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Prospective observational cohort study of the change of the marginal bone crest in relation to the prosthetic abutment height and the peri-implant vertical mucosal thickness at implants positioned subcrestally

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Abstract

Aim: To evaluate the influence on peri-implant crestal bone loss exerted by the vertical mucosal thickness and the abutment height over 12 months after placement of the restoration on subcrestal implants with change of platform, using a restoration abutment platform smaller than the implant platform.

Materials and Methods: A total of 99 implants were rehabilitated in the maxillary and mandibular posterior regions. A total of 22 implants were rehabilitated in the maxilla and 77 implants in the mandible, using digitally designed customized abutments with Atlantis weborder software, from the commercial house Dentsply Sirona (Dentsply Sirona S.A., Barcelona, Spain), version 4.6.5, adapting the height to the vertical thickness of the mucosa. Clinical and radiographic monitoring begins during the surgical procedure of placement of the implant and ends 12 months afterwards. Crestal bone loss was evaluated through the Carestream® CS8100 3D radiographic equipment.

Results: In all cases, the greatest loss of marginal bone occurred between the day of surgery (Tx) and placement of the rehabilitation (To). The average bone loss between both times was greater when the abutment height and vertical mucosal thickness did not exceed 3 mm. Subsequently, bone loss slowed and stabilized at 12 months.

Conclusions: The minimum abutment height and the vertical mucosal thickness are factors to take into account when minimizing peri-implant marginal bone loss, the abutment height having the greatest importance according to the clinical data obtained.

KEYWORDS
abutment height, biological width, dental implants, marginal bone loss, platform switching, thick mucosa, vertical mucosal thickness

Summary Box

What is know

- Peri-implant bone loss is affected by multiple factors, notable among which are the height (vertical thickness) of the peri-implant mucosa and the design of the prosthetic restoration, including the transepithelial abutment height.

What this study adds

- The average bone loss between Tx and To was greater when the abutment height and vertical mucosal thickness did not exceed the 3 mm analyzed (0.97 mm with abutment heights under 3 and 0.70 mm with abutments over 3 mm; 0.84 mm with a vertical mucosal thickness under 3 and 0.60 mm with a vertical mucosal thickness over 3 mm). Subsequently, progressive stabilization of the marginal bone loss was observed up to 12 months.
- Helping the clinician to know the influential factors in peri-implant marginal bone loss, to thereby facilitate decision making in implantological planning, surgery and rehabilitation.

1 | INTRODUCTION

The definition of success in implant treatment does not only depend on achieving osseointegration, but also on maintaining the peri-implant health of the hard and soft tissues,[1] aesthetic results and the absence of complications.[2,3] A successful result requires minimal marginal bone loss over time to avoid pathogenic microflora causing inflammation and progressive bone resorption.[4]

The study of factors affecting marginal bone levels around the implants has increased in importance in recent years, notably vertical mucosal thickness, healing abutment height and prosthetic abutment height.[5–8] These factors have been significantly associated with the risk of generating greater marginal bone resorption, being reported in numerous clinical trials on implants placed at crestal level.[5,9–14]

Galindo et al.[11] demonstrated the key role of abutment height in maintenance of the peri-implant marginal bone, indicating that the abutment height may affect the crestal bone level, this being maintained when abutments over 2 mm high are used, also suggesting that early marginal bone resorption was more influenced by the characteristics of prosthetic rehabilitation than by the post-surgical bone remodeling process, which significantly increased up to 6 months after the functional load before stabilizing.[15]

Various studies have indicated that there is less peri-implant bone loss when the abutment height is greater, because it leads to a greater vertical mismatch, resulting in a larger space for the growth of soft tissue and a greater distance with regard to the inflammatory area, leading to connection of the crown with the abutment, regardless of the rehabilitation being with a screwed or cemented prosthesis.[10,11,13,16]

It is important to take into account the recently redefined concept of peri-implant phenotype, which encompasses the term "Peri-implant Supracrestal Tissue Height (STH),"[17] which is formed by the sulcus epithelium, junctional epithelium and supracrestal connective tissue. Thus, the STH is "short" if it is under 3 mm, and "high" when it exceeds 3 mm. According to the authors, if the abutment has a low height, pressure is caused to the soft tissue in an apical direction, which would cause greater bone loss.

The restoration of these dimensions around dental implants may explain the greater quantity of bone loss around them in places with thin, soft tissue,[18] although slight bone loss after placement of the prosthesis is still considered a successful[19] and inevitable result due to the establishment of biological width.[20,21] In recent studies analyzing marginal bone loss using short and long abutments, with fine and thin mucosa, it was indicated that marginal bone loss during establishment of biological width was influenced by the height of abutments, regardless of the vertical mucosal thickness.[22]

The null hypothesis stated in this study is that there are no differences in the evolution of the marginal crestal bone level for rehabilitated implants with abutments of different heights. Conversely, the alternative hypothesis is that there are differences in the evolution of the marginal crestal bone level for rehabilitated implants with abutments of different heights.

On this basis of all of the above, the purpose of this study was to evaluate the changes caused at peri-implant bone level based on the prosthetic abutment height and vertical mucosal thickness over 12 months after the prosthetic loading.

2 | MATERIALS AND METHODS

2.1 | Study design

This is a prospective observational cohort study approved by the Andalusian Biomedical Research Ethics Coordinating Committee (Code US-DTL-2022.1) that complies with all the guidelines of the World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects[23] and following the STROBE guidelines for cohort studies.

All patients received an information sheet on the study and gave their explicit consent for participation in it, as well as for the surgical and rehabilitation procedure in question.

