Received: 22 April 2022 | Revised: 26 June 2022 | Accepted: 29 June 2022

DOI: 10.1111/cid.13122

ORIGINAL ARTICLE

WILEY

Early marginal bone loss around dental implants to define success in implant dentistry: A retrospective study

Pablo Galindo-Moreno DDS, PhD[1] | **Andrés Catena PhD**[2] | **Mario Pérez-Sayáns DDS, PhD**[3] | **Juan Emilio Fernández-Barbero MD, PhD**[4] | **Francisco O'Valle MD, PhD**[5,6] | **Miguel Padial-Molina DDS, PhD**[1]

[1]Department of Oral Surgery and Implant Dentistry, School of Dentistry, University of Granada, Granada, Spain

[2]Department of Experimental Psychology, School of Psychology, University of Granada, Granada, Spain

[3]Oral Medicine, Oral Surgery and Implantology Unit, Faculty of Medicine and Dentistry, University of Santiago de Compostela, Santiago de Compostela, Spain

[4]Department of Anatomy, School of Medicine & IBIMER, University of Granada, Granada, Spain

[5]Department of Pathology, School of Medicine & IBIMER, University of Granada, Granada, Spain

[6]Instituto de Investigación Biosanitaria, ibs.GRANADA, Granada, Spain

Correspondence
Pablo Galindo-Moreno, Facultad de Odontología, Campus de Cartuja, 18071 Granada, Spain.
Email: pgalindo@ugr.es

Abstract

Purpose: The aim of this study was to establish an objective criterion in terms of marginal bone level (MBL) to know the prognosis of an implant.

Materials and Methods: A group of 176 patients in whom 590 implants were placed were included in this retrospective study. Patients older than 18 years, presenting either Kennedy class I or II edentulous section, or totally edentulous at least in one of the dental arches were included in this study. Those with any type of disturbance able to alter bone metabolism or with nontreated periodontal disease were excluded. Data on radiographic MBL at loading, 6 and 18 months later, age, gender, smoking habits, history of periodontitis, bone substratum, implant, and prosthetic features were recorded. Nonparametric receiver operating curves (ROC) were constructed for the MBL at 18 months in order to establish a distinction among high bone loser (HBL) and low bone loser (LBL) implants. Differences as a function of main variables were also determined, particularly abutment height and periodontal disease.

Results: HBL implants lost at least 0.48 mm of MBL 6 months after loading; they reached at least 2 mm of MBL 18 months after loading. MBL rate followed a non-linear trend, except in implants restored over long prosthetic abutments and in patients with history of severe periodontitis; in whom the rate of MBL over the time was nearly zero.

Conclusion: Implants that lose more than 0.5 mm of marginal bone 6 months after loading are at great risk of not being radiographically successful anymore. Therefore, 0.5 mm of MBL is proposed as a distinctive and objective criterion of success in

Implant Dentistry within a 6-month follow-up period. A prosthetic abutment height ≥2 mm resulted the most protective factor in the peri-implant bone maintenance.

KEYWORDS
alveolar bone loss, dental implants, marginal bone loss, peri-implantitis, periodontitis, prosthetics

What is known

- Marginal bone loss is a key factor in the development of peri-implantitis.
- The level of bone loss that can be used to predict future loss is not properly defined.

What this study adds

- Implants that lose more than 0.5 mm of marginal bone 6 months after loading are at great risk of not being radiographically successful anymore.
- A value of 0.5 mm of marginal bone level at 6 months post-loading is a reference criterion to differentiate between the physiological stability of the peri-implant bone and the possible development of pathology.

1 | INTRODUCTION

Marginal bone loss is a multifactorial event happening around the cervical area of dental implants. No matter what promotes it, marginal bone loss can be considered as a key factor in the development of peri-implantitis.[1] Although MBL does not always lead to peri-implantitis, there is no peri-implantitis without the prior presence of MBL. The presence or absence of MBL conditions the staging of the peri-implant lesions. In fact, it is not possible to define peri-implantitis if no bone loss is present around the implants.[2] This is true regardless of any other clinical measurement, such as bleeding on probing (BOP), suppuration or increased probing pocket depth (PPD). Those clinical measures do not correlate with mean bone loss, and thus those measures do not stand alone for case definition.[3] According to the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions, the periodontal probe is an important tool for the diagnosis of peri-implantitis, as it is in the diagnosis of periodontitis. However, radiographic evaluation is the necessary element for differentiating peri-implantitis from mucositis.

In fact, and although there are no current uniform criteria, the definition of peri-implantitis implies "progressive loss of bone around the implants".[4] The Workgroup 4 from the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions defines peri-implantitis as "a pathological condition occurring in tissues around dental implants, characterized by inflammation in the peri-implant mucosa and progressive loss of supporting bone".[2] However, it is surprising that, according to the positioning articles of the same consensus, in the absence of previous radiographs and for epidemiologic studies, peri-implantitis can be defined as a marginal bone loss equal to or greater than three millimeters in the presence of clinical signs such as PPD > 6 mm and BOP.[5,6] This definition, in our opinion, fails fundamentally in the concept of peri-implantitis itself. Peri-implantitis, as a pathological entity, must be defined as any loss of bone that occurs gradually after the post-implant placement bone remodeling, or after its functional loading, which also establishes an interesting debate. By omitting the term "progressive loss", important diagnostic errors may arise. It would mean, for example, that all surviving implants with more than 3 mm of MBL that suffer mucositis (a transitory entity) would be classified as peri-implantitis. This will, thus, condition their treatment. Even more, it could lead to the presentation of epidemiological maps that are very far from reality, showing erroneous distributions of these entities in whole population groups. To reinforce its lack of suitability, important leaders in the elaboration of this case-definition, have recently published that this secondary case definition of peri-implantitis suggested at the 2017 World Workshop Consensus on the Classification of Periodontal and Peri-Implant Diseases and Conditions, demonstrates a low sensitivity.[7]

The absence of bone around the neck of an implant can be explained by different reasons. Among them, the most common is physiological remodeling after surgery or prosthetic loading. This remodeling could become pathological after the same events and lead to peri-implantitis. However, it may also be due to improper surgical placement of the implant, the use of one-piece implants, the tissue-level design of some implants at different heights, or, after some complex combined techniques, such as vertical bone augmentation (either using the implant as a tenting abutment or due to reabsorption of the biomaterial).[8] In these situations, the final vertical position of the bone is not at the neck of the implant. This can be stable and greater than 3 mm, but it should not be defined as peri-implantitis. Analyzing only one radiograph, even in conjunction with peri-implant probing, may lead to many false positives. Therefore, the importance of "progressive bone loss" reinforces the need for at least two separate radiographs during the time in order to consider the condition of peri-implantitis.

Thus, the next question we need to answer is: how much progressive bone loss is necessary to define that process as pathological or peri-implantitis? Historically, implantology has defined three different stages to classify an implant: success, survival, and failure. Many

classifications have tried to establish a specific numerical value to differentiate between success and survival. The search for consensus has been ineffective. In some cases, the classifications are even contradictory, and, for example, an implant can be considered in different categories at the same time. For instance, if we take the criteria from the Pisa Consensus, a Straumann 4 mm extra-short implant with two millimeters of MBL, will be within the criteria for clinical success (having lost no more than 2 mm), failure (having lost 50% of its length), and survival (being maintained in function) at the same time.[9]

A great bias in our literature is that many studies with short, medium, and long-term clinical follow-up report their results in terms of survival. However, implants with pathology are sometimes not adequately reported. Therefore, we do not know when those implants are in palliative care, giving us an inadequate view of the success of the implant treatment or of the concomitant surgical techniques to maintain them. So, again, where should the red line be established to distinguish between success or survival?

Derks and colleagues in 2016 presented a 9-year follow-up clinical study in Swedish population. They reported how many implants and patients were at different levels of MBL, from 0.5 to 4 mm.[10] Based on the 2017 definition of peri-implantitis, with this intentional arbitrary staging done by the authors, most of the groups should have been included in the term of physiological remodeling, or, at least, not in the group of implants or patients with peri-implantitis. However, using this same series of patients, in one of the posterior analyses published also in 2016, these authors establish a limited amount of bone loss to define disease or peri-implantitis: 0.5 mm.[11] In this sense, 1 year before, in 2015, our group reported that 97.5% of implants that lost more than 0.44 mm up to the 6 months follow-up exceeded the limit of 2 mm of bone loss after the first year of follow-up.[1] This proves that those implants that we defined as "high bone losers" early on would not be in clinical success in the later follow-ups. This occurred regardless of the cause of this loss, even if it was due to the remodeling after loading because of the establishment of biological width.[12] If we extrapolate these ranges to the sample used by Derks and colleagues,[10] 45% of patients and 25% of implants would not be classified as successful, even in such a highly selective population because of their access to high quality public health. Consistently, this work by Derks and colleagues and the successive studies reported by that team analyzing the same population are of great interest to the scientific community.[7,10,13-17] This Derks and colleagues' manuscript was so transcendent in its publication that introduced an important reflection in our field, verbalized in an editorial published by Giannobile and Lang[18] entitled "Are Dental Implants a Panacea or Should We Better Strive to Save Teeth?", in which we were invited to a very serious reflection about the maintenance of the patient's teeth.

