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MECHANICAL EFFECT OF SIMULATED MARGINAL BONE RESORPTION ON NARROW DIAMETER IMPLANT IN MANDIBULAR RETAINED OVERDENTURE (IN-VITRO STUDY)

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ABSTRACT

BACKGROUND: Marginal bone resorption affects implant stability and long-term success of mandibular overdentures. This study evaluates the biomechanical impact of bone resorption on narrow-diameter implants (NDIs) using Ball & Socket attachment systems.

PURPOSE: To assess the mechanical effect of simulated marginal bone resorption on NDIs supporting mandibular overdentures and evaluate strain distribution using Ball & Socket attachments.

METHOD: Fourteen epoxy resin models were divided into two groups—normal and resorbed bone. Each model received two NDIs supporting mandibular overdentures with Ball & Socket attachments. Strain gauges measured stress distribution under unilateral and bilateral loading. Statistical analysis assessed the impact of bone loss and loading conditions on strain values.

RESULTS: Bone resorption significantly increased strain values ($p < 0.001$), especially under unilateral loading. The Ball & Socket attachment system maintained consistent performance across bone conditions ($p > 0.05$). Resorbed bone models exhibited the highest strain values, emphasizing the critical importance of bone preservation for implant stability.

CONCLUSION: Marginal bone resorption increased significantly strain around NDIs supporting mandibular overdentures with Ball & Socket attachments .proper occlusal load management and bone preservation are critical as ball attachments showed compromised load distribution capacity in atrophic cases. These findings emphasize that preventive strategies should prioritize minimizing bone loss to ensure long-term prosthetic success.

KEYWORDS: Marginal bone resorption, Narrow diameter implant, Implant retained overdenture, Ball & Socket attachment, Unilateral and bilateral loading.

RUNNING TITLE: Narrow implant marginal bone resorption mechanical effect.

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INTRODUCTION

Edentulism remains a significant health burden, particularly among the aging population, impacting masticatory function, phonetics, esthetics, and overall quality of life (1). The introduction of implant-retained overdentures has greatly improved prosthetic stability and patient satisfaction compared to conventional complete dentures (2). However, the biomechanical environment surrounding dental implants is complex and influenced by several clinical variables.

One of the key challenges following implant placement is marginal bone resorption (MBR) (3). The integration of the implant in the hard and soft tissues is crucial for the durability and success of dental implants. MBR was therefore considered to be a crucial factor influencing the clinical outcome (4). Studies have shown that the implant neck experiences a 1.5–2 mm bone loss in the first year after functional loading, followed by a marginal bone loss rate (MBL) of roughly 0.2 mm annually (5,6).

Bone loss is most severe within the first year, then continues at a slower pace. The condition is further exacerbated in patients with reduced cortical bone thickness and trabecular density, both of which alter force transmission and increase mechanical stress around implants (7).

To address cases of limited bone volume, narrow-diameter implants (NDIs) have emerged as a reliable alternative to standard-diameter implants, particularly in mandibular overdenture cases (8). NDIs minimize the need for bone grafting, reduce surgical trauma, and are associated with faster healing times. Yet, NDI has identified a number of potential biomechanical risk factors (9). Stress values affecting the crestal bone are reciprocal to the diameter of the dental implant, as demonstrated by in vitro research and finite element analysis. This indicates that particularly small diameters lead to unfavorable stress peaks at the implant-bone interface (10).

For mandibular implant overdentures, a variety of overdenture attachment systems can be used to improve denture stability and retention. The most widely used attachment systems include bar, ball, and magnet kinds, as well as several separate mechanical attachments that are comparable to the ball type in size and purpose (11).

The most popular overdenture attachment is the ball attachment, which has a spherical shape for retention. A straightforward manufacturing process, a broad range of mobility, cost effectiveness, ease of use and maintenance, good retention, hygienic upkeep, and high patient satisfaction are some of its benefits (12). Studies have shown that More energy absorption is made possible by the ball and socket attachment's smaller neck, which lessens the amount of stress that is transfered to the mucosa, cortical bone, and cancellous bone (13). Despite these advantages, Previous research has defined ball attachment complications as frequent loosening, attachment deterioration, and denture breakage, which need regular replacement (14).

The risk factors of MBR or changes in bone level surrounding implants have been the subject of numerous studies in recent years, but the biomechanical behavior of NDI following MBR—particularly when utilized as an overdenture retainer has received less attention (15). Thus, the aim of this study is to analyze the mechanical effect of simulated MBR on the narrow diameter implants overdenture retained by ball & socket attachment.