2.2 | Participants

Partially edentulous patients were selected who needed treatment with implants for fixed prosthetic rehabilitation of the posterior maxilla and mandible, using for the study the teeth from the first premolar to the second molar. The inclusion criteria were the following: (a) patients over 18 years of age; (b) patients who did not have any contraindication for implant surgery; (c) patients with predisposition and capacity for complying with the study protocol explained to them and accepted through informed consent; (d) minimum bone crest of at least 5 mm wide and 8 mm high above the mandibular channel in the place where the implant was planned, following planning with Cone Bean Computer Tomography (CBCT); (e) without guided bone regeneration procedures before or during placement of the implant; (f) 6 months having passed since the extraction of the tooth corresponding to the place of implant insertion; (g) rehabilitations with 1, 2 and 3 implants; (h) good state of oral hygiene (PI <15%, BoP <15%); (i) sufficient primary stability of the implant (≥20 Ncm); (j) subcrestal placement of the implant (all implants were placed subcrestal, the depth of which depended on the initial vertical thickness of the patient's mucosa, as the aim was that later, during rehabilitation, the implants would have a prosthetic abutment (transepithelial abutment) at least 2.5 mm high).

Patients with a history of head and/or neck radiotherapy, immunocompromised patients (HIV infection or chemotherapy in the last 5 years), patients with uncontrolled diabetes, currently or previously taking intravenous bisphosphonates, patients who are pregnant, have psychiatric, alcohol abuse or drug problems, patients who smoke more than 10 cigarettes per day or participants in other studies were excluded.

All patients were selected consecutively between May 2019 and February 2021 and treated independently by two operators: one who carried out the surgical treatment consisting of the placement of the implant; and another who carried out the prosthetic treatment, consisting of the rehabilitation on this implant, and subsequent monitoring up to 12 months. This monitoring consisted of the collection of data from treatment with periapical x-rays and photographs taken on the day of implant placement (Tx), the day of prosthesis placement (To), the 1-month check-up (T1), the 3-month check-up (T2), the 6-month check-up (T3), and the 12-month check-up (T4) (Table 1).

2.3 | Surgical protocol

All patients were administered local anesthesia Articaine, Epinephrine Hydrochloride (Artinibsa® 40 mg/mL + 0.01 mg/mL; Inibsa dental, Barcelona, Spain.), following application of intraoral anesthetic gel (Hurricaine® 200 mg/g benzocaine oral gel; Laboratorios Clarben S.A., Madrid, Spain). A mid-crestal incision was made, preserving an adequate quantity of keratinised tissue on both vestibular and lingual sides.

A full thickness buccal flap was elevated and the vertical mucosal thickness (distance between the marginal mucosa and the bone crest) of the undetached lingual flap was measured (Figure 1), with a 15 mm PUNC15 periodontal probe (G. Hartzell & Son; USA), at the center of the site planned for implant placement.

Subsequently, the lingual flap was elevated, and the implant bed was prepared with copious irrigation of cold saline solution, following the manufacturer's recommendations for subcrestal placement. The Astra Tech osseospeed EV® (Dentsply Sirona; Gmbh, Rodenbacher Chaussee, Hannau-Germany) internally connected straight implants were inserted below the level of the bone, minimum 1 mm subcrestal, always depending on the measurement of the vertical thickness of the mucosa to try to have an abutment height of at least 2 mm. The implants were immediately connected to closure or healing plugs, remaining in a subgingival position within the mucosa. The flaps were sutured with simple stitches, using sterile non-absorbable Supramid® 4/0 (Aragó black TB15-CT 19 mm 3/8; Barcelona, Spain).

Patients were prescribed post-surgical antibiotic therapy (Amoxicillin/Clavulanic Acid 875/125 g) three times a day for 7 days

TABLE 1 Timeline and nomenclature of the study times.

Time of the study	Nomenclature
Surgery	Tx
Prosthesis placement	To
1-month check-up	T1
3-month check-up	T2
6-month check-up	T3
12-month check-up	T4

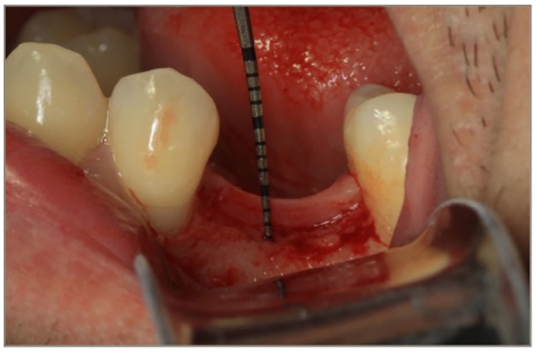

FIGURE 1 Measurement of vertical mucosal thickness with the periodontal probe (Linkevicius et al.[24]).

and non-steroidal anti-inflammatory drugs such as dexketoprofen trometamol (Enantyum® 25 mg), for 5 days if necessary.

Each patient was issued a kit with a chlorhexidine digluconate +0.12% cetylpyridinium chloride mouthwash (GUM Sunstar Iberia; Barcelona, Spain), for rinsing after eating each daily meal, as well as a chlorhexidine digluconate +0.12% cetylpyridinium chloride toothpaste.

All patients were instructed to follow a soft diet to minimize trauma to the implant site. The sutures were removed 14 days after surgery. Patients were instructed not to use removable prostheses during the whole healing period, and immediate loading was not carried out in any of the cases.

After 2 months of submerged healing, a second surgery was performed to open the plugs, changing the closing screw for a higher one so that it was juxta-gingival or supragingival.

The final impressions were taken 2 weeks after the second surgery, once the soft tissue around the healing screw had formed.

2.4 | Restorative protocol

The height of the prosthetic abutments was chosen according to the vertical thickness of the soft tissue in the implant area, so that the margin of the abutment was 1 mm subgingival, also adapting it to the diameter resulting from the healing process after placing the healing plug.

Individualized Atlantis® (Dentsply Sirona; Aminogatan 1, Mölndal, Sweden) type abutments were used through digital scanning (Cerec®, Dentsply Sirona) using IFLO (Atlantis® System) type digital scanning abutments. After the digital scanning, the file obtained was sent to the WebOrder of the system (AtlantisWebOrder®, Dentsply Sirona) to edit the individualized abutment.

