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Original Article

Chlorhexidine Gel and Marginal Bone Loss in Dental Implants: A Five-Year Clinical Study

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ABSTRACT

Chlorhexidine digluconate (CHX) has demonstrated notable potential in minimizing inflammation and marginal bone loss (MBL) at 1-year evaluations; however, evidence regarding its sustained effectiveness on peri-implant stability remains scarce. This study aimed to assess the extended effects (5-year follow-up) of a placebo gel (Group A: 16 patients) versus a 0.20% CHX gel (Group B: 15 patients), both applied during all previous surgical and prosthetic procedures. Follow-up assessments were carried out in 2022, including biological, clinical, and radiographic evaluations. Statistical analyses were performed. Across five years, implant success reached 96.7%, while 41.9% of participants failed to attend their yearly oral hygiene appointments. Mean MBL measured 1.04 ± 0.39 mm, showing no statistically significant difference between the two groups. Importantly, patients who consistently attended maintenance visits exhibited significantly lower MBL values compared to those who did not ($p < 0.05$). After 5 years, CHX's direct impact was no longer evident, with both cohorts exhibiting moderate bone loss. Nonetheless, findings indicate that initial decontamination procedures may improve both short- and long-term results. Patients who initially experienced less MBL due to CHX use maintained this advantage even after 5 years. Furthermore, the study highlights the crucial role of annual check-ups in preventing and managing biological issues at an early stage.

Keywords: Chlorhexidine gel, Marginal bone loss, Peri-implantitis, Implant success rate, Implant decontamination, Dental implant complications

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Introduction

Dental implants are considered a highly reliable and predictable solution for replacing missing teeth, with their success closely tied to the process of osseointegration, allowing fusion between the implant and the newly regenerated bone. Global reports show that implant survival rates reach approximately 90–98% at 5 years and about 89–95% at 10 years [1–4].

Despite their success, implant treatments are susceptible to various complications. Early-stage failures often involve poor osseointegration, infection, or inadequate primary stability, whereas later-stage problems include marginal bone loss (MBL), peri-implantitis, and mechanical failures [5–9].

MBL has received considerable attention due to its key role in maintaining implant function and aesthetics [10, 11]. Historically, some degree of bone loss was commonly noted within the first year of loading, with a slower rate thereafter. Albrektsson *et al*. (1986) [11] identified MBL as a major success indicator, defining up to 1 mm loss in the first year and an additional 0.2 mm annually as acceptable [11]. Numerous factors have been associated with MBL, including implant design, neck configuration, surface texture, surgical trauma, platform switching, peri-implant tissue thickness, surgical protocol, residual bone, and the microgap at the implant–abutment junction. Investigation into these factors has reduced—but not eliminated—MBL over time [8, 12–14].

The microgap has been highlighted as a critical site for bacterial colonization and thus a primary factor in MBL development [15–18]. This microscopic gap, usually 10–135 μm wide, has been the focus of extensive research aimed at minimizing its size and enhancing the implant–abutment interface [15, 17–21]. Although modern connection systems have reduced microgap dimensions, none have entirely prevented bacterial leakage during long-term function [16, 17]. Such microgaps may lead to micromovement and bacterial infiltration, triggering peri-implant inflammation and progressive bone loss [15–17]. Continuous inflammatory cell infiltration at this interface has been demonstrated in animal models, representing the host's defensive reaction to bacterial exposure [18].

To minimize bacterial contamination during both surgical and postsurgical phases, strict clinical protocols now include antiseptics like CHX. Recognized for its plaque-inhibiting and broad-spectrum antimicrobial action, CHX remains an essential adjunct in oral and implant procedures, though its benefits have often been confined to short-term use [19, 22]. A prior investigation assessed the use of CHX gel throughout surgical and prosthetic stages of single-implant therapy and reported positive findings [23]. Specifically, in this randomized controlled clinical study, the test group received CHX at all stages, whereas the control used a placebo. CHX application resulted in reduced peri-implant bone resorption within 12 months, suggesting that thorough disinfection of the microgap area can effectively preserve peri-implant bone [23]. Later, D'Ercole *et al*. (2020) examined the same patients through microbiological and immunohistochemical analyses, confirming lower bacterial loads and inflammatory markers in CHX-treated individuals [24].

Given these encouraging short-term findings regarding CHX's ability to reduce bacterial accumulation and MBL [23], this current study aimed to evaluate the same cohort after more than 5 years to assess long-term peri-implant bone stability. The null hypothesis proposed no difference in MBL between CHX and placebo groups after 5 years. The primary objective was to assess MBL at the 5-year follow-up.

