EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 70, 2487:2498, July, 2024

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 13-03-2024 • Accept Date : 16-05-2024 • Available online: 10-07-2024 • DOI : 10.21608/EDJ.2024.276457.2978

INFLUENCE OF IMPLANT INCLINATION ON PERI-IMPLANT BONE STRESS ASSOCIATED IN MANDIBULAR THREE IMPLANT OVERDENTURES: A FINITE ELEMENT ANALYSIS

Amr A. Emarah[*], Nasser Zaki Ahmed[**], Mostafa Aldesoki[***], Kamal Ghamry Metwally[****] *and* Amr Salah el-din Gomaa[*]

ABSTRACT

Purpose: This study addresses stress distribution in the peri-implant bone of mandibular overdentures supported by there implants with different inclinations.

Materials and methods: Three separate 3D FE models were prepared to simulate mandibular implant overdentures with ball attachments. Each model was modified according to distal implant's inclination (0, 15, and 25 degrees), while the midline implant was kept straight. Four loads were applied to the denture: clench, masseter, pterygoid, and temporal loads. The behavioral characteristics of the peri-implant bone and the implants were studied and recorded under the applied loads for the three implant inclinations.

Results: According to the study, the stress distribution in the mandible varied depending on the implant inclination. The maximum stress observed on the mandible ranged from 19.1 to 36.1 MPa across all cases studied. As the implant inclination increased, the maximum stress and strain increased in both the mandible and implants. However, the rate of increase was found to be less pronounced at higher fixation angles.

Conclusion: These findings suggest that implant inclination should be carefully considered to minimize stress and strain on the mandible and implants during treatment planning for implant-supported overdentures.

KEYWORDS: Finite element analysis, Implant supported overdenture, Ball attachment, Inclined implant, Stress distribution.

* Associate Professor, Department of Prosthetic Dentistry, Faculty of Dentistry, Fayoum University, Egypt.
** Associate Professor, Structural Analysis and Mechanics Department, Beni-Suef University, Faculty of Engineering, Egypt.
*** Oral Technology, University Hospital Bonn, Germany.
**** Professor, Structural Analysis and Mechanics Department, Beni-Suef University, Faculty of Engineering, Egypt.

INTRODUCTION

In recent years, the use of dental implant overdentures has become increasingly popular as a standard approach for addressing the challenge of edentulous mandibles. Various treatment methods have been applied to secure and stabilize dentures on edentulous mandibular ridges [1,2]. Among these approaches, implant-supported mandibular overdentures have emerged as a highly effective solution for edentulous patients [3,4,5,6]. Typically, mandibular overdentures gain support through the installation of 2 to 5 implants positioned between the mental foramina, along with soft tissue support in the posterior regions [7,8]. Research indicates that a more even distribution of stress occurs when the load is distributed across a greater number of implants [9,10,11]. Using 2 or 3 implants can offer a practical and cost-effective way to secure and stabilize dentures, providing economic benefts to the patient [8,12]. Furthermore, placing more than 2 implants within the interforaminal area can enhance the implant-to-bone contact area, thereby improving stress distribution and minimizing crestal bone loss[7]. Additionally, installing more than two implants in this region can introduce an angular relationship between the implants instead of a linear arrangement [8].

Numerous research studies have delved into different overdenture attachment designs [13,14]. These investigations have revealed that the incorporation of attachments in conjunction with implants can significantly improve the retention and stability of dentures, ultimately extending their longevity as well as the lifespan of the implants [14].Among the simplest types of attachments for clinical use with implant overdentures are Ball attachments. These attachments consist of a metal ball that is securely fastened into the implant, while the female part is integrated into the intaglio surface of the denture [15]. The Ball attachment offers several advantages, including the minimization of denture movement and the optimization of stress distribution [16].

In another study, a comparison was made regarding the retention of bar/clip, ball, and magnet attachments in mandibular implant-retained overdentures. The results showed that the ball and socket attachment exhibited the highest retention values, followed by the bar/clip attachment, with the magnet attachment ranking third [17].

Prolonged edentulism can lead to alveolar process resorption, which can, in turn, limit the placement of dental implants. Various approaches have been developed to address insufficient mandibular bone structure. One strategy involves the utilization of inclined implants to circumvent potential interference with the mandibular nerve[1,18]. In a two-dimensional finite element (FE) study conducted by Watanabe et al. [19], the placement of a single implant revealed that, regardless of the location and direction of the applied load, compressive stress at the bone-implant interface increased as the implant inclination angle increased. Similar findings were observed in related studies investigating non-splinted implants[20,21].

The utilization of Finite Element Analysis (FEA) has become prevalent in investigating stress and strain distribution at the peri-implant bone interface within edentulous jaws[4,22]. Despite the inherent constraints associated with this theoretical method, FEA continues to serve as a valuable instrument for the examination of stress distribution in intricate structures, such as the human alveolar bone.

