Scientific Foundation SPIROSKI, Skopje, Republic of Macedonia
Open Access Macedonian Journal of Medical Sciences. 2021 Oct 14; 9(D):202-209.
https://doi.org/10.3889/oamjms.2021.6407
eISSN: 1857-9655
Category: *D - Dental Sciences*
Section: *Prosthodontics*

OPEN ACCESS

Effect of Variable Implant Tip Distances on Stress Distribution around the Mental Foramen: A Finite Element Analysis

Waleed M. S. Al Qahtani*

Department of Prosthetic Dentistry, College of Dentistry, King Khalid University, Abha, Saudi Arabia

Edited by: Aleksandar Iliev
Citation: Al Qahtani WMS. Effect of Variable Implant Tip Distances on Stress Distribution Around the Mental Foramen: A Finite Element Analysis. Open Access Maced J Med Sci. 2021 Oct 14; 9(D):202-209. https://doi.org/10.3889/oamjms.2021.6407
Keywords: Finite element analysis; Cancellous bone; Mental nerve; Implant, Gap
***Correspondence:** Waleed M.S. Al Qahtani, Department Prosthetic Dentistry, College of Dentistry, King Khalid University, Abha, Kingdom of Saudi Arabia. E-mail: wmalqahtani@kku.edu.sa
Received: 06-May-2021
Revised: 26-Jun-2021
Accepted: 04-Oct-2021

Funding: This research did not receive any financial support
Competing Interests: The authors have declared that no competing interests exist

Abstract

AIM: This study aimed to evaluate the effect of gap between traditional implant tip and mental nerve using finite element analysis.

METHODS: Four finite element models (FEM) were prepared for dummy crowns that were supported by traditional implants that were placed vertically in laser scanned mandibular bone geometry. Where gap distance were designed to be 1.5, 2.0, 2.5, and 3.0 mm. Dummy crown, 50 μm cement layer, and implant complex models' components were modeled in 3D on engineering computer-aided design (CAD)/CAD (computer-aided manufacturer) software formerly collected in Finite Element Analysis package. Each model was subjected to two loading cases as 150N compressive load at central fossa, and 50N Oblique (45º) load at central fossa of the dummy crown.

RESULTS: Good agreement of the FEM was obtained when compared to similar studies. Under applied study loads, all resulting values of stresses and deformations of the four models were within physiological limits. The obtained data showed no effect on cortical bone, implant complex, cement layer, and dummy crown to changing of gap distance. In addition, the cancellous bone, especially around the mental canal, was considerably affected by the variation in that gap distance.

CONCLUSION: Increasing the gap distance between the dental implant tips may reduce the stress and deformation around the mental canal. Minimum gap distance of order 2.5 mm is recommended to reduce stresses and deformations around canal to favorable limits, while more gap distance is also recommended with larger bone geometries.

Introduction

Periodontal disease, caries, or trauma was the main cause of natural teeth loss and dental implants were the most effective management choice to restore the lost teeth [1]. The application of treatment was used by dental implant in dental practice as a significant prosthodontic technique with long-standing expectedness to re-establish normal oral function, preserves occlusion, and progress the life value. In fact, the insertion of dental implants is mainly to correct mandibular (distally extended), molar region, and free-end saddle. However, the application of implant in the posterior area of a mandible irregularly had certain anatomical problems anatomical structures, for example, lingual undercut of a lower jaw, minor space to the mandibular nerve and its canal, lacking of vertical dimension, and deficiency of "keratinized mucosa." Undercuts at lingual side especially, in a completely edentulous lower jaw was appeared to be related to danger of perforation in the bone at lingual cortical layer through application of dental implant and during insertion. That could cause infections or bleeding in the parapharyngeal space. The prevalence of 68% of lingual undercuts in the posterior molar area and followed at a pointedly lower percentage in the area of first molar (56%) in the area of first molar (56%) than that in the second molar (90%) [2].