The null hypothesis was that the normal group and the resorption group would have no significant differences regarding the strain surrounding the implants.

MATERIAL AND METHODS

Model Preparation

An in-vitro experimental study was conducted using fourteen epoxy resin models (Ramses Medical Products Factory, Alexandria), fabricated to represent edentulous mandibles. The models were divided into two groups:

Group I (Control): Seven models with normal bone. **Figure (1)**

Group II (Resorbed Bone): Seven models with simulated 4 mm marginal bone loss. **Figure (2)**

Two narrow-diameter implants (3.0 mm × 14 mm) (Implanova, Dental Evolutions Inc., Beverly Hills, CA, USA) were placed in the canine region of each model using a surgical guide to ensure parallel placement. The implants were positioned 22 mm apart from the midline. In the resorbed bone group, 4 mm of bone was removed around the implant platform to simulate bone loss

Each model received a Ball & Socket attachment (Naturall, Lyra ETK Implants (Euroteknika), Paris, France).The system included a ball abutment and a female socket incorporated into the overdenture.

Overdendture Fabrication

Maxillary and mandibular trial denture bases made of autopolymerizing acrylic resin (Acrostone Co Ltd, Cairo, Egypt) with wax occlusion rims were constructed on the stone models and mounted on a mean value articulator, on which maxillary and mandibular acrylic teeth (Acrostone Plus Double Layer anterior and posterior teeth; Acrostone Co Ltd, Cairo, Egypt) were arranged and adjusted .Fourteen mandibular trial denture bases were constructed on the mounted stone models. The same set mandibular acrylic teeth (size 22) with 20° cusp angle were arranged on all the trial denture bases utilizing the same mounting while keeping the opposing maxillary trial denture base in place to ensure standardization of all the mandibular implant-retained overdentures. The mandibular trial denture bases were finally processed into heat-cured acrylic dentures (Denture Base Material; Acrostone Co Ltd, Cairo, Egypt).

Two Ball&socket attachments were screwed to each of the other fourteen mandibular overdentures under torque of 25 N using a universal torque wrench. Block out spacer was placed around each abutment. Then, a female housing was seated onto each abutment. The overdentures were relieved to seat passively over the implants and attachments. Lingual windows were opened in the denture to allow excess acryl resin to escape. Cold-cure polymethyl methacrylate was mixed and placed into the housing relief areas and then the overdenture was seated over the housings and was left until the material set. Then, the overdenture was disengaged from the abutments. Then, Finishing and polishing to the acrylic resin was done.

Testing methodology (15,16)

Channels were prepared in the models with flat surfaces for strain gauge placement. Two strain gauges (Koyoma strain gauge, Japan) were attached at the buccal and lingual side of each implant at the implant-bone interface using special glue (Koyoma Electronics Instruments). Fine lead wires were connected to a strain meter (Data Logger model TDS-150, Japan) for data acquisition to measure strain distribution

Loading Protocol Using universal testing machine

A universal testing machine (Universal testing machine, (Mecmesin, Multi Test5-XT (5KN), USA) was used to apply occlusal loads:

Bilateral Loading: A 100 N force was applied at the center of a metal template positioned at the level of the occlusal plane on the region of first molar (17,18).

Unilateral Loading: A 100 N force was applied on the left first molar region. Strain values were recorded for both loaded and unloaded sides. **Figure (3)**

Statistical Analysis

The data were analyzed using IBM SPSS v25. The following statistical tests were conducted:

Two-Way ANOVA: To assess the impact of bone condition and loading condition on strain distribution.

RESULTS

A significant increase in strain values around implants was observed in group II (resorption group) compared to group I (normal group) across all loading conditions. Under bilateral loading, the mean strain in group I (normal group) was 73.25 ± 9.13 με, while in group II (resorption group) it was 210.14 ± 15.12 με, indicating a statistically significant difference ($p < 0.001$). **Table (1) Figure (4)**

In the unilateral loading, the difference between two groups became even more pronounced. On the loaded side, strain values in group I (normal bone) were 104.01 ± 2.84 με, while group II (resorption group) exhibited 474.36 ± 58.04 με ($p < 0.001$). Similarly, on the unloaded side, strain increased from 9.92 ± 3.69 με in group I(normal group) to 56.76 ± 5.39 με in group II (resorption group) ($p < 0.001$). **Table (2) Figure (5,6)**