Batisse [23] has emphasized that the success of a dental implant is influenced by multiple factors, including the quality and quantity of jawbone, implant design, implant surface texture, surgical techniques, and other variables. Among these factors, implant design has garnered increasing attention as a pivotal element. Consequently, extensive research has been conducted to evaluate how implant configuration impacts stress distribution. Hong et al. [24] conducted an examination of bone stress in the vicinity of dental implants that support mandibular overdentures under various implant positions and loading conditions. Through the use of three-dimensional models, the study explored four different implant positions and assessed the impact of varying loads. The findings revealed that unilateral loading induced greater stress on the loaded side compared to bilateral loading, which distributed stress more evenly. Notably, the second premolar implant model consistently demonstrated the most favorable biomechanical conditions. In conclusion, the research recommends the use of second premolar implants in overdenture design, underscoring the influence of occlusal loading on the distribution of bone stress.

Ebadian et al. [25] carried out a study to assess how implant inclination affects stress distribution in the bone surrounding implants that support mandibular overdentures. They examined three different implant models, each with different inclinations (0 and 20, and used a bar-and-clip attachment system. The overdenture was subjected to unilateral vertical loading, focusing on the first molar and first premolar regions. The study's results revealed a significant association between implant inclination and stress distribution, particularly when the load was concentrated on the molar area. However, this effect was notably absent when the load was directed at the premolar region. Taking into account the study's inherent constraints, the results indicate that implant inclination may not have an adverse effect on stress distribution patterns around the implants in mandibular overdentures. However, there remains a notable scarcity of comprehensive finite element analysis (FEA) studies that directly compare the stress distribution between inclined and straight implants in overdentures supported by a set of three implants. This particular investigation employs FEA techniques to delve into the effects of implant inclination on the distribution of stress and strain within the mandible. The significance of this research lies in its potential to advance the design and clinical outcomes of implant-supported overdentures by assessing how implant inclination influences peri-implant bone stress. These findings hold promise in offering valuable insights to clinicians and prosthodontists, allowing for the optimization of treatment plans and ultimately enhancing the quality of life for patients relying on such dental restorations.

MATERIAL AND METHOD

Numerical model

The modeling process comprised several sequential steps (Fig. 1). A patient with edentulous mandible and his denture was scanned with cone beam computed tomography (CBCT), and a 3D mandibular model was created in the Mimics software (Fig. 2). A 4.1mm diameter, 10mm length implants were along with the BALL attachments (Fig. 3) were designed by using the SOLIDWORKS software program. Finally, a three-dimensional (3D) finite element (FE) model was developed for the mandible, overdenture, and implants with ball attachment using ANSYS Workbench software (Fig. 4). These steps collectively formed the foundation for the modeling process.

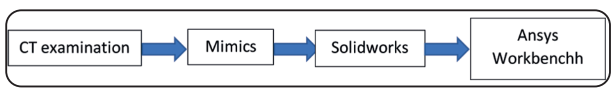

Fig. (1) Modeling process

The overdenture was anchored to the mandible using three implants one in the midline and 2 distal implants bilaterally in the second pemolar region. We developed three separate 3D FE models for the mandible supporting the implant overdenture, each featuring a distinct implant inclination, as depicted in (Fig. 5). While the midline implant remained vertical in all three models, we adjusted the fixation angle of the two end implants in the following manner:

- Model A all implants are vertically positioned.
- Model B terminal implants inclined at an angle of 15°
- Model C terminal implants inclined at an angle of 25°

