Impact of implant mesiodistal distance on peri-implant bone loss: A cross-sectional retrospective study

Wenwen Liu[1, 3#], Fangyu Zhu[1#], Lu Han[3], Pei Li[2], Hom-Lay Wang[3*]

1.Department of Geriatric Dentistry, Peking University School and Hospital of Stomatology, Beiijng, China
2.The Department of Nosocial Infection Management, Peking University Third Hospital, Beijing, 100191, China
3.Department of Periodontics and Oral Medicine, The University of Michigan School of Dentistry, Ann Arbor, Michigan, USA

Corresponding author:
Hom-Lay Wang, DDS, MSD, PhD
Professor and Director of Graduate Periodontics,
Department of Periodontics and Oral Medicine,
The University of Michigan School of Dentistry
1011 North University Avenue
Ann Arbor, Michigan 48109-1078, USA.
TEL: (734) 763-3325; FAX: (734) 936-0374 E-mail address: homlay@umich.edu

CONFLICT OF INTEREST
The authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS
Hom-Lay Wang and Wenwen Liu conceived the concept/design, Lu Han and Wenwen Liu participated in the data collection; Wenwen Liu and Fangyu Zhu involved in the Data analysis/interpretation; Wenwen Liu and Fangyu Zhu conducted the statistics; Fangyu Zhu drafted the article; Wenwen Liu and Hom-Lay Wang conducted critical revision of article; All authors approved of article.

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Summary Box
What is known:
Few studies demonstrated the effect of mesiodistal distance on peri-implant bone resorption. A mesio-distal algorithm for posterior implants was proposed previously by digitalization from the perspective of prosthodontics.
What this study adds:

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This study proved the algorithm to be beneficial to bone preservation, and offered measurable reference for clinicians to decide treatment plans.

Impact of implant mesiodistal distance on peri-implant bone loss: A cross-sectional retrospective study

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1.Department of Geriatric Dentistry, Peking University School and Hospital of Stomatology, Beiijng, China
2.The Department of Nosocial Infection Management, Peking University Third Hospital, Beijing, 100191, China
3.Department of Periodontics and Oral Medicine, The University of Michigan School of Dentistry, Ann Arbor, Michigan, USA

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Abstract

Purpose: The purpose of this study was to verify the effect of our previously proposed mesiodistal distance for multiple posterior implants on preserving peri-implant bone, and to provide a measurable criterion for predicting implant prognosis.

Methods: One hundred and two patients with dental implants placed in the posterior free-end edentulous arches were recruited in this cross-sectional study. Calibrated X-rays (peri-apical (PA) or bite-wing x-ray) were collected to measure the mesiodistal space as well as the corresponding bone resorption of implants after prosthesis placement. Implants were assigned to the test/control group according to whether their mesiodistal distance following our proposed algorithm. After adjusting covariates, logistic multivariate regression analyses were performed to examine the relationship between inter-implant distance and marginal bone loss (MBL) during each follow-up interval. The effect of smoking habits was also analyzed.

Results: Every observation period exhibited great significance between experimental and control group on peri-implant bone level (p = 0.006, 0.005, 0.001, 0.025, 0.001, correspondingly) and the difference had a tendency to grow as time went

by except 4-year (MD = -0.19, -0.39, -0.43, -0.30, -1.26, correspondingly). While no significant difference was observed between smokers and non-smokers in the same group ($p > 0.05$).

Conclusion: The mesiodistal algorithm of 4–4.6 mm (implant to adjacent canine tooth), 7– 7.4mm, 8–8.5mm, and 9–9.5 mm was proved to be effective for maintaining peri-implant bone level. It was also observed in our study that the impact of inter-implant distance outweighed that of smoking. This study provided clinicians predictable prognostic outcomes for implants and reference for deciding treatment plans.

Key words: peri-implant bone resorption, mesiodistal distance, implant prognosis, cross-section study

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Introduction

Dental implantation, as a restorative treatment modality for missing teeth through osseointegration, is widely utilized in clinical settings[1,2]. A critical determinant of its clinical success is the preservation of alveolar bone around the implant platform[3]. Bone remodeling around the implant is a natural process during the establishment of the supracrestal tissue height[4]. According to Albrektsson et al., average bone resorption in the smooth collar implant within the first year was less than 1.5 mm, followed by an annual resorption rate of 0.2 mm, which is considered within acceptable limits[5,6]. Furthermore, findings by Galindo-Moreno et al. revealed that implants lost at least 0.48 mm of marginal bone loss (MBL) after 6-month of loading, escalating to at least 2 mm MBL after 18 months[7]. Despite these findings, progressive MBL poses a significant challenge to many implantologists[8,9]. The reported prevalence of peri-implantitis varies markedly, ranging from 1% to 47%, reflecting the complexity involved in diagnosing and addressing peri-implant diseases[10].