The secondary objectives included:

- Correlating MBL results from the previous study [23] to assess long-term progression.
- Evaluating biological complications across the 5-year period.
- Additionally, mechanical complications were also recorded to provide a comprehensive overview of the implant performance during the 5-year observation period.

Materials and Methods

Study design and sample

This investigation represents the continuation of a prospective, double-blind, randomized, and controlled clinical trial carried out following the ethical standards of the Helsinki Declaration. Participants were allocated in a 1:1 ratio. Ethical clearance was granted by the Interinstitutional Ethics Committee of the University of Chieti-Pescara, Italy, on 23 July 2015 (approval no. 14). Written informed consent was obtained from all subjects prior to participation. The trial was recorded on ClinicalTrials.gov under registration ID NCT03431766. This second phase focused on the 5-year re-evaluation of the same group of patients, whose records were systematically monitored and assessed over time.

The study followed CONSORT recommendations to ensure proper reporting and methodological consistency.

Eligibility criteria—outlined in detail in the initial publication [23]—are briefly summarized here alongside relevant surgical and prosthetic details.

Eligible participants were 18–75 years old, systemically and orally healthy, and required a single-implant restoration with adequate bone and soft tissue. Those with poor oral hygiene, periodontal disease, bone deficiency, or prior grafting were excluded. Further exclusions included uncontrolled diabetes, immunological conditions, smoking, bruxism, and immediate loading cases.

A total of 34 healthy, non-smoking patients (20 men, 14 women; aged 29–75 years, mean 52.28) were recruited between December 2015 and March 2017 at the Dental Clinic, Department of Medical, Oral, and Biotechnological Sciences, "G. d'Annunzio" University of Chieti-Pescara. Participants were randomly assigned to either Group A (placebo gel; Placebo, Polifarma Wellness Srl, Rome, Italy) or Group B (0.20% chlorhexidine gel; Plak-Gel, Polifarma Wellness Srl, Rome, Italy). Randomization was generated digitally and implemented through sealed opaque envelopes handled sequentially by an independent coordinator. While participants were informed about the study steps, the type of gel used was not disclosed to them.

Sample size and randomization

Marginal bone loss (MBL) served as the basis for determining the number of participants required. Referencing Annibali *et al*. (2012) [25], 15 individuals per group were sufficient to detect a −0.55 mm difference in MBL between groups, assuming a standard deviation of 0.5 mm. The significance level

(α) was 0.05, and test power was 0.80. PASS 3 software was employed, using a two-sample t-test with equal variances. To account for potential dropouts that might compromise the analysis, the sample size was increased by 20%, bringing the total to 18 subjects per group.

Surgical and prosthetic procedures

Before surgical intervention, all candidates underwent both clinical and radiographic assessments. During each procedural step, the test group (Group B) received a 0.20% CHX gel (Plak-Gel; Polifarma Wellness Srl, Rome, Italy), while the control group (Group A) received an indistinguishable placebo gel (Placebo; Polifarma Wellness Srl, Rome, Italy). The gels were identical in packaging, color, and scent, and their identities were only revealed post-analysis. Prior to surgery, all patients rinsed for 2 minutes with a 0.2% CHX digluconate mouthwash to minimize oral bacterial presence. Antibiotic prophylaxis was administered at 2 g/day for 6 consecutive days (Augmentin; GlaxoSmithKline Beecham, Brentford, UK).

Implants (Cortex Classic, Cortex, Shalomi, Israel) were inserted by two experienced clinicians at baseline (T0). After 8 weeks, healing abutments were placed (T1), followed by temporary acrylic crowns at 16 weeks (T2). The definitive single-crown prosthesis—porcelain fused to metal—was cemented 18–20 weeks after implantation (T3). Radiographic evaluation was performed at 12 months (T4). Long-term monitoring extended to 5 years (T5), with patients encouraged to attend routine maintenance and hygiene sessions.

In 2022, all subjects were recalled for the final 5-year assessment, which included periapical radiographs to quantify MBL, along with the collection of full-mouth plaque score (FMPS), full-mouth bleeding score (FMBS), and documentation of any technical failures or complications, as further detailed in Section 2.4.

Patient evaluation

Implant performance was judged using the clinical and radiological benchmarks described by Papaspyridakos *et al*. (2012) [26]. Each subject's data were entered into personalized Clinical Record Forms (CRFs). At every phase, peri-implant indices such as FMPS and FMBS were documented. Consistent with the methodology in [23], both radiographic and clinical data were systematically recorded throughout the study period.