The editing was carried out respecting the thickness levels of the soft tissue, adapting them to the resulting situation after the healing period. After the functional and aesthetic test, cemented-screwed zirconia (Cercon® xt ML; Dentsply Sirona, Hanau-Wolfgang, Germany) and vitrified ceramic (Ivoclair Vivadent AG; Schaan/Liechtenstein), restorations were placed.

All were screwed at a torque force of 25 Ncm^2, following the manufacturer's recommendation, and the crowns were cemented to their corresponding abutment with dual resin cement (Relyx Unicem 2 Automix Self-Adhesive Resin Cement®; Neuss-Germany) outside the mouth. Once placed in the mouth, the radiographic and photographic control protocol began.

2.5 | Radiographical measures

Using Carestream® CS8100 3D equipment, a total of six digital x-rays were taken for each implant using a long cone parallelism technique with a Rinn type device. A personalized bite template was created for each patient with Elite HD + ® (Zhermack, Rovigo, Italy) type heavy silicone for the area where the implant was going to be positioned, thereby reproducing the position of the Rinn type positioner for the rest of the study x-rays.

After placement of the implant, a first x-ray was taken: baseline (Tx), the second after crown placement (To), the third, 1 month after crown placement (T1); the fourth, 3 months after crown placement (T2); the fifth, 6 months after crown placement (T3), and the sixth, 12 months after crown placement (T4) (Figure 2). Prior to surgery, the bone situation was examined to determine the volume of bone tissue available in three dimensions to house the implant, undertaking an orthopantomography and a CBCT scan.

The distance between the implant platform and the bone crest was measured at each time interval at the distal and mesial points of the implant. A positive value was assigned when the bone crest was coronal to the implant platform, and a negative value when the bone crest was apical to this platform. All x-rays were carried out by the same examiner: S.M.S. After taking the periapical radiograph, both examiners began to take measurements and record them in their own template individually and systematically. They used the same Carestream® software version 7.0.3. on the same radiograph, using the measurement function provided by the software in order to mitigate possible errors derived from the possible collection of independent data. Measurements were taken from the implant platform to the most coronal portion of the bone crest. After measurements were made, the correlation between the equivalent variables of both examiners was calculated. For this purpose, Pearson's correlation was used for variables with normal distribution, and Spearman's correlation for variables that do not follow a normal distribution. The probability was very close to 0 in all cases ($p < 1 \times 10–20$) (Table 2).

Similarly, and to ensure our results, the ICC (Intra-examiner Concordance Index) was calculated:

$$ICC = \frac{\text{MSbetween} - \text{MSwithim}}{\text{MSbetween} + (k-1) * \text{MSwithim}}$$

MSbetween is the mean of the sums of squares between groups.
Mswithim is the mean of the sums of squares within groups.
k is the number of measurements made by each examiner.

$$ICC = \frac{1.585138462 - 0.000514286}{1.585138462 + (14-1) * 0.000514286}$$

$$ICC = \frac{1.584624176}{1.593755684}$$

$$ICC \approx 0.994219$$

Since a value close to 1 indicates high inter-examiner agreement, this result suggests that the measurements made are consistent.

2.6 | Statistical analysis

Bone level changes were measured, classifying all implants into two groups according to mucosal thickness (< or >3 mm) and into two groups according to prosthetic abutment height (< or >3 mm).

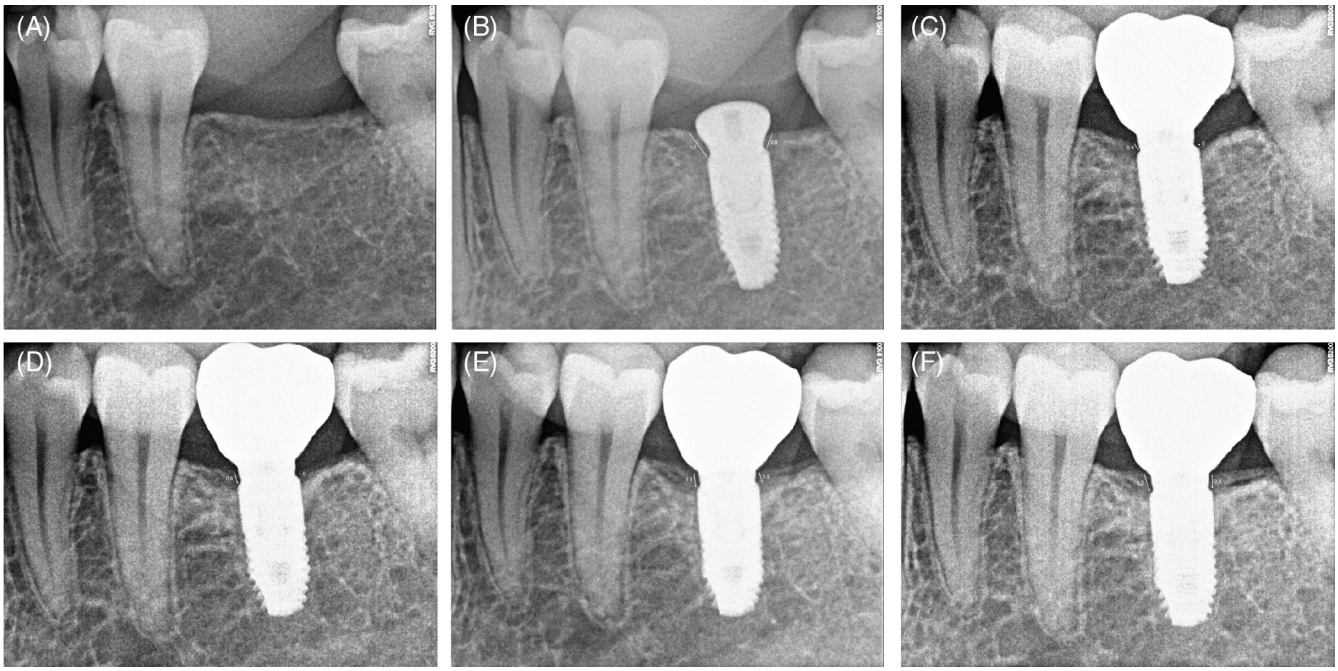

FIGURE 2 X-rays taken by patients: (A) baseline (Tx), (B) after crown placement (To), (C) 1 month after crown placement (T1), (D) 3 months after crown placement (T2), (E) 6 months after crown placement (T3), (F) 12 months after crown placement (T4).

