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QUADRILATERAL VERSUS BILATERAL LINEAR BAR DESIGNS FOR FOUR IMPLANT ASSISTED COMPLETE MANDIBULAR OVERDENTURES REGARDING PERI-IMPLANT CRESTAL BONE LOSS: A RANDOMIZED CLINICAL TRIAL

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ABSTRACT

Objective: This study aimed to assess two distinct bar designs for 4 implant-supported complete mandibular overdentures concerning peri-implant marginal bone loss. **Subjects and methods:** Twenty completely edentulous patients were chosen for that study. Patients received 4 mandibular implants in the canine and 1st molar areas and bar attachments. According to the bar design, all patients were classified equally into 2 groups: quadrilateral bar design (group I) and bilateral linear bar design (group II). Peri-implant marginal bone loss was evaluated immediately T0 and after 2 years T2 of insertion using a digital periapical X-ray. **Results:** at T0: there was a statistically insignificant difference between groups I&II, for group I the mean ±SD (0.13± 0.06), for group II the mean± SD (0.11± 0.07), and *P-value* 0.465. For posterior implants, there was a statistically insignificant difference between groups I&II, in group I the mean± SD (0.08± 0.08) in group II the mean± SD (0.09 ± 0.07), and *P-value* 0.808. At T2, for anterior implants, there was a statistically significant difference between groups I & II, in group I the mean± SD was (1.37± 0.13), and in group II the mean ± SD (1.24±0.14) and *P-value* was 0.02. For posterior implants, there was a statistically significant difference between groups I &II, in group I the mean± SD (1.64 ±0.14), and in group II the mean± SD (1.33± 0.16), and *P-value* 0.001. **Conclusion:** The bilateral linear distribution bar design is considered a better treatment option compared to the quadrilateral distribution regarding peri-implant marginal bone loss.

KEYWORDS: Implant, implant-supported overdenture, bar attachment, peri-implant bone loss.

INTRODUCTION

Implant-supported mandibular overdentures have significantly higher stability and retention over conventional mandibular dentures. They have been utilized as an alternative treatment option compared to traditional mandibular dentures for completely edentulous people, especially in the mandibular arch[(1)].

Regardless of the attachment method (balls, magnets, or bars), the McGill consensus states that 2-implant overdenture must be the initial course of management for an edentulous mandible. However more implants improve retention, reduce bone loss, and improve stress distribution to improve treatment outcomes [(2)].

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A popular therapy for those who are edentulous is totally implant-supported bar-overdentures, which have 4 to 6 implants without mucosal support. They are an excellent choice for the rehabilitation of difficult conditions [3] offering strong stability, retention, aesthetic value, and good chewing efficiency. Bars offer splinting of dental implants that appear to contribute to stress distribution and load sharing between supporting implants [4].

Crestal bone loss at the neck of an implant is one of the most common issues that occur after implantation. This bone loss can diminish the long-term effectiveness of the implant, which is essential for its longevity. The primary causes of crestal bone loss include peri-implantitis, occlusal stress, surgical trauma, and the healing process[5].

It was found that flexure of the mandible occurs during opening and closure, Gates and Nicholls [6] observed a 0.1 to 0.5 mm increase in maximum protrusion and a 0 to 0.3 mm decrease in mandibular arch width between the lower first molars during opening. When Osseo-integrated implants placed distal to premolars during the active opening, there was a documented relative movement of up to 420 μm in edentulous arch, and the condyles' medial convergence during opening ranged from 0.0 mm to 1.5 mm [7].

This phenomenon should be considered in implant prosthesis since there is no periodontal ligament in implants, a rigid device that holds implants together as a single unit when replacing a completely edentulous mandible either with an implant-supported prosthesis or a traditional fixed prosthesis, the forces are applied directly to the bone, which can lead to bone resorption [8]. Therefore, when designing the metal framework, it is essential to consider mandibular flexure as a significant biomechanical factor, particularly if implants are placed posterior to the inter-foraminal region [9].

Some authors recommend segmenting the prosthesis superstructure at the level of the symphysis to reduce the dangerous stresses that occur at this point. Using a single rigid structure can lead to an increased rate of screw loosening and fractures[10]. Conversely, other studies support a splinted superstructure, which can evenly distribute stress among the splinted implants, providing additional resistance to mandibular bending. Ultimately, all studies agree that it is better to segment the superstructure at the midline rather than create three or more segments [11].