Radiographic evaluation of peri-implant bone alterations was performed with standardized intraoral analog images processed via specialized software, ensuring measurement precision within 0.1 mm. The mean of mesial and distal readings was used in analysis.

Custom Rinn film holders were applied to ensure imaging reproducibility for each participant. Radiographs were repeated at every time point, including the 5-year follow-up (T5). On each radiograph, the vertical distances from the implant apex to the mesial and distal crestal bone at the initial bone–implant contact were measured. Implant length and diameter were also considered to correct minor angulations in imaging. A digital calibration was executed, and linear bone loss was computed with ImageJ 1.48 (Bethesda, MD, USA).

During control visits, one trained examiner collected the following data:

- Periapical radiographs;
- FMPS and FMBS values;
- Frequency of recall attendance.
- Mechanical incidents were also recorded to provide a complete overview of the functional and biological integrity of each implant system.

Statistical analysis

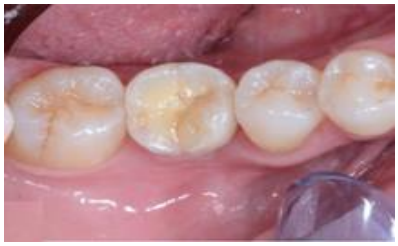
All statistical computations were performed using Microsoft Excel (Redmond, WA, USA) together with GraphPad Prism version 8 (San Diego, CA, USA). The analytical procedures were specified in advance according to the study design. Every participant who fulfilled the inclusion requirements was incorporated into the statistical assessment. Results are expressed as mean values with standard deviations (SD). Variations between experimental groups at the five assessed time intervals were examined through analysis of variance using Student's t-test. A significance threshold of $p = 0.05$ was applied.

Results and Discussion

A total of 40 individuals were initially assessed for eligibility. Based on inclusion and exclusion criteria, 34 subjects qualified for participation in single-implant–supported restoration. Six candidates were excluded due to failure to meet the criteria, and two were later withdrawn post-randomization because of poor oral hygiene observed on the surgery day. Consequently, 32 patients were enrolled at baseline. At the 5-year reassessment, 31 remained in the study, while one participant was lost to follow-up after moving away.

Among the final cohort, 16 belonged to Group A (placebo gel) and 15 to Group B (chlorhexidine gel). **Figure 1** displays intraoral photographs at two observation periods, T4 (12-month evaluation) and T5 (5-year evaluation). These cases correspond to those

reported in the previous publication that analyzed outcomes up to 12 months [23].



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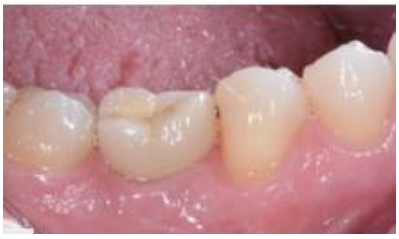

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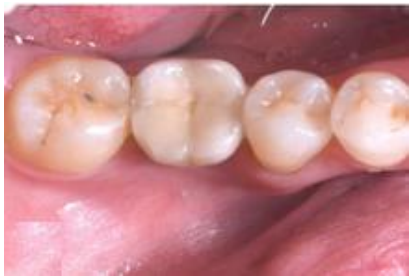

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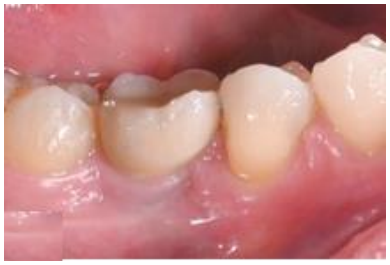


d)

Figure 1. Clinical images captured at T4 and T5: (a, b) occlusal and facial views after 12 months; (c, d) occlusal and facial views of the same subjects after 5 years.

Throughout the 5-year observation, a single implant loss occurred in Group A, yielding an overall success rate of 96.7%. During the 12-month assessment, all implants were intact (100%). The failed implant case presented with mobility and pain at the T5 visit. Initially, loosening of the prosthetic screw was suspected; however, the implant detached upon removal of the prosthesis. Apart from this case, all remaining restorations remained clinically healthy, and no participant experienced pain, sensory disturbance, or other biological complications. Comprehensive patient data are summarized in **Table 1**.