Fig. (2) CAD model of the mandible

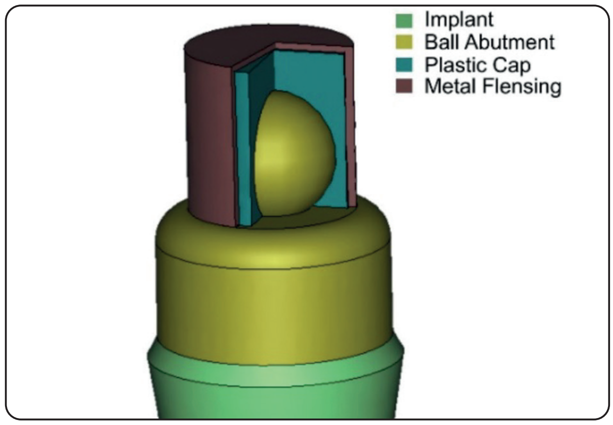

Fig. (3) Ball attachment details

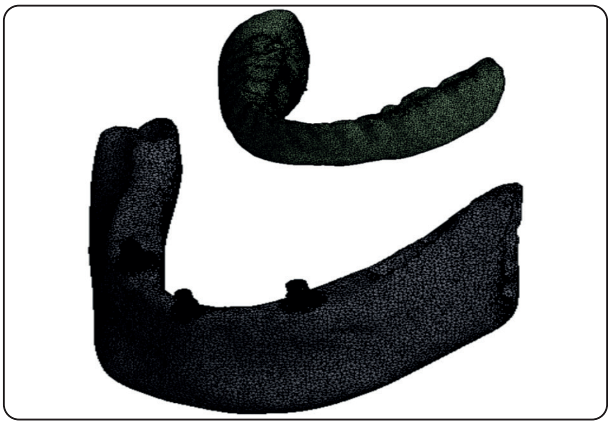

Fig. (4) Finite element meshing using Ansys Workbench program

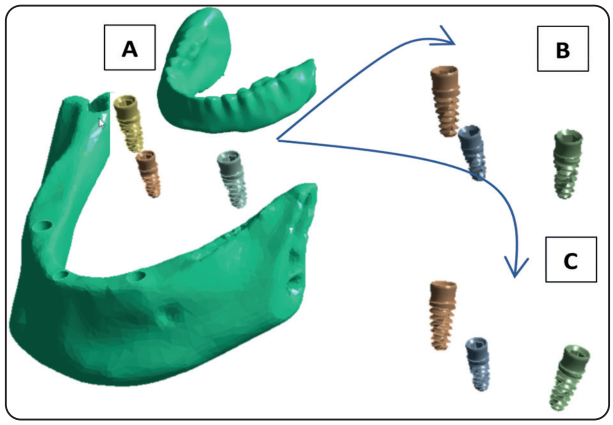

Fig. (5) Finite element models of the mandible and prosthetic components: (A) Implants with 0 degrees; (B) Implant with 15 degrees; (C) Implants with 25 degrees

The three models were meshed using 3D four-node tetrahedron elements. The total number of elements is 429713, while the total number of nodes is 116009.

Material properties

The material models were non-homogeneous with six properties: isotropic and linearly elastic. Properties of the mandible and implant components were assigned from values obtained from the literature [26] (Table 1).

TABLE (1) Isotropic material properties

Material	Elastic modulus in Megapascal unit (MPa)	Poisson's ratio
Mandible bone	13,700	0.30
Implant Titanium	1,030,000	0.35
Attached Ball	200,000	0.30
O ring rubber	5	0.45
Metal housing	200,000	0.30
Denture acrylic	8300	0.28

Boundary condition and loading

(Fig. 6) illustrates the boundary condition and loading applied to the three models. Fixed restraints were assumed at the ends of the mandible. Also, seven loads were applied to the model, listed in (Table 2). These loads were obtained from the literature [27]. The application of four distinct loads—clench, masseter, pterygoid, and temporal loads—constituted a crucial aspect of this study. These loads were chosen to simulate various masticatory and functional forces that the mandibular overdenture

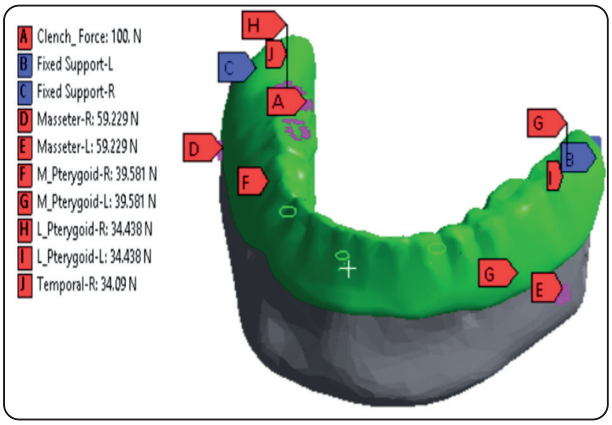

Fig. (6) Numerical model loading and boundary condition

TABLE (2) Maximum direction deformation (Z-Axis) in μm

Model	Maximum equivalent strain
A	178
B	188
C	195

may experience in real-world scenarios. The 'clench' load represents the force applied while biting down or clenching, simulating the static loading experienced during normal occlusion. This load is particularly interesting as it reflects the forces imposed on the mandibular overdenture during daily activities such as chewing. The 'masseter' load was employed to mimic the forces generated by the masseter muscle during mastication. The masseter is one of the primary muscles involved in chewing, and this load helps replicate dynamic masticatory forces on the implant-supported overdenture. The 'pterygoid' load was chosen to simulate the forces exerted by the pterygoid muscle group, which plays a role in lateral jaw movement. This load is vital as it replicates lateral forces that the overdenture may encounter during functional movements. Lastly, the 'temporal' load was applied to represent the forces generated by the temporalis muscle, another major masticatory muscle. This load accounts for the vertical forces exerted during biting and chewing. By subjecting the mandibular overdenture to these four diverse loads, our study aimed to analyze stress distribution under various functional conditions comprehensively. The results obtained under these loads offer valuable insights into the performance of implant-supported overdentures and contribute to our understanding of how implant inclination impacts stress distribution in clinical practice.

Contact management

To simulate complete implant osseointegration, total bonding between bone and implants was assumed so that no motion between the two structures occurs under applied loading.

RESULTS

The study involved the creation of three distinct models using ANSYS Workbench. The initial model, referred to as Model A, featured three vertical implants. Model B, the second iteration, also incorporated three implants, but with a distinctive characteristic – the two end implants were set at a 15-degree angle relative to the Z-axis. Model C, the final model in the series, closely mirrored its predecessors but with the notable distinction of the two end implants being fixed at a 25-degree angle. These three models served as the basis for an in-depth exploration into how varying implant fixation angles affect stress distribution in peri-implant bone, providing a comprehensive analysis of this critical aspect of dental implantology.

Maximum directional deformation

(Fig. 7) illustrates the directional deformations along the Z-axis for the three different implant inclinations. Notably, the highest deformation values were consistently observed near the applied load for all three implant fixation angles. Detailed information on the maximum deformations can be found in (Table 2), where it is evident that these values remained below 200 μm in all cases. Furthermore, there was a noticeable upward trend in deformation values as the implant fixation angle increased, indicating a correlation between increased implant inclination and heightened deformations.