Nevertheless, the distinction between high and low bone loser (HBL and LBL, respectively) implants that we introduced in 2015 could show some limitations, since we used a sample of implants with different types of connection (conical internal and hexagonal external) in patients rehabilitated only in the upper posterior maxilla.[1] The literature clearly indicates that external connection implants show more bone loss than internal connection implants.[19-21] Also that internal conical connections show less bone loss in vitro and in vivo compared to any other type of connection[22] or even clinically, less marginal bone loss than other internal connection as internal hexagonal connections.[23] Therefore, we understand that it is necessary to update the concepts of HBL and LBL, by extending the analysis to all bone locations and analyzing only implants with conical internal connection, because it is one of the safest connections in terms of bone preservation according to our current understanding of prevention of MBL.

So, the aim of this study was to establish an objective criterion in terms of MBL to allow a better determination of prognosis of an implant in the early and short-term, that helps us predict future peri-implant pathology, and to know the role that different variables can exert on it.

2 | MATERIALS AND METHODS

2.1 | Study population

This retrospective study was carried out on a sample of patients randomly selected from those who received Osseospeed™ Astra Tech TX implants in the practices of one of the faculties in the Department of Oral Surgery and Implant Dentistry of the University of Granada, Spain (487/CEIH/2018). This protocol was presented and approved by the Ethics Committee for Human Research of our University. The STROBE checklist has been followed to report our study.

To be included in this analysis, patients had to be older than 18 years, present either a Kennedy class I or II edentulous section or be totally edentulous at least in one of the dental arches, had attended all the follow-ups visits and present panoramic radiographs from, at least, each of the time points to be evaluated in this study (loading, 6 and 18 months). Patients with records of any previous medical condition, disease, or intake of medication known to alter bone metabolism, previous radiotherapy in the oral area, nontreated periodontal disease in the remaining teeth, or any type of disturbance that may infer implant placement or sinus grafting when necessary were excluded from the study.

2.2 | Surgical and restorative procedures

All surgeries were performed under local anesthesia procedure, by the same oral surgeon (PG-M) and with the specificities described elsewhere.[1,24] Alveolar preservation techniques or horizontal or vertical crestal bone augmentation techniques were not performed in any of the patients included in the study. Only maxillary sinus floor elevation was conducted in those patients in need of it. All the implants used in the surgical procedures reported in this study were OsseoSpeed™ Astra Tech TX implants with internal tapered conical connection (currently under Dentsply Implants, Mölndal, Sweden), of 3.5, 4.0, 4.5, and 5 mm in diameter and 6, 9, 11, 13, and 15 mm in length. All the implants were placed using a two-stage technique. The final surgical position of each implant was prosthetically driven. Since we avoided

any type of bone augmentation, except for maxillary sinus augmentation, when there was enough available bone, the implants were placed following the ideal criteria proposed by Misch and Silic.[25] After the surgical procedures, medication was prescribed to all patients in the following regimen: as antibiotic, a combination of amoxicillin and clavulanic acid tablets (875/125 mg, TID for 7 days) or, if allergic to penicillin, clindamycin tablets (300 mg, TID for 7 days); as anti-inflammatory, ibuprofen (600 mg every 4–6 h, as needed to a maximum of 3600 mg/day); and, finally, as analgesic, metamizole (550 mg, only if needed in between the doses of ibuprofen). The sutures were removed 7–10 days after the surgery. A wound healing follow-up program was established every 2 weeks until complete wound healing.

The second surgical stage was carried out after 8 weeks, except when maxillary sinus augmentation was performed, in which the second surgery was delayed until 6 months after implant placement. Transmucosal abutments were placed until the pertinent healing and epithelialization of the tissues were achieved. Then, impressions by opened trays were taken, passive adjustment of the structure was verified, and, finally, occlusal function was adjusted. All prostheses were screwed over straight Lila or Aqua intermediate uni-abutments of 0, 0.5, 1, 2, 4, or 6 mm in height (currently under Densply Implants). In all cases, prostheses were delivered 4–6 weeks after the second surgery. According to the prosthetic plan, eight implants were placed in totally edentulous arches so that the rehabilitation could be segmented into 3- or 4-unit bridges when possible. Partially dentate patients, 2-, 3-, or 4-unit fixed bridges were supported by two or three implants.

2.3 | Radiographic evaluation of MBL

Standardized digital panoramic radiographs (Instrumentarium 700 3D module, Finland) were obtained throughout the different clinical phases and for the corresponding follow-ups. For this study, and according to the cut-off time-points established in previous studies,[21] MBL was evaluated at (1) final restoration delivery (baseline), (2) 6 months after loading and (3) 18 months after loading. Post-surgical radiographies were not considered in the current study because it has been previously determined that MBL mainly appears after prosthesis delivery.[1] Images were exported in DICOM format and evaluated with the Image J software (NIH, Bethesda, MD). Linear measurements in the distal and mesial sides were obtained from the implant platform to the nearest supportive crestal bone. A single calibrated and experienced examiner (MP-M) conducted all the measures. Known implant length and diameter were used to calibrate each individual measurement and correct most of the possible magnification of each image.

2.4 | Additional data recorded

Patients' age at implant surgery, gender, smoking habits (positive or negative), implant location (mandible or maxilla), and need of sinus graft (grafted or pristine bone) were recorded. Information regarding implants included position in the dental arch, length, and diameter.

Other main variables included in this study were as follows: (1) Abutment height (0, 0.5, 1, 2, 4 or 6 mm). In order to analyze the effects of the abutment height in the MBL, this variable was categorized in (a) short abutment (SA) when the abutment was shorter than 2 mm (i.e., 0, 0.5, and 1 mm) and (b) long abutment (LA) when the abutment was 2 mm or taller (i.e., 2, 4, and 6 mm). The reason to discriminate in these two categories was elsewhere related.[26] (2) Type of prostheses. Prosthetically, the sample was divided into two categories: (a) fixed partial bridge, placed in partially edentulous patients with Kennedy class I or II; and (b) fixed full-arch implant-supported rehabilitation, in totally edentulous patients. (3) Periodontal status/history. Three different categories were established, according to the classification that was established at the time of initial clinical evaluation: (a) non-periodontal patients; (b) patients with mild or moderate periodontal disease; and (c) totally edentulous patients in whom all their teeth in the arch(s) were extracted because of severe periodontal disease.

2.5 | Statistical analysis

Descriptive statistics was used to describe the sample. As mentioned before, for these analyses, the abutment height variable was dichotomized as short abutment and long abutment. We established two main outcomes. Outcome 1: MBL as a function of all the other factors; Outcome 2: MBL as a function of type of prosthetic rehabilitation. For the first outcome, a linear mixed model was used to analyze mesial and distal MBL, with the patients as clusters and the implant as unit of analysis[27]; abutment height, measurement time, graft, and periodontal status were considered as factors, and age, gender, smoking habits, implant location, implant length, and implant diameter as covariates. For the second outcome, Kennedy Class I and Class II patients were pooled together, and contrasted with those who were fully edentulous at least in one arch. An autoregressive covariance matrix was applied to minimize Schwarz's Bayesian information criteria.[28] MBL was computed to clarify the interpretation. Rates for loading, 6 and 18 months were computed and the MBL divided by the time elapsed from loading. Mesial/distal measures were averaged when no interactions were observed with the remaining factors. The Bonferroni correction was applied to account for the large number of potential predictors, establishing a 0.05 significance level per comparison. The non-parametric receiver operating curves (ROC) were constructed for the MBL at 18 months to determine differences as a function of abutment height and periodontal disease. Finally, the percentage of implants with success, survival, or failure was determined for different criteria (0.5, 1, 2, 3, 4, or more mm) of MBL.

