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Original Article

Marginal bone level of dental implants using computer-aided design/computer-aided manufacturing customized abutment and prefabricated abutment—A five-year follow-up

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Five-year follow-up

Abstract *Background/purpose:* Computer-aided design/computer-aided manufacturing (CAD/CAM) allows for the customization of implant abutments as an alternative to prefabricated options. The purpose of this study was to compare the marginal bone levels of dental implants using CAD/CAM customized abutments (CA) versus prefabricated abutments (PA) over a five-year follow-up period.
Materials and methods: Implants were divided into two groups based on abutment type: CA and PA. Marginal bone level (MBL), changes in MBL and bone-to-implant contact ratio (BIC), were assessed from baseline to 5 years post-prosthetics loading. Additionally, the study analyzed based on dental arches, opposing structure types, and the distance from implant platform to the cementoenamel junction of adjacent teeth (CEJ-PL).
Results: Overall, MBL increased significantly for all implants from baseline to 5 years. The CA group in the mandible showed significantly higher MBL compared to the PA group

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(0.98 ± 0.71 mm vs. 0.54 ± 0.55 mm). Implants opposed by fixed restorations (FRs) experienced significantly more MBL compared to those opposed by natural teeth (NT) after 5 years. Implants placed at a depth greater than 3 mm (CEJ-PL > 3 mm) exhibited significantly greater changes in MBL on the distal side after 5 years compared to those placed at a shallower depth (CEJ-PL ≤ 3 mm).

Conclusion: The MBL and changes in MBL showed similar trend between the CA and PA groups in the five-year follow-up. The CA group exhibited significantly more bone remodeling after one year, particularly for implants opposing FRs and those with a CEJ-PL distance exceeding 3 mm.

Introduction

Dental implants are widely recognized as an increasingly popular approach for replacing missing teeth, providing superior stability and functionality compared to traditional dental prostheses. The maintenance of marginal bone levels surrounding dental implants is extremely important for their long-term success. A landmark study published in 1981 analyzed 2768 fixtures placed in 410 edentulous jaws over a 15-year period. The findings indicated an average bone loss of 1.2 mm throughout the healing phase and the first year after abutment connection.[1] Subsequently, marginal bone loss was limited to an average of 0.1 mm annually. In 1986, one of the success criteria for dental implants was defined as "less than 0.2 mm of annual bone loss following the first year of implant loading".[2] Significantly, more pronounced bone resorption or marginal bone loss typically occurs within the first year after implantation. This early marginal bone loss is generally considered as the part of the typical bone remodeling process rather than the consequences of peri-implantitis. Surgical trauma, occlusal overload, the presence of a microgap, and the reformation of biologic width are the potential contributing factors of early marginal bone loss.[3,4] The stability of dental implants can be influenced by various factors, including the opposing tooth structure and the vertical positioning of the implant. Implants opposed by fixed restorations have been found to be more susceptible to bone loss.[5] Additionally, significant peri-implant bone loss has been observed when implants are placed more than 3 mm apical to the cementoenamel junction (CEJ) of adjacent teeth.[6] The longevity and success of dental implants depend on a thorough understanding of these factors, which are critical for the effective prevention and management of marginal bone loss.

Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology provides personalized sizes and shapes of titanium abutments. CAD/CAM allows for the customization of abutments as an alternative to prefabricated stock options. Customized abutments (CA) are tailored to individual patients, improving the emergence profile and enhancing the aesthetic appearance of gingival tissue. However, the use of abutments and implant systems from different manufacturers may result in mechanical complications. Previous studies have indicated that CA may exhibit a higher degree of misfit compared to prefabricated abutments (PA), with some findings showing increased misfit and microleakage.[7,8] Despite these limitations, customized titanium abutments fabricated using CAD/CAM technology have demonstrated high survival rates and stable clinical performance in clinical applications.[9,10]

This study aimed to compare the marginal bone levels around dental implants utilizing CAD/CAM customized abutments versus prefabricated abutments over a five-year follow-up period. Additionally, it sought to evaluate factors influencing the long-term implant stability. The findings are expected to provide valuable insights to guide the selection of appropriate abutment types in implant treatment planning.

Materials and methods

Data collection

The study utilized radiographs obtained from Shuang Ho Hospital, Taipei Medical University, New Taipei, Taiwan, with approval from the Taipei Medical University Joint Institutional Review Board (approval number: N202103105). The radiographic data was retrospectively collected from 2010 to 2023. The study included 64 dental implants placed in 36 patients who underwent dental implant surgery at the Dental Department of Shuang Ho Hospital.

Inclusion and exclusion criteria

The data was selected based on the inclusion and exclusion criteria. The inclusion criteria were as follows: adults over 18 years of age who received dental implant treatment with cement-type prosthetics, no systemic conditions (e.g., diabetes), good oral hygiene, non-smokers or those smoking fewer than 10 cigarettes per day, sufficient bone tissue, keratinized tissue level greater than 2 mm at the time of implant surgery, and no inflammation surrounding the operation site. The exclusion criteria were as follows: radiotherapy to the head area within 12 months prior to the study, long-term oral or intravenous use of amino-bisphosphonates, pregnancy or breastfeeding, smoking more than 10 cigarettes per day, and chewing betel nuts or tobacco.