The treatment by application of dental implants is considered perfect solutions for restoring lost teeth, even while, height of the bone may be insufficient for placing long implant vertically. One limitation, on implant length selection was the gap distance between implant tip and mandibular canal to overcome these hazards, thus using the implants were may be contraindicated to repair second molar defects.

Two forms of bone are found, together in maxilla/mandible: "outer layer called cortical and inner layer called cancellous bone." These were "anisotropic materials," with alteration because "trabecular was a compact bone and cancellous was a highly porous mineralized tissue bounded in cortical bone" [3].

The transmission of load through dental implants to underlying and within bone was unequal by numerous features, for example, the using a material, the angulation/magnitude of the applied load, the morphology of dental implant as the length, the diameter, numbers of threads, or the adjacent bone quality and quantity [4]. Dental implant shape seems the most important factor of design, since the implant geometry marks the interface within the bone, implant, bone/implant (osteointegration), the contact surface zone, and stability of an implant. However, applying the same loads on different implant designs will affect distribution of forces and generated stresses within the bone [5]. Thus, there are many forms of implants which are classified as known according to its shape as: "Cylindrical/conical/stepped/screw-shaped/and hollow cylindrical." Numerous researches discovered the "conical dental implant contact surfaces or surfaces morphology with geometric gaps" caused by more active dynamic stresses in comparing to plane shapes such as screw-shaped or cylindrical [6]. Accordingly, the cylindrical shaped screw with different threaded of implants are the most frequently used [5]. Many techniques for analyzing the dental implants itself and biomechanical behavior of bone, as well as in laboratory techniques and finite element analysis to obtain the numerical simulations. As photoelastic stresses analysis method or testing, the mechanical fracture was tested during the static phase and dynamic cyclic loading performance [7]. Dental implants failure was a moderately mutual problem [8], and analysis of the abutments was needed [9]. Finite Element Analysis Technique is an important system in common dental implants filed is let scholars/researchers toward read bone and dental implant characters, implant to bone union in addition to know how to modify the design of implant for the task inside the normal physiological tolerable restrictions [10]. Finite Element Analysis contains "a computerized three-dimensional model" (3D) was widely found for expect features in bone with stress distribution close to regular implant, was noted by implant geometry and bio-mechanical connection molded among implant to bone [11]. The finite element method was the most common numerical simulation; a digital technique through software program to represents unlike cases and obtaining results/responses of high performance then powerfully rest on the precision of data, the quality of the mesh and boundary besides loading degrees [12].

"ABAQUS or ANSYS are the most popular digital software databases as morphology, geometry, material, and load data are presented" for numerical studies which usually carried out in these programs based on meshing; before, it is run for obtaining the required output results stress or strain.

The aim of this study was to assess the stresses around inferior alveolar canal (IAC) at variable implantmental foramen distances under different loading by finite element analysis.

Materials and Methods

The *in vitro* study simulated an experimental condition with a traditional dental implant was vertically placed with specified gap distance to mandibular canal as; 1.5, 2.0, 2.5, and 3.0 mm (as four models). Titanium standard implant straumann regular cross (RC fit) connection for bone level implants of 12 mm length and 3.3 mm diameter (Straumann, Basel, Switzerland) [13], with RC abutment with fixation screw cosmetic was used.

The constituents of finite element models' (FEM) like a replica crown, cement layer of 50 µm, and implant complex stayed shaped on Version 8 "Autodesk Inventor" (Autodesk Inc., San Rafael, CA, USA) Figure 1a.