TABLE 2 Correlation between both examiners.

	Examiner 1		Examiner 2		Correlation	
Variables	**Average**	**S.T.**	**Average**	**S.T.**	**Pearson**	**Spearman**
Mesial: Pillar height	3.41	0.71	3.41	0.71	1.000*	
Mesial: TX bone level surgery	2.01	0.72	2.06	0.74	0.983*	
Mesial: Placement Bone Level T0	1.33	1.09	1.34	1.10		0.985*
Mesial: 1 month bone level T1	1.26	1.24	1.24	1.19		0.986*
Mesial: 3 months bone level T2	1.17	1.06	1.16	1.07	0.988*	
Monthly: 6 months bone level T3	1.19	1.24	1.21	1.24		0.994*
Monthly: 12 months bone level T4	1.38	1.19	1.38	1.18		0.966*
Distal: Pillar height	3.05	0.80	3.05	0.80	1.000*	
Distal: TX bone level surgery	1.54	0.71	1.54	0.73	0.983*	
Distal: Bone level placement T0	0.65	0.94	0.71	0.96		0.923*
Distal: 1 month bone level T1	0.50	0.98	0.49	0.99		0.990*
Distal: 3 months bone level T2	0.55	0.89	0.55	0.91		0.984*
Distal: 6 months bone level T3	0.64	0.82	0.65	0.84		0.992*
Distal: 12 months bone level T4	0.79	0.79	0.80	0.78		0.987*

*The probability is very close to 0 in all cases ($p < 1 \times 10^{-20}$).

A complete descriptive analysis of all variables was carried out. Given the time diversity between the implant placement and sample collection date, the operation is carried out on all subjects, excluding those with over 180 days between placement and sample collection.

The normality of the numerical variables was determined using the Kolmogorov–Smirnov test. All numerical variables were normal, except ALTPIPRE, GROSVER, T0DISTAL, S1DISTAL, and S2AVERAGE.

For crosses of categorical variables and numerical variables, ANOVA is applied for normally distributed variables and Mann–Whitney *U* (dichotomous) and Kruskal–Wallis (more than two categories) for the rest. Correlations between numerical variables were carried out using Pearson's correlation, given that the majority follow a normal distribution. However, for cases in which a variable whose distribution is not normal is involved, Spearman's correlation has been used.

Statistical significance was established at $p < 0.05$.

3 | RESULTS

3.1 | Number of participants and implants

A total of 59 subjects were included, considering for the analysis the possibility of rehabilitating 1, 2 or 3 implants, with a total of 54 implants of 1 piece, 29 of 2 pieces, and 16 of 3 pieces.

All cases analyzed reached an adequate level of osseointegration and a total of 22 implants were placed in the maxilla and 77 in the mandible.

3.2 | Changes of marginal bone level in cases with vertical mucosal thickness up to 3 mm

In cases with equal vertical mucosal thickness less than 3 mm (82 patients), there was greater average marginal bone loss in the period between the day of surgery (Average Tx) and the day of placement of the rehabilitation (Average To), the average bone loss being 0.84 mm. That is, starting from a bone crest to implant neck distance of 1.69 (Average Tx), at the time of crown placement this distance had been reduced to 0.85 mm (Average To).

In subsequent measurements, bone loss stabilized, reaching a bone crest to implant neck value of 0.80 mm at T1 (Average T1) with an average loss between To and T1 of 0.05 mm; a level of 0.70 mm at T2 (Average T2), with an average loss of 0.15 mm between To and T2; a level of 0.78 mm at T3 (Average T3), with average marginal bone loss between To and T3 of 0.07; and finally a level of 0.89 mm at T4 (Average T4), with an average marginal bone loss between To and T4 of −0.04, which reflects the marginal bone recovery that occurred from 6 months to 12 months after placement of the prosthesis. That is, bone loss was not only stabilized, but a slight recovery was observed from the sixth month after prosthetic loading (Table 3) (Figure 3).

3.3 | Changes of marginal bone level with 3 mm or more of vertical mucosal thickness

When the vertical mucosal thickness is greater than or equal to 3 mm (17 patients), there was also greater mean marginal bone loss between the day of surgery (Average Tx) and the day of rehabilitation placement (Average To). The average difference was 0.60 mm. That is, starting from a bone crest to implant neck distance of 2.02 on the day of implant insertion (Average Tx), at the time of crown placement this distance had been reduced to 1.42 mm (Average To).

The bone loss subsequently stabilized over time, and evolved until reaching a bone level of 1.24 mm at T1 (Average T1), with an average loss between To and T1 of 0.18 mm, and so on progressively until reaching a level of 1.21 mm on average at T4 (Average T4), with an average marginal bone loss between To and T4 of 0.21 mm, which reflects the marginal bone recovery that occurred in the later phases of the times analyzed (Table 2) (Figure 4).

If we compare the results of both values of vertical mucosal thickness (greater or less than 3 mm) in terms of the bone loss obtained, we find that the marginal bone loss was more pronounced when the vertical mucosal thickness was less than 3 mm, the difference between Tx and To being 0.24 mm less bone loss when the vertical mucosal thickness was greater than when it was less than 3 mm. This difference was not significant.

TABLE 3 Numerical data of bone evolution depending on vertical mucosal thickness.

