Received: 18 February 2019 | Revised: 18 April 2019 | Accepted: 18 April 2019

DOI: 10.1111/clr.13450

ORIGINAL RESEARCH

CLINICAL ORAL IMPLANTS RESEARCH WILEY

Biological width establishment around dental implants is influenced by abutment height irrespective of vertical mucosal thickness: A cluster randomized controlled trial

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Abstract

Objective: Prosthetic abutment height and peri-implant mucosal thickness are considered factors that influence marginal bone remodeling during biological width establishment around dental implants. However, no clinical studies have evaluated their simultaneous effect on marginal bone loss (MBL). This study analyzes the influence of abutment height on MBL around implants surrounded by both thin and thick mucosa up to 12 months after prosthetic loading.

Material and methods: Seventy platform-switched implants with internal hex were placed equicrestally in two groups of patients with different vertical mucosal thickness: thin (≤2.0 mm) and thick mucosa (>2.0 mm). After three months of submerged healing, prosthetic abutments with a height of 1 mm (short) or 3 mm (long) were randomly assigned for single crown screwed restoration in both groups. MBL was evaluated on radiographs taken at implant placement (T_0), restoration delivery (T_1), and after 6 months (T_2) and 12 months (T_3) of loading.

Results: After 12 months of loading, 66 implants were functioning (two dropouts, two failures), resulting in a 97% survival rate. Compared with T_0, mean MBL at T_3 ranged between 0.59 and 0.80 mm in short abutment groups and between 0.28 and 0.37 mm in long abutment groups. Differences resulted statistically significant, irrespective of vertical peri-implant mucosal thickness. The MBL pattern over time showed the greatest amount of bone resorption in the first 6 months after loading, particularly around implants with short abutments.

Conclusions: Platform-switched implants restored with short abutments present greater marginal bone loss than identical implants with long abutments, without significant peri-implant mucosal thickness effects.

KEYWORDS

abutment height, dental implants, marginal bone loss, platform switching, thick mucosa, thin mucosa

1 | INTRODUCTION

One of the main criteria for long-term implant success has always been related to the limitation of marginal bone loss (MBL) around implant necks (Albrektsson, 1986). However, peri-implant bone loss of 1.5–2.0 mm during the first year of loading and an annual bone loss thereafter of <0.2 mm has generally been considered acceptable for two-piece implants. (Adell, Lekholm, Rockler, & Brånemark, 1981; Albrektsson et al., 1986). Despite numerous explanations, the multifactor etiology of MBL is not yet well understood (Oh, Yoon, Misch, & Wang, 2002; Tatarakis, Bashutski, Wang, & Oh, 2012).

Early marginal bone loss may be influenced by both surgical factors (overheating during site preparation, excessive cortical compression, insufficient crestal bone width and/or implant malpositioning, and implant crest module characteristics) and by prosthetic variables (type of implant/abutment connection, entity and location of implant/abutment microgap, multiple abutment disconnections, and cement remnants; Canullo, Bignozzi, Cocchetto, Cristalli, & Iannello, 2010; Oh et al., 2002; Qian, Wennerberg, & Albrektsson, 2012; Tatarakis et al., 2012). An important additional influence upon MBL around healthy implants is biologic width establishment following abutment connection (Broggini et al., 2006; Cochran, Hermann, Schenk, Higginbottom, & Buser, 1997; Eriksson, Nilner, Klinge, & Glantz, 1996; Hermann et al., 2001). More recent findings even suggest that early marginal bone resorption is influenced more by prosthetic rehabilitation characteristics than by the post-surgical bone remodeling process, significantly increasing up to 6 months after functional loading before stabilizing (Galindo-Moreno et al., 2015).

The influence of mucosal thickness upon MBL around implant necks was discussed by Cochran et al. (1997), suggesting that soft tissue creates a protective barrier against inflammatory infiltration toward the underlying alveolar bone. Later studies suggested that the vertical mucosal thickness necessary for biological width establishment around two-piece dental implants should be at least 2 mm to avoid MBL (Linkevicius, Apse, Grybauskas, & Puisys, 2009; Suárez-López Del Amo, Lin, Monje, Galindo-Moreno, & Wang, 2016). Other studies suggested that a variable amount of MBL may occur to provide the necessary space for biological width establishment (Berglundh, Abrahamsson, & Lindhe, 2005; Hermann et al., 2001).

More recently, this concept has been re-elaborated by Linkevicius, Apse, Grybauskas, and Puisys (2010), specifically stating that vertical keratinized mucosal thickness is a significant factor in limiting peri-implant marginal bone loss around platform-switched implants placed at crestal level. One year after loading, implants with an initial vertical mucosal thickness greater than 2 mm maintained marginal bone levels more successfully than implants with an initial mucosal thickness ≤2 mm (Linkevicius, Puisys, Steigmann, Vindasiute, & Linkeviciene, 2015). Indirect confirmation of this concept was then provided by Vervaeke, Collaert, Cosyn, and Bruyn (2016), who concluded that initial peri-implant bone remodeling was affected by mucosal thickness, even though initial mucosal thickness was not measured in their case series study. The authors postulated that abutment height was determined by mucosal thickness, as abutments were chosen at the time of implant insertion and their height was adapted to site-specific mucosal thickness.