The methods used for assessing crestal bone loss include computed tomography, digital subtraction radiography, oblique cephalometric radiographs, panoramic radiographs, and intraoral periapical (IOPA) radiographs. When evaluating bone architecture, radiographs are essential for preventing excessive alveolar bone loss [12].

When properly angled, periapical radiographs exhibit minimal distortion when using the standardized projection geometry developed by Duckworth et al.[13] Additionally, periapical radiography requires significantly less exposure than other imaging modalities. The measurements obtained from periapical radiographs are highly reliable due to the resolution and sharpness of images produced using the long cone paralleling technique [14]. Moreover, standardized periapical radiographs are likely the most trustworthy and consistent option for measuring linear distances.

The current study aimed to conduct a radiographic comparison of quadrilateral and bilateral linear bar designs for four implant-assisted complete mandibular overdentures, focusing on peri-implant crestal bone loss. The null hypothesis posited that there would be no difference in peri-implant bone changes between the overdentures with either the quadrilateral or bilateral linear bar designs.

SUBJECTS AND METHODS

Study design

Twenty edentulous individuals were chosen from Mansoura University's Faculty of Dentistry's prosthetic department. The goal of the prosthodontic and surgical procedures used in this study was explicitly explained to the patients. They signed the Mansoura University Dental Research Ethical Committee's written consent form (No. A0101024RP). based on the following standards: a healthy, firm mucosa that is entirely edentulous, free of jaw cysts and remaining roots, Class I maxillomandibular relationship is associated with adequate restorative space and alveolar bone quality (class 1-3 according to Lekholm and Zarb classification) [(15)]. The sample size was calculated using data from the former clinical trial [(16)] with effect size = 1.1, $\alpha = 0.05$, and $\beta = 0.90$. The sample size was calculated to be 20 participants. The power analysis was conducted using computer software (G*power 3.1.5, Heinrich-Heine-Universität Düsseldorf, Germany). Patients were randomly assigned to one of two groups using balanced randomization to assure group comparability in terms of peri-implant marginal bone loss, as evaluated by digital periapical x-ray. Using random numbers generated in an Excel spreadsheet, the participants were sorted into two groups: quadrilateral and bilateral linear groups.

Pre-surgical procedures

Construction of complete dentures: Primary impressions of the maxilla and mandible were made using irreversible hydrocolloid impression materials (alginate impression material, Cavex) in modified stock trays. After pouring dental stone (Lab stone, Miles dental Product, South Blend) into these impressions, customized trays were constructed from auto-polymerizing acrylic resin (Pekatray, Bayer. Dental, Lever Kusen). The green compound (Hiflex Thermoplastic green sticks, Prevest Denpro) was softened then applied to the custom trays with the appropriate extension. Final impressions were then obtained using a zinc oxide eugenol-free paste (ZOE, Cavex). These final impressions were subsequently poured into dental stone to create master casts.

Blocks were created to record the jaw relationship, and on a semi-adjustable articulator (ARH type. Denatus articulator) and using a face-bow transfer (Type AFB. Denatus facebow) a maxillary cast was mounted. Centric, protrusive, and lateral inter-occlusal data were recorded to mount the mandibular cast. Using the Becker principles of balanced lingualized occlusion, crosslinked acrylic artificial teeth (NT Unay acrylic resin teeth, Toros Dental) were arranged. Maxillary anatomic teeth were used opposing mandibular semi-anatomic teeth with reduced buccal cusps. This arrangement allowed the upper palatal cusps to be the only cusps in contact, facilitating long-centric movement. Next, the trial denture was meticulously sculpted using wax (Base plate Modeling wax, Cavex), and a try-in was performed.

The final denture was processed using a long curing cycle. To ensure proper occlusion, the denture was remounted in the laboratory to correct any dimensional changes that may have occurred during the curing process. Finally, the finished denture was carefully polished before fitting into the patient's mouth.

