surface supporting screw-retained prostheses. Both patients did not have regular maintenance therapy (<2 sessions/year).

Table 2 shows the parameters estimated from the model. MBL was significantly affected by implant position within the prosthesis; indeed, an external-position implant had on average 0.5 mm (95% CI: −0.69 to −0.31 mm, $p < .01$) less MBL than a centrally positioned implant. The prosthesis-level variables suggested that a cement-retained bridge was prone to a significant 0.82 mm (95% CI: 0.24–1.40 mm, $p = .01$) higher MBL than a screw-retained one and that an internal connection decreased MBL by on average −0.30 mm (95% CI: −0.90 to 0.28, $p = .32$) compared to the external type. When the implant was located in the posterior sectors, MBL increased on average, although not significantly, compared with that of an implant located in the anterior maxilla (1.03 and 1.20 mm for posterior maxilla and posterior mandible respectively). However, an implant located in the anterior mandible had on average a decreased MBL with respect to an implant in the anterior maxilla (−0.48 mm), and also in this case the variation was not significant. Patient-level variables were not significant. However, model estimates suggested that both neglecting maintenance therapy and aging

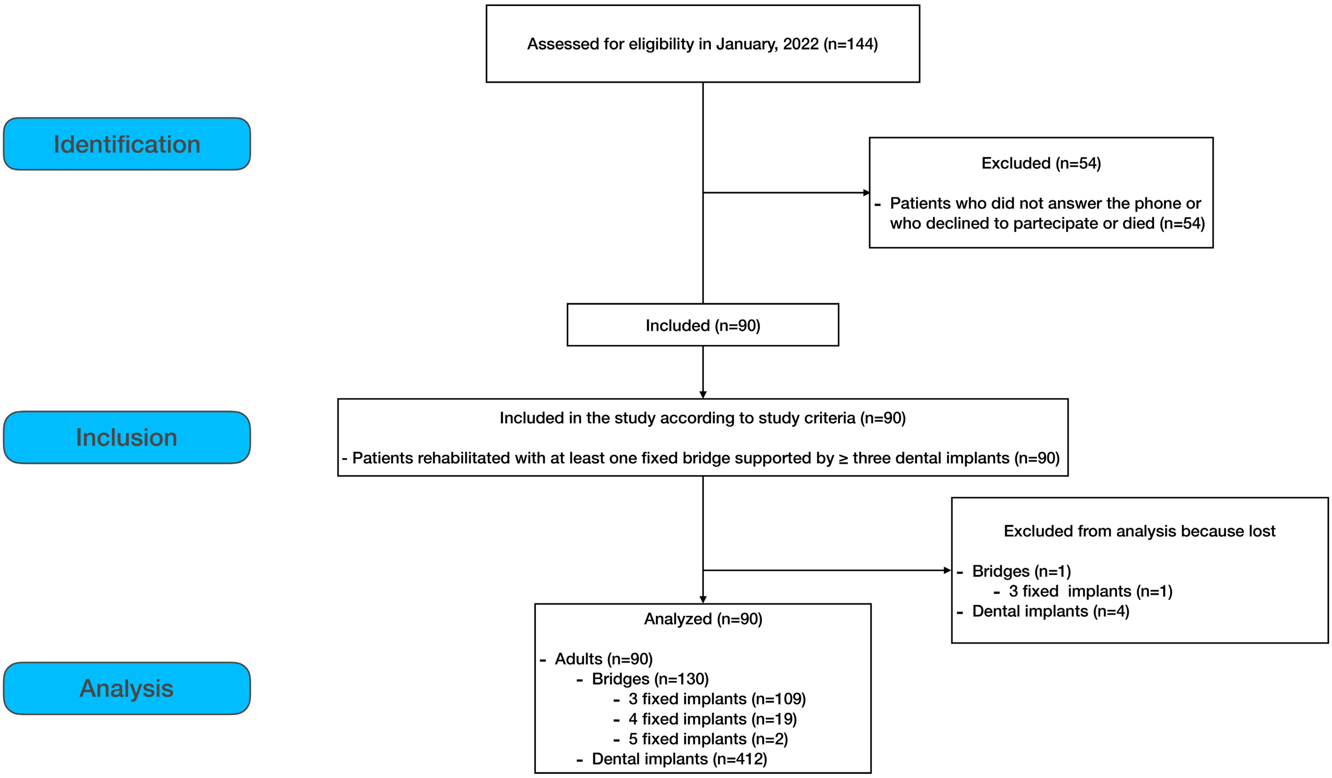

FIGURE 2 Flow chart according to STROBE guidelines including eligible patients and exclusions.