Surgical procedure and prosthetics delivery of implants

The dental implant placement procedure was performed by the experienced dentist, including implant fixture placement, soft tissue shaping, impression taking, prosthetic adjustment, and final delivery. All dental fixtures were used XiVE implants (Dentsply Sirona Implants, Charlotte, NC, USA). After osseointegration was completed, the implant second surgical stage was performed to attach the healing abutment. The impression was taken for prosthetics fabrication two weeks after soft tissue shaping. The abutments were placed with a torque wrench at 24 N/cm, as per the manufacturer's instructions, and the prosthetics were delivered two weeks post-impression. All prosthetics were cement-type porcelain-fused-to-metal restorations. The implants were divided into two groups based on the different abutments: the CA group and the PA group. The CA abutments were made of titanium, produced by ARCH Dental Laboratory (ARCH dental Co., Ltd, Taipei, Taiwan). For the PAs, the XiVE® implant system EstheticBase was used, with grade 2 commercially pure titanium as the material (Dentsply Sirona Implants).

Acquisition of radiographs

The standard long-cone paralleling technique, along with an X-ray cone indicator, was used for each periapical radiograph. Radiographic parameters were evaluated at different timelines: baseline (before loading), immediately after prosthetic loading, and 1, 3, and 5 years after loading (Fig. 1). Measurements were taken with EZ-Dental Professional Image Software (Asahi Co., Ltd., Kyoto, Japan). The implant size, diameter, and length were used as a scale to correct the radiographic image ratio. The EZ Dental software calibration tool was used to correct any deviation in the periapical films.

Evaluation of radiographs

The marginal bone level (MBL) was defined as the distance from the fixture platform (PL) to the first radiographic bone-

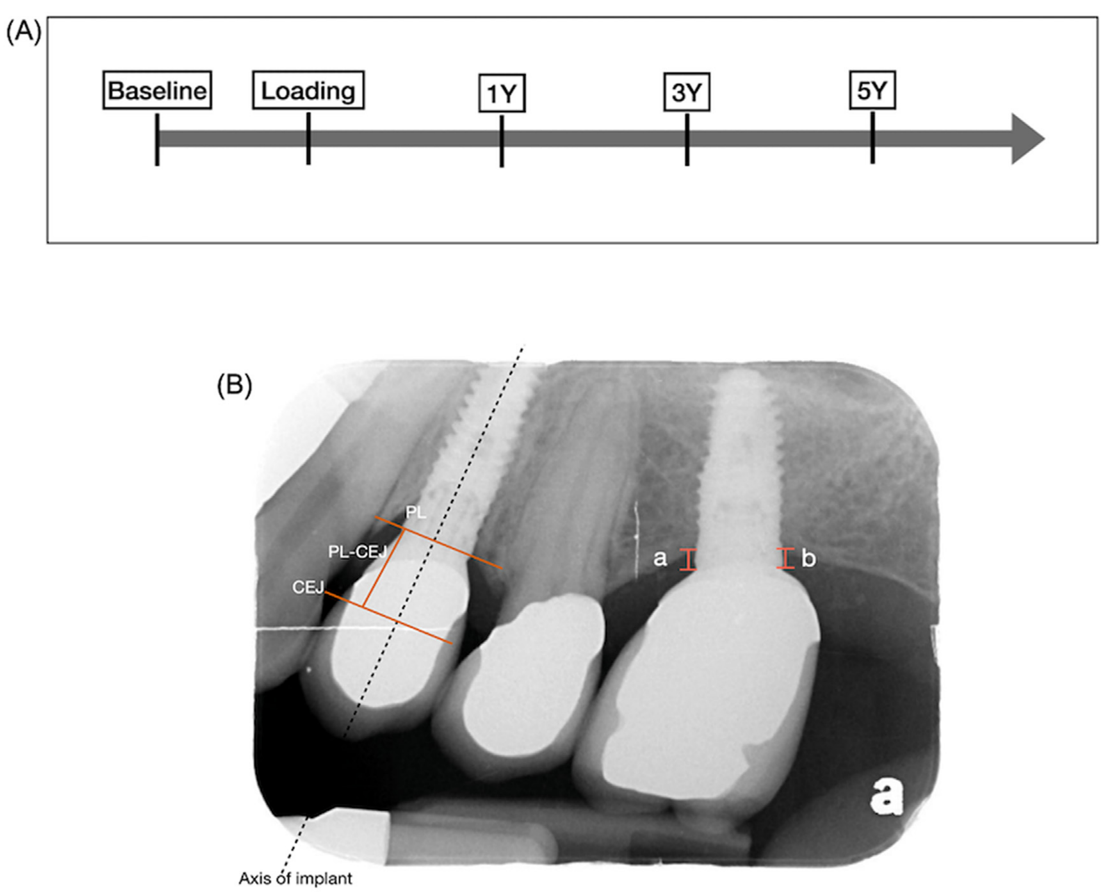

Figure 1 (A) Timepoint of acquiring radiographs. 1Y: 1-year after loading, 3Y: 3-year after loading, 5Y: 5-year after loading. (B) Measurement parameters of radiographs. CEJ: cemento-enamel junction, PL: platform of implant, CEJ-PL: distance between the implant platform and the CEJ of adjacent teeth, a: marginal bone level on mesial side of implant, b: marginal bone level on distal side of implant.