3 | RESULTS

The descriptive statistics of the sample are displayed in Table 1. There were a total of 590 implants placed in 176 patients (87 women), with a mean age of 54.48 (SE = 0.418, median = 53.5). A total of 122 implants were placed in 54 non-periodontal patients, 239 implants

TABLE 1 Descriptive analysis of the socio-demographic variables

Variable	N	%	p
Gender			
Female	87	49.4	0.874
Male	89	50.6	
Smoking			
No	106	60.2	0.007
Yes	70	39.8	
Periodontitis			
No	54	30.7	0.516
Mild/moderate	96	54.5	0.001
Severe	26	14.8	0.001
Implant location			
Maxilla	327	55.4	0.152
Mandible	263	44.6	
Sinus graft			
No	380	64.4	0.001
Yes	210	35.6	

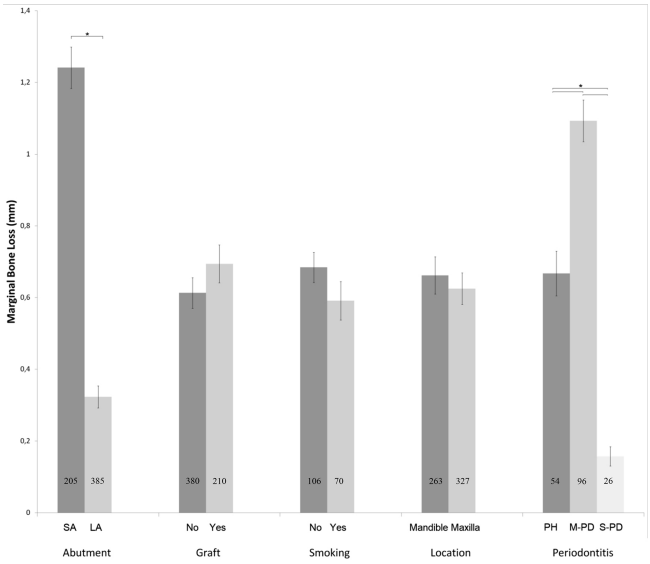

FIGURE 1 Marginal bone level as a function of the main variables of the study. SA, short abutment; LA, long abutment; PH, periodontal health; M-PD, mild/moderate periodontal disease; S-PD, severe periodontal disease. Numbers within each column indicate the number of implants

were placed in 96 patients with mild or moderate periodontal disease, and 229 implants were placed in 26 edentulous patients with previous history of severe periodontitis. The average number of implants per patient was 2.26 for the nonperiodontal group, 2.39 for those with mild and moderate periodontitis, and 8.81 for those with severe periodontitis. The average level of MBL for each of the main variables is presented in Figure 1.

The mixed linear model on mesial MBL yielded main effects of abutment height ($F[1,1043] = 36.988$, $p < 0.001$), graft ($F[1,637] =$

TABLE 2 Marginal bone level at each time after loading

Time	Site	Mean	SE	LL	UL
Loading	Average	0.064	0.012	0.040	0.087
	Mesial	0.056	0.011	0.034	0.080
	Distal	0.072	0.013	0.046	0.098
6 months	Average	0.322	0.022	0.279	0.366
	Mesial	0.298	0.022	0.255	0.342
	Distal	0.348	0.024	0.299	0.396
18 months	Average	0.642	0.034	0.576	0.708
	Mesial	0.603	0.034	0.537	0.669
	Distal	0.679	0.037	0.607	0.751

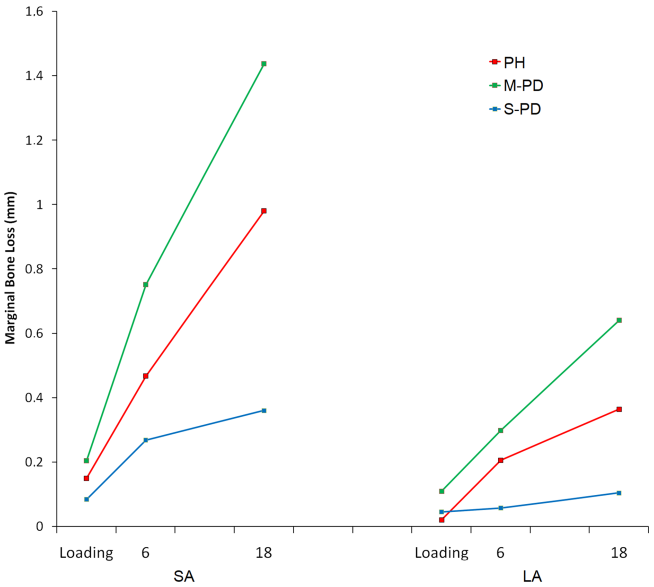

FIGURE 2 Marginal bone level as a function of abutment height (SA, short abutment; LA, long abutment), periodontal disease (PH, periodontal health; M-PD, middle/moderate periodontal disease; S-PD, severe periodontal disease) and time after loading (in months)

4.722, $p = 0.03$), periodontal disease ($F[2,440] = 21.655$, $p < 0.001$), time ($F[2,1237] = 146.982$, $p < 0.001$), and the interactions of abutment height by time ($F[1,1261] = 21.704$, $p < 0.001$), periodontal disease by time ($F[4,1230] = 18.678$, $p < 0.001$), and abutment height by periodontal disease by time ($F[4,1256] = 3.692$, $p = 0.005$). The analysis of the distal MBL yielded the very same results: main effects of abutment height ($F[1,1015] = 58.542$, $p < 0.001$), graft ($F[1,653] = 5.263$, $p = 0.03$), periodontal disease ($F[2,459] = 22.086$, $p < 0.001$), time ($F[2,1238] = 159.526$, $p < 0.001$), and the interactions of abutment height by time ($F[2,1263] = 23.038$, $p < 0.001$), periodontal disease by time ($F[4,1230] = 20.994$, $p < 0.001$), and abutment height by periodontal disease by time ($F[4,1258] = 3.777$, $p = 0.005$). Thus, the average of mesial and distal MBL was used for the following analyses.

With the average MBL (Table 2), the mixed-linear model yielded main effects of abutment height ($F[1,1072] = 53.755$, $p < 0.001$), graft

(F[1,637] = 5.717, p = 0.02), periodontal disease (F[2,436] = 24.69, p < 0.001), and time (F[2,1246] = 188.486, p < 0.001). There were also effects of abutment height by time (F[1,1114] = 27.126, p < 0.001), periodontal disease by time (F[1,1252] = 23.844, p < 0.001), and abutment height by periodontal disease by time (F[4,1264] = 4.312, p = 0.002). The detailed analysis of these effects showed that implants in grafted areas (mean loss = 0.300 mm, SE = 0.040) lose significantly less bone than those placed in pristine bone (mean loss = 0.417 mm, SE = 0.031); that implants restored with SA (mean loss = 0.522 mm, SE = 0.041) lose more bone than those with LA (mean loss = 0.195 mm, SE = 0.027); and that, as expected, there is increased bone loss as time goes by (Table 2). The main effect of periodontal disease was unexpected, as there was significantly less MBL in severe (0.138 mm, SE = 0.056), than in no periodontitis (0.364 mm, SE = 0.046) and mild or moderate periodontitis (0.573 mm, SE = 0.033).

The effects of abutment height by periodontal disease by time (Figure 2) showed that periodontal disease has a different impact on MBL as time goes on depending on the abutment height. In fact, periodontal disease has much more impact on implants restored with short than long abutments, an impact that also increases at different rates. The detailed analysis of this interaction is further clarified when MBL is expressed as rate by month after loading. Figure 3 shows that the smallest change in rate is produced in severe periodontal disease patients for the long abutment, in which we can see that the rate remains all the time around zero (no rate in fact differ from 0). The remaining ones differ from zero, excepting those of severe periodontitis for short abutment at 18 months after loading.

Regarding type of prosthesis, the same mixed linear model yielded main effects of abutment height (F[1,1303] = 32.529, p < 0.001), graft (F[1,1011] = 5.308, p = 0.02), smoking (F[1,307] = 5.20, p = 0.02), prosthesis (F[1,577] = 34.637, p < 0.001), and time (F[2,1260] = 91.095, p < 0.001). Also, there were significant interactions of prosthesis by time (F[2,1261] = 31.929, p < 0.001), and abutment height by prosthesis by time (F[2,1280] = 6.137, p = 0.002; Table 3).