TABLE 1 Patients' and prostheses characteristics.

Patients' characteristics ($n=90$)		
Age (years), median [IQR]		68 [63, 74]
Biological sex, n (%)	Female	53 (58.9)
	Male	37 (41.1)
Maintenance therapy, n (%)	No	54 (60.0)
	Yes	37 (40.0)
Number of prosthesis, n (%)	1	61 (67.8)
	2	20 (22.2)
	3	7 (7.8)
	4	2 (2.2)
Bridges' characteristics ($n=130$)		
Site, n (%)	Anterior maxilla	4 (3.1)
	Posterior maxilla	77 (59.2)
	Anterior mandible	1 (0.8)
	Posterior mandible	48 (36.9)
Restoration type, n (%)	3 fixed implants	109 (83.9)
	4 fixed implants	19 (14.6)
	5 fixed implants	2 (1.5)
Load time (months), median [IQR]		136 [69, 190]
Retention type, n (%)	Screwed	31 (23.8)
	Cemented	99 (76.2)
Connection type, n (%)	Internal	105 (80.8)
	External	25 (19.2)

corresponded on average to an increased MBL (0.43 and 0.02 mm, respectively). Finally, an implant in female subjects seemed to have an average of 0.39 mm less MBL than implants placed in male patients.

The main model estimated components of variation due to variability among patients and among prostheses nested within patients were 1.20 (95% CI: 0.49–1.75) and 0.37 (95% CI: 0.10–0.81), respectively. The component of residual variation due to variability in the implant-level measurements was 0.90 (95% CI: 0.76–1.06). These estimates allowed to calculate the ICC for patients and for prostheses within patient, which were 49% and 15%, respectively. When combined, the total ICC attributable to the hierarchical structure was 64%. These values, when compared to those obtained from the null model (patient ICC: 51%; prosthesis-within-patient ICC: 64%), suggest that the inclusion of patient- and prosthesis-level covariates in the model does not substantially reduce the variability in implant-level measurements. This observation implies that while patient and prosthesis characteristics contribute significantly to the outcome variation, a considerable portion of the variability remains unexplained by these factors. The relatively high and stable ICCs, even after adjusting for available covariates, suggest that additional implant-level predictors may be necessary to further elucidate the variability in outcomes. However, it is important to note that high ICCs in such models do not necessarily undermine the relevance or importance of the included covariates. They may also reflect inherent variability within patient populations.

The estimated marginal means are summarized in Table 3 and illustrated in Figure 3. The overall estimated mean MBL averaged over the levels of all other covariates in the model is 1.43 mm (95% CI: 0.74–2.12 mm; $p<.01$). The estimated MBL averages for central and external implants are 1.68 mm (95% CI: 0.98–2.37 mm; $p<.01$) and 1.18 mm (95% CI: 0.48–1.87 mm; $p<.01$), respectively. The estimated difference between MBL in central and external implants is 0.50 mm (95% CI: 0.31–0.69 mm; $p<.01$).

Moreover, bone levels have been reported in terms of frequency distribution for the maximum value between mesial and distal. Observations were grouped by implant position—Mesial, Central, and Distal. For each implant within its group, the maximum bone resorption between mesial and distal measurements value was determined. The resulting proportions are displayed in the tables, showing both absolute counts and relative percentages within each position group (Table 4).