Furthermore, Galindo-Moreno et al. (2014, 2016) demonstrated that abutment height may influence marginal bone level by showing that marginal bone is better preserved when abutments longer than 2 mm are used to restore multi-unit screw-retained implants. In these two radiographic retrospective studies, abutment height was not determined by mucosal thickness, which was neither recorded nor analyzed. In some cases, keratinized mucosa could be compressed apically by both short abutments and crown placement, reducing the distance from the prosthetic emergence profile to peri-implant crestal bone (Collaert & De Bruyn, 2002).

In close agreement with these outcomes, a recent randomized clinical trial has shown that short abutments (1 mm) lead to greater MBL than long abutments (3 mm) around implants surrounded by thick mucosa (≥3 mm) after 6 months of prosthetic loading with screw-retained rehabilitations (Blanco et al., 2018). This inverse correlation between MBL and abutment height has also recently been confirmed for implants restored with both single and multi-unit cement-retained prostheses (Spinato, Bernardello, Sassatelli, & Zaffe, 2017a,2017b; Spinato, Galindo-Moreno, Bernardello, & Zaffe, 2018). Moreover, the use of long abutments seems to be more effective in preventing MBL when using platform-switched implants than implants with a regular platform, probably due to a synergic action of the two aforementioned factors (Spinato et al., 2018).

However, to our knowledge, no studies are present in the literature considering the influence of abutment height on peri-implant MBL, when abutment choice was not dictated by mucosal thickness. In other words, no evidence is available to discern if biological width establishment is actually influenced only by mucosal thickness, irrespective of prosthetic abutment characteristics.

Therefore, the primary aim of this present multicenter cluster randomized controlled study is to analyze the influence of abutment height on peri-implant MBL around platform-switched implants surrounded by thick or thin peri-implant mucosa, up to 12 months after prosthetic loading. The null hypothesis of this study is that there are no differences in MBL around implants restored using short or long abutments, irrespective of vertical mucosal thickness and other clinical variables (sex, age, and oral hygiene).

2 | MATERIAL AND METHODS

2.1 | Study protocol

This multicenter cluster randomized controlled trial was reported following CONSORT guidelines (http://www.consort-statement.org). All procedures were performed in strict accordance with the recommendations of the Declaration of Helsinki, as revised in Fortaleza (2013), for investigations with human subjects (American Medical Association,

2013). The study protocol was approved by the relevant Ethical Committee (Regione Calabria, Sezione Area Nord, Nr. 67/2016) and was recorded in a public register of clinical trials (www.clinicaltrials.gov – NCT03229005). Eligible patients were thoroughly informed of the study protocol (including procedures, follow-up evaluations, potential risks involved, and possible therapeutic alternatives) and signed an informed consent form in which all procedures of the study were detailed. Patients authorized use of their data for research purposes.

2.2 | Selection criteria

Any partially edentulous patient requiring implant-supported rehabilitation in the posterior mandible was eligible for this study. Subjects were selected consecutively and treated by one of two operators (S.S. or C.S.), in their private offices, between April 2016 and July 2017. Data collection was performed by a single independent examiner (F.B.). The present study included partially edentulous patients, requiring placement of at least one single implant in pristine bone in the posterior mandible. In cases of multiple implants, only the more mesial implant was included in the study (each patient contributed to the study with one implant).

General inclusion criteria are as folllows: (a) age >18 years; (b) good general health; (c) nonsmokers; (d) absence of systemic diseases affecting bone metabolism and wound healing; (e) no regular medication consumption for at least 3 months prior to treatment; (f) patient willingness and capability to fully comply with the study protocol; and (g) written informed consent given.

Local inclusion criteria are as follows: (a) presence of keratinized mucosa with a minimum buccolingual width of 3 mm; (b) bone crest with a minimum of 6 mm of width and 9 mm of height above the mandibular canal, with no concomitant or previous bone augmentation procedures; and (c) presence of the opposing dentition.

Exclusion criteria are as follows: (a) history of head or neck radiation therapy; (b) uncontrolled diabetes (HBA1c >7.5%); (c) active infections; (d) immunocompromised patients (HIV infection or chemotherapy within the past 5 years); (e) present or past treatment with intravenous bisphosphonates; (f) patient pregnancy or lactating at any time during the study; (g) poor oral hygiene and motivation (full mouth plaque score FMPS >25%); (h) untreated periodontal disease; (i) psychological or psychiatric problems; (j) alcohol or drug abuse; (k) participation in other studies, if the present protocol could not be properly followed; and (l) lack of implant primary stability or peak insertion torque >60 Ncm.

Before implant placement, all patients received oral hygiene instructions and underwent deplaquing 1 week prior to surgery. Cone beam computed tomography was performed to evaluate crestal bone morphology and dimensions and to plan implant positioning.