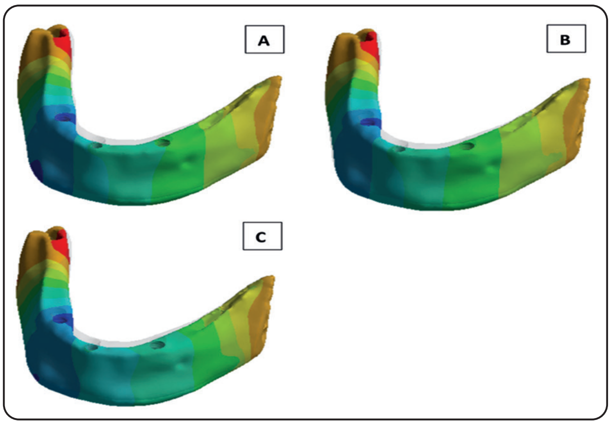

Fig. (7) Directional deformation in Z-Axis for various implant orientation angle

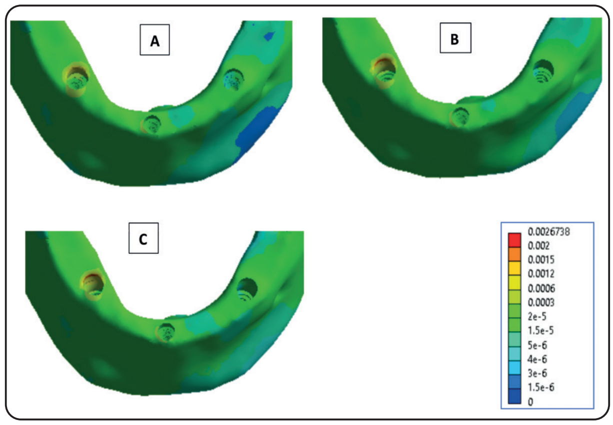

Fig. (8) Equivalent strain distribution on mandible for various implant orientation angle

Strain distribution in the mandible

(Table 3) provides a comprehensive overview of the maximum strain levels within the mandible for the three distinct implant inclinations. Notably, a discernible trend emerges, as these peak strain values consistently exhibit an upward trajectory with increasing implant fixation angles. This crucial observation underscores the influence of implant inclination on mandibular strain.

TABLE (3) Maximum equivalent strain in the mandible for various implant inclination

Model	Maximum equivalent strain
A	0.006
B	0.0063
C	0.0087

To offer a visual representation of this strain distribution, we turn to (Fig. 8). Here, we can observe that the maximum strain primarily localizes in the peri-implant bone surrounding the left implant for all three cases. However, it's worth noting that the strain values surrounding the other two implants show a notable increase in cases B and C compared to case A, indicating a significant impact of implant inclination on the strain distribution pattern within the mandible.

Stress distribution in the mandible

(Table 4) provides a comprehensive insight into the maximum equivalent strains within the mandible, considering various implant fixation angles. A noteworthy observation emerges – the maximum stress in case C is approximately twice that of case A. In comparison, case B records a maximum stress level of roughly 90% of that in case C. This indicates a clear, albeit non-linear, relationship between the degree of implant inclination and the resultant maximum stress levels. While there is a general increasing trend in maximum stress as implant fixation angles increase, it is worth highlighting that this trend is less pronounced between cases B and C, showcasing the complexity of this relationship.

To visually represent the distribution of equivalent stress, we turn to (Fig. 9). This graphical depiction underscores the localization of stresses around the left implant near the applied loads. Furthermore, a discernible but moderate increase in stress can be observed between the three cases concerning the peri-implant bone surrounding the middle and right implants.

TABLE (4) Maximum equivalent stresses in the mandible for various implant inclination

Model	Maximum equivalent stress (MPa)
A	19.3
B	32.2
C	36.1

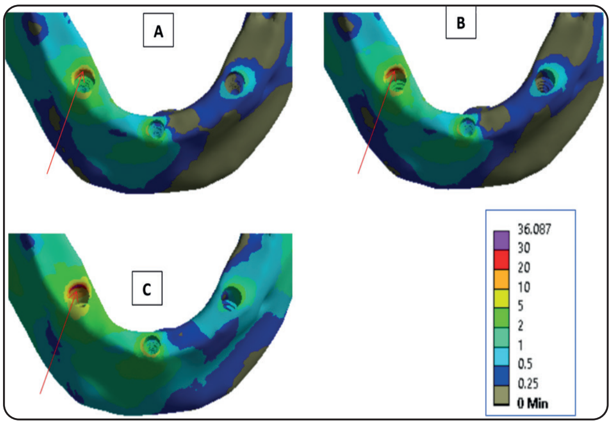

Fig. (9) Equivalent stress distribution (MPa) on mandible for various implant inclination

Stress distribution in the implants

The maximum equivalent stress in the implant for the different implant inclinations is shown in (Table 5). The maximum stress of 342.9 MPa from case A was located at the left implant near the applied load. Also, the maximum stress value of case A was about two and a half times the maximum stress value of case C. Moreover, the increasing trend can be noted in stress values with increased implant fixation angle. Stress distribution in the implants is shown in (Fig. 10). The left implant was the most stressed implant near the applied loads.