Construction of mandibular surgical guide: The labial and lingual flanges of the mandibular dentures were modified by adding at least seven gutta-percha markers. Each patient underwent a cone-beam computed tomography (CBCT) scan (CAT Vision, PA, USA) while wearing the denture in full occlusion. After this, the denture was scanned separately. The software (Realguide software version 5.1) then superimposed the two scans using the gutta-percha markers for alignment. This process allowed for assessing the available bone length and width (4.0x12mm BTK SAFE; Biotec SRL, Vicenza, Italy), for planning the placement of 4 implants in the mandible. Subsequently, a stereolithographic surgical guide was constructed based on this planning.

Implant placement surgery: Each participant was instructed to bite down on a surgical guide using the maxillary denture in centric relation and fixation pins were placed in their proper positions (Figure 1). The mucosa at the proposed implant sites was removed using a tissue punch and then subsequent drilling to prepare the osteotomy sites using a universal surgical kit until 1 size smaller than the implant diameter. The surgical guide was then removed and the final drill corresponding to implant size from the implant kit was used to prepare the osteotomy sites then implant fixtures were placed in their positions and fastened at 35nm using a torque wrench (figure 2a). Cover screws were then attached to the implants.

Direct pick-up impression

After 3 months of the Osseo-integration period, the implants were uncovered, the straight multiunit abutments were attached to the implants (Figure 2B). Next, a direct transfer open tray impression was taken to accurately capture the positions of the dental implants. This involved using long multiunit transfer copings placed in the tray, which had openings corresponding to the implant sites. The transfer copings were then splinted together using Duralay resin (*Duralay*, Worth, IL).

An impression was made with polyvinyl siloxane (PVS) material (*GHENESYL* Type-A silicone, LASCOD); the tray was loaded with putty material, and light impression material was injected into it before tray insertion. After setting the impression material, the tray was removed with impression copings, and finally, an impression was examined to ensure it was completely adapted around the direct transfer copings.