In the sensitivity analysis where loading time replaced retention type, the estimates for the model variables largely remained stable (Table S2 in the supplementary materials). The 95% CI of these estimates greatly overlapped, underscoring the robustness of the considered model. More specifically, while loading time emerged as a significant variable, its effect size was small, adding little practical impact to our understanding of bone resorption. However, the direction and magnitude of the retention type estimate changed markedly when loading time was included in the model, highlighting the collinearity between these variables and validating our decision to avoid such collinearity in our initial model. Furthermore, upon assessing the impact of loading time on the hierarchical structure's explanatory power, alterations in the ICCs were observed. The ICCs for patients and prostheses within patients shifted to 35% and 21%, respectively, with the inclusion of loading time in place of retention type. The combined ICC saw slight adjustments but remained notable at 58%. This underscores that while loading time appears to provide a clearer insight into patient-level variability than retention type, its influence on the prosthesis-level variability remains limited. Irrespective of the patient-level variable considered, a consistently high combined ICC is evident, emphasizing the pivotal role of the hierarchical structure. In the further sensitivity analysis restricted to bridges composed of three splinted crowns, the model estimates exhibited broad consistency with those of the main analysis, reinforcing the robustness of the findings (model results are shown in Table S3 in the supplementary materials).

In the sensitivity analysis where type of connection was replaced by surface, small changes in the parameter estimates were observed (Table 5). The estimate for maintenance fell from 0.42 to 0.22 mm and there was an overall slight reduction in the effects for the site variable. Crucially, the 95% confidence intervals of these new estimates overlap with the original estimates, indicating that these changes do not substantially affect the overall conclusions of the study. The estimate for the primary variable of interest, MBL, further supporting the stability of the main model. The ICCs showed a persistent pattern at the patient level (49%), while the ICC for prostheses within patients decreased from 15% to 10%. This reduction

TABLE 2 Random-intercept linear regression model for medium bone resorption. Each parameter estimation is equipped with standard error, 95% confidence interval (95% CI) and *p*-value.

	Outcome measure: Mean bone resorption			
Predictors	**Estimates**	**Std. error**	**95% CI**	***p*-value**
Intercept	−0.14	1.30	−2.61 to 2.33	.914
Patient-level variables				
Biological sex [female vs. male]	−0.39	0.30	−0.95 to 0.18	.193
Age	0.02	0.01	−0.01 to 0.04	.256
Maintenance [no vs. yes]	0.43	0.28	−0.11 to 0.97	.132
Prosthesis-level variables				
Prosthesis site [posterior maxilla vs. anterior maxilla]	1.03	0.80	−0.48 to 2.55	.200
Prosthesis site [anterior mandible vs. anterior maxilla]	−0.48	1.21	−2.80 to 1.84	.691
Prosthesis site [posterior mandible vs. anterior maxilla]	1.20	0.80	−0.33 to 2.72	.140
Connection type [internal vs. external]	−0.30	0.31	−0.90 to 0.28	.324
Retention type [cemented vs. screw]	0.82	0.30	0.24–1.40	**.008**
Implant-level variables				
Position [external vs. internal]	−0.50	0.10	−0.69 to −0.31	**<.001**
Random effects				
σ^2	0.90 (95% CI: 0.76–1.06)			
$\sigma^2_{\text{prostheses}}$	0.37 (95% CI: 0.10–0.81)			
σ^2_{ID}	1.20 (95% CI: 0.49–1.75)			
ICC $_{\text{patient}}$	0.49			
ICC $_{\text{prosthesis within patient}}$	0.15			

Bold values refers to statistically significant p values.

TABLE 3 Estimated marginal means (EMM) of mean bone levels over the whole population (overall), for central implants (C), for external implants (E), and for the difference between mean bone levels in central versus external implants (Δ).

	EMM	95% CI	*p*-value
Overall	1.43	0.74–2.12	<.01
C	1.68	0.98–2.37	<.01
E	1.18	0.48–1.87	<.01
Δ	0.50	0.31–0.69	<.01

Note: All estimates are equipped with 95% confidence interval and relative *p*-value.

suggests slightly less variability at this level in the revised model, meaning that the surface may be a less distinctive factor (or less variable) than the connection type. Overall, these results suggest that although there is some variation in estimates, the main conclusions of our study remain unchanged and reliable under this alternative modelling approach.