TABLE (5) Maximum equivalent stresses in the implants for various inclination

Model	Maximum equivalent stress (MPa)
A	133.1
B	199.1
C	342.8

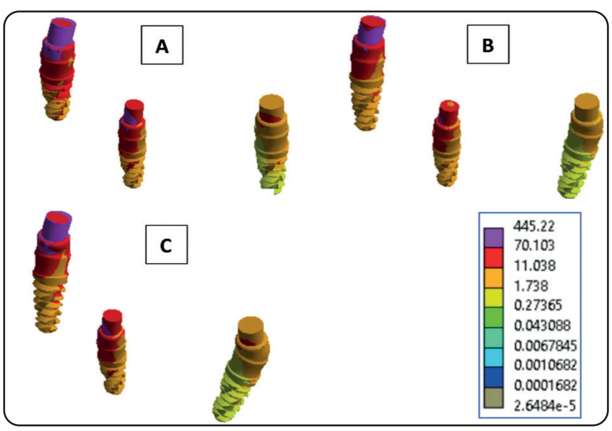

Fig. (10) Equivalent stress distribution (MPa) on implants for various implant inclination

DISCUSSION

Biomedical engineering offers a valuable platform for exploring the biomechanical properties of dental implants and prosthetic devices. It enables the assessment and quantification of the stresses acting on implants and the strains experienced by prosthetic components[28]. In clinical practice, it is often challenging to assess the distribution of stress and strain within the bone when supporting overdentures with implants. However, it is feasible to analyze stress and strain distribution at the abutment level using strain gauges[29]. In a broader context, achieving biomechanical stability for implants in implant overdentures requires the even distribution of loads to prevent excessive concentration in specific areas. Excessive stress on the bone can lead to bone resorption, while stress on both the implant fixture and the superstructure can result in complications like screw loosening, abutment fractures, or superstructure joint fractures[30].

In all the models investigated, the overdenture material demonstrated its effectiveness in absorbing a significant portion of the applied load energy, thereby ensuring the preservation of jawbone integrity. The Von Mises stresses were mainly localized on the side where the load was exerted, with minimal influence on the opposite side, aligning with results observed in previous research studies[31].

Typically, overdentures rely on either independent or splinted attachments to establish a retention system. The selection of attachments hinges on crucial factors such as retention, stress distribution, restorative space, and maintenance considerations[29]. The effective transmission of masticatory forces significantly impacts the success of implant restorations[32]. Research has indicated that utilizing non-splinted implants in overdentures, as opposed to implants with splinted bars, can reduce the concentration of stress on the supporting bone[28,32].

In cases involving spongy bone anchored with ball attachments, the independent nature of the implants enables them to adapt to bone deformations without adversely affecting it. Furthermore, the use of Ball attachments facilitates a broader distribution of stress compared to the bar and clip attachment system. The rigid bar, often used to interconnect implants, tends to counteract such adaptability, leading to increased stress on the supporting bone in bar and clip setups. An in vivo study conducted by Fromentin et al.[33] corroborates the findings of the present study, underscoring the effectiveness of the finite element model. These outcomes align with a study by Cavallaro and Tarnow[32], which concluded that unsplinted implants with ball-attachment overdentures offer advantages including improved esthetics, phonetics, cost savings, simplified placement, and easier hygiene maintenance. Furthermore, additional in vivo research by Fromentin et al.[33] corroborates the findings of the current study, providing further support for the reliability of the finite element model used.

The stress patterns surrounding implants that support overdentures are generally considered more intricate compared to those in fixed prostheses. Moreover, this complexity is compounded by the greater resilience of the mucosa and the mobility of the prosthesis. In the current study, the choice of load levels (15 and 30 pounds) was deliberate, as they fall within the range of typical occlusal masticatory forces and closely approximate the maximum loads recorded in patients with implant overdentures[8,11,34]. The selection of the first molar as the focal point was driven by the fact that this region experiences the greatest contraction of all elevator muscles during maximum bite forces. Furthermore, the first premolar was chosen to apply a load more anteriorly, corresponding to the primary area for chewing food, typically situated between the premolars and molars[30,35]. Unilateral forces were employed in this manner due to the findings of several studies, which have reported no noteworthy disparity in stress patterns generated by loading either the right or left side of the dental arch[8,21]. Moreover, researches has indicated that when unilateral loading occurs, minimal to no discernible stress is transmitted to the non-loaded side of the arch[8,21,34,35].

Numerous studies consistently revealed that as the inclination angle of implants increased, stress levels rose, especially when the implants were not splinted, leading to a more noticeable rotational force[19,21,36]. However, when implants are integrated into multi-implant-supported superstructures, the wider distribution of the implants and the increased rigidity of the superstructure serve to mitigate the resulting stress[19,36,37,38,39]. Zampelis et al. [37] concluded that this phenomenon can be attributed to the fact that stress distribution within the bone follows a similar pattern regardless of the inclination angle of the implants. Even in a study by Jofre et al. [40], it was found that mini-implants supporting a mandibular overdenture exhibited less marginal bone loss when they were splinted compared to their non-splinted counterparts.