2.3 | Surgical and restorative procedures

After administration of 4% articaine solution with adrenaline 1:100.000 (Artin, Omnia), a mid-crestal incision along the center of the edentulous bone ridge was performed. A full-thickness flap was elevated in two phases as described elsewhere (Linkevicius et al., 2010):

1. After buccal flap reflection, the mucosal thickness was measured with a periodontal probe (15 mm, PCP-UNC15; Hu-Friedy) at the center of the future implant site (Figure 1);
2. The lingual flap was subsequently elevated to expose the bone crest.

The implant location was then marked with a small-diameter pilot drill using a prefabricated surgical guide.

A two-stage protocol was adopted following the manufacturer's recommendations. The site was prepared under abundant irrigation of cold saline solution to allow insertion of an internal hex, platform-switched implant with a 1-mm machined collar (Shape1BC, i-RES – Figure 2), at crestal level, using the buccal aspect of the crest as reference for the apico-coronal implant position. All inserted implants measured 3.75 mm in diameter and operators selected appropriate implant lengths (8, 10, 11.5 mm) according to available bone height. Cover screws were then placed, and all implants were submerged by suturing flaps with the Sentineri technique using synthetic monofilament (PTFE, Omnia; Sentineri, Lombardi, Berton, & Stacchi, 2016). Patients were prescribed antibiotic therapy (amoxicillin 1 g twice a day) for 6 days and, when needed, nonsteroidal anti-inflammatory drugs (ibuprofen 600 mg). Sutures were removed 12–14 days after surgery. Patients were instructed not to use removable prostheses during the entire healing period.

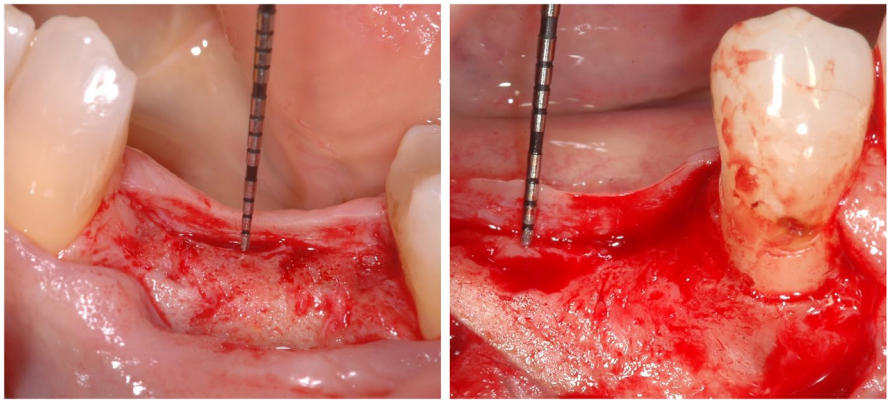

FIGURE 1 Representative vertical mucosal thickness measurement at implant placement of an A group (thin mucosa thickness ≤2.0 mm) patient (left) and a B group (thick mucosa thickness >2.0mm) patient (right)

FIGURE 2 Image showing the Shape1BC implant inserted in the 70 consecutive patients fulfilling all inclusion criteria

Second-stage surgery was performed after 3 months of submerged healing. A mid-crestal incision was performed, and vertical mucosal thickness measurement was repeated with the previously described modalities. A 3-mm-height healing abutment was connected to the implants in all cases.

Final impressions were taken 3 weeks after the second surgery.

The prosthetic framework was bonded to a prefabricated titanium abutment (of either 1 or 3 mm, randomly assigned) and, after functional and esthetic try-in, a single-unit screw-retained metal ceramic prosthesis was delivered. The fixation screw was tightened to 30 Ncm torque according to manufacturer's guidelines, and the screw access was closed with light-cured composite resin.

Patients were recalled every 6 months for hygiene maintenance and clinically checked for plaque and bleeding status by using the modified plaque index (mPI) and the modified sulcus bleeding index (mSBI) (Mombelli, Oosten, Schurch, & Lang, 1987). The mean of the four values recorded for each implant (mesial, distal, buccal, and lingual) was subsequently analyzed.

2.4 | Radiographic measurements

Digital radiographs were taken using a long-cone paralleling technique with a Rinn-type film holder, customized for each patient with a resin bite jig, at the time of implant placement (baseline), at prosthetic restoration delivery (4 months after implant placement), and after 6 and 12 months of prosthetic loading.

Marginal bone loss (MBL) was calculated on each radiograph as the linear measurement of the distance between two points, the most coronal point of the implant platform and the most coronal bone-to-implant contact. The measuring software (Kodak Digital Imaging Software, Eastman Kodak) was calibrated for each radiograph, taking the known implant length and diameter as a reference. The vertical distance between the most coronal point of the implant platform and the most coronal bone-to-implant contact was measured on both mesial and distal aspects of the implant at:

T_0 – implant placement
T_1 – prosthesis delivery (4 months after T_0)
T_2 – 6 months after implant loading (6 months after T_1)
T_3 – 12 months after implant loading (6 months after T_2).