4 | DISCUSSION

The purpose of the present retrospective study was to assess MBL around dental implants supporting fixed partial bridges, in order to evaluate whether central implants may suffer higher bone level compared to lateral implants. With a median follow-up of 136 (IQR [69, 190]) months, an implant survival rate higher than 90% was recorded, which is in line with what is reported in literature (Annibali et al., 2012; Buser et al., 2012; Lini et al., 2019). Overall, results indicated a significantly higher MBL around central implants compared to external ones.

These findings, which remain robust even in our sensitivity analysis restricted to bridges composed of three splinted crowns, are aligned with several studies that investigated biological complications in three-unit implant restorations. Yi et al. claimed that there was a 4.5 times higher risk of peri-implant pathology occurring at the level of implants placed between two others supporting a fixed partial denture. Both sensitivity analyses' results further reinforce the pertinence of these prior observations, reinforcing the notion that the positioning of the implant could be a significant factor in the manifestation of peri-implant pathology, even when focusing solely on three-unit restorations. In addition, the authors noted how bone resorption was more pronounced in prostheses characterized by a convex emergence profile with an emergence angle ≥30°. Conversely, a concave profile with an emergence angle <30° had an equal occurrence rate of disease between central and peripheral implants.

The high rate of peri-implantitis at the level of the central implant may be due to the limited accessibility of hygienic maintenance maneuvers by the patients. In other words, when adequate cleansing is

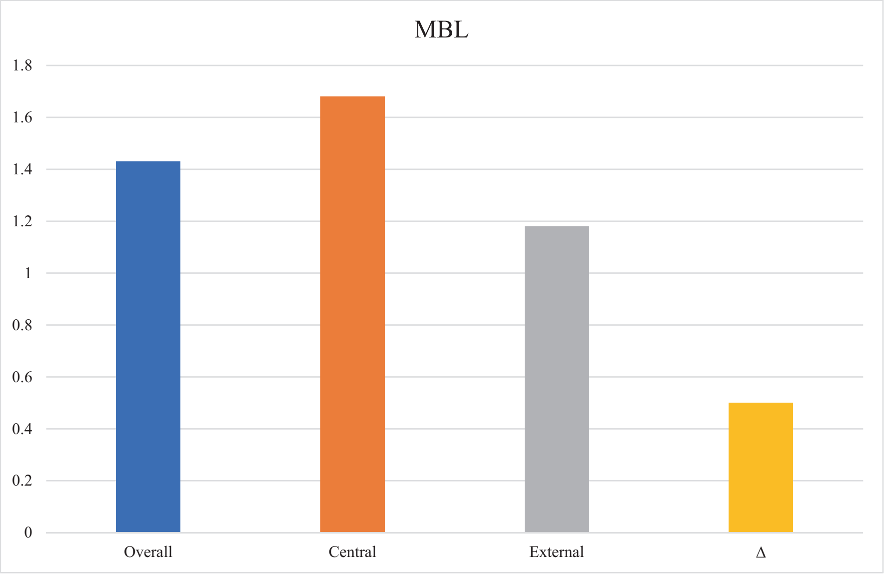

FIGURE 3 Graphical representation about estimated marginal means (EMM) of mean bone levels over the entire population (overall), for central implants (C), for external implants (E), and for the difference between mean bone levels in central implants versus external implants (Δ).

TABLE 4 Distribution of the MBL between mesial and distal.

Distribution of the MBL between mesial and distal	
Mesial—1st implant, *n* (%)	
≤0.5 mm	3 (2.75)
>0.5 and ≤1.0 mm	7 (6.42)
>1.0 and ≤2.0 mm	40 (36.7)
>2.0 and ≤3.0 mm	26 (23.9)
>3.0 mm	33 (30.3)
Central—2nd implant, *n* (%)	
≤0.5 mm,	4 (3.70)
>0.5 and ≤1.0 mm	5 (4.63)
>1.0 and ≤2.0 mm	30 (27.8)
>2.0 and ≤3.0 mm	30 (27.8)
>3.0 mm, *n* (%)	39 (36.1)
Distal—3rd implant, *n* (%)	
≤0.5 mm	9 (8.26)
>0.5 and ≤1.0 mm	15 (13.8)
>1.0 and ≤2.0 mm	31 (28.4)
>2.0 and ≤3.0 mm	26 (23.9)
>3.0 mm	28 (25.7)