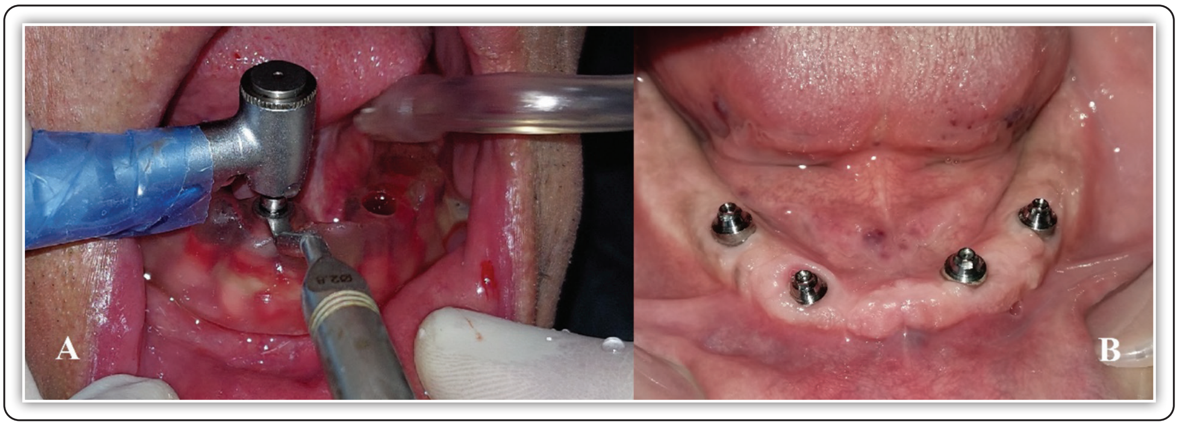

FIG (1) Surgical placement of dental implants and straight multiunit abutments

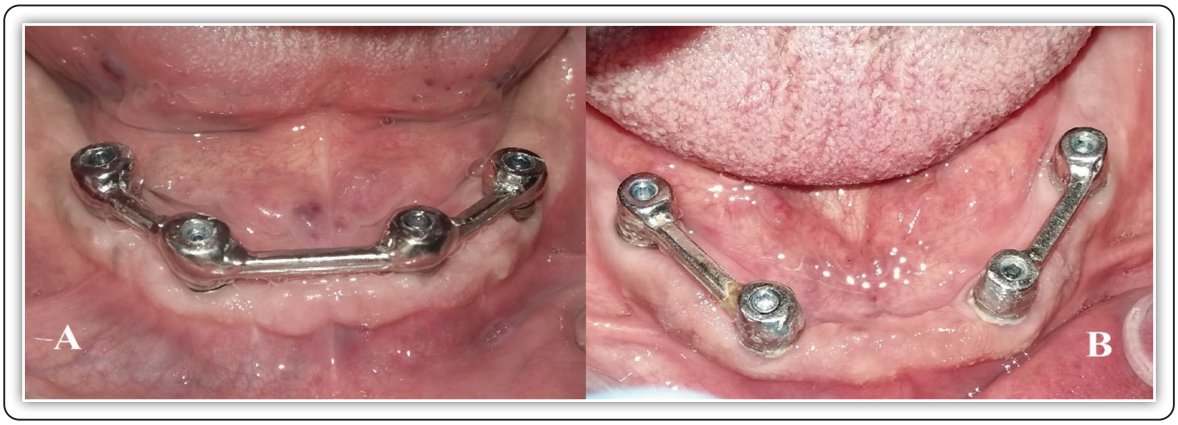

FIG (2) Bars screwed to multiunit abutments.

Multiunit analogs were attached to the direct transfer copings within the impression (Figure 3B), and the impression was poured using a type IV dental stone (Figure 4A). Subsequently, a verification jig was constructed and tried intraorally to ensure a passive fit.

All participants in the study were randomly divided into 2 equal groups based on the bar design:

- Quadrilateral Group I (n=10): Each participant received mandibular overdentures supported by 4 implants arranged in a quadrilateral distribution. A plastic, ready-made bar was cast from cobalt chromium alloy.
- Bilateral Linear Group II (n=10): Each participant in this group also received mandibular overdentures supported by 4 implants, but these were arranged in a bilateral linear distribution. Similar to Group I, a plastic, ready-made bar was cast from cobalt chromium alloy.

Bar Construction

On the master cast, 4 plastic multi-unit sleeves were screwed to the multi-unit analogs using abutment screws (Figure 4B).

In the Quadrilateral group: A quadrilateral three-bar assembly (multipurpose bar, Rhein OT) was luted to plastic abutments using Duralay resin. There should be a minimum of 1 mm of space between the bars and the ridge.

In the Bilateral linear group: Two bars (multipurpose bar, Rhein OT) were luted bilaterally to plastic abutments using duralay resin. There should be a minimum of 1 mm of space between the bars and the ridge.

Bars were tried intra-orally to check the passive fit, then invested, and cast in cobalt-chromium alloy, after divesting, finishing, and polishing of bars and then tried intraorally (Figure 2).

Construction of conventional mandibular overdentures

Wax occlusion rim was then constructed on a cold cure denture base on the master cast. Face bow record was used to document the orientation relation of the maxillary cast with maxillary complete denture and transfer this relation to semi-adjustable articulator (ARH type. Denatus articulator).

An intermaxillary jaw relation record was utilized to mount the mandibular cast. The artificial prosthetic acrylic teeth were mounted, positioned in the mouth, and adjusted for a bilaterally symmetrical occlusion. Traditional flasking methods were used to construct complete dentures, which were subsequently polished and completed using Acrostone, a heat-cured acrylic resin.

The completed dentures were remounted in the laboratory to address any occlusal inconsistencies and to check appropriate occlusal contact in both centric and eccentric positions. Intraoral occlusal contacts were also verified to ensure further corrections were made as needed. The patients received guidance on how to clean their dentures and maintain good dental hygiene.

Direct functional pick-up

Pick up of 2 yellow plastic clips in the bilateral linear group, and 3 yellow plastic clips in the quadrilateral group were done. After blocking out under the bar perforations were performed in the lingual flange opposing bars to provide skip ways to excess resin pick-up material. Clips were secured to bars, and a direct pick-up with self-curing acrylic resin was performed while the patient bit in centric relation. (Figure 3).

Calculating implant marginal bone height changes

A long cone parallel approach with a specially made film holder was used to assess each patient's vertical marginal bone loss to ensure standardized radiography analysis and avoid any magnification errors. At mesial and distal aspects of the implant, the linear distance measured in millimeters (mm) between the proximal crestal bone level and the implant shoulder.