Mesial (mMBL) and distal (dMBL) MBL were calculated as bone changes between T_0, T_1, T_2, and T_3. Therefore, an increase in vertical distance between the implant platform reference point and crestal bone (the most coronal bone-to-implant contact) was considered indicative of bone loss, while a decrease in distance would be considered indicative of bone gain.

Radiographs showing any sign of deformation, darkness, or other problems were immediately repeated. All measurements were taken by a single calibrated examiner, blinded to mucosal thickness (F.B.), on a 30-inch LED-backlit color diagnostic display. Each measurement was repeated three times at three different time points as proposed by Gomez-Roman and Launer (2016). Examiner calibration was performed by assessing ten radiographs, by a different author (M.M.) serving as reference examiner. Intra-examiner and inter-examiner concordances were 96.1% and 90.4%, respectively, for linear measurements within ± 0.1 mm.

2.5 | Predictor and outcome variables

This cluster randomized controlled study tests the null hypothesis of no differences in marginal bone loss between dental implants restored with prosthetic abutments of different height against the alternative hypothesis of a difference.

The primary predictor variables are prosthetic abutment height and vertical mucosal thickness. The following patient-related variables, possibly correlated with predictor and outcome variables, are also evaluated: (1) age and (2) gender.

Primary outcome measurement:

- Marginal bone loss (MBL) after six and twelve months of prosthetic loading.

Secondary outcome measurements:

- Implant failure: implant mobility or implant removal suggested by progressive marginal bone loss. Implant stability was tested by tightening abutment screws (35 N/cm) at prosthesis delivery.
- Any complication or adverse event.

2.6 | Treatment allocation

Based upon vertical mucosal thickness measured at second-stage surgery, patients were clustered into two groups: (A) thin mucosa group (≤2.0 mm) and (B) thick mucosa group (>2.0 mm). Patients within each group were then randomized for abutment selection. Treatment allocation was assigned by T.L. after creating two randomization lists, one for group A (thin mucosa) and one for group B (thick mucosa), generated by a randomization plan generator (www.randomization.com), in order to ascribe an abutment height of either 1 or 3 mm to each implant (Figure 3).

Assignment of patients to the different groups was performed using identical, opaque, sealed envelopes which were opened after taking the final impression, revealing the treatment to be performed to the clinician. Therefore, treatment allocation was concealed to the investigators responsible for enrolling and treating the patients (S.S. & C.S.).

2.7 | Sample size calculation and statistical power

An open source software (http://www.dssresearch.com) was used to determine the sample size of the present study. The calculation was performed based upon data published in previous studies (Galindo-Moreno et al., 2014; Linkevicius et al., 2015), expecting a difference of 0.3 mm (±0.25 mm) in MBL when using abutments of different heights. A sample of 12 patients for each treatment group was required to detect significant differences (confidence level 5% with statistical power of 80%).

2.8 | Statistical analysis

Statistical analysis was performed using Primer of Biostatistics (6th Ed.) software (Glantz, 2007). The patient was considered the statistical unit (one implant per patient). Data for descriptive statistics were expressed as mean ± SE. Data normality was assessed with the Shapiro–Wilk test, and intra- and inter-group comparisons were carried out using the one-way ANOVA test, followed by the Student–Newman–Keuls post hoc test for comparison of the means of three or four groups.

Differences in patient age, gender, plaque, and bleeding indices or MBL in pairwise comparisons of groups were considered significant for $p < 0.05$.

3 | RESULTS

3.1 | Clinical evaluation

Between April 2016 and July 2017, from a total of 178 patients undergoing 3.75-mm implant insertion in the mandible, 70 consecutive patients (C.S. 32; S.S. 38) fulfilled all inclusion criteria and were enrolled and treated.

In all 70 patients, vertical mucosal thickness measured at first surgery was confirmed at second surgery (33 patients with thin mucosa—group A, 37 patients with thick mucosa—group B).

Two A group patients were lost at 6-month follow-up (one patient of C.S. died, one patient of S.S. moved abroad). Of the remaining 68 implants placed in 68 patients, two implants, both placed in A group patients, had failed to osseointegrate at the re-opening appointment (one implant of C.S. and one implant of S.S.), resulting in a 97% implant osseointegration rate. Both of these patients refused new implant therapy. The remaining 66 patients (Table 1) completed all phases of the study and were included in the final analysis. The mean age of all patients was 51.3 years, range 26–70, with no statistical significance among subgroups for age or gender ($p > 0.05$) after ANOVA test.

Primary wound closure was obtained in all surgeries, and no complications or adverse effects were recorded during follow-up. All 66 implants were functioning satisfactorily at 6-month and 12-month follow-ups.

Of the 66 patients, 34 patients (subgroup 1) received a 1-mm-long abutment and 32 patients (subgroup 3) received a 3-mm-long abutment.

