



## Assessment of outlook and opinions regarding stress distribution in titanium implants at different angulations using finite element analysis: An original study

Dr. Shivanshu<sup>1\*</sup>, Anshika Agarwal<sup>2</sup>, Vibhuti Bhatt<sup>3</sup>, Uttkarsh Bhatt<sup>4</sup>, Kumud Gupta<sup>5</sup>, Shalini Saroha<sup>6</sup>

<sup>1,2,4</sup> Post Graduate Student, Department of Prosthodontics, Shree Bankey Bihari Dental College and Research Centre, Ghaziabad, Uttar Pradesh, India

<sup>3</sup> Private Practitioner, Dehradun, Uttarakhand, India

<sup>5,6</sup> Intern, Shree Bankey Bihari Dental College and Research Centre, Ghaziabad, Uttar Pradesh, India

### Abstract

**Background and AIM:** Implant supported prosthesis has become a routine dental treatment for restoring a natural or unnatural tooth loss. To achieve the best outcome, careful consideration of technical and biomechanical parameters, is essential. This study aimed to evaluate the present outlook and opinions regarding stress distribution in implant with parallel, mesial and lingual inclination using finite element analysis (FEM).

**Materials & Methods:** Thorough exploration of the existing pool of biomedical information was attempted. Significant and relevant studies were filtered out to outline certain concrete inferences. Data exploration was completed using user friendly interfaces of search engines, scholarly search bibliographic databases and textbooks were searched until July 2018 using MeSH (Medical Subject Headings) based keywords such as “stress distribution”, “posterior mandibular”, “edentulous bone”, “lingual inclination”. The search was limited to original researches, reviews, systematic researches and meta-analyses in various dental journals published over the last 38 years in English language only. A total of 125 articles were identified however after examining the titles and abstracts, this number was finally condensed to 55 articles. For the ease of categorization, articles were divided into four groups.

**Statistical Analysis & Results:** Data compilation was done in a logical manner. All tabulations and excel charts were sent for statistical analysis using statistical software Statistical Package for the Social Sciences. The resulting data was subjected to relevant statistical tests to obtain p values, mean, standard deviation, chi-square test, standard error and 95% CI.

**Conclusion:** Authors have concluded that none of the screened studies has precisely shown the intricate relations of stress distribution and their changing angulations. Hence, the need of hour is to have some long term reliable studies which possibly will define the exact role of various implant angulations and stress distribution. Perhaps it will also build more comprehensive understanding in this perspective.

**Keywords:** stress distribution, posterior mandibular, edentulous bone, finite element analysis (FEM)

### Introduction

The science of Implantology is highly dynamic. Ever since its introduction into the field of dentistry by Dr. Branemark, it has undergone numerous modifications and improvements. With each improvement and advancement made, implantology has proved to be a boon to the society and hence its acceptance by the general population has widely increased despite it being a relatively expensive treatment modality. Initially, Implant dentistry aimed to restore fully edentulous arches using implant-fixed complete dentures <sup>[1]</sup>. Due to the successful trials, same principles of the implant treatment were applied in the restoration of partially edentulous patients <sup>[2]</sup>. Implant supported prosthesis has become a routine dental treatment for restoring a natural or unnatural tooth loss. To achieve the best outcome, careful consideration of technical and biomechanical parameters, is essential <sup>[3]</sup>. Producer firms provide all technical possibilities available for oral implants to be used more commonly and to place easily by the dentist. Big difficulty, however, begins after this, which means that it is required to reciprocate the forces either vertical or parallel to

tooth axis and to transmit them to the mandible. The forces can cause collapse or sometimes piling up of the natural tissue. A tissue placed around tooth rests and called periodontal membrane warns the brain by reflection to prevent these actions on mandible. But great amount of this tissue is lost around an implant hole in the case where implant is applied to the mandible. Therefore, it is very important to determine the stresses that occur around the holes where dental implant is applied to the mandible <sup>[4]</sup>. A thorough understanding of this phenomenon might lead to a reduction in the undesirable stresses produced within the jawbone. The load transfer at the bone-implant interface depends upon the type of loading, implant and prosthesis material properties, implant length and diameter, shape, structure of the implant surface, prosthesis and quality of bone. The load transmission and resultant stress distribution are significant in determining the success or failure of an implant <sup>[5]</sup>. In an ideal situation, in order to achieve the best stress distribution implants must be inserted parallel to each other and to the adjacent teeth <sup>[6]</sup>. In natural dentition, the axes of teeth are inclined in mesial and

lingual direction, in accordance with the curve of Spee and Monson's curve. The direction of implant placement is closely related to the transfer of the occlusal force and it is considered desirable to place the implants as parallel as possible to achieve structural stability and a precise fit to the superstructure [7]. But such condition does not always exist, and it is very difficult to place two or more implants in parallel manner in the posterior mandibular region. So, some amount of angular divergence among the implants in the posterior mandibular region is reported. The direction of placement of implants in accordance with the curve of spee and Monson's curve, likewise of the natural teeth, may have some biomechanical rationale. In light of all these intermingling facts, authors aimed to evaluate the present outlook and opinions regarding stress distribution in implant placement in with parallel, mesial and lingual inclination using finite element analysis (FEM). Authors have also attempted to authenticate their clinical applicability that can best retain the implants with minimal failure.