	Vertical mucosal thickness				
	<3 mm		>3 mm		
Variable	Average	D.E.	Average	D.E.	Sign.
Mesial Tx	1.99	0.78	2.16	0.58	
Distal Tx	1.38	0.59	1.87	0.78	<0.01
Average Tx	1.69	0.56	2.02	0.63	<0.05
Mesial To	1.15	1.01	1.72	1.39	<0.05
Distal To	0.54	0.78	1.11	0.98	<0.05
Average To	0.85	0.77	1.42	1.03	<0.05
Mesial T1	1.12	1.00	1.50	1.42	
Distal T1	0.47	0.75	0.98	1.08	<0.05
Average T1	0.80	0.77	1.24	1.12	<0.05
Mesial T2	0.96	0.96	1.51	1.60	Quasi
Distal T2	0.43	0.66	0.84	1.11	<0.05
Average T2	0.70	0.72	1.17	1.25	<0.05
Mesial T3	1.02	0.97	1.51	1.66	
Distal T3	0.53	0.72	0.84	1.09	
Average T3	0.78	0.77	1.17	1.27	Quasi
Mesial T4	1.13	1.03	1.63	1.68	
Distal T4	0.64	0.76	0.79	1.01	
Average T4	0.89	0.81	1.21	1.20	

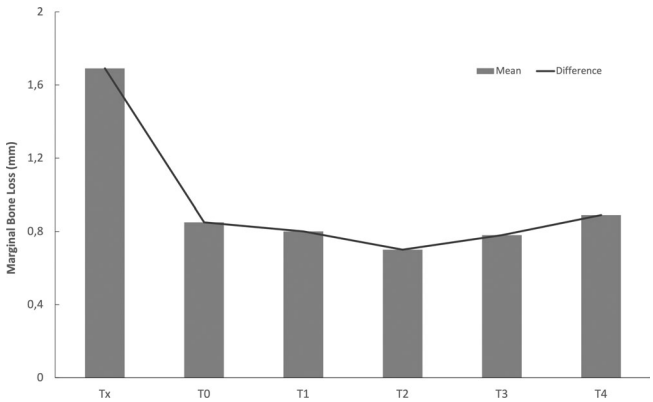

FIGURE 3 Evolution of the bone level when the vertical mucosal thickness is under 3 mm.

3.4 | Changes of marginal bone level with less than 3 mm abutment height

With a prosthetic abutment height of less than 3 mm (47 rehabilitations), the greatest marginal bone loss occurred in the same way as described above, between the day of surgery (Tx) and the day of placement of the prosthetic rehabilitation (To), the loss being 0.97 mm between both times recorded. That is, starting from 1.57 mm bone height of the crest at Tx (Average Tx), it was reduced to a level of 0.60 mm bone height at To (Average To). Subsequently, there was a bone loss of 0.05 mm between To and T1 and of 0.15 mm between To and T2, reaching a measured bone crest height of 0.45 mm. Between To and T3, bone loss of 0.09 mm occurred, a slight recovery therefore being observed in this phase. Between To and T4 there was no bone loss, but instead a recovery of 0.01 mm (Table 4).

There was a stabilization of marginal bone loss from To where bone loss was much slower until T2, and from there a slight recovery until T4 (Figure 5).

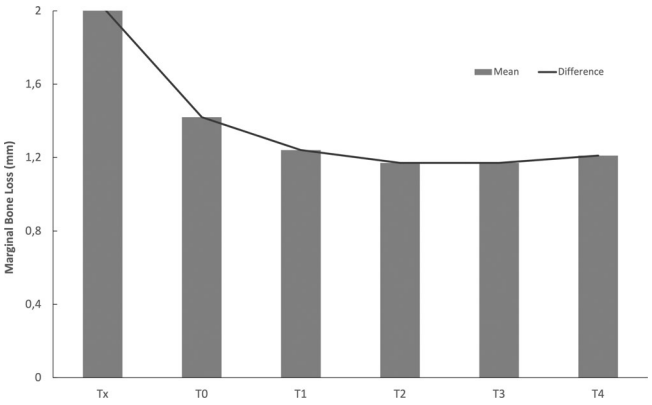

FIGURE 4 Evolution of the bone level when the vertical mucosal thickness is greater than 3 mm.

3.5 | Changes of marginal bone level with more than 3 mm abutment height

With a prosthetic abutment height greater than 3 mm (52 rehabilitations), the greatest marginal bone loss also occurred between the day of surgery (Tx) and the day of placement of the prosthetic rehabilitation (To); specifically starting with a crestal height of 1.84 mm, there was a bone loss of 0.7 mm between Tx and To, reaching a crestal bone level of 1.14 mm at To. There was a bone loss of 0.08 mm between To and T1, reaching a crestal bone level of 1.06 mm at T1, and a marginal bone loss of 0.17 mm between To and T2, reaching a crestal bone level of 0.97 mm at T2. Between To and T3 there was a marginal bone loss of 0.10 mm, and between To and T4 there was a marginal bone loss of 0 mm, there being no loss in this last phase, as occurred previously. (Table 3).

TABLE 4 Numerical data of bone evolution depending on abutment height.

	Abutment height (average of mesial and distal)				
	<3 mm		>3 mm		
Variable	Average	D.E.	Average	D.E.	Sign.
Mesial Tx	1.73	0.69	2.19	0.73	<0.01
Distal Tx	1.41	0.66	1.49	0.64	
Average Tx	1.57	0.56	1.84	0.57	<0.05
Mesial To	0.85	1.17	1.49	0.98	<0.01
Distal To	0.36	0.79	0.80	0.83	<0.05
Average To	0.60	0.82	1.14	0.79	<0.01
Mesial T1	0.81	1.14	1.40	0.98	<0.01
Distal T1	0.29	0.80	0.71	0.81	<0.05
Average T1	0.55	0.84	1.06	0.79	<0.01
Mesial T2	0.69	1.13	1.27	1.04	<0.01
Distal T2	0.20	0.78	0.67	0.70	<0.01
Average T2	0.45	0.82	0.97	0.80	<0.01
Mesial T3	0.74	1.14	1.32	1.05	<0.01
Distal T3	0.28	0.77	0.76	0.75	<0.01
Average T3	0.51	0.84	1.04	0.84	<0.01
Mesial T4	0.85	1.23	1.64	1.08	<0.05
Distal T4	0.37	0.85	0.84	0.73	<0.01
Average T4	0.61	0.91	1.14	0.82	<0.01