The analysis of the ROC curve (Figure 4) showed differences as a function of abutment height (χ^2(1) = 9.44, p = 0.002), which implies that the Youden criterion for classifying MBL at 18 months as a function of the MBL at 6 months is much higher for SA (1.39 mm) than for LA (0.35 mm), with an average of 0.48 mm. The ROC curve as a

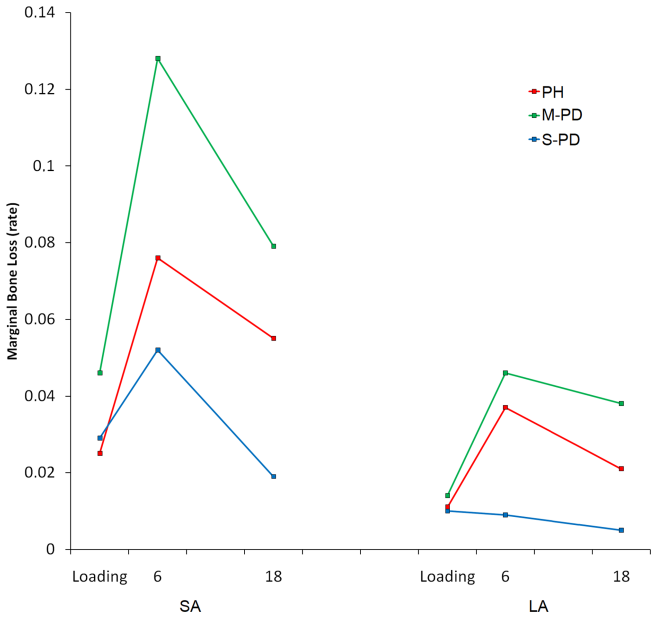

FIGURE 3 Rates of marginal bone level as a function of abutment height (SA, short abutment; LA, long abutment), periodontal disease (PH, periodontal health; M-PD, middle/moderate periodontal disease; S-PD, severe periodontal disease) and time after loading (in months)

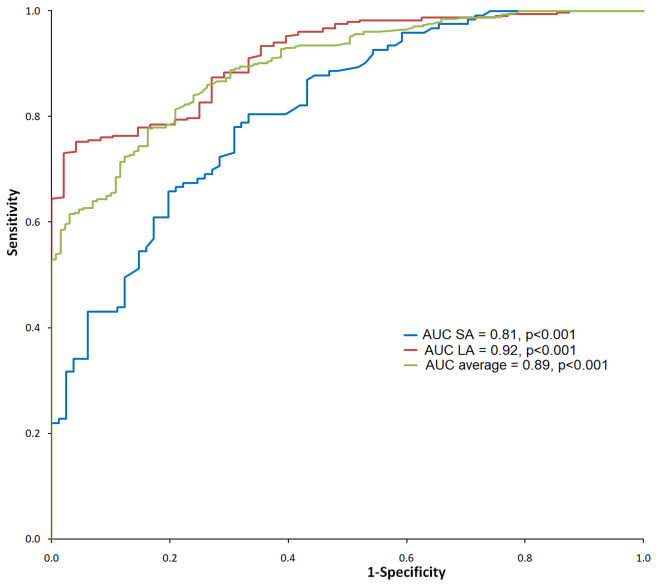

FIGURE 4 Receiver operating curves comparing the classification of marginal bone level as a function of abutment height (less/more than 2 mm)

TABLE 3 Mean (standard error) of the marginal bone level per abutment height and type of prosthesis at each time point

			Time		
Abutment	***N***	**Prosthesis**	**Loading**	**6 months**	**18 months**
Short AH	185	Partial	0.186 (0.038)	0.656 (0.039)	1.303 (0.038)
	20	Complete	0.081 (0.119)	0.266 (0.128)	0.358 (0.121)
Long AH	176	Partial	0.087 (0.041)	0.275 (0.042)	0.548 (0.041)
	209	Complete	0.059 (0.045)	0.043 (0.045)	0.09 (0.045)

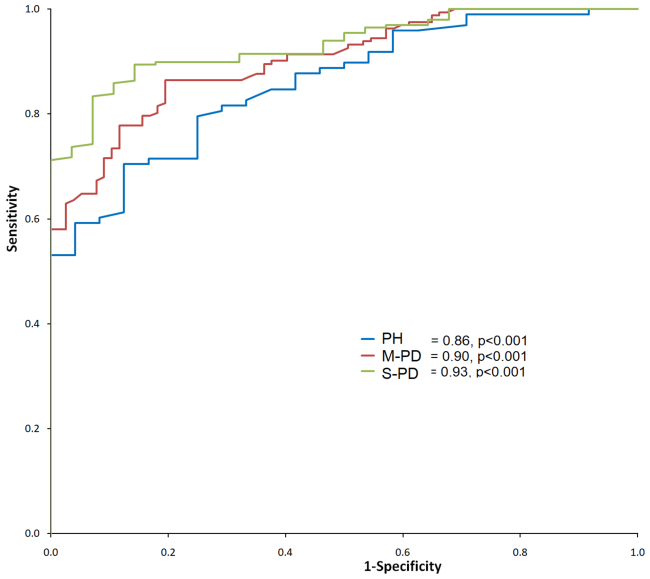

FIGURE 5 Receiver operating curves comparing the classification of marginal bone level as a function of severity of periodontal disease (PH, periodontal health; M-PD, middle/moderate periodontal disease; S-PD, severe periodontal disease)

TABLE 4 Percentages of implants with different levels of MBL as a function of abutment height category

	MBL					
	<0.5	0.5 < 1	1 < 2	2 < 3	≥3	*N*
Short abutment	20.00	65.85	11.71	1.46	0.98	205
Long abutment	77.66	19.74	2.08	0.52	0.00	385
Total	57.63	35.76	5.42	0.85	0.34	590

Abbreviation: MBL, marginal bone level.

function of severity of periodontal disease (Figure 5) did not reach statistical significance ($\chi^2(1) = 3.64$, $p = 0.16$).

Finally, the percentages of success/survival/failure for the two different categories of abutment height (Table 4) showed that many more implants remained fully successful (<0.5 mm) in the long than in the short abutment category ($p < 0.0001$). Also, only 2.44% of the implants with short abutments (5 out of 205) exceeded 2 mm of MBL, while only 0.52% of the implants restored with long abutments (2 out of 385) did so. Thus, only those can be considered survivors or failed, according to the criteria of ≥2 mm of MBL as red line to define the status of the implants.

4 | DISCUSSION

The definition of success in Implant Dentistry has evolved in recent years, and has been revolutionized since 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions by the Characterization of Peri-implant Health.[5] It can read that "healthy peri-implant tissues have become synonymous with implant success". This literally means that the clinical absence of erythema, bleeding on probing, inflammation, and suppuration, without considering specific ranges of probing depth or clinical or radiological bone loss, is currently synonymous with peri-implant health.[29]

In our opinion, this is much of a periodontal vision of the matter, which detracts from much diagnostic and therapeutic potential to this problem. For some authors, such as Papaspyridakos and colleagues, assessing success should be related to at least four levels of integration related to implant level, peri-implant soft tissue, prosthesis, and patient's subjective evaluation.[30]

The most common etiology in the late implant loss is peri-implantitis,[31] being associated to almost 50% of the cases in several studies.[10] Beyond the clinical parameters proposed in the current definition, marginal bone loss around implants ought to be the key parameter in the peri-implantitis definition. Discerning between physiological and pathological bone loss is of paramount importance in Implant Dentistry, mainly because adequate peri-implantitis treatment remains unclear. According to the results related in the present manuscript, we agree with the criteria established by Derks and colleagues in their studies.[10,11] The results presented in this study support their proposal, based on their clinical studies, and as a value of 0.5 mm of MBL post-loading as a reference criterion to differentiate between the physiological stability of the peri-implant bone and the possible development of pathology. With this foundation, the 0.5 mm is neither an arbitrary number nor a mark for measurement error but a true value according to the results presented here and previously.[1]

The Classification of Periodontal and Peri-Implant Diseases and Conditions elaborate during a World Workshop in 2017 defined peri-implantitis as presence of bleeding and/or suppuration on gentle probing, increased probing depth compared to previous examinations (characteristics shared with diagnosis of mucositis) and, differentially, presence of bone loss beyond the level of changes in the crestal bone that result from initial bone remodeling.[5] Thus, according to this definition that introduces the concept "level of changes in the crestal bone", at least two different radiographs separated on time might be required. This is the essence of the diagnosis of peri-implantitis, radiological analysis, because radiographic techniques prevail as the only diagnostic tool capable of accurately verifying whether or not these bone changes are occurring. In the absence of those two radiographs separated on time, the clinical diagnosis of peri-implantitis ought to be cautiously maintained or not considered.

Nevertheless, on the contrary, in the absence of such previous radiographs, the aforementioned consensus established that peri-implantitis could be defined as the presence of bleeding and/or suppuration on gentle probing, probing depths of 6 mm or more, and bone level at 3 mm or more apically from the most coronal aspect of the intraosseus part of the implant.[5] This definition was also recommended to define peri-implantitis in epidemiological studies. However, it is quite remarkable that in latter studies, the same authors leading this classification and their colleagues have recently reported that sensitivity of the case definition suggested by the 2017 World Workshop of Periodontology (BoP/SoP ≥ 1 site & bone level ≥3 mm &

PPD ≥ 6 mm) was low.[7] The mentioned study leaves in a very compromised situation the current case-definition proposed for epidemiological studies. This is because according to those results, this low sensitivity indicates a high inability to diagnose diseased implants, as truly pathological. Moreover, the validity of the proposed clinical criteria for the diagnosis of peri-implantitis is also in question, since they also have reported that while blood on probing showed a high level of sensitivity, the sensitivity of probing pocket depth was generally low.[32] But even more, bleeding on probing must be interpreted with caution, as it may originate not only because of a true pathological condition but also as a consequence of trauma upon the own maneuver of probing.[33]Thus, as mentioned earlier, many clinical situations may lead to false positives with this definition, which introduces large biases that may even affect how patients are treated. Even more, and even if we use that definition for epidemiological studies and not for clinical practice, the absence of sequential radiographic examination can lead to nonrealistic statistics on the magnitude of the peri-implantitis problem in a population because of errors in this case definitions. Therefore, it seems reasonable that at least two radiographs are needed in the diagnosis of peri-implantitis.