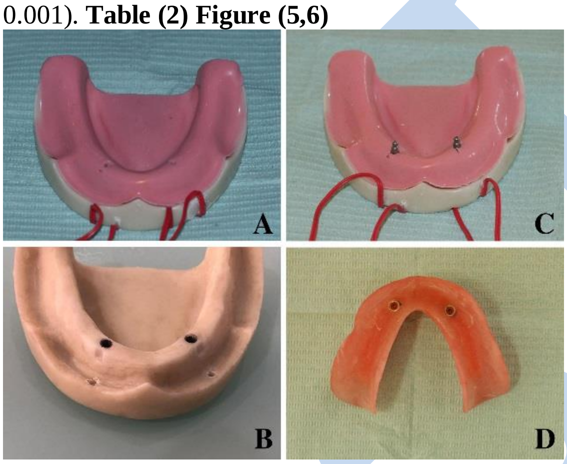

Figure (1): Group I – Normal Bone Model with Narrow-Diameter Implants and Attachment System. **(A)** Normal bone overdenture model. **(B)** Narrow diameter implant. **(C)** Ball and socket attachment. **(D)** Ball and socket housing cap.

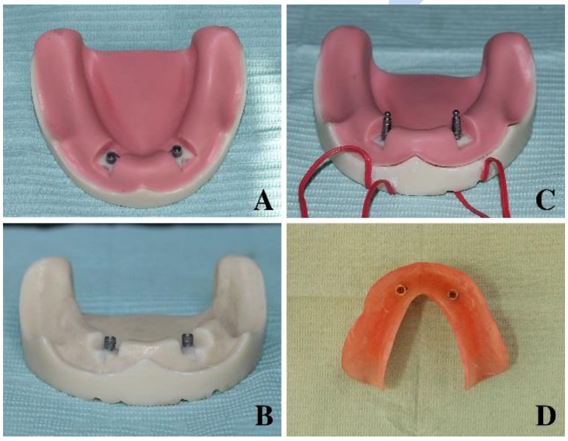

Figure (2): Group II – Resorbed Bone Model with Narrow-Diameter Implants and Attachment System. **(A)** Resorbed bone overdenture model. **(B)** Narrow diameter implant. **(C)** Ball and socket attachment. **(D)** Ball and socket housing cap.

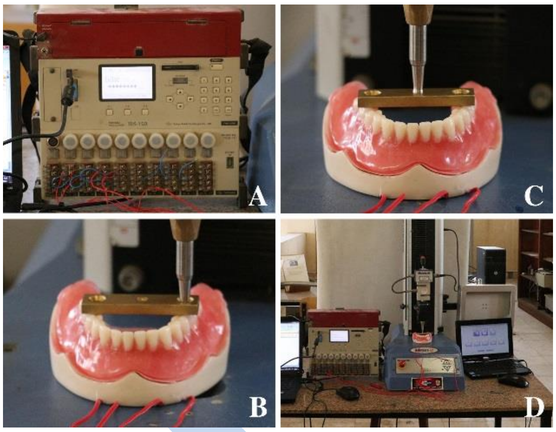

Figure (3): Group I & II – Unilateral loading, Bilateral loading, Measure strain. **(A)** Strainmeter. **(B)** Unilateral Load. **(C)** Bilateral Load. **(D)** Universal testing machine & Strainmeter.