to-implant contact at both mesial and distal sites (Fig. 1 (B)). The MBL of the two sides was averaged to determine the mesiodistal bone level. Changes in MBL were assessed by comparing baseline measurements with those recorded at various follow-up intervals. Additionally, the Bone-to-Implant Contact (BIC) percentage of submerged dental implants was evaluated. BIC is defined as the ratio of the implant surface in direct contact with bone to the total length of the implant. For implants placed adjacent to natural teeth, the cementoenamel junction (CEJ) of the adjacent teeth was identified. The distance between the implant platform and the CEJ of adjacent teeth (CEJ-PL) was also measured parallel to the long axis of dental implant. Furthermore, all dental implants were opposed by either natural teeth (NT) or fixed restorations (FRs). The FRs group included implant-supported teeth (IT) and fixed partial dentures (FPD). The opposing structures were documented, and an analysis was performed to evaluate the association between the opposing structure and MBL.

Statistical analysis

The data of measurement were categorized into two main groups based on the type of abutment: CA group and PA group. Subgroup analyses were conducted based on implant locations (maxilla/mandible), opposing structures (NT/FRs), and vertical position of implant (CEJ-PL $>$ 3 mm/CEJ-PL $\leq$ 3 mm). The statistical differences of each parameter between the groups were assessed by using Student's t-test and Mann–Whitney U test. Statistical analyses were performed by using IBM SPSS v.27 (IBM Co., Armonk, NY, USA) and the level of significant was considered at the value of $P < 0.05$.

Results

Descriptive data of subjects and dental implants

The demographic data of subjects and implants are presented in Table 1. A total of 64 dental implants in 36 patients who were followed-up for over 5 years. The average age of the patients was 56 $\pm$ 9.99 years old (male: 21 and female: 15). The CA group was a total of 36 implants (20 in the maxilla and 16 in the mandible), and the PA group was a total of 28 implants (9 in the maxilla and 19 in the mandible). All dental implants were placed in the posterior edentulous area. Implant sizes ranged from 3.4 mm to 5.5 mm in diameter and 9.5 mm–13 mm in length. Dental implants were survived completely after a five-year follow-up without complications.

Marginal bone level and marginal bone level changes of all implants

Table 2 shows the MBL and changes in MBL for all implants. The mean of MBLs increased significantly from 0.36 $\pm$ 0.47 mm at baseline to 0.89 $\pm$ 0.72 mm at 5 years ($P < 0.001$). Statistically significant differences were also noted in the changes in MBL from 0.25 $\pm$ 0.34 mm at loading to 0.53 $\pm$ 0.6 mm at 5 years ($P < 0.001$).

Comparison between customized abutments group and prefabricated abutments group

In the comparison between the CA group and the PA group, the value of both average MBL and changes in MBL were

Table 1 Demographic data of subjects and implants.

Basic profile of subjects		
Age (year)	56 $\pm$ 9.99	
Patient	n = 36	
Gender	Male (n = 21); female (n = 15)	
Implant parameter	CA (n = 36)	PA (n = 28)
Location (all in posterior region)		
Maxilla	20	9
Mandible	16	19
Diameter (mm)		
3.4	4	1
3.8	7	15
4.5	24	11
5.5	1	1
Length (mm)		
9.5	15	8
11	21	18
13	0	2
Opposing structure		
Natural teeth (NT)	20	13
Fixed restorations (FRs)	FPD: 7	FPD: 5
	IT: 9	IT: 10

CA: customized abutment, PA: prefabricated abutment, FPD: fixed partial dentures, IT: implant-supported teeth.

Table 2 Marginal bone level (MBL), changes in MBL of all implants at different timepoints.

	Timepoint	Mean (mm)	*P* value			
			Baseline (before loading)	Immediately after loading	1-year after loading	3-year after loading
MBL	Baseline (before loading)	0.36 ± 0.47				
	Immediately after loading	0.6 ± 0.55	<0.001			
	1-year after loading	0.76 ± 0.66	<0.001	0.004		
	3-year after loading	0.81 ± 0.62	<0.001	0.001	0.31	
	5-year after loading	0.89 ± 0.72	<0.001	<0.001	0.048	0.07
Changes in MBL	Immediately after loading	0.25 ± 0.34				
	1-year after loading	0.41 ± 0.45		0.004		
	3-year after loading	0.45 ± 0.45		0.001	0.3	
	5-year after loading	0.53 ± 0.6		<0.001	0.048	0.07

MBL: marginal bone level.

increased (Table 3). The CA group had an average MBL of 0.4 ± 0.52 mm at baseline, which increased to 0.91 ± 0.79 mm after 5 years. Meanwhile, the PA group had an average MBL of 0.3 ± 0.4 mm at baseline, which increased to 0.87 ± 0.64 mm after 5 years. In the CA group, the changes in MBL increased from 0.21 ± 0.31 mm at loading to 0.51 ± 0.66 mm after 5 years. In the PA group, the changes in MBL increased from 0.29 ± 0.38 mm at loading to 0.57 ± 0.51 mm after 5 years. However, these differences were not statistically significant in both average MBL and changes in MBL ($P > 0.05$). The analysis of the average BIC percentages for both groups also showed no statistically significant difference.