### Materials & methods

Treatment with implant supported fixed partial prosthesis has been established as an option for partially edentulous patients. From the biomechanical standpoint it is considered desirable to place implants into jawbone as parallel as possible to achieve structural durability and precise fit to the superstructure. Searches of biomedical literature are largely dependent on internet-based online tools that support the easy retrieval of biomedical information. Some of the distinguished internet based popular tools are search engines, scholarly search bibliographic databases and textbooks. We attempted to explore the data until July 2018 using MeSH (Medical Subject Headings) based keywords such as "stress distribution", "posterior mandibular", "edentulous bone", "lingual inclination", "Finite Element Analysis (FEM)". The search was restricted to original researches, reviews, systematic researches and meta-analyses in various dental journals published over the last 38 years in English language only. A total of 125 articles were identified however after extensive scrutinization of their title, methodologies and results, this number was finally condensed to 55 articles. For the ease of categorization, searched data was divided into four groups according to their year. Group I was having searches of 1981-1990 and group IV was having the search results of year 2011 onwards. We have determined to carry out this study on 'data exploration' basis because these studies are extremely useful in acquiring detailed information, clinical opinions and decision makings. They are also capable of saving time and money while processing the data at group and individual levels. Additionally, these types of studies also provide a wide range of inferences with enhanced clarification and understanding. Results thus obtained was tabulated and subjected to basic statistical analysis. P value less than 0.05 was considered significant ( $p < 0.05$ ).

### Statistical analysis and results

All the studied parameters and records were assembled and

sent for statistical analysis using statistical software Statistical Package for the Social Sciences version 21 (IBM Inc., Armonk, New York, USA). The resultant data was subjected to relevant statistical tests to obtain p values, mean, standard deviation, chi-square test, standard error and 95% CI. For the ease of study and data categorization, the searched data were divided into four groups according to their year. P value less than 0.05 was considered significant ( $p < 0.05$ ). For the ease of study and interpretations, the searched workers were divided into four Groups. Each and every group was studied and analyzed carefully to depict noteworthy inferences. Group I was having searches of 1981-1990, Group II was having searches of 1991-2000, Group III was having searches of 2001-2010 and group IV was having the search results of year 2011 onwards. Group I had only 2 workers and the p value was not significant with Chi Square Test (Pearson  $\chi^2$ ) value 0.02. Group II had 12 workers and the p value was not significant with Chi Square Test (Pearson  $\chi^2$ ) value 0.65. Group III had also 12 workers and the p value was not significant with Chi Square Test (Pearson  $\chi^2$ ) value 0.55. Group IV had 29 workers and the p value was significant with Chi Square Test (Pearson  $\chi^2$ ) value 0.28. (Table 1-2 and figure 1-3).

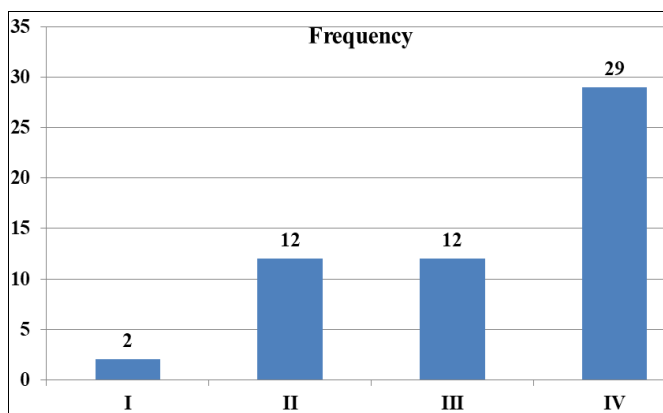
**Table 1:** Year wise distribution of screened works (Group I to IV) with their Frequency, Standard Deviation and Standard Error

Group	Year Range	Frequency	Standard Deviation	Standard Error
I	1981-1990	2	0.437	0.007
II	1991-2000	12	0.234	0.065
III	2001-2010	12	0.843	0.489
IV	2011- Till Date	29	0.452	0.089