FIG (3) Pick-up of bar clips

The RINN methodology was implemented using XCP instruments with the extension cone parallel technique. This method consists of a directing rod, a bite block, and a guide ring. A disposable sleeve was placed over the sensor to prevent cross-infection. The sensor was inserted into a slot of the bite block to ensure accurate proper placement of the film during each radiographic procedure. Each patient had a custom putty rubber bite made to help position the film holder while their mouth was closed. This allowed the block to be removed and repositioned precisely in the same location for each evaluation.

The radiographic tube was aligned flush with the ring, and the exposure was taken. All patients received a uniform exposure time and dosage. After the exposure, the image was displayed on the computer screen and archived in the patient's record. This process can be refined during each assessment period. The distance between the implant shoulder and the level of the nearby crestal bone on the mesial and distal sides of the implant was measured by a single examiner who assessed the radiographs.

Measurements were performed using image measurement software (CorelDraw® version 10TM, Kodak Digital Science) [14]. Radiographic evaluation of peri-implant marginal bone loss was measured immediately (T0), after two years (T2) after overdenture insertion (Figure 4).

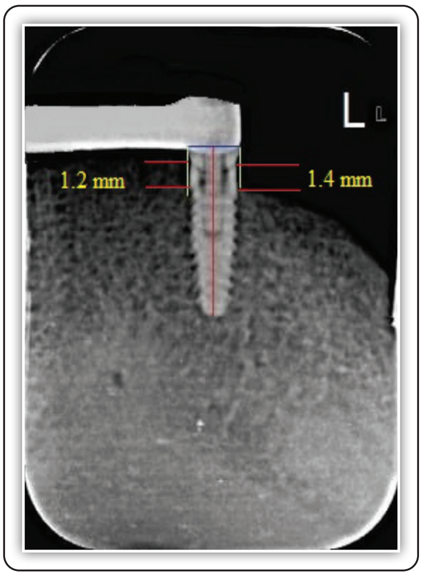

FIG (4) Marginal bone height evaluation using digital peri-apical x-ray.

Statistical Analysis

The collected data were analyzed using SPSS program version 26. A one-sample Kolmogorov-Smirnov test was employed to assess the normality of the data. Continuous variables with a normal distribution were represented as means ± standard deviation (SD). To compare the two groups, an independent t-test was conducted, while comparisons within paired groups were analyzed using a paired t-test. Results were considered significant when $p<0.05$, with the significance threshold set at 5%.

RESULTS

TABLE (1) Comparison between the quadrilateral and linear group at the time of overdenture insertion (T0).

T0		Quadrilateral group (n=10)	Linear group (n=10)	Test of significance	p-value
Anterior implants	Mean ± SD Median Min-Max	0.13±0.06 0.10 0.00-0.20	0.11±0.07 0.10 0.00-0.20	Z=0.731	0.465
Posterior implants	Mean ± SD Median Min-Max	0.08±0.08 0.10 0.00-0.20	0.09±0.07 0.10 0.00-0.20	Z=0.243	0.808

There was no statistically significant difference between both groups. In Group I, the mean ± standard deviation (SD) was 0.13 ± 0.06, while in Group II, it was 0.11 ± 0.07, with a p-value of 0.465. For posterior implants, the results were also statistically insignificant between the two groups. In Group I, the mean ± SD was 0.08 ± 0.08, and in Group II, it was 0.09 ± 0.07, with a p-value of 0.808.

TABLE (2) Comparison between the quadrilateral and linear group after two years of overdenture insertion (T2).

T2		Quadrilateral group (n=10)	Linear group (n=10)	Test of significance	p-value
Anterior implants	Mean ± SD Median Min-Max	1.37±0.13 1.40 1.10-1.60	1.24±0.14 1.30 1.00-1.50	Z=2.324	0.02*
Posterior implants	Mean ± SD Median Min-Max	1.64±0.14 1.60 1.40-1.90	1.33±0.16 1.40 1.00-1.60	Z=4.150	≤0.001*

There was a statistically significant difference between groups I &II, in group I the mean ± SD was 1.37± 0.13, in group II the mean ± SD was 1.24 ± 0.14, and *P* = 0.02. For posterior implants: there was a statistically significant difference between groups I &II, in group I the mean ± SD was 1.64 ± 0.14, in group II the mean ± SD was 1.33 ± 0.16, and the *P*= 0.001.