ensured by an appropriate prosthetic design, the risk of developing peri-implantitis in central implants decreased (Yi et al., 2020). This demonstrated how the prosthetic features can influence the incidence of peri-implantitis, as also reported by Farronato et al. (2021). In addition, Souza et Al. suggested the use of slim abutments to facilitate the maintenance of peri-implant tissue health (Souza et al., 2018). Yi et al. (2013) reported that the plaque index and buccal pocket depth were higher in fixed partial dentures supported by three implants than bridges supported by two dental implants. The same authors also reported data confirming that over-countered protheses increase the risk of peri-implantitis, particularly at the level of implants located between the first and last (Yi et al., 2022). Ravidà et al. compared different treatments used to rehabilitate patients presenting a posterior partial edentulism. The findings showed that splinted restorations supported by three implants were more subjected to develop peri-implant disease, with a higher incidence at the level of the central implant. In addition, the implant between the first and the last showed a six-fold higher incidence rate of peri-implantitis than the central implants in rehabilitations with separate crowns (Ravidà et al., 2019). Both authors suggested that impaired hygienic measures might be responsible for this behavior. This can be attributed to a suboptimal design of the hygienic spaces of the prosthetic structure. It is worth noting that, according to studies conducted by Monje et al. and Serino & Strom, more than 70% of implant sites do not allow adequate access to the interproximal spaces, which impedes proper oral hygiene maneuvers by the patients (Monje et al., 2016; Serino & Ström, 2009).

All of this taken together may explain why, in the present study, there was a tendency toward higher MBL at central implants irrespective of the frequency of professional oral hygiene sessions. This might suggest that the maintenance of peri-implant tissue health is highly influenced by domiciliary home care.

In regard to the type of connection, our findings resulted partly in agreement with data available in the literature. It seems that the type of connection did not have a statistically significant influence on the primary outcome. Initially, Yi et al. showed that external connection type implants had higher risk of peri-implantitis (Yi et al., 2020), while in the latest publication, the same authors observed no statistically significant differences between the two types of connection (Yi et al., 2022). However, results showed that abutments fractured more frequently between components of the internal conical connection type, especially in prostheses that used gold cylinders (C-Gold, S-UCLA) (Yi et al., 2021). In 2018, Palacios et al. published a systematic review aimed at assessing the amount of peri-implant bone resorption that plagued different implant connection types. The results showed that both internal and external

TABLE 5 Random-intercept linear regression model for medium bone resorption using surface instead of connection type (sensitivity analysis). Each parameter estimation is equipped with standard error, 95% confidence interval (95% CI) and *p*-value.

	Outcome measure: Mean bone resorption			
Predictors	**Estimates**	**Std. error**	**95% CI**	***p*-value**
Intercept	1.79	1.35	−0.72 to 4.31	.188
Patient-level variables				
Biological sex [female vs. male]	−0.45	0.28	−0.97 to 0.08	.114
Age	0.01	0.01	−0.02 to 0.03	.648
Maintenance [no vs. yes]	0.22	0.27	−0.29 to 0.73	.426
Prosthesis-level variables				
Prosthesis site [posterior maxilla vs. anterior maxilla]	0.83	0.76	−0.59 to 2.24	.279
Prosthesis site [anterior mandible vs. anterior maxilla]	0.07	1.14	−2.06 to 2.20	.950
Prosthesis site [posterior mandible vs. anterior maxilla]	0.87	0.76	−0.56 to 2.29	.259
Retention type [cemented vs. screw]	0.30	0.31	−0.28 to 0.89	.337
Implant-level variables				
Surface [DAE vs. AS]	−1.04	0.45	−1.88 to 0.19	**.022**
Surface [DCD vs. AS]	−1.42	1.39	−4.01 to 1.17	.310
Surface [HA vs. AS]	−0.61	0.52	−1.61 to− 0.36	.243
Surface [HYBRID vs. AS]	1.12	0.76	−0.33 to 2.54	.146
Surface [SLA vs. AS]	−0.89	0.35	−1.54 to −0.24	**.012**
Surface [TPSS vs. AS]	0.65	0.46	−0.21 to 1.51	.163
Position [external vs. internal]	−0.50	0.10	−0.69 to −0.31	**<.001**
Random effects				
σ^2	0.90 (95% CI: 0.62–0.91)			
$\sigma^2_{\text{prostheses}}$	0.23 (95% CI: 0.11–0.81)			
σ^2_{ID}	1.10 (95% CI: 0.43–1.68)			
ICC $_{\text{patient}}$	0.49			
ICC $_{\text{prosthesis within patient}}$	0.10			