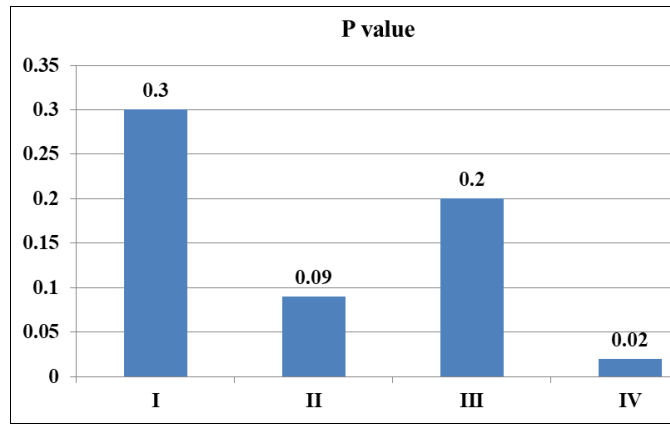
**Table 2:** Year wise distribution of screened works (Group I to IV) with Chi Square Test (Pearson  $\chi^2$ ) and evaluation of level of significances

Group	Year Range	Chi Square Test (Pearson $\chi^2$ )	P value	Std. Deviation
I	1981-1990	0.02	0.30	1.233
II	1991-2000	0.65	0.09	1.472
III	2001-2010	0.55	0.20	0.234
IV	2011- Till Date	0.28	0.02*	1.263

\* $p < 0.05$  significant



**Fig 1:** Frequency table showing group wise distribution of literature screening



\*p<0.05 significant

Fig 2: P value table showing group wise status of level of significance

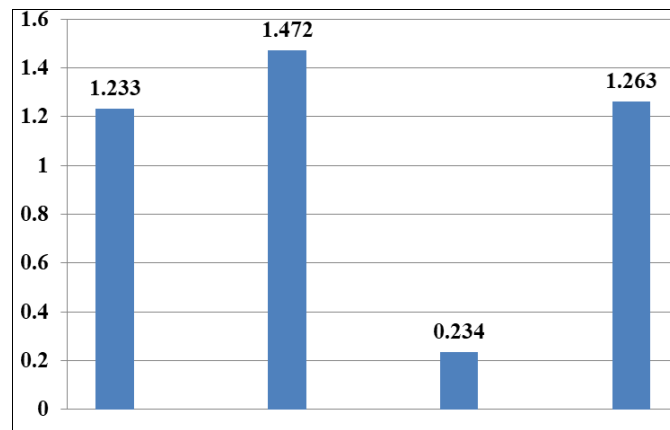


Fig 3: Std. Deviation values for Group I to IV

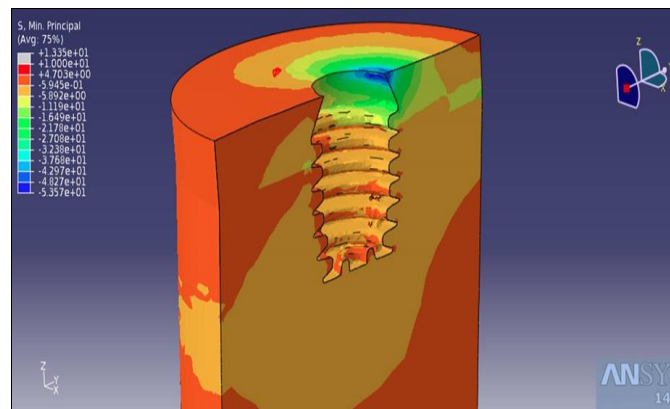


Fig 4: Schematic representation of Finite Element Modeling [FEM] for implant stress distribution

**Discussion**

The placement of implants in the posterior maxilla with reduced bone availability is a challenge for dental implantology. The options that can facilitate placement of conventional implants include use of bone graft; however, this modality of treatment is associated with high costs and morbidity. The reactionary stresses developed on various intraoral tissues in response to these loading forces were evaluated on animals, therefore the results may vary. In vivo measurement of these stresses is difficult, thus the