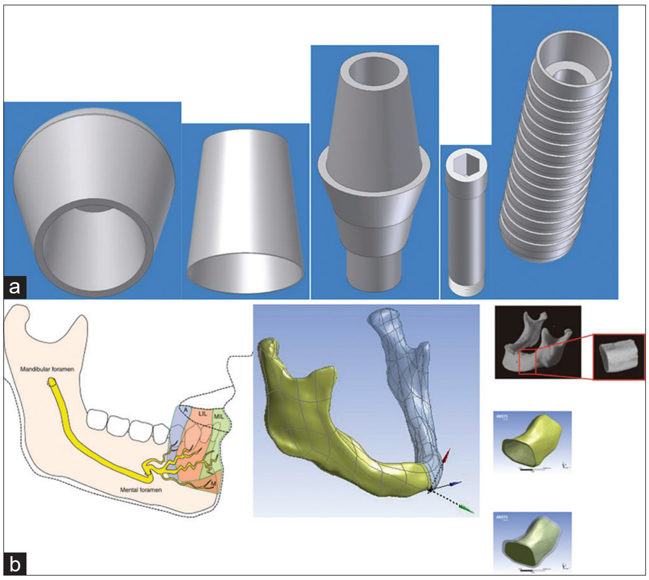

Figure 1: (a and b) Screen shots of the two models components during creation of geometric models

Bone geometry was acquired by laser scanning for edentulus mandible plastic model. (Geomagic Capture, 3D Systems, Cary, NC, USA) the laser scanner was used to create file of data having a bank of cloud to organizes the points. Transitional software were utilized to fit a recently shaped planes through the developed sockets (Rhino 3.0 - McNeel Inc.; Seattle, WA, USA) (Figure 1b).

All the models' components were exported as STEP files [14], and then accumulated by "ANSYS" Workbench (ANSYS Inc., Canonsburg, PA, USA) atmosphere. Finally, traditional Boolean procedures were used to create common surfaces and to adjust canal position. Material properties were fed to the finite element software and were expected as isotropic, linearly elastic, and uniform as shown in Table 1.

Table 1: Mechanical properties of study materials used in finite element model (s) construction

Material	Young's modules (GPa)	Poisson's ratio
Crown zirconia	210.0	0.35
Cement resin	4.04	0.30
Implant abutment complex	110.0	0.35
Cortical bone	13.7	0.30
Cancellous bone	1.37	0.30

Very fine meshing the four models after assigning material properties caused in enormous numbers in the form of points called nodes and a lot of elements to build the model structure Table 2, while screen shots from ANSYS presented the four models Figure 2.

The least values were found at regions of the outer layer of bone (cortical bone) and were traditional to be static in area like a "boundary condition." Although the application compressive loading of 150 N, and Oblique load (45º) of 50N both were placed at central fossa as two loading cases. "Solid modeling" plus finite element linear static analysis was performed on a (Dual Intel Xeon E5-2670 v2 processors, 2.5 GHz, 64.0 GB RAM) Workstation HP Z820, by marketable multipurpose finite element software program bundle (version 16.0 ANSYS), the outcomes of these numerical simulated models were proved in contradiction of related researches [15], [16], [17], and showed good agreement.

Results

All values of total deformations as well as "Von Mises" stresses appeared in models' constituents were within physiological limit under applied loads. Where, all these components results indicated to be insensitive to gap distance except the spongy bone. Changes in deformations and stresses were observed in the gap zone; therefore, making cut section around the canal can show considerable differences.

For overall generated types of deformations and stresses two types were discussed: Total deformation in addition Von Mises on each component in model as shown in Figure 3. For digging deeper in discussing results, it was demonstrated cut sections around canals in the four models under vertical loading in Figure 4.

Comparing IAC zone extreme Von Mises stress and total deformation values appeared in the four models under both loading cases. Figure 5 showed the effect of gap distance. Appling curve fitting to find equation for decreasing total deformation and stress with increasing gap distance showed that polynomials of second order can describe the decrease in total deformation and Von Mises stress by increasing gap distance. In addition, it was found that increasing gap distance to be more than 2.5 mm did not change the values of deformation and stresses significantly. The results, under vertical loading, showed differences between the two cases of 2.0 and 2.5 mm gap distance of order 0.5 μm in total deformation, and about 0.326 MPa in maximum Von Mises stress. The values decreased to be 0 μm and 0.133 MPa under oblique loading.