Abbreviations: AS, Anodized Surface; DAE, Double Etched Surface; DCD, Discrete Crystalline Deposition of Calcium Phosphate Nanoparticles; HA, Hydroxyapatite Superficial Surface, HYBRID, Sla + Machined Surfaces; SLA, Sandblasted Large Grit and Acid-Etched Surface; TPSS, Titanium Pull Spray Superficial.

Bold values refers to statistically significant p values.

connections had high survival rates. However, due to the qualitative nature and inhomogeneity of the clinical studies considered, the authors were unable to state whether there was a statistically significant difference in peri-implant bone resorption between the two connection types (Palacios-Garzón et al., 2018). In addition, it should be emphasized the importance of a correct passivation technique of the prosthetic suprastructure. If not performed correctly, there is the possibility of tensile forces being generated that are discharged onto the implant structure. Clearly, this situation arises when several implants are used joined together by a rigid structure. They could be generated when each screw is tightened and are transmitted from the prosthetic structure to the fixtures. These forces are due to precision defects in the prosthetic framework and condition the implant by forcing it to move in both vertical and horizontal planes.

Once transmitted to the implant these are discharged at the level of the surrounding peri-implant bone, generating stress that can compromise the osseointegration that has already taken place. Maiorana et al. demonstrated the importance of the passivation technique in screw-retained prostheses to reduce the masticatory stresses that implant components transmit to the peri-implant bone (Calderini et al., 2007).

Data obtained in the present study indicated that cement-retained prostheses were significantly more prone to develop higher MBL than screw-retained ones. This corroborates emerging evidence suggesting that the presence of undetected subgingival cement remnants can lead to increased MBL which in turn may trigger the onset of peri-implantitis (Kim et al., 2022; Staubli et al., 2017). In a retrospective study by Alhammadi et al. (2021) 454 patients with a total of 1673 implants were examined. The results showed that complications of a biological nature were higher in cemented prostheses (70%) than in screw-retained prostheses (15%). Dalago et al. (2017) also reported that cemented prostheses have a higher risk of marginal bone loss around dental implants, probably due to the presence of residual cement in the sulcus. In a systematic review conducted by Sailer et al. it was observed that cemented-retained protheses showed more severe biological complications, whereas screw-retained rehabilitation showed more technical problems. According to the authors, screw-retained protheses were more easily salvageable than cemented restorations and, therefore, technical, and possibly biological complications can be managed more easily. For this reason, the authors recommended the use of the last-mentioned (Sailer et al., 2012). Similar results were also reported by Gaddale et al. (2020). To avoid such complications, Linkevicius et al. suggested that prosthetic margins should be placed coronal to the peri-implant tissues so as to facilitate the removal of any excess cement. Furthermore, any undercuts within the prosthetic framework should be minimized, if not eliminated, to provide better removal of excess cement, regardless of the diameter and position of the implants within the rehabilitation (Vindasiute et al., 2015).

In a study conducted by Hingsammer et al., the location influencing bone resorption around implants supporting a single-unit prosthesis was evaluated. The authors reported a significantly higher mean MBR around implants placed in the mandible compared to those placed in the maxilla, however, the splinting position was not considered. Moreover, there was significantly less resorption around implants placed in sites with a high amount of spongy bone (>60%) compared to implants placed in alveolar bone with a more represented cortical component. However, the number of dental implants considered was significantly lower (72 implants) than the sample taken in the present study (Hingsammer et al., 2017). Instead, the only significant difference observed by Yi et al. (2020) was between anterior and posterior mandible, being higher at the front. In the present study, the groups were divided into maxilla (anterior and posterior) and mandible (anterior and posterior), and no statistically significant differences were found between these groups.