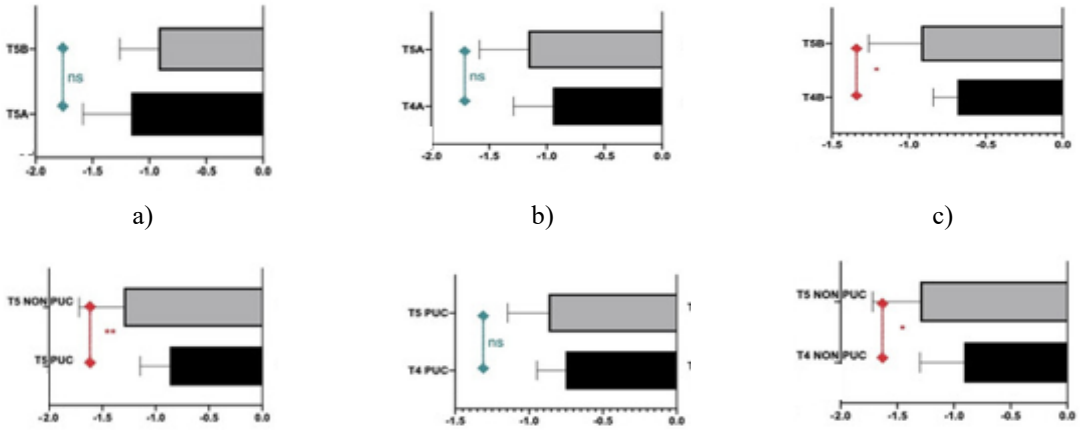
Table 1. Patient profile at T5 including survival percentages, gingival scores, and statistical comparisons for FMPS and FMBS. PUC = subjects maintaining periodontal care; NO-PUC = subjects without such maintenance. Significance levels: **** ($p \leq 0.0001$), *** ($p \leq 0.001$), ns = not significant.

Description	**Value**
Total number of patients	32
Patients assessed at 5-year follow-up	31
Patients in Group A	16
Patients in Group B	15
Implant failures	1 (Group A) implant removed
Survival rate	96.7%
Patients under strict hygienic control (PUC)	58.1%
Global Full-Mouth Plaque Score (FMPS)	21.38% ± 5.65
Global Full-Mouth Bleeding Score (FMBS)	20.96% ± 4.76
Parameters	**Group A**
FMPS (Group A vs. Group B)	22.59% ± 5.93
FMBS (Group A vs. Group B)	21.37% ± 5.46
FMPS (PUC vs. NO-PUC)	17.81% ± 3.37
FMBS (PUC vs. NO-PUC)	18.17% ± 2.88

Eighteen patients attended routine maintenance and professional hygiene visits throughout the study, while thirteen failed to do so, representing 41.9% who did not remain under dental supervision. At T5, all individuals underwent periodontal evaluation followed by professional cleaning. The average periodontal index for the entire sample was below 25%. When subdivided by category, variations appeared. No significant distinction was noted between Groups A and B; however, a meaningful difference ($p < 0.05$) was

observed between those under periodontal maintenance and those without, as indicated in **Table 1**.

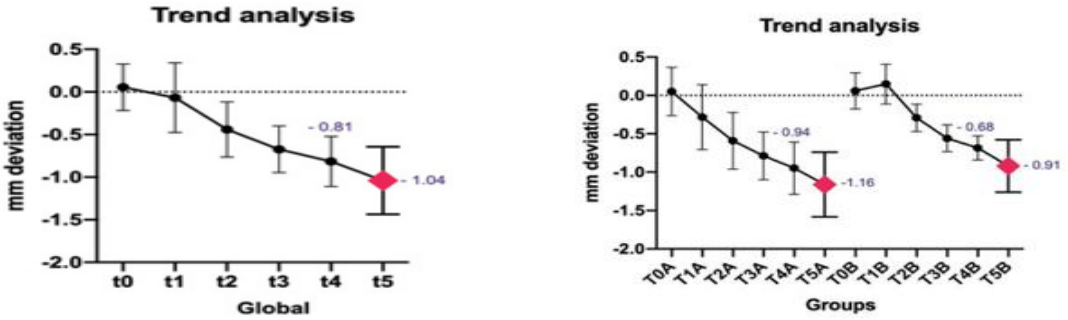
Radiographic assessments permitted longitudinal tracking of marginal bone level (MBL) variations across the 5-year period. The total average bone reduction was 1.04 ± 0.39 mm. To better interpret bone remodeling patterns, additional comparisons were made. MBL data categorized by treatment group are provided in **Table 2**, **Figures 2 and 3**, showing no significant intergroup differences. **Figure 4** depicts MBL changes from T0 to T5. A statistically significant difference was identified between patients receiving annual periodontal control and those neglecting maintenance procedures.



a) b) c)