development of an effective model for analyzing them is required. The finite element method (FEM) is one such technique used to analyze structural stress [Figure 4]. Used in engineering for years, this method uses the computer to solve large numbers of equations to calculate stress on the basis of the physical properties of structures being analyzed. Some of the important FEM studies of implants including various parameters and methods conducted over the years are summarized hereby. Clelland NL *et al.* used three-dimensional finite element stress analysis to determine the pattern and concentration of stresses within the Screw-Vent endosseous implant and its supporting tissues. For this commercially pure titanium implant, maximum stresses were located within the implant collar immediately below the bony crest [8]. Holmes DC *et al.* used the finite element method to model a 4.0 x 13.0-mm IMZ implant, restored with a cast gold crown, to examine the influence of the polyoxymethylene (POM) intramobile element (IME) on the transmission of vertical and oblique forces<sup>9</sup> Kregzde M they reported a method for determining the optimum arrangement of implants and the optimum scheme of prosthesis splinting using biomechanics and three-dimensional finite element analysis. The results of the analysis showed that force distribution on occlusal surfaces does not change significantly with changes in the scheme of prosthesis splinting or implant positions.<sup>10</sup> Benzing UR stated that two essentially different implant-prosthetic concepts are known for the treatment of edentulous maxillae. One concept propagates a "concentrated" arrangement of four to six implants in the premolar and anterior regions with a fixed cantilever superstructure [11]. Van Zyl *et al.* proposed a three-dimensional finite element stress analysis method which was used to determine the distribution of stresses in and around a model of six implants which supported typical fixed complete-arch prosthesis in a simulated human mandible. A load of 100 N was applied at different intervals along the cantilever segment [12]. Vaillancourt H stated that limited crestal bone loss has been observed around dental implants partially covered with a porous coating. The results of a two-dimensional finite element analysis suggested that for this implant design, the observed crestal bone loss is the result of low stresses acting on bone around the uncoated superior region of the implant, causing disuse atrophy of bone [13]. Barbier L and Schepers E presented an experimental animal model for the analysis of the influence of axial and nonaxial loading on bone remodeling around oral implants. Axial and nonaxial loading conditions were introduced by placing a bilaterally supported fixed partial prosthesis and a cantilever fixed partial prosthesis on two IMZ implants in the mandibles of beagle dogs [14]. Sato T, *et al.* used three-dimensional finite element analysis method to assess stress in bone around titanium implants using three treatment designs for a partially edentulous mandible, under axial (AX), buccolingual (BL), or mesiodistal (MD) loads [15]. Barbier L showed that the influence of axial and non-axial occlusal loads on the bone remodelling phenomena around oral implants in an animal experiment is simulated in a finite element analysis. The axial and non-axial loading conditions were introduced by inserting a bilaterally supported fixed partial prosthesis and a cantilever fixed partial prosthesis on two IMZ implants in the mandible of beagle dogs [16]. Geramy A and Margano SM stated that the

optimal method of implant support for a single mandibular molar crown is controversial because commonly used, threaded, root-form implants developed by Branemark were not originally designed to support individual crowns [17]. Kacovsky A, *et al.* showed that the masticatory forces acting on dental implants can result in undesirable stress in adjacent bone, which in turn can cause bone defects and the eventual failure of implants [18]. Zobitz M, *et al.* conducted finite element analysis to determine the magnitude of stress in the supporting bone when implants were arranged in either a straight-line or an offset configuration. In addition, the effects of axial and nonaxial loading and changes in prosthesis height were assessed [19]. Ko CC, *et al.* studied three-dimensional finite element (FE) models of splinted prosthetic crowns were studied and stress analyses were evaluated with different types of implant support, including standard, wide or two implant(s) for partial, posterior edentulous restorations [20]. Sangur R *et al.* attempted to understand the basics of biomechanics with a view on finite-element stress distribution analysis in three situations The three-dimensional (3-D) finite-element mesh model was modeled with the standard dimension of the implant with 11-mm long and 4-mm wide using the software package 'NISA'. Results and Discussion: The design, number and placement of implants play an important role [21]. Kilicarsian MA, *et al.* concluded that for the bone qualities investigated, stress concentrations in compact bone followed the same distributions as in the D3 bone model, but because the trabecular bone was weaker and less resistant to deformation than the other bone qualities modeled, the stress magnitudes were greatest for D3 and D4 bone [22]. Han CH, *et al.* investigated the effect of 3 different abutment types on the stress distribution in bone with inclined loads using finite element analysis. It was concluded that abutment type has significant influence on the stress distribution in bone because of different load transfer mechanisms and the differences in size of the contact area between the abutment and implant [23]. Climini CA, *et al.* conducted a comparative finite element analysis between the straight and angled wedge-shaped implant designs. Stresses in the angled implant were in general lower than in the straight implant, and the differences between the 2 designs studied were more relevant for the vertical load. No indication was found that angled implants of the type described generate stress-induced problems compared to straight implants [24]. Mezzomo LA, *et al.* assessed the magnitude and distribution of axial forces and bending moments in abutments as a function of cantilever length and inclination of implants. The results suggest that the inclination of distal implants does not have any deleterious biomechanical effect on abutments of the tested models and may reduce the cantilever effect on force magnitude [25]. Luzuriaga F, *et al.* evaluated the influence of the length, diameter, and geometry of Biotechnology Institute dental implants on stress distribution in bone. Additionally, the use of shorter and wider implants might be a reasonable alternative in sites limited by the height of the residual ridge [26]. Anwar MIE and Zawahry MME studied implant diameter and length are the most effective parameters affecting stress distribution in surrounding bones. Analysis of results showed that increasing implant diameter and length generate better stress distribution on spongy and cortical bones. Approximate design equations