Further analysis focusing on implants placed in the maxilla revealed no significant differences between the CA and PA groups (Fig. 2(A–C)). Both groups demonstrated similar average MBL and changes in MBL at the 3-year and 5-year follow-ups. Moreover, no significant variations in average BIC percentages were observed between the two groups (Table 4).

In contrast, the analysis of implants in the mandible revealed differences between the CA and PA groups. The CA group showed a more pronounced increase in MBL, rising from 0.47 ± 0.6 mm at baseline to 1.1 ± 0.85 mm after 5 years (Fig. 2 (B)). The PA group, however, exhibited a more modest increase, from 0.26 ± 0.38 mm at baseline to 0.78 ± 0.64 mm at 5 years. A statistically significant difference in average MBL was observed at the 1-year mark ($P < 0.05$), with the CA group showing higher values. Regarding the changes in MBL, the CA group experienced an increase from 0.24 ± 0.3 mm at loading to 0.64 ± 0.79 mm after 5 years, while the PA group showed a less pronounced change, from 0.34 ± 0.41 mm at loading to 0.52 ± 0.53 mm after 5 years (Fig. 2 (D)). However, the difference in MBL changes at the 1-year mark did not reach statistical significance ($P > 0.05$).

Comparison of opposing teeth: natural teeth and fixed restorations

The average MBL was assessed for both the NT group and the FRs group, which shown in Fig. 3. In the NT group, the mean MBL increased from 0.34 ± 0.51 mm at baseline to

Table 3 Marginal bone level (MBL), changes in MBL and average bone to implant contact ratio comparison between customized abutment group and prefabricated abutment group.

		Baseline	Loading	1Y	3Y	5Y
MBL		Mean ± SD (mm)				
	CA (n = 36)	0.4 ± 0.52	0.61 ± 0.62	0.84 ± 0.71	0.83 ± 0.67	0.91 ± 0.79
	PA (n = 28)	0.3 ± 0.4	0.6 ± 0.45	0.66 ± 0.59	0.78 ± 0.55	0.87 ± 0.64
	P Value	0.43	0.94	0.28	0.72	0.83
Changes in MBL		Mean ± SD (mm)				
	CA (n = 36)		0.21 ± 0.31	0.45 ± 0.47	0.43 ± 0.45	0.51 ± 0.66
	PA (n = 28)		0.29 ± 0.38	0.36 ± 0.43	0.47 ± 0.45	0.57 ± 0.51
	P Value		0.32	0.45	0.74	0.71
Average BIC		Mean ± SD (%)				
	CA (n = 36)	96.05 ± 5.23	94 ± 6.25	91.71 ± 7.03	91.79 ± 6.74	91 ± 8.05
	PA (n = 28)	97.14 ± 3.92	94.35 ± 4.31	93.72 ± 5.71	92.6 ± 5.45	91.73 ± 6.33
	P Value	0.37	0.8	0.22	0.61	0.7

MBL: marginal bone level, BIC: bone-to-implant contact ratio, CA: customized abutment, PA: prefabricated abutment, 1Y: 1-year after loading, 3Y: 3-year after loading, 5Y: 5-year after loading.