Discussion

Finite element analysis was one of the most popular numerical methods for human being for using in dental regular implant filed. This was practiced by several researches as an accurate technique for studying or simulating clinical cases. Many researches had documented the difference of bone density as the type of bone and position; the criteria of material for the maxilla and the mandible were homogeneous,

Table 2: Numbers of all nodes and elements in FEA meshed skeleton

Volume	Gap 1.5 mm(case #1)		Gap 2.0 mm(case #2)		Gap 2.5 mm(case #3)		Gap 3.0 mm(case #4)	
	Number of Nodes	Number of Elements	Number of Nodes	Number of Elements	Number of Nodes	Number of Elements	Number of Nodes	Number of Elements
Crown	11,908	7,604	11,908	7,604	11,908	7,604	11,908	7,604
Cement	5,922	2,891	5,922	2,891	5,922	2,891	5,922	2,891
Abutment	12,961	8099	12,961	8099	12,961	8099	12,961	8099
Screw	9170	5582	9170	5582	9170	5582	9170	5582
Implant	71,486	47,940	71,486	47,940	71,486	47,940	71,486	47,940
Cortical	63,174	37,617	63,174	37,617	63,174	37,617	63,174	37,617
Cancellous	401,079	284,517	402,248	285,471	401,760	285,126	399,094	283,226