and curves were obtained as a result of this study [27]. Rungsiyakull P, *et al.* studied effects of occlusal inclination and loading on mandibular bone remodeling using finite element analysis. The purpose of this study was to provide a preliminary understanding of the biomechanics with respect to the effect of cusp inclination and occlusal loading on the mandibular bone remodeling [28]. Muraru L, *et al.* studied influence of implant design on biomechanical environment of immediately placed implants using computed tomography based nonlinear three dimensional finite element analysis. This study suggested that implant overloading in initial stages should be avoided and high initial stability should be ensured [29]. Tealdo T, *et al.* conducted a study to compare and analyze, via 3-dimensional (3-D) finite element analysis, stresses transmitted to tilted versus vertical implants and the surrounding periimplant bone in the maxillae [30]. Lee J, *et al.* studied stress distribution on scalloped implants with different microthread and connection configurations using three-dimensional finite element analysis [31]. Kim Y, *et al.* studied effect of implant position, angulation and attachment height on peri-implant bone stress associated with mandibular two implant overdentures using finite element analysis. The lowest stress and the best stability of implants in mandibular two-Implant overdentures were obtained when implants were inserted in lateral Incisor areas with shorter attachments and were placed parallel to the long axes of the teeth [32]. Yeung TC *et al.* studied biomechanical effect of a zirconia dental implant crown system using a three dimensional finite element analysis. A similar pattern of stress distribution in cancellous bone was observed, not only on the palatal side of the platform but also in the apical area of both types of implants [33]. Haung CC, *et al.* studied distribution of micro-motion in implants and alveolar bone with different thread profiles in immediate loading using a finite element analysis. This indicates that initial stability in immediate loading may be affected by thread design. An implant with an ST profile might provide the best primary stability in an immediate loading situation [34]. Moreira AN, *et al.* studied the effect of prosthesis length and implant diameter on the stress distribution in tooth-Implant-supported prosthesis using a finite element analysis. The authors found that TISPs with a short span and wider-diameter implants resulted in more homogenous stress distribution and less stress concentration on the Implants [35]. Kim YS, *et al.* studied bone implant interface with simulated insertion stress around immediately loaded dental implant in anterior maxilla using a three dimensional finite element analysis. More favorable stress distribution was seen with increasing implant length. In the maxilla, when immediate loading was applied after implant placement, 11.5- and 13.0-mm-long single implants showed more favorable stress patterns than the others analyzed [36]. Manne SD, *et al.* performed a finite element analysis of stresses in the peri-implant area around the Titanium and Zirconium dental implant [37]. Kalavathy N, *et al.* evaluated the pattern of stress distribution with two different implant designs in four different densities of bone using 3D finite element analysis. The study concluded that the cylindrical implant design was more favorable in softer bone than the threaded implant design [38]. Mahesh B and George D concluded that there is higher stress induced through angled

abutment at the cervical zone of the implant due to forces and the moments could be a dominant factor that may aggravate the peri-implant bone loss or changes the existing peri-implantitis direction<sup>[39]</sup>. Mardegan F, *et al.* analyzed and compared the stress distribution in the cortical and trabecular bone between the internal hexagon and the Morse taper system, both with straight abutment<sup>[40]</sup>. Elkerdawy M, *et al.* conducted a study to evaluate the effect of changing implant dimensions on the stress distribution in the supporting structures in implant-supported partial over-dentures. From the results of this study, it could be achieved that the increase in the implant diameter significantly reduced the stresses transmitted to the supporting bone compared to increasing the implant length and that the wider the implant diameter, the better the dissipation of the masticatory forces<sup>[41]</sup>. Trivedi S reviewed the role of finite element analysis in implant dentistry<sup>[42]</sup>. Kakade D, *et al.* reviewed an alternative available for the bone augmentation and sinus lift procedure. This article broadly discusses this "All on Four" concept in all aspects, its effects on bone, prosthesis survival, forces acting etc along with various related studies<sup>[43]</sup>. Oswal MS, *et al.* studied the influence of different thread designs on stress distribution on the implant using 3D finite element analysis. The stresses were calculated as Von Misses Stress criterion. Maximum Stresses were seen at the cortical bone and were transferred to the implant. The stresses were observed least at the cancellous bone and maximum at the implant<sup>[44]</sup>. Solmaz MY, *et al.* studied the stress distribution with three different loads in two different geometric and threaded types of dental implant by finite element analysis. Thus, the implant could remain in the mouth for longer periods Variable-thread tapered implants can increase the implant and bone contact<sup>[45]</sup>. Gupta G and Goyal V conducted a study to compare the micromotion between two crestal and one basal implant-supported crown, when the mesio-distal space is 14mm in the mandibular first molar region. It was concluded that two crestal implants can be used to replace the mandibular first molar with the mesio-distal space 14mm compared with basal implant to replace the mandibular molar<sup>[46]</sup>. Kim M, *et al.* conducted a study to analyze the influence of the platform switching concept on an implant system and peri-implant bone. Due to the stress concentration generated in the implant and the prosthodontic components of the platform switched implant, the mechanical complications might occur when platform switching concept is used<sup>[47]</sup>. Geramizadeh M *et al.* assessed stress and strain patterns in cortical and cancellous bones surrounding newly designed dental implants with different thread patterns<sup>[48]</sup>. Zarei M stated that dental implant is a method to replacement of missing teeth. It is important for replacing the missed anterior teeth. In vitro method is a safe method for evaluation of stress distribution<sup>[49]</sup>. Dhattrak P investigated the stress distribution pattern around implant-bone interface of commercially available different thread profile dental implants using finite element analysis and experimental verification by photo elastic stress analysis<sup>[50]</sup>. Allahyar G assessed the biomechanical state of splinting in implant-supported maxillary overdentures<sup>[51]</sup>. Therefore at last we can say that biomechanics play an important role in the long term survival of the implants. In the posterior mandibular region, natural teeth tend to incline in mesial and lingual