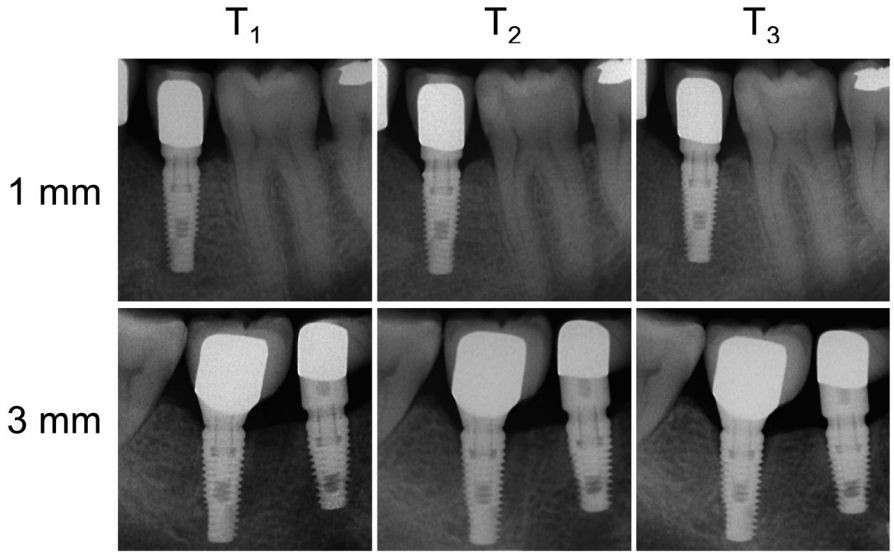

FIGURE 3 Radiographs showing implants with short (1 mm) abutment (above) and long (3 mm) abutment (below) immediately after prosthetic restoration (T_1), 6 months (T_2), and 12 months (T_3) after prosthetic loading. Note: In the lower images, MBL was calculated around the mesial implant

TABLE 1 Demographics and implant characteristics of patients included in the final analysis

A group (*n* = 29) Mucosal thickness ≤2.0 mm											
AH 1 mm *n* = 15						AH 3 mm *n* = 14					
Females			Males			Females			Males		
Age	Site	IL	Age	Site	IL	Age	Site	IL	Age	Site	IL
26	45	8	38	46	10	26	35	8	36	35	10
33	36	10	48	36	8	33	44	8	38	35	8
34	44	10	50	36	10	40	44	8	42	36	10
36	46	8	55	45	10	56	45	11.5	42	36	11.5
36	34	10	66	36	11.5	57	36	10	50	46	10
38	46	10	70	45	8	59	46	10	66	44	10
45	46	10				60	46	8	70	36	10
57	46	8									
60	36	10									
B group (*n* = 37) Mucosal thickness > 2.0mm											
AH 1 mm *n* = 19						AH 3 mm *n* = 18					
Females			Males			Females			Males		
Age	Site	IL	Age	Site	IL	Age	Site	IL	Age	Site	IL
34	35	10	46	46	10	39	46	10	42	46	11.5
45	45	10	51	35	8	45	36	10	44	46	10
47	46	10	51	36	10	46	46	8	46	36	10
48	46	10	52	35	10	49	34	10	49	46	10
52	36	10	56	35	10	52	46	10	55	45	10
57	46	10	60	37	10	60	44	10	58	44	10
58	36	10	65	34	10	60	46	10	61	36	11.5
64	34	8	65	44	10	68	36	8	63	44	10
68	44	8	66	45	10				64	35	8
			69	36	10				66	36	10

Abbreviations: AH, abutment height; IL, implant length; *n*, number.

mPI and mSBI resulted similar in all 66 implants irrespective of abutment height and mucosal thickness at both 6 and 12 months (Table 2).

3.2 | Radiographic evaluation

In all 66 patients, limited bone loss (MBL of all patients = 0.12 ± 0.01 mm) was recorded at T_1 (Figure 4) at both mesial and distal aspects of all implants (Figure 3), without significant differences among groups (Tables 2 and 3).

In thin mucosa group (A group), MBL significantly increased in both A1 and A3 groups (Table 3). At both T_2 and T_3, MBL was significantly greater in the short abutment group than in the long abutment group (Table 3). In both A1 and A3 groups, MBL values at T_3 showed further increase when compared with T_2, but without reaching statistical significance (Table 3).

In thick mucosa group (B group), MBL significantly increased in both B1 and B3 groups (Table 4). At both T_2 and T_3, MBL was significantly greater in the short abutment group than in the long abutment group (Table 4). In both B1 and B3 groups, the MBL values at T_3 showed further increase when compared with T_2, but without reaching statistical significance (Table 4).

MBL progression rate trend in relation to time for both thin (A) and thick (B) mucosa groups is graphically presented in Figure 4.

Mean MBL values at T_1 ranged between 0.09 and 0.17 mm, and did not differ across the 4 groups (p = 0.71).