To reinforce our proposition, we can also highlight that some of the same authors who promoted 2017 consensus on peri-implantitis definition, in their own clinical studies use other parameters to characterize their study population. So, in 2016, in a study of high impact about the prevalence of peri-implantitis in a Swedish population, Derks and colleagues established the definition of peri-implantitis as BOP/suppuration and detectable bone loss (>0.5 mm; exceeding the measurement error). Implant sites presenting with BOP/suppuration and bone loss >2 mm were considered as moderate/severe peri-implantitis.[10] Interestingly, these criteria have been maintained in many other studies from the same group even after the definition of the 2017 Consensus.[7,10,11,14-17]

Taking into consideration the related findings reported in all their manuscripts using this same series, this distinguished group of researchers in peri-implantitis used a combination of intraoral radiographs (78.1% of implants) and panoramic radiographs (21.9% of implants) for evaluating bone loss.[10] It is even more interesting that to define the onset and pattern of progression of peri-implantitis in their population, the assessment was solely based on radiographic and not clinical signs of progressive MBL.[11] In this same sense, it is important to note that, although some studies associate clinical parameters to the severity of peri-implant diseases,[34] the meta-analytic evaluation of more than 4000 patients treated with more than 9500 implants of different brands and treatment protocols found no correlation between mean probing depth and mean bleeding on probing with mean MBL, which was also irrespective of follow-up.[3]

Based on the definition of peri-implantitis at 0.5 mm of radiographical bone loss, used by Derks and colleagues in 2016, in the analyzed Swedish population, with a really good dental and implantology tradition, and a very good public health system, a 45% of patients and 24.9% of implants would have peri-implantitis; almost half the population in their random sample would show peri-implantitis and one in four implants.[10] This led to an interesting wake-up call editorial about the really high level of disease associated to the treatment with dental implants.[18] Therefore, we must ask ourselves why to assume that requirement (0.5 mm) and if we could not be more relaxed in the definition and adopt those 2 mm as the cut-off value described earlier to define success or disease. Nevertheless, in the series of Swedish manuscripts, 2 mm of radiographical bone loss was defined by the authors as moderate/severe peri-implantitis, and the numbers went down to 14.5% of patients and only 8% of implants with peri-implantitis, which is less alarming. It is interesting that this radiographical level of 2 mm of bone loss, strictly defined as moderate/severe peri-implantitis by Derks and colleagues, is the cut-off value up to which success or survival can still be defined, according to most of the pre-established criteria in the literature or previous consensus anterior to 2017 World Workshop. Moreover, although a more relaxed parameter than those 0.5 mm of MBL is even stricter from the 3 mm defined in the 2017 World Workshop for epidemiological studies, if there were no previous radiological data.

Therefore, according to our current results, again we support that the criterion of 0.5 mm of MBL as a red line between the physiological and the pathological is correct.[1,10] In a previous study, our group already established that some implants had an aggressive initial peri-implant bone loss so that, after a certain time, that implant would hardly stop losing bone and would become non-successful in the following follow-up.[1] Those implants were defined as high bone losers: when MBL was >0.44 mm at 6 months post-loading, they were much more likely to have ≥2 mm of MBL at the 18 months follow-up. In other words, 96.1% of implants with MBL of ≥2 mm at 18 months had a 6 months value above the cutoff value (0.44 mm MBL). Moreover, the OR for an implant with less than 0.44 mm of MBL at 6 months to show an MBL <2 mm at 18 months was 25.66. Although that study provided very important data, in our opinion it had two important limitations. (1) Both internal and external connection implants were analyzed. The literature is currently consistent in that implants with external connection lose more bone than implants with internal connection.[19-21] (2) Only implants in the posterior regions of the upper posterior maxilla were analyzed. It is reported that the type of bone in which the implant is placed, which varies in the different locations of the oral cavity, may play a role in the MBL.[35] In order to overcome those limitations, the present study evaluated implants in all intraoral locations and of only one micro and macro-design, that is, Osseospeed Astra Tech TX implants. With these considerations, in the present work, high bone loser implants are defined as those with an MBL >0.48 mm at 6 months post-loading, a very similar results to our previous study.[1]

The mean MBL in our sample at the time of the prosthetic loading was 0.064 ± 0.012 mm, progressed to 0.322 ± 0.022 mm at 6 months post-loading and to 0.642 ± 0.034 mm 1 year later, 18 months post-loading. These data further support previous findings that established that the MBL begins at the time of the disruption of the seal between the implant and its cover screw. This is, it initiates in the second surgical stage, but it is not related to surgical events relative to the implant placement.

In terms of the type of prosthesis that is connected to the implant, Toia and colleagues clearly stated that, after 1 year of

loading, implants supporting fixed partial dentures directly screwed showed greater MBL and soft tissue inflammation than those implants and screw retained fixed partial dentures with intermediate abutments.[36] Our study was carried out with restorations on multiple implants; a direct connection between the prosthesis and the implant was never done, so the use of multiunit abutments was mandatory. As also found in previous studies by our group and others before and after, the height of the intermediate transmucosal abutments was the most important factor in the preservation of the peri-implant bone.[26,37-39] In the current study, those implants restored with abutments shorter than 2 mm lost 0.522 ± 0.041 mm of bone while those restored with abutments higher than two lost only 0.195 ± 0.027 mm. We use 2 mm as a limit to categorize abutment heights following our previous studies that demonstrate this mark as the important level.[26] Although other studies agree that short abutments induce higher loss of bone, different limits are used to categorize abutment heights, but completely arbitrary as admitted by the authors themselves.[40]

According to the staging and success criteria proposed by Derks and colleagues,[10] with the 0.5 mm limit, only 20% of the implants in the current study restored with short abutment remained successful, while 77.66% of implants restored with long abutment did not exceed that limit after 18 months of occlusal function. On the other hand, only 2.44% of the implants with short abutments exceeded 2 mm of MBL, while only 0.52% of the implants restored with long abutments did so. A recent meta-analysis estimated a prevalence of 12.8% of implants exceeding 2 mm of MBL.[41] The low numbers in our sample can be due to multiple factors. Above all, the heterogeneity of the implants included in the meta-analysis vs. the homogeneity of our study. Finally, if the 2017 World Workshop criteria of 3 mm or more of MBL is applied to our sample, only 1.19% of the implants could be considered as suffering from peri-implantitis.

Our study also analyzed the influence of history of periodontal disease, which has been classically defined as a predisposing factor for the development of peri-implantitis.[42] There are many studies and meta-analyses supporting the idea of a higher MBL associated to periodontitis patients.[35,43] There are also many supporting just the contrary.[40,44-46] There are some plausible explanations for both affirmations. The current study shows surprising results regarding the role that periodontitis plays in the MBL. Edentulous patients with a history of severe periodontitis, that in fact led to having all the teeth extracted because of it, showed the lowest rates of bone loss in the entire series, and the lowest absolute values of MBL (0.138 ± 0.056 mm). However, patients with stable mild or moderate periodontitis had their implants with greater bone loss (0.573 ± 0.033 mm) than those placed in periodontally healthy patients (0.364 ± 0.046 mm). It seems as if the severity of periodontal disease would behave as a protective factor for implant MBL by conditioning individualized clinical scenarios in which bone loss is reduced. In our opinion, these results may be due to a number of factors. It is known that, despite the extraction of all teeth in patients with severe periodontitis, periodontopathogenic bacteria remain in the oral cavity in specific reservoirs.[47,48] Therefore, a patient's bacterial footprint does not seem to disappear. However, edentulous patients do show a reduction of the periodontopathogenic bacterial load because there are fewer active niches as periodontal pockets disappear. Also, those patients who lose teeth because of periodontal disease may change their habits of oral hygiene and, if they are replaced with dental implants, they become more aware of the importance of maintenance. The biological and economic costs are truly known to them at that point. In fact, it has been demonstrated that periodontal patients trained with a systematic supportive periodontal therapy have significantly reduced risk of suffering peri-implantitis.[49] On the other hand, partially dentate patients with stable periodontitis would have a higher bacterial load. However, this might not be the reason as recent studies assert that implants adjacent to teeth in periodontal patients do not show significant differences in terms of MBL compare to those implants adjacent to teeth in periodontally healthy patients.[50,51] In addition, there are some differences between the biofilms developed in teeth and implants, even they are adjacent to one another.[52] Thus, the differences in our groups of periodontal disease should be due to other factors.