direction according to the curve of Spee and Monson's curve. So there is an immediate need to determine biomechanical rationale for inclination of implants in the posterior implant supported FPD, similar to that of natural teeth<sup>[52-55]</sup>.

### Conclusion

Our study results clearly showed the present literature and clinical opinions regarding the stress distribution in implant placement with parallel, mesial and lingual inclination along with their clinical applicability. Authors have clearly shown that plentiful researches and analyses have been done by various renowned workers. Conversely none of the screened studies has precisely shown the intricate interrelations of stress distribution and their changing angulations. Hence, the need of hour is to have some long term reliable studies which possibly will define the exact role of various implant angulations and stress distribution. Conceivably it will also build more comprehensive understanding regarding clinical treatment planning and decision makings. Our study results may be considered as suggestive for estimating clinical outcomes for such critical situations. However, we expect some other large scale studies to be conducted that could further establish certain valid prospects in these concerns.

### Funding

No external funds were allocated for this study.

### Statement of conflict of interest

In the opinion of the author, there was no conflict of interests.

### References

1. Adell R, Lekholm U, Rockler B, Branemark P. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg.* 1981; 10:387-416.
2. Brunski JB. Biomechanics of oral implants: future research directions. *J Dent Edu.* 1988; 52:775-9.
3. Behnaz E, Ramin M, Abbassi S, *et al.* The effect of implant angulation and splinting on stress distribution in implant body and supporting bone: A finite element analysis. *Eur J Dent.* 2015; 9:311-8.
4. Mehmet Sami. Stress analysis around dental implant in human mandible. *Mathematical & Computational Application.* 1998; 3(2):83-91.
5. Geng JP, Tan KBC, Liu GR. Application of finite element analysis in implant dentistry: A review of the literature. *J Prosthet Dent.* 2001; 85:585-98.
6. Sethi A, Kaus T, Sochor P. The use of angulated abutments in implant dentistry: five-year clinical results of an ongoing prospective study. *Int J Oral Maxillofac Implants.* 2000; 15(6):801-10.
7. Ishiura Y. The accuracy of working casts for implants: Effects of inclination of implant abutment. *J Jpn Prosthodont Soc.* 1999; 43:809-20.
8. Clelland NL, Ismil YH, Zaki HS, Pipko D. Three dimensional finite element stress analysis in and around screw vent implant. *Int J Oral Maxillofac Implants.* 1991; 6:391-8.
9. Holmes DC, Grigsby WR, Goel VK, Keller JC. Comparison of stress transmission in the IMZ implant system with Polyoxymethylene or titanium intra mobile