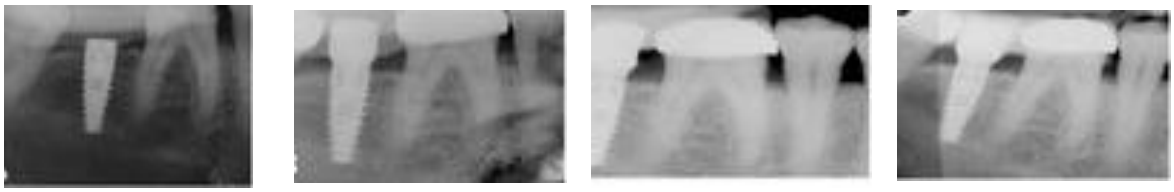
d) e) f)

Figure 2. Marginal bone level (MBL) assessment:
(a) T5 comparison between Groups A and B—no significant difference observed;
(b) MBL from T4 to T5 within Group A—no significant change detected;
(c) MBL from T4 to T5 within Group B—minor difference, $p \leq 0.05$;
(d) Comparison between PUC and NO-PUC at T5—statistical significance present, $p \leq 0.001$;
(e) PUC patients, T4 vs. T5—no notable variation;
(f) NO-PUC patients, T4 vs. T5—significant difference, $p \leq 0.05$.



a) b)

Figure 3. MBL progression across clinical stages up to T5:
(a) cumulative MBL changes;
(b) comparison between Groups A and B.



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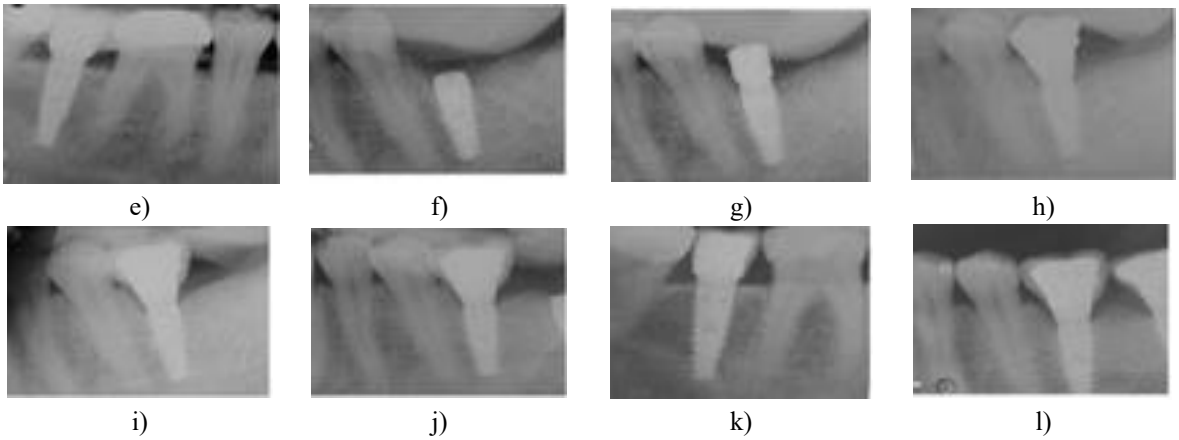


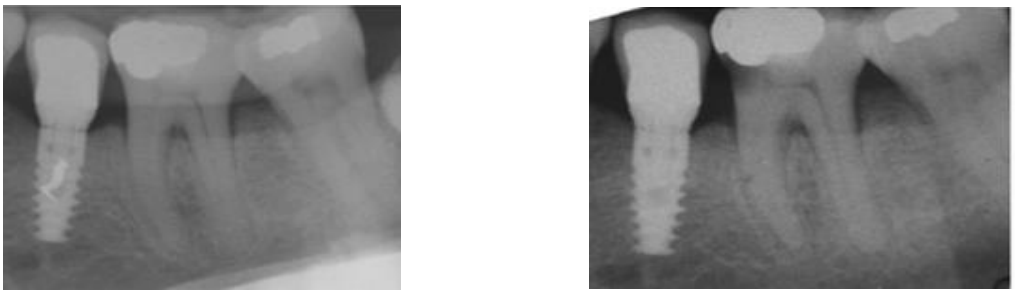
Figure 4. Radiographic sequence of both study groups. (a–e) represent images from a Group B (test group) subject taken between T0 and T4, where a minor bone gain was observed during the second surgical phase. (f–j) show radiographs of a Group A (control group) patient, and (k) presents a 5-year (T5) follow-up radiograph of the same case, displaying no signs of bone resorption. (l) depicts another radiograph from a Group A patient at T5, where a slight bone reduction was observed at the 5-year evaluation.