TABLE (3) Comparison between the amount of marginal bone loss at different times of overdenture insertion in the quadrilateral group and linear group

		Quadrilateral group (n=10)		P value	Linear group (n=10)		P value
		T0	T2		T0	T2	
Anterior implants	Mean ± SD Median Min-Max	0.13±0.06 0.10 0.00-0.20	1.37±0.13 1.40 1.10-1.60	Z=3.47 P=0.001*	0.11±0.07 0.10 0.00-0.20	1.24±0.14 1.30 1.00-1.50	Z=3.42 P=0.001*
Posterior implants	Mean ± SD Median Min-Max	0.08±0.08 0.10 0.00-0.20	1.64±0.14 1.60 1.40-1.90	Z=3.42 P=0.001*	0.09±0.07 0.10 0.00-0.20	1.33±0.16 1.40 1.00-1.60	Z=3.42 P=0.001*

There was a statistically significant difference between both groups for anterior & posterior implants with a *P*= 0.001.

DISCUSSION

Dental implants have become increasingly popular as a treatment for edentulous mandibles. However, the biomechanical environment significantly influences the long-term success of these implant therapies. One of the primary reasons for posterior implant failure in these restorations is the displacement of the mandible [16]. The shape of the mandible resembles a "U" or horseshoe, functioning as a curved beam that supports both the unilateral and bilateral loads. When the masticatory muscles attached to the condyles exert force on the jaw, deformation occurs in the elastic, anisotropic, and non-homogeneous tissues. As a result, the width of the mandibular arch can vary by a few microns up to 1 mm, with an average reduction of about 0.073 mm[17].

The primary objective of restorations supported by implants is to guarantee the best possible bio-mechanical distribution of the implant and the prosthetic superstructure. Because of full-arch construction that firmly joins the implants, the mandible's elastic flexion is limited in this study. By contrast, the framework might be more naturally flexible when it is divided into individual components [11].

Assessment of the peri-implant bone level changes by using digital periapical radiographs are a suitable method for evaluating bar attachments. Standardized intraoral periapical radiographs are preferred over panoramic images due to their accuracy in measuring peri-implant bone loss. This method employs the long cone parallel technique and offers lower radiation exposure compared to cone beam computed tomography (CBCT) [18,19].

This current study demonstrated significant bone loss in both groups over time (T0-T2) for anterior and posterior implants, with a p-value of 0.001 for the quadrilateral group and 0.001 for the bilateral linear group. This bone loss can be attributed to remodeling after surgery and the functional stresses imposed by the prosthesis following implant loading, as noted in existing literature. This effect is particularly pronounced within the 1st year after implant insertion [20].

The results of this study indicated that the average radiographic bone loss after two years was 1.37 ± 0.13 mm for anterior implants and 1.64 ± 0.14 mm for posterior implants in the quadrilateral group. In contrast, the bilateral linear group showed an average bone loss of 1.24 ± 0.14 mm for anterior implants and 1.33 ± 0.16 mm for posterior implants over the same period. All these values fall within the normal range. According to Adell et al [21], The marginal bone loss around implants should not be exceed 1.5 mm in the 1st year and 0.1 mm in each following year. The less than 1 mm peri-implant marginal bone loss observed in both study groups indicate the quality and effectiveness of the implants used, as well as the surgical protocols followed [22].

Several factors may be contributed to the decline in marginal bone levels. Firstly, the natural decrease in bone levels surrounding implants, like that observed around natural teeth with age, should not be overlooked [23].

Bryant observed that patients who had been edentulous for an extended period experienced significantly less peri-implant marginal bone loss within four years of implant function compared to those who had been edentulous for a shorter duration. This finding suggests that crestal bone loss around implants may occur more rapidly in areas where teeth have recently been lost, as opposed to those placed in stable basal bone [24].

The literature discusses multiple factors that contribute to the bone loss around dental implants, identifying at least 85 potential causes over the years [25]. According to Oh et al [26] the primary reasons for crestal bone loss in implants in their 1st year of placement include pathological occlusal stress, micro gaps at or below the bony crest, the development of biological width, and the design of the implant's crest module. However, it was determined that neither the formation of biological width nor the presence of micro gaps significantly affects the stability of the marginal bone level.