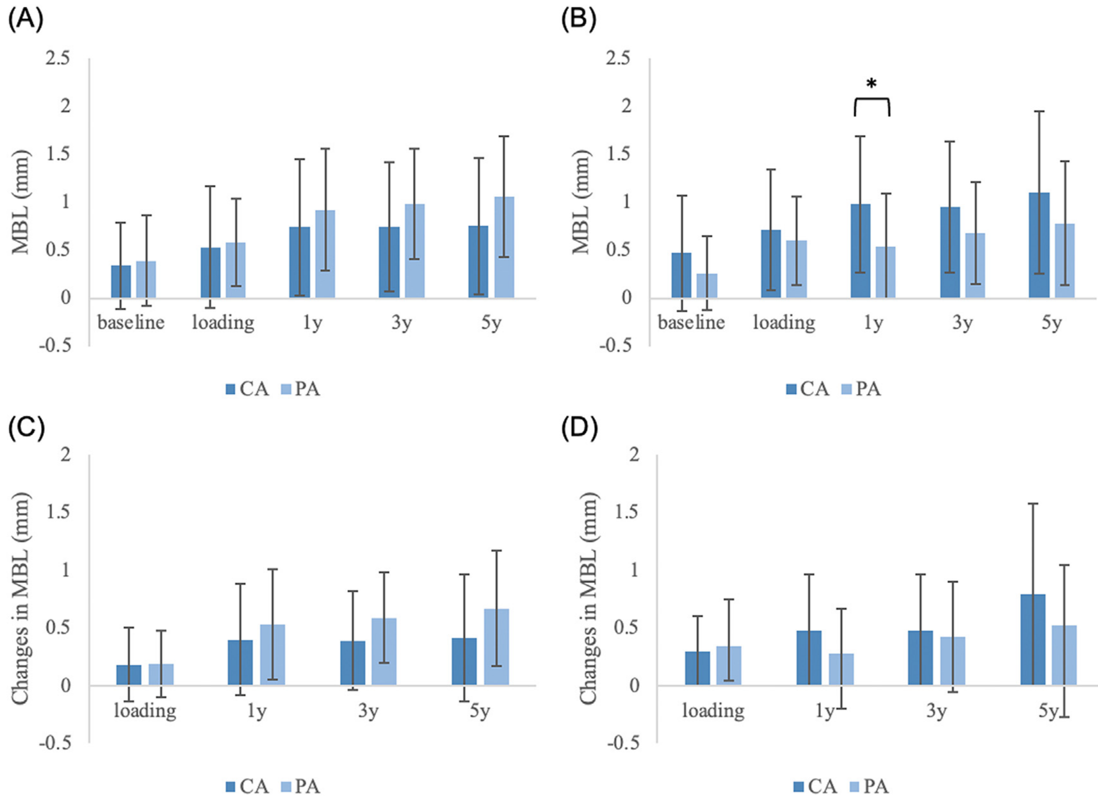

Figure 2 MBL of CA and PA group (A) in maxilla and (B) in mandible. Changes in MBL of CA and PA group (C) in maxilla and (D) in mandible. MBL: marginal bone level, CA: customized abutment, PA: prefabricated abutment, 1y: 1-year after loading, 3y: 3-year after loading, 5y: 5-year after loading. (*$P < 0.05$).

Table 4 Average bone to implant contact ratio comparison between customized abutment group and prefabricated abutment group.

		Baseline	Loading	1Y	3Y	5Y
Maxilla		Mean ± SD (%)				
	CA (n = 20)	96.75 ± 4.2	94.98 ± 6.03	92.97 ± 6.74	92.98 ± 6.37	92.8 ± 6.92
	PA (n = 9)	96.22 ± 4.87	94.42 ± 4.75	91.23 ± 6.56	90.76 ± 6.19	90.03 ± 0.32
	P Value	0.84	0.47	0.56	0.47	0.32
Mandible		Mean ± SD (%)				
	CA (n = 16)	95.18 ± 6.33	92.78 ± 6.5	90.13 ± 7.28	90.31 ± 7.1	88.76 ± 8.1
	PA (n = 19)	97.57 ± 3.44	94.31 ± 4.22	94.9 ± 5.01	93.47 ± 5.00	92.53 ± 6.11
	P Value	0.44	0.48	0.03	0.17	0.22

CA: customized abutment, PA: prefabricated abutment, 1Y: 1-year after loading, 3Y: 3-year after loading, 5Y: 5-year after loading.

0.72 ± 0.69 mm after 5 years. Similarly, the FRs group showed an increase in mean MBL from 0.37 ± 0.44 mm at baseline to 1.07 ± 0.71 mm after 5 years. A statistically significant difference in MBL between the NT and FRs groups was identified at the 5-year follow-up ($P = 0.048$).

A similar pattern was observed in the changes in MBL over time, with both the NT group and the FRs group showing gradual increases. At the five-year follow-up, the NT group exhibited an MBL change of 0.38 ± 0.53 mm, whereas the FRs group demonstrated a more pronounced change of 0.7 ± 0.64 mm. Statistical analysis revealed a significant difference between the two groups at the five-year mark ($P = 0.03$).

Comparison customized abutments group and prefabricated abutments group in opposing natural teeth and fixed restorations

Analysis of the CA and PA groups with opposing NT revealed progressive increases in MBL over time for both groups, with the CA group exhibiting a slightly higher increase, though not statistically significant (Fig. 3 (C)). At loading, the mean