Table 2. This table lists all participating patients divided into Group A (control) and Group B (CHX gel). PUC = patients receiving periodic periodontal care; NO-PUC = patients who did not undergo maintenance. Marginal bone level (MBL) data from T0 to T5 and FMPS/FMBS values at T5 are presented. Patient ID34 experienced implant removal.

Patient ID	Implant Site	Treatment Group	Regular Hygiene (PUC/NO-PUC)	T0	T1	T2	T3	T4	T5	Full-Mouth Plaque Score (FMPS)	Full-Mouth Bleeding Score (FMBS)
2	16	A	NO-PUC	0.22	−0.06	−0.49	−0.73	−1.51	−1.6	22.4	24.5
5	14	A	PUC	0	−0.38	−0.55	−0.82	−1.07	−1.1	21.3	19.45
7	46	A	PUC	0.49	0.12	−0.2	−0.84	−0.95	−1.2	24.5	17.54
11	16	A	NO-PUC	−0.62	−1.53	−1.75	−1.76	−1.84	−2.2	25.6	18.34
14	47	A	PUC	−0.39	−0.92	−0.89	−0.65	−0.8	−0.87	19.3	18.5
17	36	A	NO-PUC	−0.06	−0.38	−0.43	−0.68	−0.73	−0.88	29.4	28.76
20	36	A	PUC	0.06	0	−0.44	−0.6	−0.63	−0.7	16.6	19.5
21	46	A	PUC	0.16	−0.29	−0.53	−0.73	−0.94	−0.9	14.3	14.5
23	46	A	NO-PUC	−0.13	−0.2	−0.74	−1.01	−1.05	−1.68	31.4	29.04
24	35	A	NO-PUC	−0.06	−0.2	−0.44	−0.59	−0.64	−1.5	30.7	31.84
25	22	A	PUC	0.6	−0.06	−0.46	−0.71	−0.77	−0.82	24.3	19.12
29	36	A	PUC	−0.11	−0.15	−0.78	−0.94	−1.06	−1.25	17.5	18.76
30	37	A	PUC	0.05	−0.09	−0.25	−0.38	−0.58	−0.87	15.4	14.45
32	24	A	NO-PUC	0.35	−0.05	−0.52	−0.79	−0.9	−1.1	29.87	27.12
33	36	A	PUC	0.21	−0.05	−0.4	−0.58	−0.74	−0.74	16.3	19.09
34	46	A	NO-PUC	−0.08	−0.21	−0.58	−0.61	−0.8	REMOVED	26.5	23.45
1	36	B	NO-PUC	0.57	0.62	0	−0.47	−0.55	−1	25.8	26.09
4	36	B	PUC	−0.17	0.03	−0.5	−0.71	−0.81	−1.32	14.6	21.45
8	46	B	NO-PUC	0.2	0.21	−0.48	−0.74	−0.79	−1.2	29.45	24.59

10	36	B	PUC	−0.04	0	−0.38	−0.53	−0.61	−0.6	20.5	19.4
12	24	B	PUC	0	0.1	−0.35	−0.lower	−0.71	−1.1	20.4	22.22
13	36	B	NO-PUC	−0.02	0.15	−0.37	−0.67	−0.89	−1.25	19.3	18.41
15	36	B	NO-PUC	0.16	0.39	−0.08	−0.61	−0.74	−1.45	17.9	19.45
16	46	B	PUC	0.12	0.59	−0.23	−0.49	−0.61	−0.72	15.9	18.54
18	15	B	PUC	0	−0.36	−0.57	−0.69	−0.77	−0.8	14.1	13.4
19	46	B	PUC	0.34	0.24	0	−0.16	−0.31	−0.56	14.5	12.23
22	24	B	PUC	0.29	0.28	−0.29	−0.88	−0.95	−0.23	14.5	16.98
26	45	B	PUC	−0.35	−0.08	−0.15	−0.41	−0.66	−1.12	16.4	19.5
27	37	B	NO-PUC	0	−0.05	−0.21	−0.54	−0.59	−0.62	27.8	24.98
28	25	B	PUC	0.06	0.18	−0.3	−0.37	−0.57	−0.72	20.12	22.45
31	26	B	NO-PUC	−0.26	−0.08	−0.46	−0.56	−0.7	−1.1	26.23	26.23
Mean									−0.8151613 mm	21.38 %	20.96 %
St. Dev									0.28814199	5.6525 5588	4.7676 7566

Over the observation period, several mechanical complications were also recorded, including prosthetic screw loosening, minor ceramic fractures or chipping, and crown decementation. Specifically, seven crowns (22.5%) presented screw loosening, despite proper tightening in accordance with manufacturer guidelines. In five of these cases (16.1%), the issue reoccurred multiple times. Additional minor events included crown decementation in three patients (9.6%), no ceramic coating fractures, and two instances of veneer chipping (6.4%). One patient who missed annual hygiene appointments developed dental caries on the mesial surface adjacent to the implant restoration, as shown in **Figure 5**. No major mechanical failures, such as abutment or implant fractures, were detected.



a) b)

Figure 5. Periapical radiographs at (a) T4 (12-month review) and (b) T5 (5-year review). This patient did not attend routine control visits, and a carious lesion appeared beneath the old restoration on the mesial aspect of the neighboring tooth.