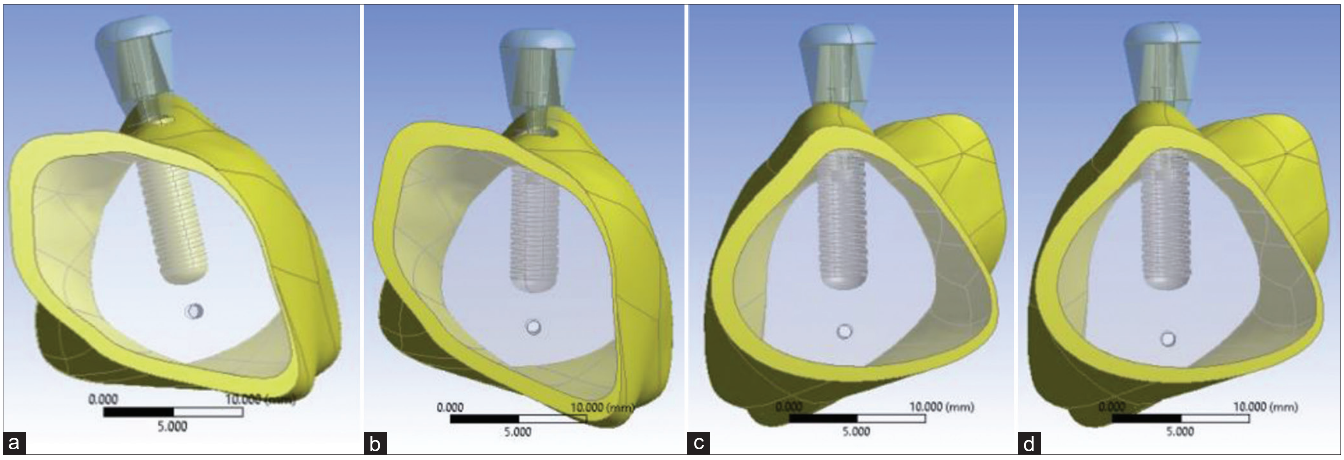

Figure 2: (a-d) screen shots of cross-section in the four models

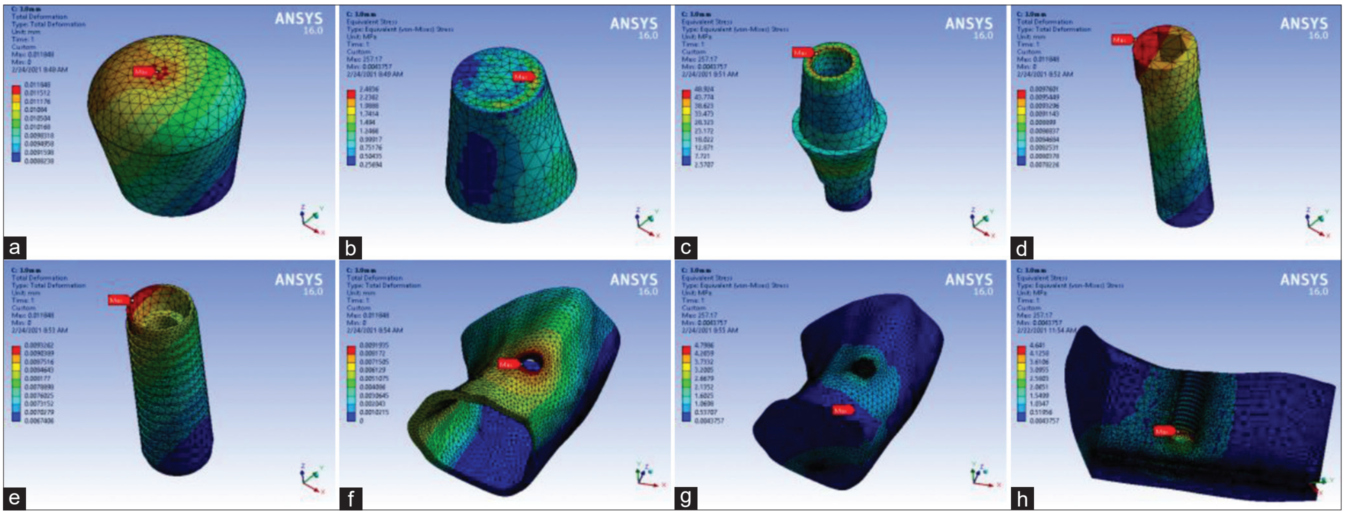

Figure 3: Example of Von Mises and total deformation stresses spreading on model #4 (gap 3.0 mm) under compressive load of 150N; (a) crown, (b) cement, (c) abutment, (d) connecting screw, (e) implant, (f) cortical bone, (g) cancellous bone, and (h) cut section in cancellous bone

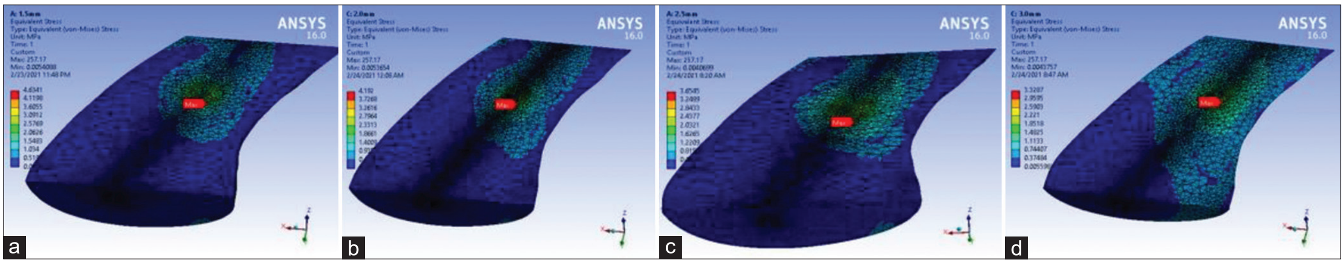

Figure 4: Cut sections in the four models showing Von Mises stress under compressive load of 150 N; (a) gap 1.5 mm, (b) gap 2.0 mm, (c) gap 2.5 mm, and (d) gap 3.0 mm

isotropic, and homogenous. Thus, the result of this alteration was neglected with the approval of movement of natural structures and metallic implants because of its high modulus of elasticity and very minor degree of strain when compared with soft tissues, for example, tempro mandibular joints and periodontal ligaments. The target of such study was to estimate the occlusal forces distribution on all surfaces. Occlusal forces were measured and correlated to the distance between the nerve and osseointegrated implants [2].

Dental metallic implants and implant-supported overdentures were used as a routine treatment as restoration for several cases. The achievement of dental implant behaviors was which affected, through many causes, by the quality of healthy bone, the target was to study the effect of the bone classification on stresses were generated in implants or natural bone using the Finite Element Analysis for dental society [18].