- element: a finite element analysis. *Int J Oral Maxillofac Implants*. 1992; 7:450-8.
10. Kregzde M, Ing D. A method of selecting the best implant prosthesis design using a three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 1993; 8:662-73.
  11. Benzing UR, Gall H, Weber H. Biomechanical aspects of two different implant-prosthetic concepts for edentulous maxillae. *Int J Oral Maxillofac Implants*. 1995; 10:188-98.
  12. Van Zyl PP, Grundling NL, Jooste CH, *et al*. Three-Dimensional finite element model of a Human mandible incorporating six osseointegrated implants for stress analysis of mandibular cantilever Prostheses. *Int J Oral Maxillofac Implants*. 1995; 10:51-7.
  13. Vaillancourt H, Pilliar RM, McCammond D. Factors affecting crestal bone loss with dental implants partially coated with porous coating: a finite element analysis. *Int J Oral Maxillofac Implants*. 1996; 11:351-9.
  14. Barbier L, Schepers E. Adaptive bone remodelling around oral implants under axial and nonaxial loading conditions in the dog mandible. *Int J Oral Maxillofac Implants*. 1997; 12:215-23.
  15. Stegaroiu R, Sato T, Kusakari H, Miyakawa O. Influence of restoration type on stress distribution in bone around implants: a three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 1998; 13:82-90.
  16. Barbier L, Sloten JV, Krzesinski G, *et al*. Finite element analysis of non-axial versus axial loading of oral implants in the mandible of the dog. *J Oral Rehab*. 1998; 25:847-58.
  17. Geramy A, Morgano SM. Finite element analysis of three designs of implant-: supported molar crown. *J Prosthet Dent*. 2004; 92:434-40.
  18. Himmlova L, Dostalova T, Kacovsky A, *et al*. Influence of implant length and diameter on stress distribution: A three dimensional finite element analysis. *J Posthet Dent*. 2004; 91:20-5.
  19. Stupideler M, Eckert SE, Zobitz M, *et al*. Finite element analysis of effect of prosthesis height, angle of force application., and implant offset on supporting bone. *Int J Oral Maxillofac Implants*. 2004; 19:819-25.
  20. Huang HL, Huang JL, Ko CC, *et al*. Effect of splinted prosthesis supported a wide implant or two implants: a three dimensional finite element analysis. *Clin Oral Impl Res*. 2005; 16:466-72.
  21. Jingade RRR, Rudraprasad IV, Sangur R. Biomechanics of dental implants: A FEM study. *J Ind. Prostho Soc*. 2005; 5:18-22.
  22. Sevimay M, Turhan F, Kilicarslan MA. Eskitascioglu G. Three dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant supported crown. *J Prosthet Dent*. 2005; 93:227-34.
  23. Chun HJ, Shin HS, Han CH, Lee SH. Influence of implant abutment type on stress distribution in bone under various loading conditions using finite element analysis. *Int J Oral Maxillofac Implants*. 2006; 21:195-202.
  24. Las Casas EB, Ferriera PC, Cimini CA, *et al*. Comparative 3 D finite element stress analysis of straight and angled wedge shaped implant design. *Int J Oral Maxillofac Implants*. 2008; 23:215-25.
  25. Geremia T, Naconecy MM, Mezzomo LA, *et al*. Effect of cantilever length and inclined implants on axial force and bending moment in implant-supported fixed prostheses. *Rev Odonto*. 2009; 24(2):145-50.
  26. Anitua E, Tapia R, Luzuriaga F, *et al*. Influence of implant length, diameter and geometry on stress distribution: A finite element analysis. *Int J Periodontics Restorative Dent*. 2010; 30:89-95.
  27. El-Anwar MI, El-Zawahry MM. A three dimensional finite element study on dental implant design. *Journal of Genetic Engineering and Biotechnol*. 2011; 9(1):77-82.
  28. Rungsiyakull C, Rungsiyakull P, Li Q, *et al*. Effect of occlusal inclination and loading on mandibular bone remodelling: A finite element analysis. *Int J Oral Maxillofac Implants*. 2011; 26:527-37.
  29. Pessoa RS, Goelho PG, Muraru L, *et al*. Influence of implant design on the biomechanical environment of immediately placed implants: Computed tomography based nonlinear three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2011; 26:1279-87.
  30. Bevilacqua M, Teleado T, Menini M, *et al*. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. *J Prosthet Dent*. 2011; 105(1):5-13.
  31. Choi KS, Park S, Lee J, *et al*. Stress distribution on scalloped implants with different microthread and connection configurations using three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2012; 27:29-38.
  32. Hong HR, Pae A, Kim Y, *et al*. Effect of implant position, angulation, and attachment height on peri-implant bone stress associated with mandibular two implant overdentures: A finite element analysis. *Int J Oral Maxillofac Implants*. 2012; 27:69-76.
  33. Chang CL, Chen CS, Yeung TC, *et al*. Biomechanical effect of a zirconia dental implant-crown system: A three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2012; 27:49-57.
  34. Chang PK, Chen YC, Haung CC, *et al*. Distribution of micro-motion in implants and alveolar bone with different thread profiles in immediate loading: A finite element study. *Int J Oral Maxillofac Implants*. 2012; 27:96-101.
  35. Paula GA, Mota AS, Moreira AN, *et al*. The effect of prosthesis length and implant diameter in stress distribution in tooth-implant supported prosthesis: A finite element analysis. *Int J Oral Maxillofac Implants* 2012; 27:19-28.
  36. Lee JS, Cho IH, Kim YS, *et al*. Bone implant interface with simulated insertion stress around an immediately loaded dental implant in the anterior maxilla: A three dimensional finite element analysis. *Int J Oral Maxillofac Implants*. 2012; 27:295-302.
  37. Gujjarlapudi MC, Nunna NV, Manne SD, *et al*. Predicting Peri-implant stresses around Titanium and Zirconium dental implants-A finite element analysis. *J Indian Prosthodont Soc*. 2013; 13(3):196-204.
  38. Premnath K, Sridevi J, Kalavathy N, *et al*. Evaluation of stress distribution in bone of different densities using different implant designs: A three- Dimensional Finite element analysis. *J Indian Prosthodont Soc*. 2013; 13(4):555-9.
  39. Arun Kumar G, Mahesh B, George D. Three dimensional