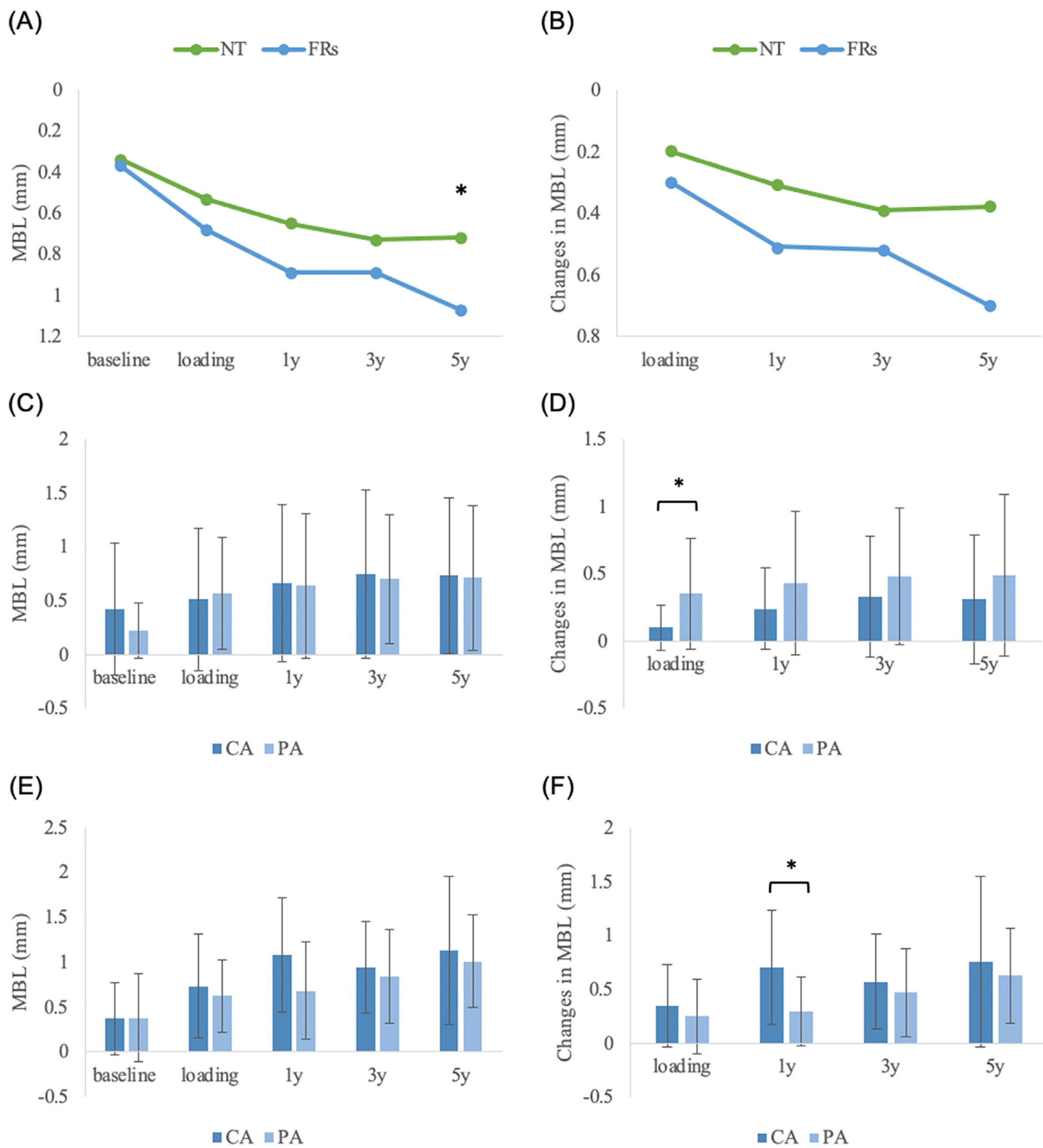

Figure 3 Comparison of implants with NT or FRs as opposing structures. (A) MBL, and (B) Changes in MBL of NT group and the FRs group. (C) MBL, and (D) Changes in MBL of CA group and the PA group in opposing NT. (E) MBL, and (F) Changes in MBL of CA group and the PA group in opposing FRs. MBL: marginal bone level, NT: natural teeth, FRs: fixed restorations, CA: customized abutment, PA: prefabricated abutment, 1y: 1-year after loading, 3y: 3-year after loading, 5y: 5-year after loading. (*$P < 0.05$).

changes in MBL for the CA group was 0.1 ± 0.17 mm, compared to 0.35 ± 0.41 mm for the PA group. This difference was statistically significant at loading ($P = 0.03$) but not at subsequent follow-ups at 1, 3, or 5 years.

In the groups with opposing FRs, the CA group's average MBL increased from 0.37 ± 0.4 mm at baseline to 1.13 ± 0.82 mm after 5 years, while the PA group's average MBL rose from 0.38 ± 0.49 mm at baseline to 1.01 ± 0.52 mm after 5 years. Although the difference in average MBL between the groups was not statistically significant at the 1-year follow-up (Fig. 3 (E)), an analysis of MBL changes indicated that the CA group exhibited significantly higher mean changes at 1 year compared to the PA group ($P = 0.045$).

Marginal bone level and marginal bone level changes based on vertical position of implants

To investigate the influence of vertical implant position on MBL, implants adjacent to natural teeth with identifiable CEJ were analyzed. A total of 42 implants were included in the analysis, categorized into two groups: implants with CEJ-PL distances ≤3 mm (n = 6) and those with CEJ-PL distances >3 mm (n = 36). Both groups demonstrated progressive bone resorption over time. In the ≤3 mm group, the mesial MBL increased from 0.37 ± 0.6 mm at baseline to 0.65 ± 0.79 mm after 5 years, whereas the >3 mm group showed an increase from 0.18 ± 0.39 mm at baseline to 0.61 ± 0.74 mm at 5 years. Regarding mesial changes in

MBL, the ≤3 mm group exhibited an increase from 0.03 ± 0.08 mm at loading to 0.28 ± 0.44 mm at 5 years, while the >3 mm group showed an increase from 0.25 ± 0.39 mm at loading to 0.44 ± 0.7 mm at 5 years (Table 5). However, statistical analysis was not conducted due to the highly unequal sample sizes between the two groups.