Of special interest in our study is the interaction between the history of periodontitis, the height of prosthetic abutment and time. As shown in Figure 2, the MBL in absolute terms evolves over time, but it follows different patterns in each group of periodontal disease, which is clearly conditioned by the height of the abutment. This interaction determines that even if classified in the same group of periodontal disease, those implants restored with short abutments lose much more bone than those implants restored with long abutments. In contrast, patients with a history severe periodontitis with implants restored with long abutments, lose very few bone over time. These data highlight the importance of prosthetic abutment over any other variable in the maintenance of bone around implants. This is even more evident when we analyze the rate of progression of bone loss (Figure 3). The rate of MBL is clearly not linear, as found in many other studies.[53,54] So, after an initial bone remodeling processes, the bone loss rate decreases considerably, something that has been known since the dawn of implantology.[55] However, these rates are much lower in those implants restored with long abutments. The rate of MBL in implants placed in patients with history of severe periodontitis restored with long abutments follows a marked different trend from the rest of clinical situations: there is a continuous decrease. This is different from any previous pattern published in the literature.[11,56] We have to consider that in our study, there were a high number of implants in this category, in which the MBL rate always remained around zero.

Another relevant result in our study was the statistically significant relationship for the interaction of abutment height by prosthesis by time ($p = 0.002$), described in Table 3. The MBL in implants that supported full-arch restorations was lower than that of partial fixed bridges, including those supported by long abutments. Interestingly, in fact, the combination of screw-retained implant-supported full-arch restorations and long abutments did not show any MBL over time.

Classically, literature has reported highly satisfactory outcomes with implant-supported fixed full-arch dental prostheses, independently of the specific configuration used.[57] The average bone loss associated to this kind of restorations ranges from 0.7 mm[58] to 2.65 ± 1.34 mm.[59]

The problem is that the majority of the long-term clinical studies on implant-supported fixed dental prostheses report their data in terms of survival, but there is limited information on MBL. This may indicate that most of those surviving implants are not truly successful, or even worse, are associated with peri-implant pathology. Even more, to our knowledge, there are no studies analyzing the role of abutment height on long-term MBL around implants supporting full-arch rehabilitations. However, there are some previous studies highlighting that a long abutment is a preventive factor to avoid MBL around either cemented or screw-retained implant-supported single crowns, fixed partial dentures or overdentures.[24,26,37,39,53,60-63] From our current results in terms of type of prosthesis used, it can also be inferred that the height of the prosthetic abutment could be an important key factor in the preservation of peri-implant bone regardless of the type of restoration.

One of the objectives of this study was to analyze if the type of bone depending on implant location could affect the MBL around implants. As in other studies,[65] our results did not show significant differences neither in implants placed in the upper or lower jaw, nor in implants placed in pristine bone versus grafted bone in the maxillary sinus area. In some interactions of the mixed linear analysis, placing implants in grafted bone turned out to be a protective factor for MBL. These results contradict those published by our group in 2014.[66] However, the population evaluated in that previous study clearly differs from the one in the current analysis. In those studies, implants with internal and external connection were analyzed. In this study, we only evaluated internal conical connection implants. Secondly, in the previous sample there were no severe periodontal patients, while in the current population many implants had been placed in this kind of patients, which has been already discussed. Third, in this study, many of the implants placed in grafted bone were included in screw-retained implant-supported full-arch dentures versus many partial bridges analyzed in the previous study. As also discussed, with full-arch prosthesis, MBL was always lower. A similar explanation can be attributed to the effect of tobacco consumption. In some of the mixed linear model analyses, smoking showed a marginal effect in the MBL, but related to prosthetic restoration. No interaction was found with any of the other significant variables. In the main analysis, statistically significant differences were not found between smokers and non-smokers (Figure 1). In previous studies, we related a positive relationship between smoking and MBL around implants,[66,67] as many other authors.[44,68,69] Nevertheless, we were unable to corroborate that relationship in the present study, surely due to differences in the heterogeneity of the samples. In addition, other studies recently published also failed to demonstrate this association.[70,71]

This study has some possible limitations. First, it is a retrospective study; therefore, some of the clinical variables could not be obtained, being mainly a radiographical study. Many other relevant studies in the literature suffer from this very same limitation. But as discussed earlier, MBL, the distinctive factor between peri-implantitis and mucositis can only be evaluated by imaging techniques. We must keep in mind the low sensitivity shown by the previously discussed clinical variables. Secondly, in this study, digitalized panoramic radiographies were used, like most of the studies in our series on MBL. Although some authors recommend periapical techniques to measure MBL,[72] due to their greater sensitivity, it is worth bearing in mind some factors that invite us to use panoramic radiographs in our studies. Periapical radiographic techniques are, by definition, retro-alveolar techniques. This can obviously only be used in clinical situations where there is an alveolar ridge. In the analysis of one or two implants it is feasible. However, in edentulous patients, with maxillary atrophy, periapical techniques are frequently unfeasible because the alveolar ridge usually does not exist. If carried out, they should be done with the bisector technique, which in addition to distorting the image, does not allow a proper reproducibility in the following follow-ups. Panoramic radiographs are based on parallelism techniques, in which the image distortion is lower, and the position of the maxilla is more reproducible over time. In addition, the literature also endorses the use of panoramic radiographical tools. In fact, in the Swedish study series initiated by Derks and colleagues, 20% of measurements were made on panoramic radiographs.[10] Moreover, more recent studies conducted and published by others also use data from panoramic radiographies to analyze MBL around implants.[7,32] It is remarkable that in the most recent consensus,[2,73] "intraoral radiographies" are not required specifically, surely due to the important limitations of the intraoral radiographies described above. In any case, in the current study, all radiographical measurements were calibrated with the known diameter and length of each analyzed implant.

5 | CONCLUSION

In our sample, the vast majority of implants that exceed 0.5 mm of marginal bone loss 6 months after loading, do not demonstrate radiographic success in the subsequent follow-up 12 months later. Therefore, we propose a limit of 0.5 mm of radiographic marginal bone loss as a distinctive criterion of dental implant success. Additionally, the height of the prosthetic abutment is once again confirmed as the most relevant factor in the preservation of peri-implant bone. A minimum of 2 mm abutment height is recommended to get adequate protection against peri-implant bone resorption.

AUTHOR CONTRIBUTIONS

Pablo Galindo-Moreno: Contributed to conception, data interpretation, and drafting and critically revised the manuscript. **Andrés Catena:** Contributed to data analysis, data interpretation, and drafting and critically revised the manuscript. **Mario Pérez-Sayáns:** Contributed to interpretation and critically revised the manuscript. **Juan Emilio Fernández-Barbero:** Contributed to interpretation and critically revised the manuscript. **Francisco O'Valle:** Contributed to data analysis and critically revised the manuscript. **Miguel Padial-Molina:** Contributed to data acquisition, interpretation, and drafting and critically revised the manuscript. All authors gave their final approval and agreed to be accountable for all aspects of the work.

FUNDING INFORMATION

The authors of this manuscript are partially supported by Research Groups #CTS-138, #CTS-176 and #CTS-1028 (Junta de Andalucía,

Spain). This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. Funding for open access charge: Universidad de Granada / CBUA.

CONFLICT OF INTEREST

Pablo Galindo-Moreno is usual speaker for Dentsply Implants Company, among other companies. However, the authors declare no conflict of interest, either directly or indirectly, in any of the products listed in the manuscript.

DATA AVAILABILITY STATEMENT

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

ORCID

Pablo Galindo-Moreno https://orcid.org/0000-0002-6614-6470
Andrés Catena https://orcid.org/0000-0002-0775-5751
Mario Pérez-Sayáns https://orcid.org/0000-0003-2196-9868
Juan Emilio Fernández-Barbero https://orcid.org/0000-0001-9281-4973
Francisco O'Valle https://orcid.org/0000-0001-9207-2287
Miguel Padial-Molina https://orcid.org/0000-0001-6222-1341