Causes of bone resorption are multifactorial, roughly divided into four types: patient-, implant-, surgically- and prosthodontic-related factors[11-14]. Among these, the distance between teeth and implants, also known as the inter-dental/implant distance, is crucial. Previous studies have suggested that the minimum distance between implants should be 3 mm at the implant shoulder edges and at least 1-2 mm away from the outer edge of the buccal bone in order to maintain the marginal bone level, both vertically and laterally[15-17]. In addition, the center-to-center distance of implants in posterior edentulous cases has also been investigated. Our prior research introduced a mesiodistal algorithm for multiple posterior implant placement which recommended 4 - 4.6 mm (implant to adjacent canine tooth), 7– 7.4 mm, 8–8.5mm, and 9–9.5 mm for inter-implant/tooth distance from first premolar to second molar, with the application of a digital software[18]. This formula was put forward upon the above principles, and it also aims to provide an easily accessible guide for clinicians.

Adherence to such guidelines typically ensures the preservation of the peri-implant tissue health, and that promoting easier maintenance of oral hygiene for patients [18].

One significant limitation in the current body of literature is that the majority of studies exploring the relationship between inter-implant/teeth distance and bone loss focus predominantly on the aesthetic zone and seldom address the posterior regions, particularly in cases of free-end edentulism[15,19]. Additionally, the exact correlation between inter-implant distance and changes in crestal bone hasn't been conclusively established.[20,21] Furthermore, when it comes to placing molar implants, clinicians often focus on anatomic structures, such as mandibular canal or maxillary sinus, basing the drilling location on considerations of bone volume and shape. Unfortunately, this can lead to the oversight of other critical factors such as the establishment of proper occlusion and ensuring accessibility for hygiene maintenance, which are equally vital for long-term implant stability and success[22,23].

Therefore, the purpose of this study was to conduct a cross-section analysis that not only assessed the validity of our previously proposed mesiodistal algorithm for multiple posterior implant placement, but also offered a measurable criterion for predicting implant prognosis. This research endeavors to guide clinical practice and inform the formulation of surgical plans. (**Figure 1**)

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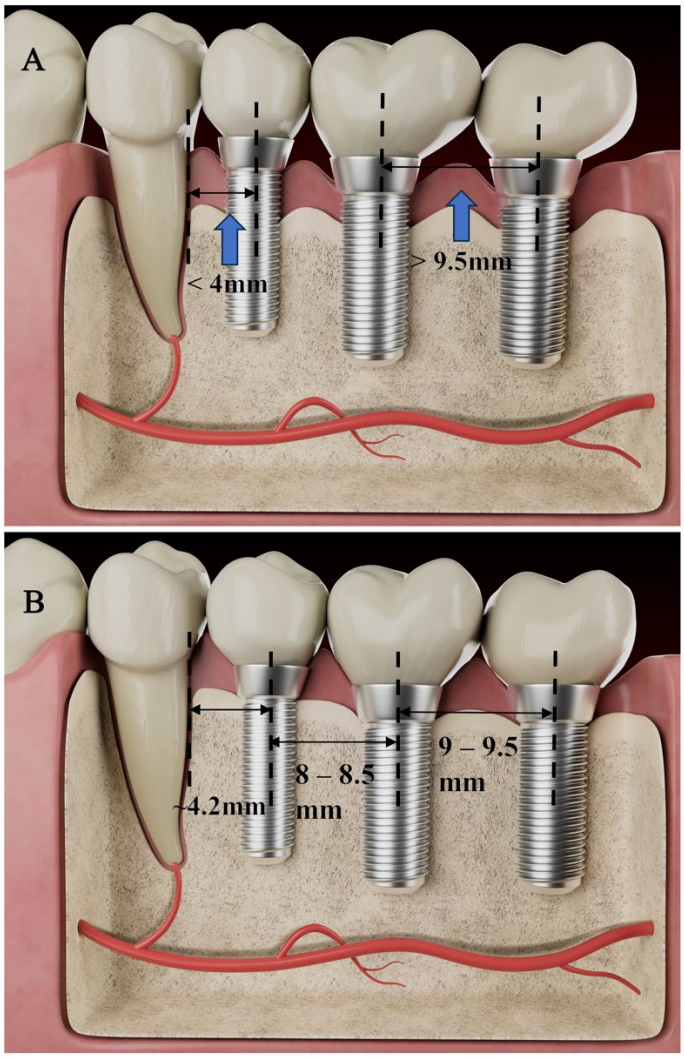


Figure 1 Schematic drawing of the impacts of implant mesiodistal distance on implants. (A, implants not following the mesiodistal algorithm showed peri-implant bone loss; B, implants following the mesiodistal algorithm exhibited satisfied treatment effect.)

Materials and Methods

Study design

This retrospective study was conducted at the University of Michigan School of Dentistry, Ann Arbor, MI, USA, and was approved by the Institutional Review Board for Human Subjects Research (HUM00223051). The investigation encompassed all patients receiving implant therapy between January 2012 and October 2020, to receive crowns for restoring a posterior free-end edentulous area. The records of

eligible patients, both physical and digital, were systematically screened and evaluated by three examiners (LW, ZF, LH) using predetermined eligibility criteria.

2.1 Inclusion Criteria

1. Partially edentulous patients who have been treated with one or more implants to restore a posterior (molars and premolars) maxillary or mandibular free-end edentulous area and have a documented follow-up of at least one-year after implant loading.