For distal MBL, 21 implants adjacent to natural teeth with identifiable CEJ were analyzed. The two groups, implants with CEJ-PL distances ≤3 mm (n = 9) and >3 mm (n = 12), were compared due to their relatively balanced sample sizes. The ≤3 mm group demonstrated a higher initial average MBL, but a lower final average MBL compared to the >3 mm group. However, no statistically significant differences were identified between the two groups. Regarding changes in MBL, both groups exhibited a progressive increase over time, with the >3 mm group showing a more pronounced change (Fig. 4). At the 5-year follow-up, a statistically significant difference was observed between the groups (P = 0.03), indicating that implants placed deeper (CEJ-PL > 3 mm) are more prone to bone loss over time, particularly in the long term.

Discussion

Early bone loss or remodeling within the first year of loading is generally recognized as the most crucial stage. According to our findings, when comparing CA and PA in terms of average MBL and changes in MBL, both abutment types increased with time. However, the difference did not become statistically significant within a year.

A recent retrospective study by Lin HT et al. examined the impact of PA and CA on MBL around dental implants over a one-year period. The study found that both types of abutments were effective in maintaining stable bone levels. However, the CA group exhibited a significantly greater changes in MBL of 0.46 ± 0.12 mm (P = 0.001) after one year of functional loading.[11] This result differs from the findings of the present study. In our analysis, the CA group showed a one-year changes in MBL of 0.45 ± 0.47 mm. When compared to the changes in MBL of the PA group, the P value did not reach statistical significance. However, for implants opposed by fixed restorations (FRs), the difference in the changes in MBL between the CA and PA groups was statistically significant at the one-year follow-up ($P < 0.05$).

The microgap and micromovement at the implant-abutment interface may contribute to the increased bone remodeling observed with CA abutments after one year of functional loading.[12,13] Microgaps, an inherent characteristic of the two-piece implant design, can facilitate bacterial colonization, potentially triggering an inflammatory response that leads to bone loss. Additionally, micromovements during mastication can cause cyclical opening and closing of the microgap, creating a pump-like effect. This mechanism can introduce bacterial endotoxins and

Table 5 Comparison of CEJ-PL >3 mm versus CEJ-PL ≤3 mm at the mesial side. CEJ-PL: the distance between the implant platform and the CEJ of adjacent teeth.

		Baseline	Loading	1Y	3Y	5Y
MBL		Mean ± SD (mm)				
	≤3 mm (n = 6)	0.37 ± 0.6	0.4 ± 0.67	0.48 ± 0.8	0.72 ± 0.86	0.65 ± 0.79
	>3 mm (n = 36)	0.18 ± 0.39	0.43 ± 0.5	0.57 ± 0.6	0.62 ± 0.54	0.61 ± 0.74
Changes in MBL		Mean ± SD (mm)				
	≤3 mm (n = 6)		0.03 ± 0.08	0.12 ± 0.2	0.35 ± 0.4	0.28 ± 0.44
	>3 mm (n = 36)		0.25 ± 0.39	0.39 ± 0.56	0.44 ± 0.5	0.44 ± 0.7

MBL: marginal bone level, 1Y: 1-year after loading, 3Y: 3-year after loading, 5Y: 5-year after loading.

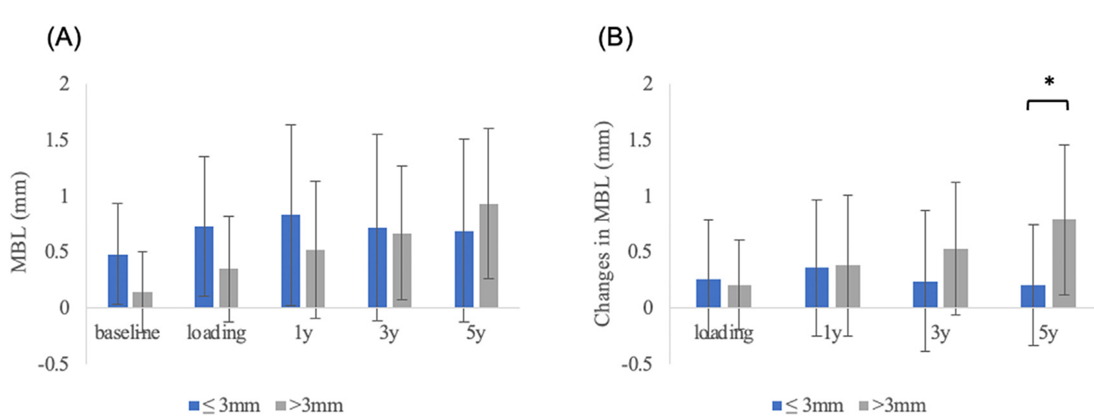

Figure 4 Comparison of CEJ-PL groups: >3 mm vs. ≤3 mm (A) distal MBL and (B) changes in MBL. MBL: marginal bone level, CEJ-PL: distance between the implant platform and the CEJ of adjacent teeth, 1y: 1-year after loading, 3y: 3-year after loading, 5y: 5-year after loading. (*$P < 0.05$).

acidic byproducts from fluids within the implant fixture cavities into the peri-implant tissues, further exacerbating bone loss.[14] Zipprich H et al. conducted an in vitro study to evaluate the micromechanical behavior of implant-abutment connections under dynamic loading. The study revealed that dynamic loading of 100 N or greater caused cyclical opening and closing of gaps at the implant-abutment interface, potentially allowing toxic fluids to contaminate peri-implant tissues.[15] Conical connections demonstrated superior performance, exhibiting minimal or no gap formation during dynamic loading of up to 200 N, compared to flat connections.[16] Specifically, the microgaps in the Xive S Plus implant were measured at 0 μm under a 25 N load and increased to 11.6 μm under 200 N dynamic loading. The findings further indicated that the size of microgaps increased proportionally with occlusal force, emphasizing the importance of the effect of implant-abutment design.