REFERENCES

1. Galindo-Moreno P, León-Cano A, Ortega-Oller I, Monje A, O'valle F, Catena A. Marginal bone loss as success criterion in implant dentistry: beyond 2 mm. *Clin Oral Implants Res*. 2015;26(4):e28-e34. doi:10.1111/clr.12324
2. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *J Clin Periodontol*. 2018;45:S246-S266. doi:10.1111/jcpe.12954
3. Doornewaard R, Jacquet W, Cosyn J, De Bruyn H. How do peri-implant biologic parameters correspond with implant survival and peri-implantitis? A critical review. *Clin Oral Implants Res*. 2018;29-(Suppl 1):100-123. doi:10.1111/clr.13264
4. Albrektsson T, Canullo L, Cochran D, De Bruyn H. "Peri-implantitis": acomplication of a foreign body or a man-made "disease". Facts and fiction. *Clin Implant Dent Relat Res*. 2016;18(4):840-849. doi:10.1111/cid.12427
5. Berglundh T, Armitage G, Araujo MG, et al. Peri-implant diseases and conditions: consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Periodontol*. 2018;89:S313-S318. doi:10.1002/JPER.17-0739
6. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: case definitions and diagnostic considerations. *J Periodontol*. 2018;89:S304-S312. doi:10.1002/JPER.17-0588
7. Romandini M, Berglundh J, Derks J, Sanz M, Berglundh T. Diagnosis of peri-implantitis in the absence of baseline data: a diagnostic accuracy study. *Clin Oral Implants Res*. 2021;32(3):297-313. doi:10.1111/clr.13700
8. Vázquez Álvarez R, Pérez Sayáns M, Gayoso Diz P, García GA. Factors affecting peri-implant bone loss: a post-five-year retrospective study. *Clin Oral Implants Res*. 2015;26(9):1006-1014. doi:10.1111/clr.12416
9. Misch CE, Perel ML, Wang HL, et al. Implant success, survival, and failure: the International Congress of Oral Implantologists (ICOI) Pisa consensus conference. *Implant Dent*. 2008;17(1):5-15. doi:10.1097/ID.0b013e3181676059
10. Derks J, Schaller D, Håkansson J, Wennström JL, Tomasi C, Berglundh T. Effectiveness of implant therapy analyzed in a Swedish population: prevalence of peri-implantitis. *J Dent Res*. 2016;95(1):43-49. doi:10.1177/0022034515608832
11. Derks J, Schaller D, Håkansson J, Wennström JL, Tomasi C, Berglundh T. Peri-implantitis - onset and pattern of progression. *J Clin Periodontol*. 2016;43(4):383-388. doi:10.1111/jcpe.12535
12. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. *J Clin Periodontol*. 1996;23(10):971-973.
13. Derks J, Ichioka Y, Dionigi C, et al. Prevention and management of peri-implant mucositis and peri-implantitis: a systematic review of outcome measures used in clinical studies in the last 10 years. *J Clin Periodontol*. 2022. doi:10.1111/jcpe.13608
14. Fagbamigbe AF, Karlsson K, Derks J, Petzold M. Performance evaluation of survival regression models in analysing Swedish dental implant complication data with frailty. *PLoS One*. 2021;16(1):e0245111. doi:10.1371/journal.pone.0245111
15. Karlsson K, Derks J, Håkansson J, Wennström JL, Petzold M, Berglundh T. Interventions for peri-implantitis and their effects on further bone loss: a retrospective analysis of a registry-based cohort. *J Clin Periodontol*. 2019;46(8):872-879. doi:10.1111/jcpe.13129
16. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T. Occurrence and clustering of complications in implant dentistry. *Clin Oral Implants Res*. 2020;31(10):1002-1009. doi:10.1111/clr.13647
17. Karlsson K, Derks J, Wennström JL, Petzold M, Berglundh T. Health economic aspects of implant-supported restorative therapy. *Clin Oral Implants Res*. 2022;33(2):221-230. doi:10.1111/clr.13885
18. Giannobile WV, Lang NP. Are dental implants a panacea or should we better strive to save teeth? *J Dent Res*. 2016;95(1):5-6. doi:10.1177/0022034515618942
19. Peñarrocha-Diago MA, Flichy-Fernández AJ, Alonso-González R, Peñarrocha-Oltra D, Balaguer-Martínez J, Peñarrocha-Diago M. Influence of implant neck design and implant-abutment connection type on peri-implant health. Radiological study. *Clin Oral Implants Res*. 2013;24(11):1192-1200. doi:10.1111/j.1600-0501.2012.02562.x
20. Laurell L, Lundgren D. Marginal bone level changes at dental implants after 5 years in function: a meta-analysis. *Clin Implant Dent Relat Res*. 2011;13(1):19-28. doi:10.1111/j.1708-8208.2009.00182.x
21. Galindo-Moreno P, Fernández-Jiménez A, O'Valle F, et al. Influence of the crown-implant connection on the preservation of peri-implant bone: a retrospective multifactorial analysis. *Int J Oral Maxillofac Implants*. 2015;30(2):384-390.
22. Schmitt CM, Nogueira-Filho G, Tenenbaum HC, et al. Performance of conical abutment (Morse taper) connection implants: a systematic review. *J Biomed Mater Res A*. 2014;102(2):552-574. doi:10.1002/jbm.a.34709
23. Galindo-Moreno P, Concha-Jeronimo A, Lopez-Chaichio L, Rodriguez-Alvarez R, Sanchez-Fernandez E, Padial-Molina M. Marginal bone loss around implants with internal hexagonal and internal conical connections: a 12-month randomized pilot study. *J Clin Med*. 2021;10(22):5427. doi:10.3390/jcm10225427
24. Galindo-Moreno P, León-Cano A, Monje A, Ortega-Oller I, O'Valle F, Catena A. Abutment height influences the effect of platform switching on peri-implant marginal bone loss. *Clin Oral Implants Res*. 2016;27(2):167-173. doi:10.1111/clr.12554
25. Misch CE, Silc JT. Key implant positions: treatment planning using the canine and first molar rules. *Dent Today*. 2009. https://www.dentistrytoday.com/sp-337104617/
26. Galindo-Moreno P, León-Cano A, Ortega-Oller I, et al. Prosthetic abutment height is a key factor in Peri-implant marginal bone loss. *J Dent Res*. 2014;93(7 Suppl):80S-85S. doi:10.1177/0022034513519800
27. West BT, Welch KB, Galecki AT. *Linear Mixed Models: A Practical Guide Using Statistical Software*. 1st ed. Chapman & Hall/CRC Press; 2006.