2. Patients who have received implants loaded with titanium prefabricated abutments and crowns.

3. The presence of opposing occlusion (teeth/implants) is necessary.

2.2 Exclusion Criteria

1. Patients with a follow-up period of less than one year.

2. Patients with a restored edentulous area in the anterior zone.

3. Patients with ambiguous or incomplete documentation.

4. Medically compromised patients (with any records of uncontrolled diabetes, radiation and chemotherapy treatment, or psychological problems), and severe bruxism cases (diagnosed and self-reported) are not eligible for the study.

2.3 Data collection

All patient records were initially screened and evaluated according to the aforementioned eligibility criteria. As part of the data collection process, all relevant patient information, including age, gender, and presence of a smoking habit was obtained. Additional data including the number of implants and their positions, and implant description (brand, length, diameter, neck design, abutment type, crown type, etc.) were also collected.

2.4. X-ray data acquisition

Calibrated X-rays (peri-apical (PA) or bite-wing x-ray) were obtained from the Department of Periodontics and Oral Medicine at the University of Michigan, School of Dentistry. All X-rays were collected to measure the mesiodistal space as well as the

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corresponding bone resorption of implants after prosthesis placement. All the files were exported as JPEG format for measurement.

2.5. Measurement

Measurements of digital radiographs were conducted using commercially available software (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA).

2.5.1 standardization: Each radiograph was calibrated using the known implant diameter and length. If the complete implant wasn't exhibited, then the length of the neck section was adopted (**Figure 2**). The corresponding length for each implant brand type was looked up at their official website.

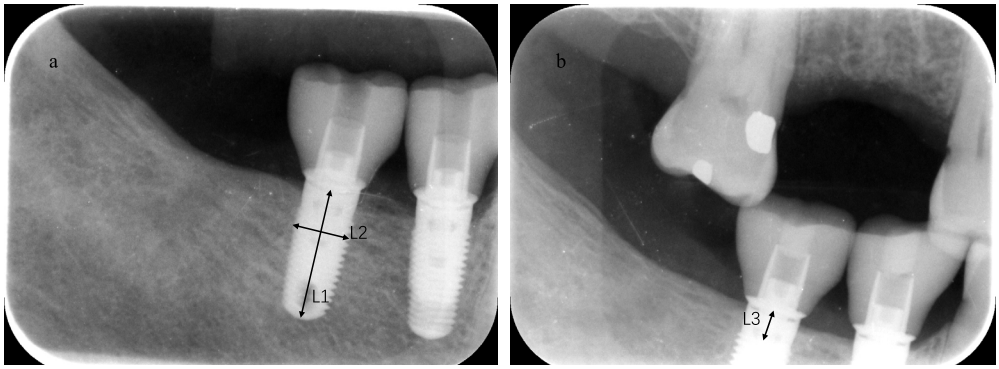


Figure 2 Illustration of radiograph calibration. L1: implant length; L2: implant diameter; L3: collar height.

2.5.2 grouping: During the examination, calibrated examiners measured the horizontal distances between the distal root surface of adjacent natural teeth (3mm apical to the CEJ) and the long axis of the implant body. Implants with distance in accord with the mesiodistal algorithm would be assigned to the experimental group and the others to the control group.

2.5.3 Measurements: Marginal bone levels of both mesial and distal sides were measured at baseline (time of prosthodontic loading) and each visit as illustrated in **Figure 3**. The measurements were conducted twice collaboratively by two authors (W.L. and Z.F) who weren't involved in the treatment process. With limited intra- and inter-examiner variability, the final result was decided by averaging their values.

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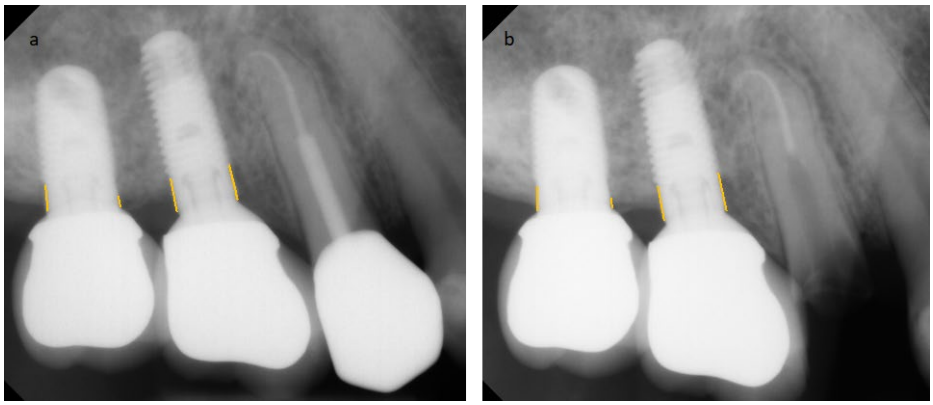


Figure 3 Radiographic illustration of the measurement of MBL from both mesially and distally at different follow-ups (yellow line). a: one year after crown installation; b: 3 years after crown installation.

The duration of the follow-up period was defined as the time elapsed between the baseline assessment and the last radiograph where the presence of bone around the implants was observable.