When comparing the microgaps of CA and PA, Kowalski J et al. reported that, while the microgap sizes were statistically similar between the two types, CA abutments exhibited larger and more variable microgaps than PAs.[17] Although CAD/CAM manufacturing offers numerous advantages, such as customization and precision, it may not entirely eliminate the risk of micromovement, particularly under occlusal forces. In the oral cavity, the larger and more variable microgap size of CA abutments may become more pronounced when subjected to occlusal loads. This effect could be especially relevant in cases where FRs serve as opposing teeth, as they typically exert greater occlusal forces compared to natural teeth. This hypothesis may explain why the CA group with FRs as opposing teeth demonstrated statistically significantly greater bone remodeling in the current study.

In this study, both CA and PA exhibited a consistent increase in MBL and changes in MBL over the 5-year observation period, with no statistically significant differences identified between the two groups. These findings suggest that both abutment types are equally effective in maintaining long-term bone stability around dental implants. This result shows clinical significance for dental practitioners, as it indicates that the choice between CA and PA abutments does not have a substantial impact on long-term bone preservation. Furthermore, these findings align with previous clinical investigations demonstrating the consistent performance of CA abutments.[9,10]

The finding that the FRs group, as opposing teeth, exhibited significantly greater late-stage bone loss compared to the NT group raises important considerations. This influence of the opposing structure on crestal bone levels has been previously documented in the literatures.[5,18] In a prior 3-year retrospective study evaluating the impact of opposing structures on marginal bone loss, it was observed that dental implants opposed by FRs demonstrated a higher likelihood of bone loss. Specifically, the opposing FRs group exhibited significantly greater changes in MBL at 3 and 6 months; however, no statistically significant differences were noted at the 1-year and 3-year follow-ups.[5] In the current study, similar trends were observed. While the group with opposing FRs showed greater changes in MBL compared to the NT group at earlier intervals, these differences did not reach statistical significance at the 1-year and 3-year follow-ups. However, by the 5-year mark, a statistically significant difference was identified ($P < 0.05$). This suggests that implants opposed by fixed restorations may be at an increased risk of late-stage bone loss, potentially attributable to variations in occlusal forces or other biomechanical factors associated with the opposing structure.

The vertical positioning of the implant may also influence changes in marginal bone level. Our study demonstrated that implants with a CEJ-PL distance greater than 3 mm exhibited a greater change in MBL at the 5-year follow-up compared to those with a CEJ-PL distance of 3 mm or less. This difference was statistically significant ($P = 0.03$) for the distal MBL change. However, an analysis of the mesial side was not performed due to an insufficient sample size. These findings are consistent with previous studies, which suggest that posterior implants placed more than 3 mm vertically from the CEJ of the adjacent tooth are associated with increased mesial and distal peri-implant bone loss.[6] While the exact mechanism of the vertical position of the implant in the influence of MBL remains unclear, we suspect that it likely involves a combination of factors. These factors may include occlusal overloading, altered stress distribution, and biological responses that occur when implants are placed farther from the CEJ. Additionally, implants placed deeper are likely to have an increased crown-to-implant ratio. However, in a systematic review, Naert I et al. were unable to establish a clear association between occlusal overload and peri-implant MBL due to the limited availability of unbiased evidence in the literature.[19] Nevertheless, they noted that supra-occlusal contacts worsened plaque-induced bone loss in animal studies when peri-implant inflammation was present.[19] Furthermore, a systematic review and meta-analysis concluded that the crown-to-implant ratio does not significantly influence changes in peri-implant marginal bone levels or implant survival rates.[20] However, it is important to consider that deeper implant placement may compromise oral hygiene accessibility, which could potentially elevate the risk of peri-implant inflammation and subsequent bone loss. Additional research is required to establish the specific mechanisms involved depending on the complexity of these interactions.

Within the limitations of this study, the five-year follow-up comparing MBL changes in dental implants using CA versus PA yielded several important findings. Both the CA and PA groups showed an increase in MBL and changes in MBL over the study period; however, no statistically significant differences were observed between the two groups in the long term. The CA group exhibited significantly more bone remodeling than the PA group after one year, particularly for implants opposing FRs and those with a CEJ-PL distance exceeding 3 mm demonstrated an increased risk of late-stage bone loss, with a statistically significant difference noted at the 5-year follow-up. These findings suggest that both customized and prefabricated abutments can effectively preserve long-term bone levels around dental implants. However, clinicians should be aware of the potential for increased early bone remodeling with customized abutments. Further research with larger sample sizes is necessary to confirm these findings regarding implant success and longevity.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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