After 6 months of prosthetic loading (T_2), the average MBL values compared with T_1 increased more (+414% average increase) in short

TABLE 2 mPI and mSBI of the four groups at different times

n	A1 15 m ± *SE*	A3 14 m ± *SE*	B1 19 m ± *SE*	B3 18 m ± *SE*	*p*
mPI					
T_2	0.52 ± 0.10	0.52 ± 0.09	0.53 ± 0.07	0.53 ± 0.07	0.99
T_3	0.55 ± 0.09	0.54 ± 0.09	0.57 ± 0.06	0.56 ± 0.06	0.99
mSBI					
T_2	0.42 ± 0.08	0.46 ± 0.08	0.46 ± 0.07	0.46 ± 0.06	0.97
T_3	0.47 ± 0.08	0.52 ± 0.08	0.50 ± 0.07	0.50 ± 0.07	0.98

Abbreviations: 1, 1-mm abutment height; 3, 3-mm abutment height; A, thin mucosa group (≤2.0 mm); B, thick mucosa group (>2.0 mm); m ± *SE*, mean ± standard error; mPI, modified plaque index; mSBI, modified sulcus bleeding index; *n*, number of patients; *p*, statistical significance after ANOVA test (4 treatment groups); T_2, 6 months of loading; T_3, 12 months of loading.

abutment groups (A1 and B1 – range 0.52–0.70 mm) than (+145% average increase) in long abutment groups (A3 and B3 – range 0.22–0.32 mm), irrespective of vertical mucosal thickness, although statistically significant only when comparing B1 with A3 and B3 (Figure 4).

From 6–12 months of prosthetic loading (T_3), the average MBL values slightly increased in both short (+14% average increase – range 0.59–0.80 mm) and long abutment groups (+17% average increase – range 0.28–0.37 mm), irrespective of vertical mucosal thickness. Results are statistically significant comparing both A1 and B1 with A3 and B3 (Figure 4).

Particularly, at the mesial aspect of subgroup 3 (3-mm abutment height), the mean MBL recorded in B group (thick mucosa) was less than that of A group (thin mucosa) at both T_2 (–26%) and T_3 (–18%), although with no statistical significance.

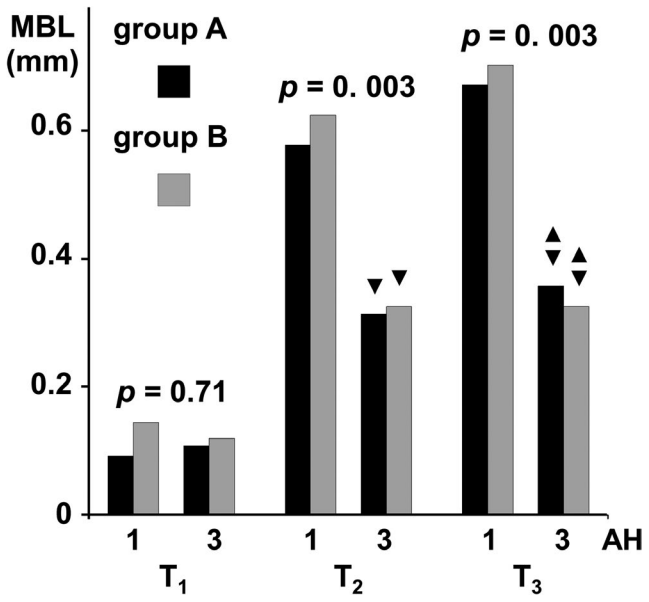

FIGURE 4 Marginal bone loss (MBL) in group A (thin mucosa ≤2.0 mm) and group B (thick mucosa >2.0 mm), with 1- and 3-mm abutments (AH, abutment height), at the three evaluation times. MBL increased from T_1 to T_3, but at different rates: greater in A1 and B1 than in A3 and B3, irrespective of vertical mucosal thickness. Values recorded at T_1 are similar in the four groups. T_2 values, which are greater than T_1, showed a difference between 1- and 3-mm AH groups. Values recorded at T_3 are slightly greater than those recorded at T_2. No differences between group A and group B were recorded at either T_1, T_2, or T_3. Mean MBL is expressed in mm. *P* = probability after ANOVA test (4 treatment groups). ▲ = $p < 0.05$ vs. A1 after Student–Newman–Keuls post hoc test. ▼ = $p < 0.05$ vs. B1 after Student–Newman–Keuls post hoc test

4 | DISCUSSION

The present cluster randomized controlled trial evaluated the effect of prosthetic abutment height on early peri-implant bone resorption in relation to vertical mucosal thickness. To the best of the authors' knowledge, no clinical studies have yet been performed to evaluate the simultaneous influence of abutment height and mucosal thickness on MBL.

Twelve-month outcomes consistently showed that platform-switched implants placed at crestal level and restored with short abutments (1 mm), demonstrated twice the bone loss of identical implants restored with long abutments (3 mm), irrespectively of mucosal thickness. These results strongly agree with a recent 6-month prospective evaluation conducted using 1- and 3-mm-high abutments with screw-retained prostheses (Blanco et al., 2018). Nevertheless, in this latter clinical trial, the authors did not correlate mucosal thickness and abutment height with MBL, as they only performed cases with thick mucosa (≥3 mm).