2.6 Statistical analysis

Initially, we examined whether the distribution of potential influencing factors such as gender, age, implant details across the groups could affect the study's results. Categorical variables were analyzed using chi-square tests, while continuous variables were assessed with t-tests. As indicated in **Table 1 and 2**, the distribution of age, gender as well as implant/crown characteristics showed no significant differences between groups ($p \geq 0.05$). However, the proportion of smokers differed significantly between the groups ($p < 0.05$). Detailed calculations were listed in **Figure S1-S2**.

Table 1 Comparisons of the distributions of covariates (categorical variables)

Variable	***N***	***%***	***p***
	Gender		
Experimental			0.582
Male	31	57.4%	
Female	23	42.6%	
Control			
Male	33	62.3%	
Female	20	37.7%	

Position			
Experimental			0.366
Maxilla	28	34.1%	
Mandible	54	65.9%	
Control			
Maxilla	22	26.5%	
Mandible	61	73.5%	
Smoking			
Experimental			0.042*
Yes	6	11.1%	
No	48	88.9%	
Control			
Yes	11	20.7%	
No	42	79.3%	
Implant connection			
Experimental			0.248
Internal	82	100%	
External	0	0%	
Control			
Internal	80	96.4%	
External	3	3.6%	
Neck design			
Experimental			1.000
Bone level	77	93.9%	
Soft tissue level	5	6.1%	
Control			
Bone level	78	94.0%	
Soft tissue level	5	6.0%	
Abutment type			
Experimental			NA
Platform-switched	77	100%	
Platform-matched	0	0%	
Control			
Platform-switched	78	100%	
Platform-matched	0	0%	
Abutment height			
Experimental			0.563
< 2mm	58	70.7%	
≥ 2mm	24	29.3%	
Control			
< 2mm	63	75.9%	
≥ 2mm	20	24.1%	

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Crown design			
Experimental			0.652
Splinted	25	30.5%	
Non-splinted	57	69.5%	
Control			
Splinted	29	34.9%	
Non-splinted	54	65.1%	
Opposing dentition			
Experimental			0.57
With	73	89.0%	
Without	9	11.0%	
Control			
With	77	92.8%	
Without	6	7.2%	

*: $p < 0.05$, meaning having significant differences.

Table 2 Comparisons of the distributions of covariates (continuous variables)

Variable	***Mean***	***SD***	***p***
Age			
Experimental	67.8	11.61	0.507
Control	69.0	11.05	
Diameter			
Experimental	4.54	0.53	0.928
Control	4.54	0.56	
Length			
Experimental	10.71	1.20	0.485
Control	10.84	1.28	
Baseline			
Experimental	1.72	0.89	0.610
Control	1.66	0.71	

$p > 0.05$, meaning not having significant differences.

After group comparison, logistic multivariate regression analysis was performed to examine the connection between inter-implant distance and MBL. To begin with, vertical bone loss was first averaged by the mesial and the distal, and the mean MBL of both groups for each year was also calculated, expressed as mean ± standard deviation (SD) in millimeters. Considering the sample size, if the follow-up duration

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was more than 5 years then the results of the longest observation time would be chosen. Afterwards, the multivariate logistic regression was conducted to identify factors associated with MBL. The *p* value, mean difference (MD) and 95% confidence interval (95% CI) of both group for each follow-up interval were calculated. Additionally, we conducted an inter-group comparison to examine the impact of smoking habits. The above analyses were conducted using R software. This study was in accordance with the STROBE guidelines[24].

Results

A total of 102 patients (62 males and 40 females, mean age 68.4 years) with 165 implants were enrolled in this study. 54 patients with 82 implants (28 in maxilla, 54 in mandible) following our mesiodistal algorithm were classified in the experimental group and 53 persons with 83 implants (22 in maxilla, 61 in mandible) were in the control group, with 5 persons counted twice as some of their implants met the criteria for our algorithm while some didn't. Among all the patients, 16 (15.7%) were current smokers. As for the implant information, though the diameter and length of implants varied, implants of 3.7 mm x 10 mm were the most adopted kind for premolars (25.9%) and implants of 4.7 mm x 10 mm topped in molars (26.1%). The majority of implants (93.9%) were inserted at bone level. All except 3 implants from one patient were designed with internal connections, entirely with switched platform. As for the superstructures, 67.3% of the crowns were non-splinted. In addition, over ninety-percent of implants (90.9%) were with opposing dentition. General information regarding patients and implants was depicted in **Table 3**.

Table 3 Descriptive characteristics regarding patients and implants

	Gender	**Age**	**Smoker**	**Implant**	
Experiment	Male: 31	67.8 ± 11.6 years	Yes: 6	Maxilla: 28	Premolar: 9
					Molar: 19
	Female: 23		No: 48	Mandible: 54	Premolar: 3

					Molar: 51
Control	Male: 33	69.0 ± 11.1 years	Yes: 11	Maxilla: 22	Premolar: 6
					Molar: 16
	Female: 20		No: 42	Mandible: 61	Premolar: 9
					Molar: 52

The cohort was followed for up to 9 years, with an average follow-up duration of 3.95 years. Bone measurements were performed at aforementioned time after installation. Mean MBL for each period was demonstrated in **Table 4** and illustrated in **Figure 4**. In the experiment group, the average MBL per year was relatively stable and in line with Albrektsson's theory, with an average annual resorption of 0.2 mm. In contrast, the MBL in the control group was nearly doubled that of the experimental group, displaying a tendency to increase with each successive year. Notably, the mean difference in MBL between the experimental and control groups increased after one year, and after five years, the difference was 3 to 4 times greater compared to the difference observed between 2 and 4 years. This suggests that inter-implant distance may influence the long-term success of dental implants.