The objective of this investigation was to assess whether chlorhexidine (CHX) could enhance the long-term stability of single-implant-supported prostheses. Findings indicated no statistically meaningful difference between the test and control groups concerning the main outcome. Thus, the null hypothesis was accepted, showing that CHX did not significantly affect marginal bone loss (MBL) over a 5-year follow-up. Nonetheless, analysis of secondary outcomes revealed notable differences that warrant discussion.

At the 1-year assessment, all implants remained functional, corresponding to a 100% survival rate. Among patients completing the 5-year evaluation, one implant failed, producing an overall success rate of 96.7%, which aligns with results reported for comparable implant systems [27–29]. For instance, Doornewaard *et al*. documented a 5-year survival rate of 97.3%, independent of implant surface characteristics [29].

Long-term evaluation, however, highlighted subtle variations between the two groups. Overall MBL

showed minor bone resorption in both, with a mean loss of 1.04 ± 0.39 mm. Such values can be influenced by multiple factors, including implant geometry, patient variability, surgical protocol, and neck design [8]. Some degree of bone remodeling within the first functional year is generally anticipated [8, 11, 23]. Additional investigations have examined MBL progression in different patient cohorts [30–32]. For example, Zumstein *et al*. (2019) analyzed bone-level trends in implants with distinct morphologies, with or without guided bone regeneration (GBR) [30]. They reported similar outcomes, noting no significant group difference and an average MBL of 0.7 ± 0.7 mm after one year and 0.8 ± 0.6 mm after five years, comparable to our findings. In their analysis, variables such as age, gender, implant site, soft-tissue biotype, implant diameter and length, treatment indication, loading method, and initial stability (ISQ) all influenced bone remodeling [31].

The data from the present study suggest that CHX application exerted no measurable impact on 5-year MBL. Interestingly, at the 12-month mark, a statistically significant distinction had been observed [23]. At T4, MBL values were 0.68 ± 0.15 mm for the CHX-treated group and 0.94 ± 0.34 mm for controls. At T5, these values were 0.91 ± 0.33 mm and 1.16 ± 0.42 mm, respectively. Although differences were no longer statistically significant at 5 years, the CHX group maintained a measurable advantage in bone preservation. Trend analyses confirmed that the benefit persisted throughout the observation period. Similar to Zumstein *et al*. (2019), who found that early group advantages in MBL were maintained over time depending on specific factors such as patient age, implant site, and gingival type [31], patients treated with CHX in this study continued to show improved outcomes at the 5-year review. These findings suggest that early decontamination of the implant–abutment interface with CHX may contribute to reduced bacterial impact and slower long-term bone remodeling.

The role of CHX has also been widely examined in peri-implantitis management [19, 22]. However, its efficacy tends to diminish due to its transient presence. Laboratory data have demonstrated CHX's ability to eliminate bacteria within biofilms on titanium surfaces [21, 33, 34], though its biofilm-removal capacity remains limited [35]. Its antibacterial effect is time-dependent, diminishing with shorter exposure durations. Therefore, early use of CHX appears to be beneficial in minimizing microbial contamination, which likely explains the reduced MBL observed during the first 12 months [23]. Complementary microbiological and immunohistochemical analyses from D'ercole *et al*. (2020), conducted on the same patient sample, reported decreased inflammatory markers and bacterial loads in the CHX-treated cohort [24]. While these benefits were no longer evident at the 5-year follow-up, the MBL advantage persisted, indicating a lasting influence from early-stage intervention.