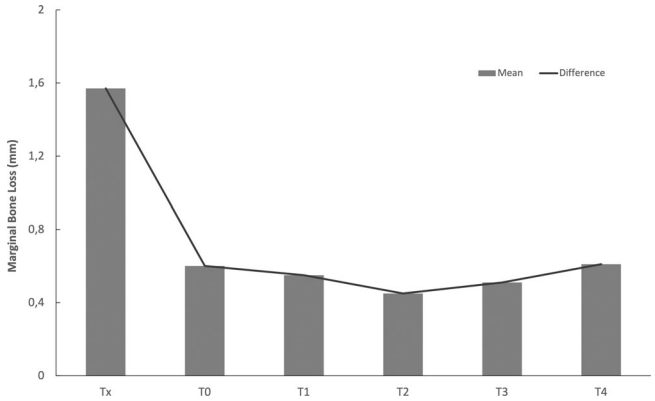

FIGURE 5 Evolution of the bone level when the abutment height is under 3 mm.

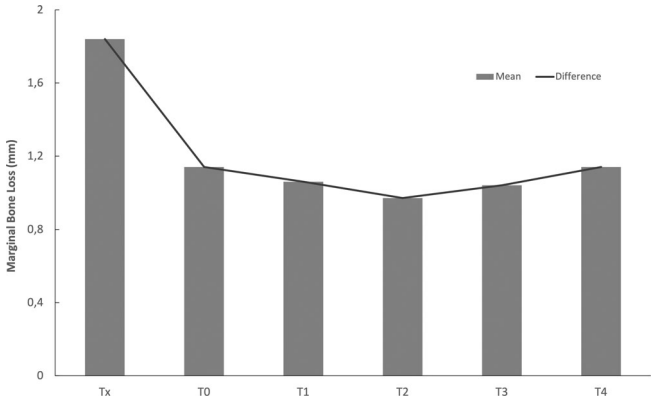

FIGURE 6 Evolution of the bone level when the abutment height is over 3 mm.

The greatest marginal bone loss in terms of prosthetic abutment height occurred between surgery and the placement of the rehabilitation, but for abutments over 3 mm high, the difference in loss was less, because with abutments over 3 mm high there was an average marginal bone loss of 0.70 mm between Tx and To, while for abutments under 3 mm high the marginal bone loss was 0.97 mm between Tx and To. In both cases, there was subsequently a stabilization of the marginal bone loss (Figure 6).

3.6 | Correlations between the mucosa thickness/abutment height and bone-level changes

Regarding the correlations between the vertical thickness of the mucosa and the height of the rehabilitative abutment with respect to the bone level (mesial, distal, and medial), there was no significant correlation for the variable vertical thickness of the mucosa, but there was a negative correlation for the variable height of the abutment, as the significance value, where there was a statistically significant difference, was $p < 0.05$ and <0.01, indicating that the higher the height of the abutment, the greater the bone level (Table 5).

Similarly, the correlations between the vertical thickness of the mucosa and the height of the rehabilitative abutment with respect to the degree of bone loss between the different moments of measurement from Tx and T0 only show significance by p-value <0.05 between T0 and T1 with a positive correlation (Table 6), since when the vertical thickness of the mucosa was greater, greater bone loss was obtained in this section. No further significant differences were reached.

TABLE 5 Correlations (original variables).

Variables	Vertical mucosal thickness[a]	Abutment height (average)
TX Mesial	−0.013	0.148
TX Distal	0.152	0.222*
TX Average	0.089	0.220*
T0 Mesial	0.135	0.151
T0 Distal[a]	0.137	0.322**
T0 Average	0.159	0.241*
T1 Mesial	0.072	0.147
T1 Distal	0.145	0.342**
T1 Average	0.097	0.263**
T2 Mesial	0.117	0.153
T2 Distal	0.123	0.376**
T2 Average	0.132	0.271**
T3 Mesial	0.048	0.203*
T3 Distal	0.069	0.410**
T3 Average	0.070	0.315**
T4 Mesial	0.095	0.219*
T4 Distal[a]	0.049	0.424**
T4 Average	0.091	0.320**

[a]Spearman's correlation has been applied to correlations involving any of these variables, and Pearson's correlation has been applied to the rest.
*The correlation is significant $p < 0.05$ (bilateral).**The correlation is significant $p < 0.01$ (bilateral).

4 | DISCUSSION

There are multiple factors that influence marginal bone loss around implants. The present study focuses mainly on prosthetic factors and soft tissue thickness, but it should not be forgotten that there are other very interesting factors to be taken into account, such as periodontal health and smoking. Several systematic reviews and clinical trials have suggested that implant failure and associated margin-al bone loss are greater in patients with a history of periodontitis. Microbiota-environmental factors have been identified in both situations, and recent analyses have shown that there are no significant differences between bacterial genera on implants and teeth in supragingival and subgingival biofilms. The diseased peri-implant and periodontal tissues shared a similar microbiota. Periodontal disease has been estimated to induce additional bone loss in implant installation

TABLE 6 Correlations (derived variables).

Variables	Vertical mucosal thickness[a]	Abutment height (average)
Difference TX—T0 Mesial	−0.064	−0.054
Difference TX—T0 Distal	−0.023	−0.118
Difference TX—T0 Average	−0.063	−0.094
Difference TX—T1 Mesial	−0.014	−0.047
Difference TX—T1 Distal	−0.042	−0.175
Difference TX—T1 Average	−0.034	−0.117
Difference TX—T2 Mesial	−0.103	−0.055
Difference TX—T2 Distal	−0.056	−0.190
Difference TX—T2 Average	−0.096	−0.127
Difference TX—T3 Mesial	−0.030	−0.110
Difference TX—T3 Distal	0.041	−0.225*
Difference TX—T3 Average	−0.011	−0.178
Difference TX—T4 Mesial	−0.079	−0.135
Difference TX—T4 Distal	0.076	−0.212*
Difference TX—T4 Average	0.010	−0.191
Difference T0—T1 Mesial	0.225*	0.014
Difference T0—T1 Distal[a]	0.073	−0.113
Difference T0—T1 Average	0.165	−0.060
Difference T0—T2 Mesial	0.013	−0.007
Difference T0—T2 Distal[a]	0.042	−0.069
Difference T0—T2 Average[a]	0.046	−0.064
Difference T0—T3 Mesial	0.094	−0.100
Difference T0—T3 Distal	0.114	−0.145
Difference T0—T3 Average	0.131	−0.138
Difference T0—T4 Mesial	0.026	−0.124
Difference T0—T4 Distal	0.155	−0.110
Difference T0—T4 Average	0.114	−0.138