- finite element analysis of stress distribution around implant with straight and angled abutments in different bone qualities. *J Indian Prosthodont Soc.* 2013; 13(4):466-72.
40. Hanaoke M, Gehrke SA, Mardegan F, *et al.* Influence of implant/ Abutment connection on stress distribution to Implant-Surrounding bone: A finite element analysis. *J Indian Prosthodont Soc.* 2014; 23:565-71.
  41. Saad A, Eskander A, Elkerdawy M, *et al.* Stress Distribution with Different Implant Dimensions in Implant-Supported Partia Overdentures. *J Res Practice Dent.* 2014; (2014):1-18.
  42. Trivedi S. Finite element analysis: A boon to dentistry. *J Oral bio Craniof Res.* 2014; 4:200-3.
  43. Asawal N, Bulbule N, Kakade D, *et al.* Angulated Implants: An alternative to bone augmentation and sinus lift procedure: Systemic review. *J Clin Diagnos Res.* 2015; 9(3):10-3.
  44. Oswal MM, Amasi UN, Oswal MS, *et al.* Influence of three different implant thread designs on stress distribution: A three-dimensional finite element analysis. *J Indian Prosthodont Soc.* 2016; 16(4):359-65.
  45. Dundar S, Topkaya T, Solmaz MY, *et al.* Finite element analysis of the stress distributions in peri-implant bone in modified and standard-threaded dental implants, *Biotechnology & Biotechnological Equipment.* 2016; 30(1):127-33.
  46. Gupta G, Goyal V. A comparative finite element analysis study for the micromotion around the basally osseointegrated and the crestal osseointegrated implant in mandibular first molar region. *Int J Oral Implantol Clin Res.* 2016; 7(2):30-3.
  47. Moon S, Lim Y, Kim M, *et al.* Three dimensional finite element analysis of platform switched implant. *J Adv Prosthodont.* 2017; 9:31-7.
  48. Geramizadeh M, Katoozian H, Amid R, Kadkhodazadeh M. Finite Element Analysis of Dental Implants with and without Microthreads under Static and Dynamic Loading. *J Long-Term Effects Medical Implants.* 2017; 27:25-35.
  49. Zarei M, Jahangirnezhad M, Yousefimanesh H, Robati M, Robati H. A comparative study on the stress distribution around dental implants in three arch form models for replacing six implants using finite element analysis. *J Indian Soc Periodontol.* 2018; 22:127-32.
  50. Dhattrak P, Shirsat U, Sumanth S, Deshmukh V. Finite Element Analysis and Experimental. Investigations on Stress Distribution of Dental Implants around Implant-Bone Interface Materials Today: Proceedings. 2018; 5:5641-8.
  51. Allahyar G, Sareh H. Stress Distribution in Splinted and Unsplinted Implant-Supported Maxillary Over dentures: A 3D Finite Element Analysis. *Implant Dent.* 2018; 27:56-62.
  52. Cho SY, Huh YH, Park CJ, Cho LR. Three-Dimensional Finite Element Analysis on Stress Distribution of Internal Implant-Abutment Engagement Features. *Int J Oral Maxillofac Implants.* 2018; 33(2):319-27.
  53. Hamed HA, Marzook HA, Ghoneem NE, Mohamed I. Angulated Dental Implants in Posterior Maxilla FEA and Experimental Verification. *J Med Sci.* 2018; 6(2):397-401.
  54. Chang Y, Tambe AA, Maeda Y, Wada M. Finite element analysis of dental implants with validation: to what extent can we expect the model to predict biological phenomena? A literature review and proposal for classification of a validation process. *Int J Imp Dent.* 2018; 4(7):119-25.
  55. Fernandez EM, Gonzalez LG, Lanchares HD, Quevedo MAM, Velasco AB, Arenal AA. Mandibular Flexure and Peri-Implant Bone Stress Distribution on an Implant-Supported Fixed Full-Arch Mandibular Prosthesis: 3D Finite Element Analysis. *Biomed Res Int.* 2018; 13:1-9.