MBL was also examined by categorizing participants into two groups: those maintaining rigorous periodontal care (minimum one check-up annually) and those without regular maintenance. Significant statistical differences were noted between these groups, with the latter demonstrating markedly higher MBL values. Among the key risk factors for implant failure, the adherence to oral hygiene and routine maintenance visits continues to pose difficulties. Conversely, improper application of hygiene devices can modify the titanium surface texture, fostering bacterial adhesion. Therefore, both appropriate maintenance practices and correct use of cleaning techniques and tools are essential for optimal implant follow-up [36]. Numerous studies have shown that patients with periodontitis tend to experience lower implant survival rates and increased post-restoration complications [37, 38]. The prevalence of peri-implantitis is also higher among these individuals than in those with healthy periodontal tissues [39, 40]. The importance of recall appointments for ensuring oral health has been thoroughly supported in the literature, including among patients with special healthcare needs, where controlled periodontal status correlates with a more positive prognosis [41]. Nonetheless, some publications have indicated that when periodontitis is strictly managed, implant survival can still remain high [42–45].

Patients demonstrating poor periodontal hygiene maintenance exhibited not only greater MBL but also higher gingival index values and additional complications than those under close supervision. The mean periodontal indices (plaque and bleeding indices) remained below 25%, yet a significant difference ($p < 0.05$) emerged between the maintenance and non-maintenance groups. Existing literature presents variable outcomes on this matter; certain studies report implant loss exceeding 15% among untreated periodontitis cases, while others describe comparable survival rates in patients with well-managed disease [31]. These findings suggest that despite CHX decontamination at connection sites, inadequate hygiene ultimately leads to a deterioration in gingival indices and MBL, negating early CHX benefits.

Moreover, peri-implant soft tissue height may affect the selection of transmucosal pathway height, bone remodeling processes, and hygiene efficacy [46]. In the treated cohort, the implant system facilitated the customized selection of abutment heights guided by clinical evaluation. Based on soft tissue thickness, each abutment was positioned approximately 1 mm below the tissue surface. As a result, despite height variations, all prosthetic crowns displayed ideal emergence profiles, supporting effective hygiene. It must also be highlighted that, beyond biological parameters (gingival indices, MBL, and survival), hygiene control contributes to minimizing mechanical failures and other complications. Among the poorly maintained group, one patient developed secondary caries beneath an old restoration on a tooth next to the implant. Mechanical complications were observed in 22.5% of patients, with screw loosening being the most frequent despite proper torqueing procedures. This issue remains among the most common implant-related failures [47–49].

Jemt *et al*. reported 27.3% screw loosening among 107 single-implant restorations in over 90 patients [48]. Similarly, Kreissl *et al*. followed partially edentulous patients for 5 years, noting 6.7% loosening events [49]. Cho *et al*. evaluated 213 patients over 3–7 years, finding loosening in 10.3% of single and 12.1% of multiple restorations [50]. Overall, loosening was identified in 7.2% of implants—occurring once in 77.7%, twice in 14.4%, and more than twice in 7.9% of cases—most frequently within 6 months after loading (50.4%). Data variation correlates with implant width and retention type (screw- vs. cement-retained) [47]. Within our study, 22.5% exhibited loosening, and 16.1% faced multiple occurrences, confirming that abutment instability remains the main mechanical complication in cement-retained designs. Ceramic chipping occurred in 6.4%, while crown decementation was observed in 9.6%, both lower than previously reported rates.

A notable limitation of this research lies in the MBL assessment via intraoral radiographs, as bone density and morphology variations can influence readings. However, this was mitigated by following a standardized imaging protocol, ensuring consistent data collection and measurement accuracy. Hence, intraoral radiography remains the preferred diagnostic method for MBL analysis. The findings confirm high survival rates of single-implant-supported prostheses, with minimal bone loss (1–5 years), particularly under strict periodontal control. Comparable results were previously seen in two-piece implants with horizontal offsets, showing stable bone levels near the implant shoulder [47]. The bone loss patterns observed here align with typical expectations—mainly within the first post-loading year, especially among those without CHX treatment.

Conclusion

After five years, the effectiveness of CHX had clearly diminished, with moderate bone loss evident in both groups. The initial study demonstrated that CHX use throughout surgical and prosthetic stages led to lower MBL at 12 months, and the same group retained less MBL at 5 years. This suggests that early-stage management may yield long-term benefits. Future investigations could explore extended CHX delivery methods, such as hydrogel-based systems designed for sustained CHX release around implants [51]. De Cremer *et al*. (2017) [52] provided in vitro validation of continuous CHX release from Ti/SiO_2 matrices, effectively preventing biofilm formation on implant surfaces. Broader exploration of such systems may deepen understanding of controlled CHX release potential.

Ultimately, patients lacking adequate periodontal control exhibited greater MBL and higher periodontal index scores. Thus, consistent periodontal hygiene remains fundamental to implant management, enabling early detection and prevention of both biological and mechanical complications affecting implants or neighboring teeth.

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