Table 4 Peri-implant bone loss (mm) of different follow-up interval

Time	n	Experiment	Control	MD	95%CI	*p*
1-year	83	0.15 ± 0.11	0.40 ± 0.39	-0.19	(-0.33, -0.06)	0.006**
2-year	71	0.21 ± 0.19	0.60 ± 0.55	-0.39	(-0.66, -0.12)	0.005**
3-year	61	0.23 ± 0.18	0.58 ± 0.48	-0.43	(-0.68, -0.18)	0.001**
4-year	41	0.20 ± 0.15	0.58 ± 0.45	-0.30	(-0.52, -0.04)	0.009**
5-9 year	44	0.22 ± 0.18	1.25 ± 1.19	-1.26	(-1.94, -0.58)	0.001**

Mean and standard deviation (SD) of the marginal bone loss (mm) of experimental and control groups for each observation period, and the result of logistic regression; **: $p < 0.01$, meaning having great significant differences.

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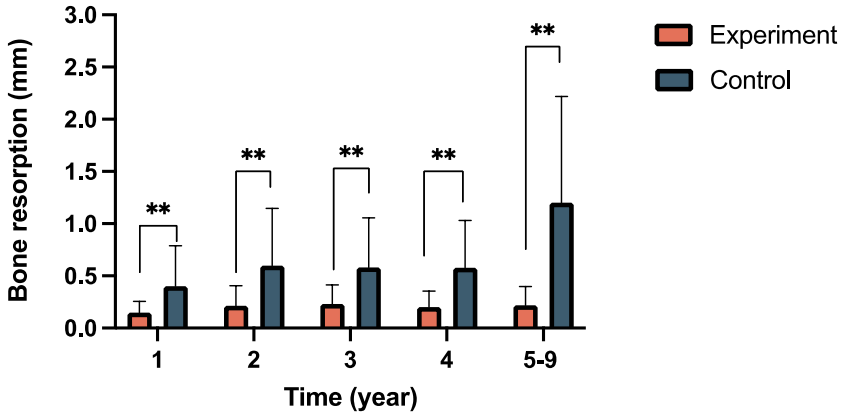


Figure 4 Peri-implant bone loss (mm) of implants regarding different follow-up interval. **: $p < 0.01$, meaning having great significant differences.

After adjusting for covariates, multivariate logistic regression analyses were conducted for each follow-up interval. Results showed that the experiment and control group had significant differences in MBL at all observation period ($p < 0.05$, **Table 4**). Implants placed according to our algorithm had a significant greater probability of reducing MBL, whereas implants not following our algorithm tended to exhibit increased bone loss compared with baseline. Specific data were illustrated in **Figure S3-S8**.

Furthermore, within the same group, we compared the MBL of smokers to non-smokers at each follow-up interval, adjusting for other covariates. Interestingly, no smoking-related differences in MBL were observed within either the experimental and control group (**Table 5, Figure S9-S13**).

Table 5 Inter-group comparisons of smoking habits (smokers VS non-smokers)

Time	Experimental group			Control group		
	MBL (smoker)	**MBL (non-smoker)**	***p***	**MBL (smoker)**	**MBL (non-smoker)**	***p***
1-year	0.203 ± 0.114	0.144 ± 0.105	0.166	0.279 ± 0.129	0.430 ± 0.423	0.273
2-year	0.131 ± 0.063	0.226 ± 0.203	0.601	0.350 ± 0.275	0.636 ± 0.604	0.089
3-year	0.131	0.235 ± 0.185	0.830	0.521 ± 0.447	0.596 ± 0.485	0.654
4-year	/	0.202 ± 0.152	/	0.597 ± 0.528	0.575 ± 0.435	0.581

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5-9 year	0.218 ± 0.009	0.227 ± 0.188	0.454	0.723 ± 0.306	1.418 ± 1.315	0.614

p > 0.05, meaning not having significant differences.

Discussion

Marginal bone loss (MBL) is a prognostic parameter for the success of dental implant and is influenced by various factors such as STH establishment, microgaps at the implant-abutment interfaces, crown emerging angle, history of periodontitis, among others.[25-28] In this present study, we focused on the impact of inter-implant distance. For posterior teeth, the aim of implant restoration is to re-establish patients' occlusion and masticatory function[29]. Bone resorption in the posterior alveolar ridge can affect implant stability and may also result in a reduction of attached keratinized mucosa as well as vestibular depth[15]. Apart from the original bone quality and quantity, the proper sizing and spacing of implants along with postoperative cleansing, are crucial for long-term implant stability. Adequate spacing is essential for maintaining both hard and soft tissue, and conversely, improper spacing can lead to complications. Placing the implant too far from the adjacent teeth/implant could result in unfavorable cantilever forces, instability, or restorative overhang, whereas placing implants too close can jeopardize the alveolar bone crest and create a compromised contour between them making difficulty in cleaning implants[30]. Tarnow et.al have recommended that a minimal distance of 3 mm is necessary to preserve the interproximal papilla between two adjacent implants[15]. Similarly, Scarano et al. found that vertical bone loss was reduced as the distance between the implants increased, with a 5-mm separation resulting in only 0.23 mm of crestal bone loss, in contrast to 1.98 mm in a 2-mm separation.[31] However, some disagreements exists as certain preclinical studies reported that implants could be placed 2 mm apart without inducing inter-implant MBL in minipigs and canine models[32,33]. Nevertheless, these studies also reported a significant decrease in tissue vascularity between implants when the inter-implant distance was as narrow as 2 mm[34]. In summary, the