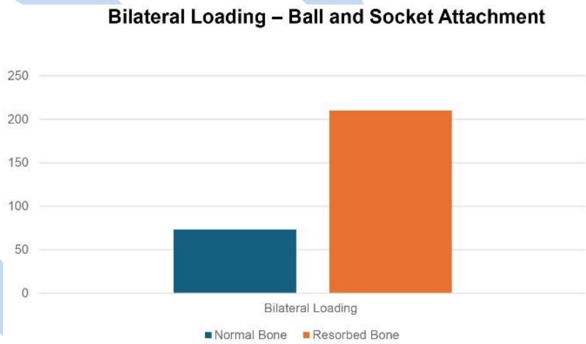

Figure (4): Bilateral Loading

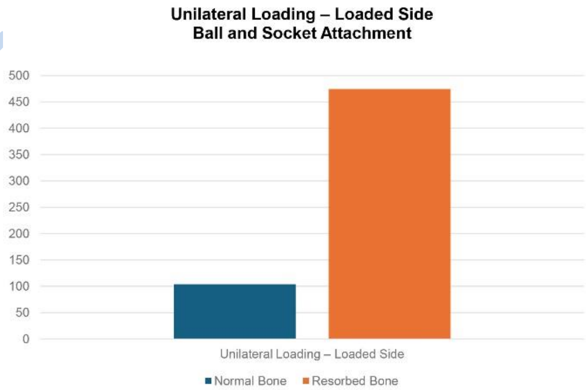

Figure (5): Unilateral Loading – Loaded Side

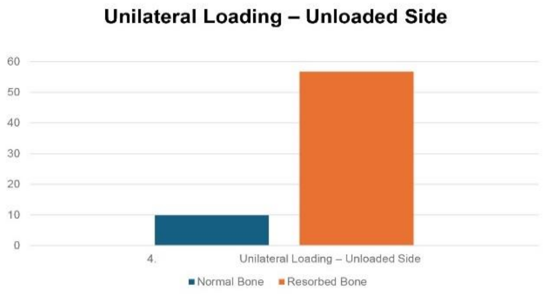

Figure (6): Unilateral Loading – Unloaded Side

The effect of bone condition and loading pattern was further evaluated using a two-way ANOVA. Results showed highly significant main effects for both groups ($F = 1097.11$, $p < 0.001$) and loading pattern ($F = 1327.19$, $p < 0.001$), with large effect sizes (partial eta squared = 0.958 and 0.965, respectively). Furthermore, a significant interaction effect between bone type and loading was identified ($F = 5.50$, $p = 0.023$), indicating that the influence of loading is not independent of bone condition. Strain levels under unilateral loading were significantly exacerbated in the resorbed bone model. **Table (3)**

Table (1): Bilateral Loading – Ball and Socket Attachment

Bone Type	Mean Strain ± SD	95% CI	p-value
Normal Bone	73.25 ± 9.13	64.80 – 81.69	
Resorbed Bone	210.14 ± 15.12	196.15 – 224.13	<0.001*

Table (2): Unilateral Loading (Loaded– Unloaded) Side

Bone Type	Mean Strain ± SD	95% CI	p-value
Loaded			
Normal Bone	104.01 ± 2.84	101.38 – 106.64	
Resorbed Bone	474.36 ± 58.04	420.69 – 528.03	<0.001*
Unloaded			
Normal Bone	9.92 ± 3.69	6.51 – 13.34	
Resorbed Bone	56.76 ± 5.39	51.77 – 61.74	<0.001*

Table (3): Two-Way ANOVA (Bone Type × Loading Effect on Ball and Socket)

Source	Mean Square	F	p-value	Partial Eta Squared
Bone Type	660334.70	1097.11	<0.001*	0.958
Loading (Uni vs Bi)	798818.30	1327.19	<0.001*	0.965
Bone Type × Loading	3311.70	5.50	0.023*	0.103

DISCUSSION

The null hypothesis was rejected as the invitro study demonstrated significantly higher strain around implants in group II (resorption group) compared to group I (normal group) across all loading conditions ($p<0.001$). Under bilateral loading, strain values in group II (resorption group) nearly tripled those in group I (normal group) which suggests that even symmetrical occlusal forces generate significantly greater mechanical stress in compromised bone. The elevated strain levels may contribute to progressive bone loss.

During unilateral loading, The difference in strain values became even more pronounced, where the loaded side in group II (resorption group) showed a 4.5-fold increase in strain compared to group I (normal group). The ball attachment system's compromised load distribution capacity in resorbed bone was particularly evident from the significant strain transfer to the unloaded side, indicating that bone loss compromises the entire implant system's ability to distribute occlusal forces effectively. This finding has particular clinical relevance as many edentulous patients develop unilateral chewing patterns.

The selection of narrow-diameter implants (NDIs) was selected for this study, as they represent the only viable option for severely atrophic mandibles while providing higher strain sensitivity due to reduced surface area (19). 14 mm implant length was selected as it is thought to be an adequate length to achieve the best possible stress distribution around the implants. According to Georgiopoulos et al (20). Implants shorter than 10 mm do not substantially decrease the strain field, but implants between 10 and 14 mm cause less stress on bone tissue during both immediate and delayed implant loading. Although implant diameter is generally more critical for minimizing peri-implant stress, longer implants still play a notable role in reducing stress particularly when bone quality is poor. Short implants with a larger diameter can also achieve low stress, but if diameter cannot be increased due to anatomical limitations, increasing length is beneficial for stress distribution (21).

The surgical guide ensured standardized implant positioning, eliminating placement variables that could affect strain measurements. Because the alveolar crest around the implant's neck is typically where stresses and bone loss begin, and because compression of the cortical bone there may result in overloading, strain gauges were glued to the crest of the ridge surrounding the implants (10,22). Ball attachments were tested as they're the most clinically prevalent and cost-effective option (23,24).