The results reported herein should be interpreted cautiously due to the limits of the present study related to the retrospective nature, as reported by several studies of the same nature (French et al., 2019; Galindo-Moreno et al., 2022; Hingsammer et al., 2017; Ravidà et al., 2019). Heterogeneous follow-up times, and many implant lines with different micro- and macro-geometries were included, a fact that may have had some influence in the global resorption pattern. Furthermore, due to the retrospective radiographic nature of the study itself, no recordings of clinical parameters, and in particular the periodontal status, were made. Additionally, the lack of baseline radiographic documentation led to the assessment of MBL rather than bone resorption, which may not be accurate in identifying incipient bone loss, particularly in case of MBL <2 mm (Romandini et al., 2021). At the same time, the analyses focused on the implant position within the rehabilitation without taking into consideration the type of recipient bone, namely native or regenerated, or eventual soft tissue augmentation procedures performed before or after the delivery of the prostheses. It should be mentioned that all implants within the same prosthesis did not differ with respect to the implant line, underwent the same surgical sessions, and were followed for the same amount of time. Furthermore, a LMM was used to investigate variables related to MBL at patient, prosthesis, and implant levels. All of this taken together might have partially reduced the retrospective bias of the present study.

Another limitation to be considered is that the effect of the presence or absence of adjacent teeth to implants has not been evaluated. It is known that teeth compared to adjacent implants within the same patients yield more stable MBL (Rasperini et al., 2014). Accordingly, Berglundh et al. (2021) also noted that neighboring teeth may confound the history of bone loss. However, it should also be considered that recent evidence (Weigel et al., 2023) did not find this association, as comparable changes in the peri-implant MBL at implant sites with and without adjacent teeth was observed. Another limit to be mentioned is the fact that no evaluations were made on emergence profiles and angles of the prosthetic restorations investigated, which seem to have a certain impact on peri-implant bone remodeling (Yi et al., 2020). However, it is worth noting that more recent studies have not found a statistically significant correlation between prosthetic profiles and peri-implant bone resorption (Atieh et al., 2023). While our study provides valuable insights into some factors influencing MBL, the power to detect differences or associations with patient-level variables may be limited due to our sample size, and this constitutes an additional limitation of the present study. Furthermore, we also acknowledge that the scope of our work is limited to a single center. To strengthen the applicability of our findings, future research should focus on multi-center studies that cater to a more diverse and random patient population. This approach will help mitigate potential selection bias inherent to single-center studies and enhance the generalizability.

The resulting ICCs from analysis underscored two key points. Firstly, the consistently high combined ICCs demonstrate the necessity of adopting a study design that accommodates the hierarchical structure inherent in our data, as we did. This structure heavily influences the outcome variability, emphasizing the importance of properly accounting for it in similar clinical contexts. Secondly, given the still-present residual variation, it suggests that additional implant-level variables may be needed to further explain variability in outcomes, indicating a possible direction for future studies.

5 | CLINICAL IMPLICATIONS

Based on the current results, a higher MBL was observed at the level of the central implants. Where possible, from a biological standpoint, in case of fixed partial dentures of 3 or more elements, central implants should be avoided. In addition, the results indicate that the use of screw-retained prostheses should be preferred in order to avoid biological complications caused by undetected cement remnants.

6 | CONCLUSIONS

Within the limitations of the present study, in case of splinted bridges supported by ≥3 fixtures, central implants were more predisposed to

MBL compared to adjacent lateral implants. At the prosthesis level, implants supporting cement-retained bridges were statistically more susceptible to MBL compared to screw-retained ones. A less marked association was also found for implant surface characteristics at the implant-level.

AUTHOR CONTRIBUTIONS

Conceptualization: C.M., M.M., M.B., P.P.P.; formal analysis: C.M., M.B., P.P.P., M.R., V.V.; investigation: F.R., M.M., V.V.; data curation and statistical analysis: V.V. e M.R.; writing—original draft preparation: M.M., P.P.P., F.R., V.V.; writing—review and editing: C.M., M.B., M.R., V.V.; supervision, P.P.P., M.R., M.B.; project administration, C.M. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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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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