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relationship between inter-implant distance and MBL is not yet fully understood and appears to be complex, warranting further research for definitive guidelines.

Moreover, placing multiple contiguous implants posed a greater challenge for clinicians than single-implant cases, especially the formation of inter-implant papillae. It has been noted that creating a papilla between adjacent implants is far more difficult than maintaining a papilla between an implant and a natural tooth, as the preservation of the latter's papilla seems to be reliant on the clinical attachment level of the neighboring tooth[19,35,36]. Besides the original peri-implant phenotype, the mesiodistal distance also played a vital role in preservation of soft tissue. The literature indicates that papillae were absent in 60-70% of the cases when horizontal distance between implants was less than 2.5-3 mm, whereas full papilla fill was more likely to occur when the horizontal distance was between 3-4 mm[35]. Gingival recession is of concern not only for esthetic concern, but also because it can be indicative of localized inflammation and poor oral hygiene[37]. Therefore, achieving a proper prosthetic profile and ensuring easy access for cleaning is of paramount importance for the long-term success of implant restorations.

The mesiodistal algorithm specifying distances of 4–4.6 mm (implant to adjacent canine tooth), 7–7.4 mm, 8–8.5 mm, and 9–9.5 mm for inter-implant/tooth spacing from the first premolar to the second molar has been recommended to achieve ideal occlusion and esthetics. The success of dental implant cases was largely dependent on establishing proper occlusion, as outlined in Sheridan *et al*[38]. Ideally, implants should mimic a patient's natural dentition as closely as possible. In this retrospective study, we tested our hypothesis that maintaining adequate bone volume is crucial. The consistency we observed supports the concept that an ideal prosthesis, designed following natural tooth morphology and positioning, can guide precise implant placement.

The findings of this study indicate that implants placed in accordance with our proposed algorithm exhibited a significant reduction in marginal bone loss (MBL) over

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a follow-up period of up to nine years. These results are in harmony with Tarnow's theory, which we further expounded upon for posterior teeth. We also noted that differences between groups widened over time, suggesting that the detrimental effects of improper inter-implant distances became more pronounced, potentially impacting peri-implant health. This increased bone loss could be attributed to factors such as food impaction and poor access for hygiene, which can lead to the accumulation of dental calculus and subsequent inflammation around the implant.

Our algorithm offers substantial evidence to assist clinicians in determining the optimal drill locations for free-end arches in a diverse patient population, with or without the use of preoperative guide templates. Surgeons should make such decisions based on several factors, including restorative space, alveolar ridge anatomy, and proximity to adjacent teeth or opposing arches, when applying this algorithm.

Additionally, this retrospective study helps predict implant prognosis, allowing clinicians to tailor treatment plans accordingly. For example, when a planned implant site presents with a pit-like bone defect, the clinician must decide whether to place the implant farther away where sufficient bone mass is available, or at the original location after performing guided bone regeneration (GBR). This decision should be informed by a comprehensive assessment of the distance to critical anatomical structures, the patient's periodontal condition, and other relevant factors. In cases where the ideal distances cannot be met, it is crucial for prosthodontists to manage patient expectations preoperatively, advising them of the increased likelihood of food impaction and potentially compromised masticatory function. It is important to manage patient expectations realistically in such scenarios.

It was worth noting that confounding factors such as gender, age, smoking habits, implant type, implant-abutment design and crown design may affect bone resorption. Therefore, we analyzed the distribution of these covariates across different groups to account for their potential effects. We observed that the proportion of smokers varied between the groups; thus, we employed logistic multivariate regression as our method

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of analysis to adjust for these factors and mitigate any confounding influence. To further examine the impact of smoking on the outcomes, inter-group comparisons were carried out. Upon comparison with the non-smoking counterparts, smoking did not demonstrate a significant difference in its effect. This suggests that, compared to smoking, the distance between implants may have a more pronounced influence on MBL. However, the relatively small number of smokers in each group should also be considered as a potential influencing factor. These findings underscore the significance of maintaining appropriate inter-implant distances and highlight the benefits of a restoration-oriented approach to implant design.

However, this study was not without limitations. A majority of patients did not maintain regular visit after 3 years, which resulted in significantly smaller sample sizes for the longer follow-up periods. Furthermore, while we calibrated the periapical radiographs using diameters and lengths to adjust for magnification, these evaluations are inherently two-dimensional. This limitation may lead to potential deformation and inaccuracies in the analysis. Soft tissue characteristics was also an important factor in deciding the prognosis of implants, which will be discussed in future study.