Epoxy resin is a suitable material for fabricating edentulous jaw models in biomechanical studies investigating bone loss effects. Its consistent mechanical properties and ability to mimic modulus of elasticity similar to that of jaw bones make it ideal for standardized laboratory experiments (25,26).

The 4 mm vertical bone loss (28.6% of the 14 mm implant length) was selected as it represents a critical biomechanical threshold where implant stability becomes compromised. This specific bone loss reduces the bone-implant contact area by approximately 30%, significantly altering load distribution by shifting stress concentrations from the crestal to apical regions. The 28.6% bone loss threshold was selected because it reflects clinical situations where bone loss exceeding 3–4 mm usually necessitates therapeutic intervention to avoid catastrophic failure, and it captures the transitional phase where the implant system is still functional but exhibits obvious mechanical deterioration. This degree of simulated bone loss effectively reveals the progressive nature of biomechanical compromise in atrophic cases (27).

The use of two implants in this study aligns with the McGill (2002) and York (2009) consensus guidelines, which established two-implant overdentures as the gold standard for edentulous mandibles due to their optimal balance of function, cost-effectiveness, and minimal invasiveness. This approach allowed us to evaluate mechanical stress distribution under clinically relevant, high-risk conditions of marginal bone resorption (22,28).

In the current study the strain recorded exceeding 400 με in group II (resorption group) under unilateral loading far surpass the 200-300 με range considered physiologic for bone maintenance, potentially triggering further bone resorption. This may be due to a longer crown implant ratio increases the moment arm, which raises the possibility of occlusal overload on the supporting bone and prosthesis. This finding gains support from Nguyen et al (2019) (29) who reported that strain patterns increased rapidly on the loading side as bone loss levels increased, though their study focused on standard-diameter implants.

The consistency between findings suggests that bone quality may be more critical than implant diameter in determining strain distribution patterns .The findings also suggest that increased strain around implants associated with bone loss could predispose to further bone resorption or implant failure if bone condition and load conditions are not optimized.

The study by Rismanchian et al (2016) (30) investigated the biomechanical performance of implant-supported overdentures, they examined stress distribution in ball and locator attachments across tissue-level and bone-level implants .A key agreement between the two studies is the significant influence of bone quality on stress and strain distribution. They found that tissue-level implants transferred higher stresses to surrounding bone compared to bone-level implants, particularly when used with locator attachments. Similarly, the current study demonstrated that group II (resorption group) exhibited substantially higher strain values around implants than group I (normal bone) under both unilateral and bilateral loading conditions. These findings collectively underscore the biomechanical vulnerability of compromised bone, emphasizing the need for careful treatment planning in patients with poor bone support.

However, the studies differ in their focus on attachment systems. Rismanchian et al (30) concluded that ball attachments in bone-level implants had a higher risk of screw fracture due to concentrated stress at the hex and first thread regions. In contrast, the current study did not evaluate different attachment types but instead highlighted the biomechanical disadvantages of marginal bone loss, particularly under unilateral loading. This suggests that while attachment selection is crucial for prosthetic longevity, bone quality remains a dominant factor in overall implant success.

Another study by Guo et al (2021) (15) investigated the biomechanical effect of marginal bone resorption on the mandibular mini implant-retained overdenture retained by magnetic attachment system on the edentulous model. He confirmed that MBR increases strain values around implants reporting a 1.5-fold rise at 50% bone loss versus our finding of 3-4.5-fold elevation. This disparity likely stems from differing attachment systems as magnetic attachments in Guo et al.'s study reduced strain through stress-breaking effects.

Key clinical implications emerge from these findings. For moderate MBR (30-50% bone loss), magnetic systems provide superior force distribution with only annual monitoring required. In contrast to the current study, ball attachments demand rigorous maintenance and should be avoided when MBR exceeds 50%. The findings confirmed that bilateral loading reduces strain values compared to unilateral loading, reinforcing the importance of balanced occlusion. Based on the above results, the MBR severity should guide attachment selection in prosthodontic practice, with magnetic systems preferred for compromised bone cases.

CONCLUSION

Within the limitations of this study, the following conclusions were obtained:

- Bone resorption significantly increased strain around implants (3 fold in bilateral loading, 4.5 fold in unilateral loading).
- Ball attachments showed limited ability to compensate for bone loss, particularly under unilateral forces.

- Based on the obtained results, bilateral loading is preferable, and alternative retention systems should be considered for atrophic cases. These findings highlight the critical role of bone quality in implant biomechanics.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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