28. Cnaan A, Laird NM, Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med*. 1997;16(20):2349-2380. doi:10.1002/(SICI)1097-0258(19971030)16:203.0.CO;2-E
29. Schwarz F, Ramanauskaite A. It is all about peri-implant tissue health. *Periodontol 2000*. 2022;88(1):9-12. doi:10.1111/prd.12407
30. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry. *J Dent Res*. 2012;91(3):242-248. doi:10.1177/0022034511431252
31. Tomasi C, Derks J. Etiology, occurrence, and consequences of implant loss. *Periodontol 2000*. 2022;88(1):13-35. doi:10.1111/prd.12408
32. Berglundh J, Romandini M, Derks J, Sanz M, Berglundh T. Clinical findings and history of bone loss at implant sites. *Clin Oral Implants Res*. 2021;32(3):314-323. doi:10.1111/clr.13701
33. Dukka H, Saleh MHA, Ravidà A, Greenwell H, Wang HL. Is bleeding on probing a reliable clinical indicator of peri-implant diseases? *J Periodontol*. 2021;92(12):1669-1674. doi:10.1002/JPER.20-0890
34. Derks J, Ichioka Y, Dionigi C, et al. Prevention and management of peri-implant mucositis and peri-implantitis: a systematic review of outcome measures used in clinical studies in the last 10 years. *Clin Oral Implants Res*. 2022. doi:10.1111/clr.13925
35. Ramanauskaite A, Becker K, Schwarz F. Clinical characteristics of peri-implant mucositis and peri-implantitis. *Clin Oral Implants Res*. 2018;29(6):551-556. doi:10.1111/clr.13152
36. Ibañez C, Catena A, Galindo-Moreno P, Noguerol B, Magán-Fernández A, Mesa F. Relationship between long-term marginal bone loss and bone quality, implant width, and surface. *Int J Oral Maxillofac Implants*. 2016;31(2):398-405.
37. Toia M, Stocchero M, Becktor JP, Chrcanovic B, Wennerberg A. Implant vs abutment level connection in implant supported screw-retained fixed partial dentures with cobalt-chrome framework: 1-year interim results of a randomized clinical study. *Clin Implant Dent Relat Res*. 2019;21(2):238-246. doi:10.1111/cid.12717
38. Vervaeke S, Dierens M, Besseler J, De Bruyn H. The influence of initial soft tissue thickness on peri-implant bone remodeling. *Clin Implant Dent Relat Res*. 2014;16(2):238-247. doi:10.1111/j.1708-8208.2012.00474.x
39. Collaert B, De Bruyn H. Early loading of four or five Astra tech fixtures with a fixed cross-arch restoration in the mandible. *Clin Implant Dent Relat Res*. 2002;4(3):133-135. doi:10.1111/j.1708-8208.2002.tb00163.x
40. Spinato S, Galindo-Moreno P, Bernardello F, Zaffe D. Minimum abutment height to eliminate bone loss: influence of implant neck design and platform switching. *Int J Oral Maxillofac Implants*. 2018;33(2):405-411. doi:10.11607/jomi.5604
41. Lombardi T, Berton F, Salgarello S, et al. Factors influencing early marginal bone loss around dental implants positioned Subcrestally: amulticenter prospective clinical study. *J Clin Med*. 2019;8(8):1168. doi:10.3390/jcm8081168
42. Rakic M, Galindo-Moreno P, Monje A, et al. How frequent does peri-implantitis occur? A systematic review and meta-analysis. *Clin Oral Investig*. 2018;22(4):1805-1816. doi:10.1007/s00784-017-2276-y
43. Renvert S, Quirynen M. Risk indicators for peri-implantitis. A narrative review. *Clin Oral Implants Res*. 2015;26(Suppl 11):15-44. doi:10.1111/clr.12636
44. Heitz-Mayfield LJA, Huynh-Ba G. History of treated periodontitis and smoking as risks for implant therapy. *Int J Oral Maxillofac Implants*. 2009;24(Suppl):39-68.
45. Vianna TT, Taiete T, Casarin RCV, et al. Evaluation of peri-implant marginal tissues around tissue-level and bone-level implants in patients with a history of chronic periodontitis. *J Clin Periodontol*. 2018;45(10):1255-1265. doi:10.1111/jcpe.12999
46. Theodoridis C, Grigoriadis A, Menexes G, Vouros I. Outcomes of implant therapy in patients with a history of aggressive periodontitis. A systematic review and meta-analysis. *Clin Oral Investig*. 2017;21(2):485-503. doi:10.1007/s00784-016-2026-6
47. Ragucci GM, Giralt-Hernando M, Méndez-Manjón I, Cantó-Navés O, Hernández-Alfaro F. Factors affecting implant failure and marginal bone loss of implants placed by post-graduate students: a 1-year prospective cohort study. *Mater Basel Switz*. 2020;13(20):E4511. doi:10.3390/ma13204511
48. Cortelli JR, Aquino DR, Cortelli SC, et al. Detection of periodontal pathogens in oral mucous membranes of edentulous individuals. *J Periodontol*. 2008;79(10):1962-1965. doi:10.1902/jop.2008.080092
49. Van Assche N, Van Essche M, Pauwels M, Teughels W, Quirynen M. Do periodontopathogens disappear after full-mouth tooth extraction? *J Clin Periodontol*. 2009;36(12):1043-1047. doi:10.1111/j.1600-051X.2009.01477.x
50. Klinge B, Klinge A, Bertl K, Stavropoulos A. Peri-implant diseases. *Eur J Oral Sci*. 2018;126(Suppl S1):88-94. doi:10.1111/eos.12529
51. Cecchinato D, Marino M, Lindhe J. Bone loss at implants and teeth in the same segment of the dentition in partially dentate subjects. *Clin Oral Implants Res*. 2017;28(5):626-630. doi:10.1111/clr.12847
52. Cecchinato D, Marino M, Toia M, Cecchinato F, Lindhe J. Bone loss at implants and teeth in the same inter-proximal unit: a radiographic study. *Clin Oral Implants Res*. 2018;29(4):375-380. doi:10.1111/clr.13132
53. Dabdoub SMM, Tsigarida AAA, Kumar PSS. Patient-specific analysis of periodontal and peri-implant microbiomes. *J Dent Res*. 2013;92-(12 Suppl):168S-175S. doi:10.1177/0022034513504950
54. Borges T, Leitão B, Pereira M, Carvalho Á, Galindo-Moreno P. Influence of the abutment height and connection timing in early peri-implant marginal bone changes: a prospective randomized clinical trial. *Clin Oral Implants Res*. 2018;29(9):907-914. doi:10.1111/clr.13343
55. Borges T, Almeida BL, Pereira M. Periimplant bone changes in different abutment heights and insertion timing—three-year results from a randomized prospective clinical trial. *Clin Oral Implants Res*. 2019;30(S19):37. doi:10.1111/clr.61_13508
56. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants*. 1986;1(1):11-25.
57. Schwartz-Arad D, Herzberg R, Levin L. Evaluation of long-term implant success. *J Periodontol*. 2005;76(10):1623-1628. doi:10.1902/jop.2005.76.10.1623
58. Bagegni A, Abou-Ayash S, Rücker G, Algarny A, Att W. The influence of prosthetic material on implant and prosthetic survival of implant-supported fixed complete dentures: a systematic review and meta-analysis. *J Prosthodont Res*. 2019;63(3):251-265. doi:10.1016/j.jpor.2019.02.001
59. Papaspyridakos P, Bordin TB, Natto ZS, et al. Complications and survival rates of 55 metal-ceramic implant-supported fixed complete-arch prostheses: a cohort study with mean 5-year follow-up. *J Prosthet Dent*. 2019;122(5):441-449. doi:10.1016/j.prosdent.2019.01.022
60. Pera P, Menini M, Pesce P, Bevilacqua M, Pera F, Tealdo T. Immediate versus delayed loading of dental implants supporting fixed full-arch maxillary prostheses: a 10-year follow-up report. *Int J Prosthodont*. 2018;32(1):27-31. doi:10.11607/ijp.5804
61. Vervaeke S, Collaert B, Cosyn J, De Bruyn H. A 9-year prospective case series using multivariate analyses to identify predictors of early and late Peri-implant bone loss. *Clin Implant Dent Relat Res*. 2016;18(1):30-39. doi:10.1111/cid.12255
62. Nóvoa L, Batalla P, Caneiro L, Pico A, Liñares A, Blanco J. Influence of abutment height on maintenance of Peri-implant Crestal bone at bone-level implants: a 3-year follow-up study. *Int J Periodontics Restorative Dent*. 2017;37(5):721-727. doi:10.11607/prd.2762
63. Pico A, Martín-Lancharro P, Caneiro L, Nóvoa L, Batalla P, Blanco J. Influence of abutment height and implant depth position on interproximal peri-implant bone in sites with thin mucosa: a 1-year randomized clinical trial. *Clin Oral Implants Res*. 2019;30(7):595-602. doi:10.1111/clr.13443

64. Spinato S, Stacchi C, Lombardi T, Bernardello F, Messina M, Zaffe D. Biological width establishment around dental implants is influenced by abutment height irrespective of vertical mucosal thickness: a cluster randomized controlled trial. *Clin Oral Implants Res*. 2019;30(7):649-659. doi:10.1111/clr.13450
65. Geckili O, Bilhan H, Geckili E, Cilingir A, Mumcu E, Bural C. Evaluation of possible prognostic factors for the success, survival, and failure of dental implants. *Implant Dent*. 2014;23(1):44-50. doi:10.1097/ID.0b013e3182a5d430
66. Galindo-Moreno P, Fernández-Jiménez A, Avila-Ortiz G, Silvestre FJ, Hernández-Cortés P, Wang HL. Marginal bone loss around implants placed in maxillary native bone or grafted sinuses: a retrospective cohort study. *Clin Oral Implants Res*. 2014;25(3):378-384. doi:10.1111/clr.12122
67. Galindo-Moreno P, Fauri M, Avila-Ortiz G, Fernandez-Barbero JE, Cabrera-Leon A, Sanchez-Fernandez E. Influence of alcohol and tobacco habits on peri-implant marginal bone loss: a prospective study. *Clin Oral Implants Res*. 2005;16(5):579-586. doi:10.1111/j.1600-0501.2005.01148.x
68. Rinke S, Ohl S, Ziebolz D, Lange K, Eickholz P. Prevalence of periimplant disease in partially edentulous patients: a practice-based cross-sectional study. *Clin Oral Implants Res*. 2011;22(8):826-833. doi:10.1111/j.1600-0501.2010.02061.x
69. Windael S, Vervaeke S, De Buyser S, De Bruyn H, Collaert B. The long-term effect of smoking on 10 years'survival and success of dental implants: aprospective analysis of 453 implants in a non-university setting. *J Clin Med*. 2020;9(4):E1056. doi:10.3390/jcm9041056
70. Aguirre-Zorzano LA, Estefanía-Fresco R, Telletxea O, Bravo M. Prevalence of peri-implant inflammatory disease in patients with a history of periodontal disease who receive supportive periodontal therapy. *Clin Oral Implants Res*. 2015;26(11):1338-1344. doi:10.1111/clr.12462
71. Dalago HR, Perrotti V, Torres de Freitas SF, et al. Prospective longitudinal comparison study of surgical therapies for peri-implantitis: 3-year follow-up. *Aust Dent J*. 2019;64(3):237-245. doi:10.1111/adj.12693
72. Albrektsson T, Buser D, Chen ST, et al. Statements from the Estepona consensus meeting on peri-implantitis, February 2–4, 2012. *Clin Implant Dent Relat Res*. 2012;14(6):781-782. doi:10.1111/cid.12017
73. Jepsen S, Schwarz F, Cordaro L, et al. Regeneration of alveolar ridge defects. Consensus report of group 4 of the 15th European workshop on periodontology on bone regeneration. *J Clin Periodontol*. 2019;46(Suppl 21):277-286. doi:10.1111/jcpe.13121

How to cite this article: Galindo-Moreno P, Catena A, Pérez-Sayáns M, Fernández-Barbero JE, O'Valle F, Padial-Molina M. Early marginal bone loss around dental implants to define success in implant dentistry: A retrospective study. *Clin Implant Dent Relat Res*. 2022;24(5):630-642. doi:10.1111/cid.13122