Conclusion

Within the limitations of this retrospective study, it can be concluded that implants placed accordance with the mesiodistal algorithm of 4–4.6 mm (implant to adjacent canine tooth), 7– 7.4mm, 8–8.5mm, and 9–9.5 mm are conducive to bone level preservation. The impact of inter-implant distance on marginal bone loss was found to be greater than that of smoking habits. This study's results facilitate predictable prognostic outcomes for various implants. Additionally, they provide clinicians with a valuable reference for determining appropriate treatment plans and setting realistic patient expectations.

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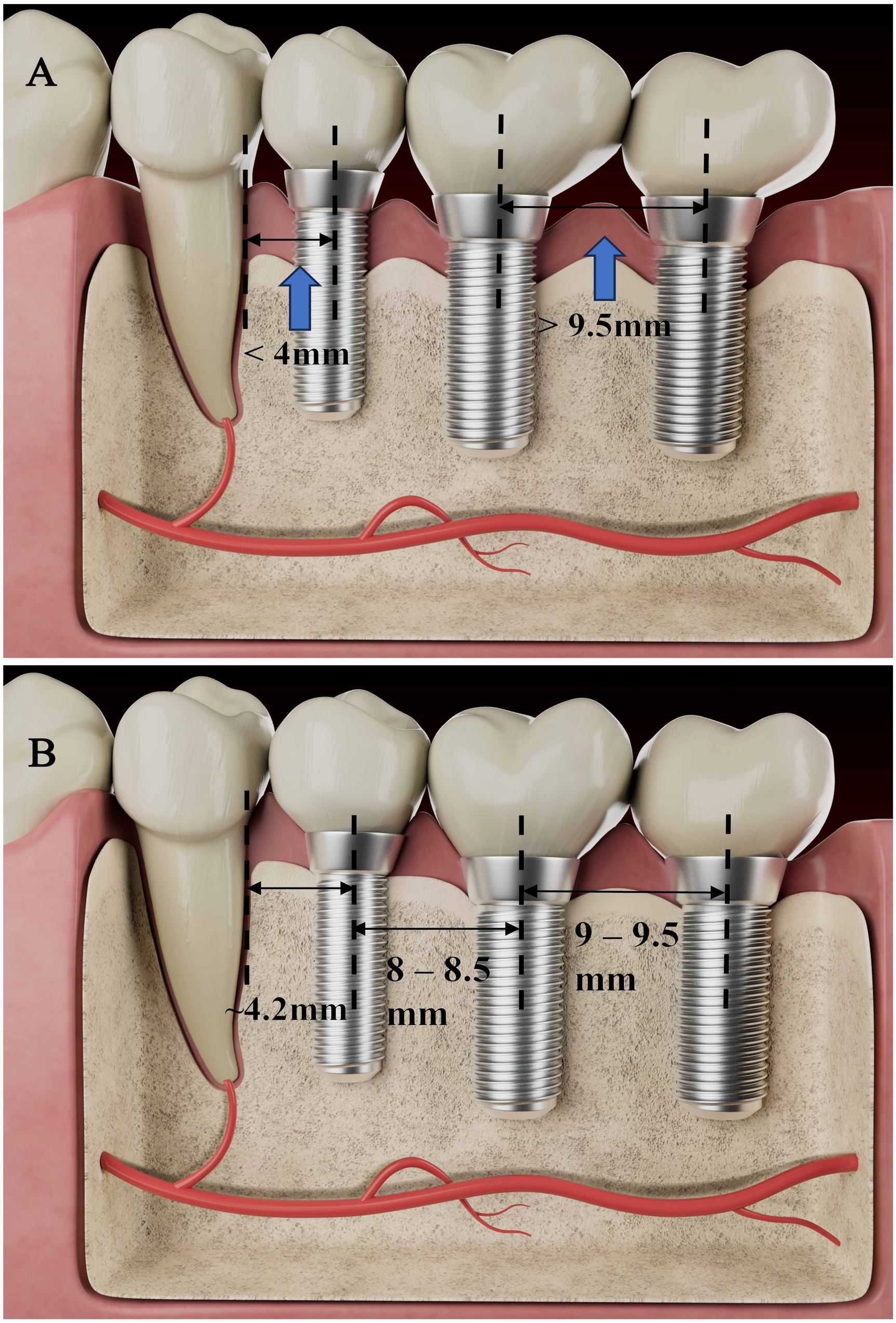


Figure 1 Schematic drawing of the impacts of implant mesiodistal distance on implants. (A, implants not following the mesiodistal algorithm showed peri-implant bone loss; B, implants following the mesiodistal algorithm exhibited satisfied treatment effect.)