Moreover, the outcomes of the present investigation confirm previous retrospective studies firmly establishing the inverse relationship between abutment height and MBL around implants restored with screw-retained prostheses (Galindo-Moreno et al., 2014, 2016). In these latter studies, however, mucosal thickness was neither recorded nor analyzed; therefore, no evaluation of the simultaneous influence of mucosal thickness and abutment height on MBL was performed. The concept that the higher the abutment, the lower the MBL has also been demonstrated for cement-retained implant prostheses in three other studies, but, in all cases, with no evaluation of mucosal thickness at implant placement (Spinato, Bernardello, Sassatelli, & Zaffe, 2017a,2017b; Spinato et al., 2018).

TABLE 3 Thin mucosa group. MBL progression (mm) at different time points, taking implant insertion (T_0) as reference

Group	*N*	T_1 m ± *SE*	T_2 m ± *SE*	T_3 m ± *SE*	*p*
A1	15	0.09 ± 0.03	0.58 ± 0.09 ▲	0.67 ± 0.11 ▲	0.001
A3	14	0.11 ± 0.04	0.31 ± 0.08 ▲	0.35 ± 0.09 ▲	0.039
	P	0.743	0.030	0.035	

Abbreviations: ▲, $p < 0.05$ vs. T_1 after Student–Newman–Keuls post hoc test; A1, 1-mm abutment height; A3, 3-mm abutment height; m ± *SE*, mean ± standard error; MBL, marginal bone loss; *n*, number of patients; *p*, statistical significance after ANOVA test; T_1, prosthesis delivery; T_2, 6 months of loading; T_3, 12 months of loading.

TABLE 4 Thick mucosa group. MBL progression (mm) at different time points, taking implant insertion (T_0) as reference

Group	*n*	T_1 m ± *SE*	T_2 m ± *SE*	T_3 m ± *SE*	*p*
B1	19	0.14 ± 0.03	0.62 ± 0.08 ▲	0.70 ± 0.10 ▲	0.001
B3	18	0.12 ± 0.03	0.33 ± 0.05 ▲	0.33 ± 0.05 ▲	0.002
	P	0.589	0.003	0.002	

Abbreviations: ▲, $p < 0.05$ vs. T_1 after Student–Newman–Keuls post hoc test; B1, 1-mm abutment height; B3, 3-mm abutment height; m ± *SE*, mean ± standard error; MBL, marginal bone loss; *n*, number of patients; *p*, statistical significance after ANOVA test; T_1, prosthesis delivery; T_2, 6 months of loading; T_3, 12 months of loading.

In this present study, the authors attempted to minimize variables influencing MBL in order to better evaluate the specific contribution of mucosal thickness and abutment height. Implant insertion in pristine bone, minimum crestal width of 6 mm, standardized protocol for implant site preparation, abundant irrigation with cold saline solution, and peak insertion torque limited to 60 Ncm were only part of the strict inclusion criteria adopted in the attempt to reduce possible confounding factors. In particular, single crowns screwed directly to the implant were delivered in all cases in order to prevent possible cement remnants from becoming a clinical variable influencing MBL, especially in the presence of a short abutment and thick peri-implant mucosa, where complete excess cement removal is unpredictable (Korsch, Robra, & Walther, 2015; Sancho-Puchades et al., 2017; Wilson, 2009). Furthermore, from second-stage surgery to prosthesis delivery, clinical procedures were standardized in all patients in order to minimize possible biases (use of healing abutments with the same length—3 mm; same number of abutment connections/disconnections).

Results of this present study suggest that MBL is not influenced by mucosal thickness, which plays only a limited role when comparing MBL around implants of both A and B groups restored with 3-mm abutments. B group (thick mucosa) showed less marginal bone resorption than A group (thin mucosa), at the mesial aspect, although with no statistical significance. These outcomes agree with a recent clinical and histologic prospective cohort trial (Canullo et al., 2017) but disagree with other studies reporting a significantly greater bone loss when vertical mucosal thickness was ≤2 mm (Linkevicius et al., 2009, 2010, 2015; Vervaeke, Dierens, Besseler, & De Bruyn2014; Vervaeke et al., 2018). In these latter investigations, however, prosthetic abutment height was not considered to be an influencing factor by the authors who, in every case, adapted the abutment height to specific mucosal thickness (i.e., thin mucosa with short abutment).

The authors of this present 12-month investigation specifically identified two main clinical scenarios determined by mucosal thickness. In the first scenario, when thick peri-implant mucosa (>2.0 mm) is present, a long prosthetic abutment (≥2 mm) can safely be used, obtaining acceptable esthetic results and leaving sufficient space for peri-implant biological width establishment with minimal MBL. In the second scenario, thin peri-implant mucosa (≤2 mm) determines an unfavorable environment which should be carefully evaluated when planning prosthetic restoration. Three different options are available when facing this challenging situation with an implant placed at crestal level: a) use of a short abutment (<2 mm), with momentary good esthetic results, but with greater MBL related to biological width establishment; b) use of a long abutment (≥2 mm), preventing peri-implant MBL but esthetically questionable due to the supra-gingival location of the crown-abutment margin (Figure 5); and c) perform vertical thickening of peri-implant mucosa at implant placement in order to modify the biotype of the specific site (Puisys, Vindasiute, Linkeviciene, & Linkevicius, 2015).