In a study conducted by Celik et al.[8], load transfer characteristics were compared across four distinct attachment systems for a mandibular overdenture supported by three implants, which included both vertically oriented and inclined implants (0 and 20 degrees). For the scenario involving inclined implants in Celik's study, it was noted that moderate stresses were observed in non-splinted designs, while low stresses were recorded in splinted designs, particularly on the side with the loaded implant.

In the context of this study, it was observed that applying a load in the molar region led to a reduction in the overall stress within the bone surrounding the implants, while loading in the premolar region did not alter the stress distribution pattern in the surrounding bone. These findings collectively indicate that posterior loading, even with inclined implants, does not substantially increase the stress in the bone surrounding the implants. Some studies have also noted that applying loads more toward the posterior region tends to enhance the transfer of stress to the edentulous ridge through the denture base, concurrently reducing the load on the implant on the same side [8,21].

The findings of the current study present a contrast to earlier research concerning the localization of the highest resultant stress during molar region loading. Previous studies consistently reported that simulated occlusal forces in the molar region resulted in the highest stresses on the contralateral implant, leading to reduced load transfer to the adjacent implant, irrespective of the anchorage design[8,11,20,34,35]. It is important to note that the present study differs from these prior investigations in terms of the number of implants, connector design, and the presence of resilient mucosa beneath the overdenture.

Another potential explanation for this contrast lies in the distinctive rotational movement observed in the design of the 3-implant-retained mandibular overdenture in this study, as opposed to other research. This variation may be attributed to premature contact between the acrylic denture base and the contralateral implant, underscoring the importance of precise relief of the acrylic denture base around the overdenture abutments, especially when employing more resilient rings for the ball attachment. Unexpectedly, the study noted that there was minimal to no discernible stress on the middle implant, and it experienced lower stress levels than the remaining residual ridge. In terms of stress distribution, it can be deduced that using more than two implants to support mandibular overdentures may be superfluous. This observation is in agreement with specific other studies that have also concluded that there seems to be no requirement for more than two implants to support an overdenture[9,10].

Nonetheless, the approach of placing three implants and linking them with a crossbar has been discussed in the literature, where the middle implant function as an indirect retainer for the prosthesis[8,41,42]. This configuration comes with benefits, including a reduced risk of screw loosening and an increased implant-to-bone contact surface, promoting more uniform force distribution and lessening crestal bone loss[7]. In our present study, when the load application point shifted toward the posterior, it resulted in reduced stresses at the ipsilateral and middle implants while increasing the stress generated in the contralateral implant and the residual ridge. These findings are in accordance with Federick et al.[21], particularly concerning the stress applied to the residual ridge.

When the load in the molar region was increased in the current study, going from 15 to 30 pounds, the resulting stress followed a similar escalating pattern. This observation aligns with findings from Tashkandi et al.[43] and Kennedy et al.[44], where the strain patterns remained consistent with increasing loads. Therefore, it can be deduced that as the load intensifies, the strains transferred to both the implant and the surrounding bone increase. It's essential to recognize that finite element studies come with inherent theoretical limitations when predicting how biological tissues respond to applied loads[37,45]. Consequently, making conclusive clinical decisions solely based on these studies is not advisable. It's crucial to acknowledge that peri-implant tissues are intricate, and their representation in finite element analysis remains an approximation[37].

In the present study, we assumed complete adherence at the bone-implant interface, which may not mirror the actual clinical scenario[46], where osseointegration defects in the peri-implant region are possible[47,48]. Additionally, the connecting screws at the implant-abutment interface were not modeled, although some authors indicating that including the screw in the model is not essential [37].

CONCLUSION

This study examined the impact of implant inclination on peri-implant bone stress in the context of mandibular overdentures supported by three implants. The insights obtained from the finite element analysis in this research enhance our comprehension of the biomechanics related to implant-supported overdentures. The conclusions drawn from this study hold particular significance in:

- The research highlights that the inclination of dental implants significantly affects the distribution of stress within the peri-implant bone. As the inclination angle increases, the stress concentration at the implant-bone interface also increases, with the greatest stress observed around the implant near the applied load at an implant inclination of 25 degrees
- The careful evaluation of implant angulation is an essential step in treatment planning for clinicians. Precise angulation can effectively alleviate stress concentration and curtail the incidence of peri-implant bone complications.
- With a greater implant inclination, there was an observed increase in maximum stress and strain in both the mandible and implants. Nevertheless, the rate of this increase was comparatively less significant at higher fixation angles
- Applying the load in the molar region resulted in a decrease in bone stress around the implants, while loading in the premolar region maintained the existing stress distribution pattern in the surrounding bone unchanged.
- The study suggests that an optimal implant inclination exists, which promotes a more even distribution of stress across the peri-implant bone. This finding can guide implant placement and surgical techniques to enhance long-term implant success
- Clinicians should consider patient-specific factors, such as bone quality, ridge morphology, and occlusal forces, when determining the optimal implant angulation. This individualized approach can help mitigate stress-related complications
- The study acknowledges its limitations, including the simplifications made in the finite element model. Future research should explore a wider range of clinical variables and incorporate more complex models to provide a more comprehensive understanding of the topic.
- The research contributes to the field of dental implantology by offering valuable biomechanical insights into the factors that influence peri-implant bone stress, enhancing the evidence-based approach to treatment planning.