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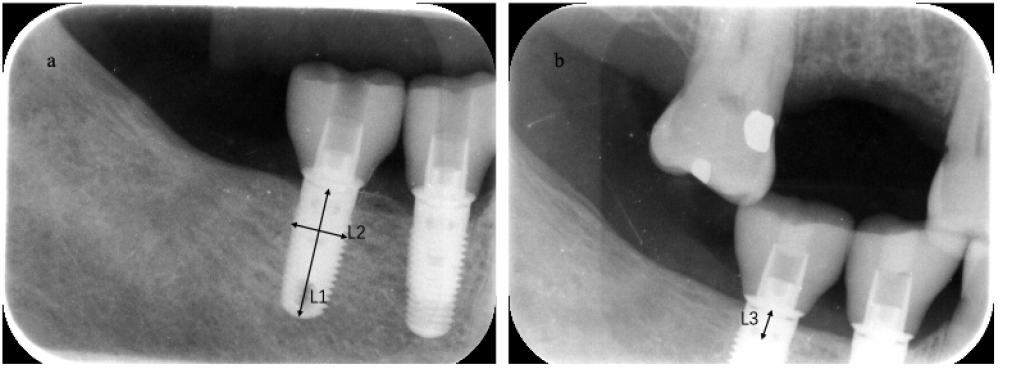


Figure 2. Illustration of radiograph calibration. L1: implant length; L2: implant diameter; L3: collar height.

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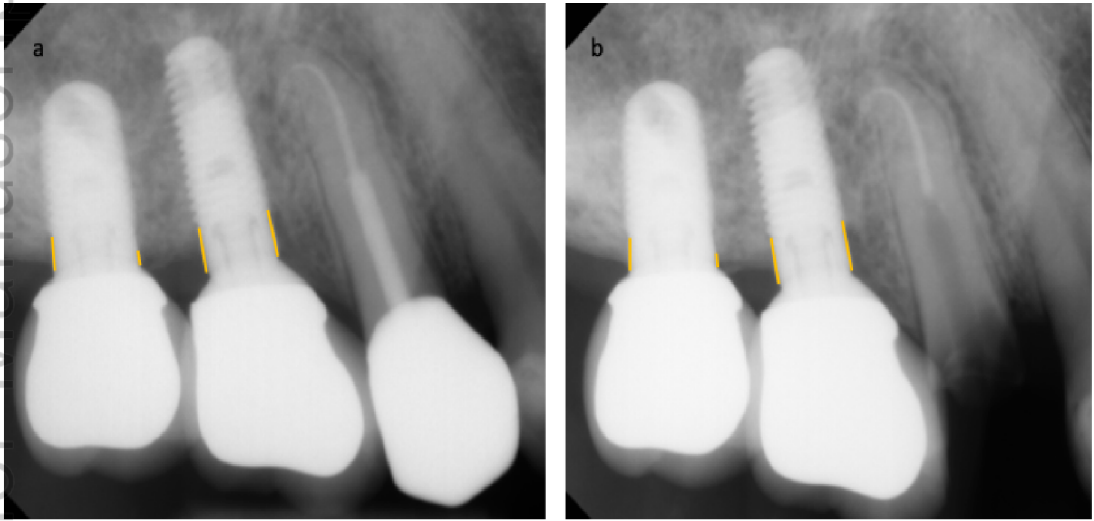


Figure 3 Radiographic illustration of the measurement of MBL from both mesially and distally at different follow-ups (yellow line). a: one year after crown installation; b: 3 years after crown installation.

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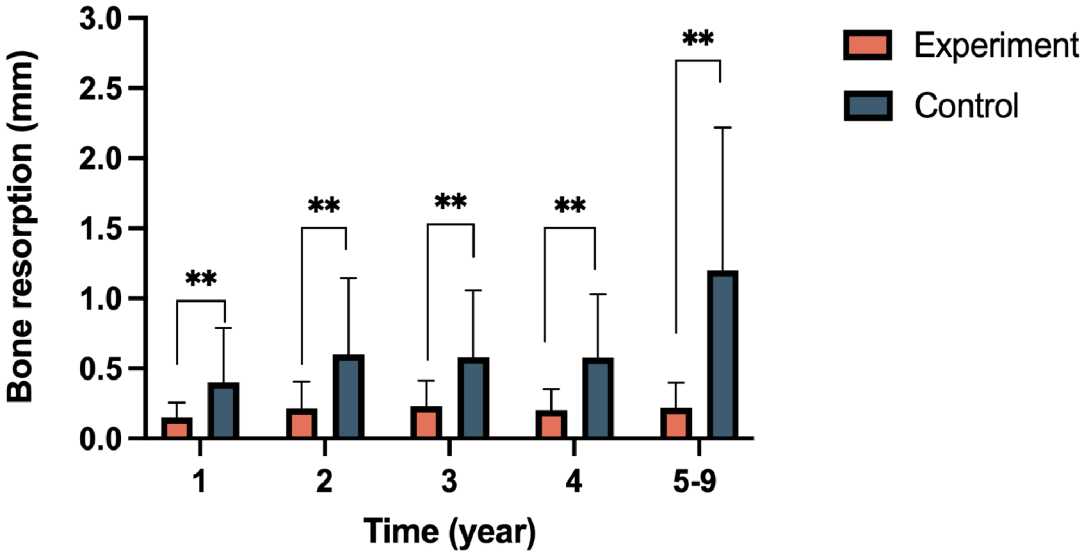


Figure 4 Peri-implant bone loss (mm) of implants regarding different follow-up interval. **: $p < 0.01$, meaning having great significant differences.