In this present investigation, MBL was analyzed in three temporal frames: an initial phase of 4 months from implant placement to prosthetic delivery (T_1), the first 6 months of prosthetic loading (T_2), and the following 6 months (T_3). MBL increased during all phases, but at different rates.

Limited but noticeable marginal bone loss occurred in the first period (T_1 – T_0) before loading, as recently described elsewhere (Borges, Leitao, Pereira, Carvalho, & Galindo-Moreno, 2018). MBL was similar in the 4 groups (A1, A3, B1, B3) during this period and is probably due to the remodeling process caused by surgical trauma related to implant insertion and uncovering, and to the two healing abutment disconnections performed for prosthetic reasons (impression taking and subsequent try-in of the crown) (Koutouzis, Gholami, Reynolds, Lundgren, & Kotsakis, 2017; Tatarakis et al., 2012).

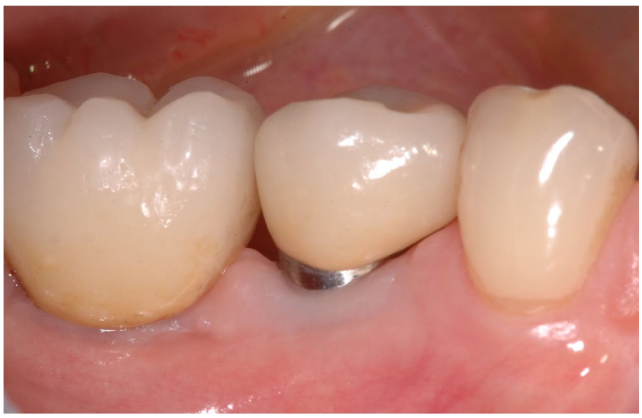

FIGURE 5 Clinical image of the implant already seen in Figure 3, restored with a long abutment. The supra-gingival location of the crown-abutment margin in the presence of thin mucosal thickness resulted in a questionable esthetic outcome

The greatest amount of MBL was recorded during the first 6 months ($T_2 - T_1$) after prosthesis delivery. Particularly, A1 and B1 groups (short abutment) exhibited significantly greater MBL than A3 and B3 groups (long abutment). Thus, these outcomes seem to indicate that mucosal thickness does not automatically affect MBL. MBL occurs when the space necessary for establishment of vertical biological width (2 mm from the bone crest) is invaded by the prosthetic restoration, in the presence of both thin and thick mucosa. Therefore, a 3-mm abutment can minimize MBL more successfully than a 1-mm abutment.

In the third period ($T_3 - T_2$), probably due to loading structural changes of bone, MBL increase was negligible in all groups and dropped to values similar to those recorded in the first period ($T_1 - T_0$).

Some limitations of this present study should be considered when interpreting the results. The method used to measure vertical mucosal thickness could be questioned due to the deformable nature of soft tissue. Nevertheless, the method used in this investigation has been widely adopted in many clinical trials (Linkevicius et al., 2009, 2010, 2015) and, at present, there exists no scientific evidence confirming that this approach is less predictable than either ultrasonic or bone sounding measurement methods (Vervaeke et al., 2018).

Furthermore, this present study collected data from only a selected pool of patients with specific characteristics (e.g., nonsmokers) and in a specific site (posterior mandible). Therefore, further investigation is necessary to generalize these results to a broader population and to different areas of the mouth.

5 | CONCLUSIONS

The results of this present study showed that platform-switched implants with internal hex placed at crestal level and restored with short abutments (1-mm height) presented greater marginal bone loss than identical implants restored with long abutments (3-mm height), with no significant effects of peri-implant mucosal thickness. The pattern of marginal bone loss over time showed that the greatest amount of marginal bone resorption occurs during the first 6 months after prosthetic loading in all groups.

Additional studies with a larger number of patients are warranted to definitely establish the absence/presence of peri-implant mucosal thickness effects.

ACKNOWLEDGEMENTS

The authors wish to thank dr. Sergio Dovigo, dr. Federico Berton, and dr. Antonio Rapani for their precious help in conducting this study.

CONFLICT OF INTEREST

The authors have no conflict of interest related to this study.

AUTHOR CONTRIBUTIONS

CS, MM, SS, and TL involved in concept/design; FB and TL involved in data collection; DZ involved in statistics; DZ, CS, FB, MM, SS, and TL involved in data analysis/interpretation; DZ, CS, and SS drafted the article; FB, MM, and TL involved in critical revision of article; DZ, CS, FB, MM, SS, and TL approved the article.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: 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 Impl Res*. 2019;30:649–659. https://doi.org/10.1111/clr.13450