In conclusion, the findings of this finite element analysis emphasize the importance of implant inclination in mandibular overdenture treatments. Understanding the biomechanical implications of implant angulation can help clinicians make informed decisions to optimize implant success and patient outcomes. This research represents a valuable addition to the body of knowledge in the field of implant dentistry and paves the way for further exploration of this critical aspect of implant-supported prosthetic design.

REFERENCES

1. Bellini CM, Romeo D, Galbusera F, Taschieri S, Raimondi MT, Zampelis A, et al. Comparison of tilted versus non-tilted implant-supported prosthetic designs for the restoration of the edentuous mandible: a biomechanical study. Int J Oral Maxillofac Implants. 2009;24:511–517
2. Naert I, Gizani S, Vuylsteke M, van Steenberghe D. A 5-year randomized clinical trial on the influence of splinted and unsplinted oral implants in the mandibular overdenture therapy. Part I: peri-implant outcome. Clin Oral Implants Res. 1998;9:170–177.
3. Von Wowern N, Gotfredsen K. Implant-supported overdentures, a prevention of bone loss in edentulous mandibles? A 5-year follow-up study. Clin Oral Implants Res. 2001;12:19–25.
4. Prakash V, D'Souza M, Adhikari R. A comparison of stress distribution and flexion among various designs of bar attachments for implant overdentures: a three dimensional finite element analysis. Indian J Dent Res. 2009;20:31–36.
5. Chun HJ, Park DN, Han CH, Heo SJ, Heo MS, Koak JY. Stress distributions in maxillary bone surrounding overdenture implants with different overdenture attachments. J Oral Rehabil. 2005;32:193–205.
6. Ortegon SM, Thompson GA, Agar JR, Taylor TD, Perdikis D. Retention forces of spherical attachments as a function of implant and matrix angulation in mandibular overdentures: an in vitro study. J Prosthet Dent. 2009;101:231–238.

7. Misch CE. The edentulous mandible: an organized approach to implant-supported overdenture. In: Misch CE, ed. Contemporary Implant Dentistry. 3rd ed. St. Louis, Mo: Mosby; 2008:293–313.

8. Celik G, Uludag B. Photoelastic stress analysis of various retention mechanisms on 3-implant-retained mandibular overdentures. J Prosthet Dent. 2007;97:229–235.

9. Meijer HJ, Starmans FJ, Steen WH, Bosman F. A three-dimensional finite element study on two versus four implants in an edentulous mandible. Int J Prosthodont. 1994; 7:271–279.

10. Batenburg RH, Raghoebar GM, Van Oort RP, Heijdenrijk K, Boering G. Mandibular overdentures supported by two or four endosteal implants. A prospective, comparative study. Int J Oral Maxillofac Surg. 1998; 27:435–439.

11. Mericske-Stern R. Force distribution on implants supporting overdentures: the effect of distal bar extensions. A 3-D in vivo study. Clin Oral Implants Res. 1997;8:142–151.

12. Ochiai KT, Williams BH, Hojo S, Nishimura R, Caputo AA. Photoelastic analysis of the effect of palatal support on various implantsupported overdenture designs. J Prosthet Dent. 2004;91:421–427.

13. Ahmed Y A. Attachments Used With Implant Supported Over Denture. Adv Dent & Oral Health. 2016; 1(2): 555560.

14. DeBoer J. Edentulous implants: overdenture versus fixed. J Prosthet Dent. 1993; 69:386-90.

15. .Martínez-Lage-Azorín JF, Segura-Andrés G, Faus-López J, Agustín-Panadero R. Rehabilitation with implant-supported overdentures in total edentulous patients: A review. J ClinExp Dent. 2013; 5:e267-72.

16. El-Anwar M I, Yousief S, Soliman T A, Saleh M M, Omar W S. A finite element study on stress distribution of two different attachment designs under implant supported overdenture. The Saudi Dental Journal 2015; 27: 201–207.

17. Shastry T, Anupama NM, Shetty S, Nalinakshamma M. An in vitro comparative study to evaluate the retention of different attachment systems used in implant-retained overdentures. J Indian Prosthodont Soc. 2016; 16:159-66.

18. Krekmanov L, Kahn M, Rangert B, Lindstrom H. Tilting of posterior mandibular and maxillary implants for improved prosthesis support. Int J Oral Maxillofac Implants. 2000;15:405–414.

19. Watanabe F, Hata Y, Komatsu S, Ramos TC, Fukuda H. Finite element analysis of the influence of implant inclination, loading position, and load direction on stress distribution. Odontology. 2003;91:31–36.

20. White SN, Caputo AA, Anderkvist T. Effect of cantilever length on stress transfer by implant-supported prostheses. J Prosthet Dent. 1994;71: 493–499.

21. Federick DR, Caputo AA. Effects of overdenture retention designs and implant orientations on load transfer characteristics. J Prosthet Dent. 1996;76:624–632.

22. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a threedimensional finite element analysis. J Prosthet Dent. 2008;100:422–43

23. Batisse C, Bonnet G, Bessadet M, Veyrune JL, Hennequin M, Peyron MA, et al. Stabilization of mandibular complete dentures by four mini implants: Impact on masticatory function. J Dent 2016;50:43-50

24. Hong HR, Pae A, Kim Y, Paek J, Kim HS, Kwon KR. Effect of implant position, angulation, and attachment height on peri-implant bone stress associated with mandibular two-implant overdentures: a finite element analysis. International Journal of Oral & Maxillofacial Implants. 2012 Oct 1;27(5).

25. Ebadian B, Mosharraf R, Khodaeian N. Finite element analysis of the influence of implant inclination on stress distribution in mandibular overdentures. Journal of Oral Implantology. 2015 Jun 1;41(3):252-7.

26. Barão VA, Delben JA, Lima J, Cabral T, Assunção WG. Comparison of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible–a computed tomography-based three-dimensional finite element analysis. Journal of biomechanics. 2013 Apr 26;46(7):1312-20.

27. Abdelwahab M, Abdulwahed S, Ghamry M. Finite element analysis of three patterns of internal fixation of the mandibular subcondylar fractures (comparative study). Egyptian Journal of Oral and Maxillofacial Surgery. 2018 Oct 1;9(4):168-73.

28. Barão VA, Assunção WG, Tabata LF, Delben JA, Gomes EA, deSousa EA, Rocha EP. Finite element analysis to compare complete denture and implant-retained overdentures with different attachment systems. J CraniofacSurg 2009; 20:1066- 71.

29. Tokuhisa M, Matsushita Y, Koyano K. In vitro study of amandibular implant overdenture retained with ball,

magnet, or bar attachments: comparison of load transfer and denture stability. Int J Prosthodont 2003; 16:128-34.

30. Gupta S, Gupta H, Tandan A. Technical complications of implant-causes and management: A comprehensive review. Natl J Maxillofac Surg. 2015;6:3-8.

31. Ebadian B, Farzin M, Talebi S, Khodaeian N. Evaluation of stress distribution of implant-retained mandibular overdenture with different vertical restorative spaces: A finite element analysis. Dent Res J (Isfahan). 2012;9:741-7.

32. Cavallaro JS Jr, Tarnow DP. Unsplinted implants retaining maxillary overdentures with partial palatal coverage: report of 5 consecutive cases. Int J Oral Maxillofac Implants. 2007; 22:808-14.

33. Fromentin O, Lassauzay C, Nader SA, Feine J, de Albuquerque RF Jr. Clinical wear of overdenture ball attachments after 1, 3 and 8 years. Clin Oral Implants Res. 2011; 22:1270-4.

34. Sadowsky SJ, Caputo AA. Stress transfer of four mandibular implant overdenture cantilever designs. J Prosthet Dent. 2004;92:328–336.

35. Sadowsky SJ, Caputo AA. Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures. J Prosthet Dent. 2000;84:327–334.

36. Canay S, Hersek N, Akpinar I, Asik Z. Comparison of stress distribution around vertical and angled implants with finite-element analysis. Quintessence Int. 1996;27:591–598.

37. Zampelis A, Rangert B, Heijl L. Tilting of splinted implants for improved prosthodontic support: a two-dimensional finite element analysis. J Prosthet Dent. 2007;97(suppl 6):S35–S43.

38. Menicucci G, Lorenzetti M, Pera P, Preti G. Mandibular implantretained overdenture: finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants. 1998;13:369–376.

39. Assuncao WG, Tabata LF, Barao VA, Rocha EP. Comparison of stress distribution between complete denture and implant-retained overdenture2D FEA. J Oral Rehabil. 2008;35:766–774.

40. Jofre J, Cendoya P, Munoz P. Effect of splinting mini-implants on marginal bone loss: a biomechanical model and clinical randomized study with mandibular overdentures. Int J Oral Maxillofac Implants. 2010;25:1137– 1144.

41. Mericske-Stern RD, Taylor TD, Belser U. Management of the edentulous patient. Clin Oral Implants Res. 2000;11(suppl 1):108–125.

42. Ben-Ur Z, Gorfil C, Shifman A. Anterior implant-supported overdentures. Quintessence Int. 1996;27:603–606.

43. Takahashi T, Shimamura I, Sakurai K. Influence of number and inclination angle of implants on stress distribution in mandibular cortical bone with All-on-4 Concept. J Prosthodont Res. 2010;54:179–184.

44. Kenney R, Richards MW. Photoelastic stress patterns produced by implant-retained overdentures. J Prosthet Dent. 1998;80:559–564.

45. Assuncao WG, Barao VA, Tabata LF, de Sousa EA, Gomes EA, Delben JA. Comparison between complete denture and implant-retained overdenture: effect of different mucosa thickness and resiliency on stress distribution. Gerodontology. 2009;26:273–281.

46. Rismanchian M, Dakhilalian M, Bajoghli F, Ghasemi E, SadrEshkevari P. Implant-retained mandibular bar-supported overlay dentures: a finite element stress analysis of four different bar heights. J Oral Implantol. 2012;38:133–139.

47. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a threedimensional finite element analysis. J Prosthet Dent. 2008;100:42.

48. Saab XE, Griggs JA, Powers JM, Engelmeier RL. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: a finite element study. J Prosthet Dent. 2007;97:85–92.