[a]In the correlations involving any of these variables, Spearman's correlation was applied, and Pearson's correlation was used for the rest.
*The correlation is significant $p < 0.05$ (bilateral).

in periodontally diseased patients compared to periodontally healthy patients. There is evidence that patients with existing or ongoing periodontitis are more likely to experience implant failure and biological complications.[25,26] However, due to the high heterogeneity among studies and methodological variability, it is difficult to draw solid conclusions. Articles on chronic periodontitis showed an increased risk of implant failure, with ORs between 3.1 and 4.7 for affected patients.[26] Patients with a history of aggressive periodontitis can be worse off, with an increased risk of implant failure (OR = 4.80), mucositis (OR = 3.61), and peri-implantitis (OR = 14.09).[27]

However, other studies warn that smoking and a history of periodontitis are particularly influential in the late stages of implant failure. In a prospective study, it was shown that interproximal bone loss was significantly related to tobacco or alcohol use, increased plaque levels, and gingival inflammation. A subsequent retrospective study demonstrated lower survival rates and increased marginal bone loss in tobacco smokers with a history of treated and maintained periodontitis.[28] A recent systematic review stated that implant insertion in smokers resulted in higher failure rates, postoperative infections, and marginal bone loss.[29] In our study, we excluded all patients who smoked more than 10 cigarettes per day, as well as patients with poor oral hygiene (PI >15%, BoP >15%).

Another of the multiple factors that influencing peri-implant marginal bone loss are prosthetic factors. It has been reported that early marginal bone loss is more influenced by the characteristics of the prosthetic rehabilitation than by the post-surgical bone remodeling process.[15] Other studies have indicated that changes in the crestal bone occur during the initial phase of healing, once the implant has been placed and loaded,[19,30] demonstrating that after implant surgery a remodeling occurred that was characterized by a reduction of bone dimensions, both horizontally and vertically.[31]

In this study, a more acute peri-implant marginal bone loss occurred between surgery (Tx) and prosthesis placement (To), specifically of 0.84 mm when the vertical mucosal thickness was under 3 mm, 0.60 mm when the vertical mucosal thickness was greater than 3 mm, 0.96 mm when the abutment height is under 3 mm, and

0.70 mm when the abutment height is over 3 mm. Subsequently, the results showed that peri-implant bone loss tends to stabilize over time.

Different technical aspects were applied in creation of the prostheses; thus, the concept of *platform change* was taken into account, consisting of a horizontal misalignment of the prosthetic abutment with regard to the implant platform. The effect of this on the reduction of bone resorption was documented, it thus being shown that marginal bone loss was significantly reduced[24,32–40] with a diameter mismatch greater than 0.4 mm compared with a misalignment smaller than 0.4 mm. In our study, the concept of platform change was applied in all cases studied, without differences between each of the rehabilitations with regard to the distance of the horizontal misalignment of the abutment with the coronal portion of the implant, so that there was no type of influence due to this factor.

It has also been suggested that the type of implant-abutment connection may influence the crestal bone so that in the case of external connections greater bone loss would occur compared with internal type connections.

Despite the above, it has been suggested that bone resorption would be predominantly related with biological factors such as establishment of biological width, rather than with the mechanical factors previously mentioned.[41]

With regard to the influence of the type of crown placement technique, cemented or screwed, there are authors such as Brandão et al.[42] who have suggested that marginal bone loss would be greater for cemented crowns, although the difference was not significant. However, screwed restorations would be advantageous for plaque control, due to being easier to remove. Additionally, emphasis has been placed on the risk entailed by cement residue in cemented crowns that are often impacted in soft tissue, which causes a foreign body reaction that can trigger peri-implant marginal bone loss.[43] The use of high abutments to connect cemented prostheses to implants provides not only greater height for restoring biological width, but also easier removal of excess cement from soft tissue to prevent mucositis and peri-implantitis.[44]

In this study, both lithium disilicate and zirconia crowns were cemented in the dental laboratory on customized Atlantis® (Dentsply Sirona) type abutments, with the aim of creating a cemented-screwed prosthesis and thereby prevent marginal bone loss resulting from potential excess residual cement. The height of the abutment was determined based on the peri-implant vertical mucosal thickness. As several authors indicate, the greater the height of the abutment, the greater the growth of the peri-implant soft tissue and the greater the distance separating the marginal bone from a potential contaminated area of the crown-abutment connection, regardless of whether the restoration is cemented or screwed.[10–13,16] Several authors have shown that the abutment height influences the level of the marginal bone, which is better preserved when abutments larger than 2 mm are used to restore screwed implants with several units.[11] The height of the abutment therefore plays a critical role in maintaining the marginal bone in screwed prostheses, despite the distance caused by the application of the platform change concept.[10,11] Therefore, if low height abutments are used, apical compression of the peri-implant soft tissue occurs, with the resulting peri-implant marginal bone loss.[18]

The randomized clinical trial by Blanco et al.[6] also demonstrated that in implants surrounded by a peri-implant mucosa of over 3 mm, greater marginal bone loss occurred in short abutments (1 mm high) compared with long abutments of 3 mm, after 6 months of prosthetic loading in screwed rehabilitations. This inverse correlation between marginal bone loss and abutment height has also been recently confirmed for implants restored with both single and multiple cemented prostheses.[13,45,46]