In a literature review conducted by Qian and their colleagues. The clinical data suggested that numerous factors could contribute to marginal bone loss. These concerns included clinical management (such as surgeon and prosthodontist experience), implant qualities (such as surface roughness and design), and patient variables (such as health, smoking habits, genetic illnesses, and accessible bone). This idea explains how marginal bone loss affects both implants and patients [(27)].

There is increasing evidence that osseointegration can be interpreted as the body's way of encapsulating the foreign implant, which can lead to a foreign-body reaction [(28)]. When the immune system identifies a foreign substance, it typically triggers an inflammatory response. This response works to engulf and digest the foreign material or to isolate it from surrounding tissues by encasing it in fibrous or bony material. In such cases, the surface of the foreign body experiences ongoing mild inflammation, which is associated with the presence of the macrophages and the multinucleated giant cells that form around the foreign substance [(29)].

Overreaction or disruption of the body immune system can cause the body's defense-repair balance to shift toward tissue death and persistent inflammation. According to Trindade et al [(30)], the immune system's protective response to a dental implant is in harmony with the bone tissue reaction surrounding the implant, which aims to isolate it from vital host tissues. Even in the absence of infection, an overactive or imbalanced immune system can cause a substantial shift in bone levels when the ratio of osteoblasts to osteoclasts tilts in favor of osteoclasts [(31)].

The findings of this study did not support the null hypothesis, showing a significant difference in marginal bone loss between the two groups. The quadrilateral group experienced greater bone loss than the bilateral linear group after two years, with P-values of 0.02 for anterior implants and ≤ 0.001 for posterior implants. This increased bone loss may be related to the influence of mandibular flexure, which has a stronger impact on implant therapy when four connected implants are widely distributed. Since Osseo-integrated implants do not have a periodontium, they cannot adapt to the flexion of the mandible during movement. The stress from the fixed prosthesis can lead to loosening or breakage of the screw , as well as resorption of the surrounding bone, potentially resulting in implant loss [(32)]. Moreover, a splint that connects the implants is more rigid than the surrounding bone, which can generate high stress during the mandibular movements.

A research study by Hobrik and Havthoulas [(8)] demonstrated that connecting implants results in a greater extrusion force and a broader distribution of loads. When implants are positioned widely throughout the mandibular arch and connected with a rigid framework, the study found that mandibular deformation during functional use significantly influences high stresses on the implant-abutment complex.

Recent case reports have shown that patients have experienced relief from pain and symptoms when their prosthesis is divided into several sections [(33)]. This improvement can be related to the potential misalignment between the position of the implant and the prosthesis. With a segmented superstructure, making small adjustments becomes easier, allowing for better passive seating and reducing stress on both the restoration and the mandible. Additionally, advocates for segmented superstructures argue that they do not interfere with the natural bending of the mandible and may help decrease stress at the midline of the superstructure [(11)].

According to a recent study, prostheses divided into two or three sections are advantageous because they enable the rebuilt mandible to flex more naturally [34]. This design strategy is thought to lessen the concentration of stress on the anterior and posterior implants. In this instance, the occlusal scheme of mandibular fixed implant-supported prosthesis was improved and greater posterior extension was made possible by the implantation of posterior implants, which were meant to shorten the lever arm. This modification improves the prosthesis' stability and aids in the more efficient distribution of occlusal stresses. Additionally, the split framework's accurate and passive fit might have decreased the mandibular flexure effect on the posterior implants' bone-implant interface, hence extending the prosthesis' lifespan [35].

Some limitations need to be addressed. The small sample size (n=20) may limit the ability to generalize the findings of larger populations due to resource constraints. Second, the short evaluation period may not provide information about long-term effects. However, this study still allowed for preliminary conclusions and offered valuable insights into marginal bone loss about quadrilateral and bilateral linear bar designs for implants supporting overdentures. Future research is needed to include a larger sample size, extend the evaluation period, and assess mechanical strains around the implants.

CONCLUSION

Within the limitations of this current study, the bilateral linear distribution bar design is regarded as a superior treatment option compared to the quadrilateral distribution in terms of the peri-implant marginal bone loss.

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