The importance of using long prosthetic abutments to restore juxta-osseous implants that allow the correct establishment of the supracrestal insertion tissue[6,7] has been reported in numerous retrospective[10,12,40] and prospective studies.[13,39] Furthermore, Spinato et al.[22] showed that after 12 months, implants at the crestal level, restored with short abutments (1 mm) and with platform change, obtained double the bone loss as identical implants restored with long abutments (3 mm), regardless of the vertical mucosal thickness. These results are consistent with those described in the previous prospective study by Blanco et al.,[6] with 6 months of evolution, carried out with 1 and 3 mm high abutments with screwed prostheses, and with a recent clinical and histological prospective cohort trial by Canullo et al.[40]

The choice of the height of the transmucosal abutment will depend on the level of the implant platform in relation with the edge of the gingival margin, it being observed that the crown line must be at least 1 mm lower to obtain an aesthetic result, especially on the vestibular surface.[47]

In this study, it was observed how in abutments over 3 mm high there was an average marginal bone loss of 0.70 mm between Tx and To, while for abutments under 3 mm high, this loss was 0.96 mm, being consistent with what the aforementioned authors published. Subsequently, as other studies also indicate, there was a stabilization of peri-implant marginal bone loss. Therefore, it is confirmed in this study that the greater the height of the abutment, the lower the marginal bone loss.

The initial vertical mucosal thickness (distance between the marginal mucosa and bone crest) has also been shown to be one of the influential factors in peri-implant bone stability. In fact, authors such as Abrahamsson et al.,[48] already reported that the minimum dimension of the mucosal height to achieve this objective was 3 mm. This concept of the influence of mucosal thickness on marginal bone loss around implant necks was discussed by Cochran et al.,[49] suggesting that the soft tissue creates a protective barrier against the infiltration of inflammatory cells into the underlying alveolar bone. Subsequent studies suggested that the vertical mucosal thickness necessary for establishing correct biological width around two-piece dental implants should be at least 2 mm to avoid marginal bone loss.[9,50] However, recent studies such as that by Muñoz et al.[51] report that the vertical mucosal thickness does not influence marginal bone loss, as had previously been suggested by Spinato et al.[22] Conversely, other authors such as Linkevicius et al.[24] state that a minimum of 2 mm vertical

mucosal thickness is necessary to preserve the crestal bone. In this same study, it was indicated that the vertical mucosal thickness is a significant factor for limiting peri-implant marginal bone loss around implants placed at crestal level and rehabilitated applying the concept of *platform change*. Similarly, in another more recent study by Linkevicius et al.[52] it was concluded that rehabilitated implants with an initial vertical mucosal thickness greater than 2 mm maintained marginal bone levels more successfully than implants with an initial thickness less than 2 mm. As in the study by Galindo-Moreno et al.[10] in which prosthetic abutments smaller than 2 mm were used, marginal bone loss increased significantly regardless of the width of the keratinised tissue.

In our study, it was observed that there was a slight influence of the vertical mucosal thickness, because when it was less than 3 mm, specifically between surgery (Tx) and placement of the rehabilitation (To), a difference of 0.24 mm less bone loss was observed than when the vertical mucosal thickness was greater than 3 mm. The level of bone loss was greater when the vertical mucosal thickness was under 3 mm. However, it is important to indicate that in this study, the vertical mucosal thickness is what determines the abutment height; therefore, the greater the vertical thickness, the higher the abutment. In both cases, both in the influence of the height of the abutments and in the influence of the vertical mucosal thickness, a much more pronounced bone loss occurred between the period from surgery (Tx) to prosthetic rehabilitation (To).

It has been observed that it is possible to prevent peri-implant bone remodeling if we adapt the vertical position of the implant to the thickness of the soft tissue.[12,53] In 2014, these authors evaluated the influence of the initial thickness of the soft tissue on the level of the peri-implant bone, and changes in the bone level with the decrease in the height of the abutments, after monitoring for 1 and 2 years, suggesting adapting the vertical position of the implant based on the vertical thickness of the soft tissue, which is more feasible in edentulous areas. In the controlled clinical study by Linkevicius et al.[9] abutment height was classified into two categories—less or more than 2 mm—and greater bone loss was observed when the mucosal thickness was 2 mm or less (1.38 mm), in contrast with tissue greater than 2 mm (loss of 0.25 mm), suggesting that the influence of the initial thickness at the time of implant placement could be more important in early bone remodeling than the position of the microgap.

In our study, we carried out this work technique, where the vertical mucosal thickness was first measured with a periodontal probe, and the implant was positioned at subcrestal level based on this vertical mucosal thickness. Subsequently, rehabilitation was carried out by designing the height of the abutment in relation with this vertical thickness of the residual mucosa.

5 | CONCLUSION

As described in previous studies, prosthetic rehabilitations on subcrestally positioned implants influence peri-implant marginal bone loss, it being important to consider certain factors that influence this remodeling such as the height of the prosthetic abutment or the vertical mucosal thickness. In both cases, greater bone loss occurs when the abutment height and vertical mucosal thickness are lower, while the bone loss will be lower when the prosthetic abutment and the vertical mucosal thickness are higher.

Peri-implant marginal bone loss is more pronounced in the period from implant surgery to placement of the prosthetic rehabilitation, with tissue stabilization being observed subsequently.

AUTHOR CONTRIBUTIONS

Serafín Maza-Solano: Contributed to conception, data acquisition, data analysis, data interpretation, and drafting the manuscript. **María Baus-Domínguez**: Contributed to data interpretation and drafting and critically revised the manuscript. **Manuel-María Romero-Ruíz**: Contributed to data analysis and data interpretation. **Aida Gutiérrez-Corrales**: Contributed to interpretation and critically revised the manuscript. **Daniel Torres-Lagares**: Contributed to conception, data analysis and critically revised the manuscript. **María-Ángeles Serrera-Figallo**: Contributed to data interpretation and critically revised the manuscript. All authors gave their final approval and agreed to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

PATIENT CONSENT STATEMENT

All patients gave written informed consent to participate before inclusion in the study.

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