Finite elements analysis was acted as a brilliant method in the medical field overall, and in field of dentistry in specific. The results providing through software models based on the "finite elements considerations, as mesh definitions and elements, material properties, and margin and applying loads settings" [19]. Many stress analysis dental cases have been achieved by finite element technique at static conditions, but the analysis of cyclic loading of dental implants has not been done with finite element

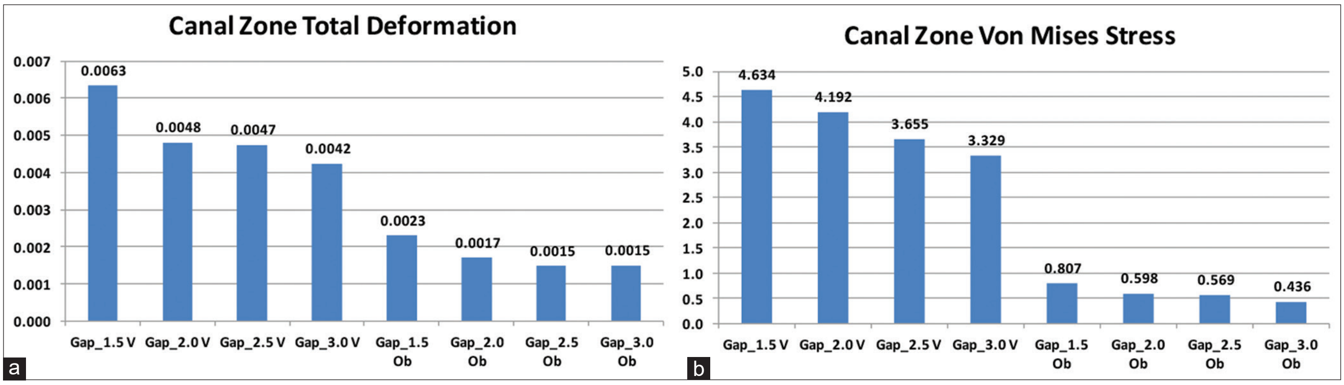

Figure 5: (a and b) Total deformation and Von Mises extreme values comparison around inferior alveolar canal

studies as it consumes a lot of time with extremely high computer resources [20].

Increasing implant length increases stability and success rate. The treatment procedure for cases with lowers vertical alveolar bone space as adding new bone procedures was mandatory before to build up regular dental implants [21]. The restoration of grafted alveolar bone happens through bone resorption, because of the remodeling of various developed processes. Depending on local and general factors, up to 25% of the primary volume was resorbed [22]. Short dental implants (<8 mm) were considered acceptable and consistent treatment choice for the orofacial therapy of resorbed mandibles or maxillae, which was founded an alternative to vertical ridge grafting [23]. The high scenario of short dental implants and patient satisfaction was achieved [24].

According to finite element analyses, the implant stress values were showed and application points showed lower for cortical bone with the implant diameter were increased [25]. Furthermore, the implant diameter more effectively reduced outer layer of bone strain with increased diameter, when comparing to the implant length when increasing (3.5-fold vs. 1.7-fold) [26].

One of the most recent criteria to select implants studied the variation of implant length and diameter in addition to threading, ended to, selection based on increasing the numerical value of the ratio; implant side-area to cross-sectional area will reduce stresses exerted on bone. Thus, it was recommended to use implants with higher ratio of side-area to cross-section area, with weak bone [27].

Available implant selection criterion did not discuss the effect of gap distance to minimize the implant effect on mandibular nerve. Studying the location and anatomy of the “IAC” besides the measurement of the outer layer of bone, in two-dimensional (2D) radiography and three-dimensional (3D) computed tomography [28]. A relationship of the dimensions and many changes, for example, gender and patient age. The character of computed topography imaging was investigated in introducing at first the data in implantology procedures. The previous studies concentrated on mutually dentulous and edentulous cases. The length and height of the residual bone were analyzed in healthy with full teeth cases will help to focus on the regeneration processes of bone, for prediction any necessity of adding bone substitutes, with the choice of most appropriate implant size [29].

Increasing gap distance logically reduce stresses and deformation around mandibular canal (reduce effect of implant placement on nerve). Axial and extra-axial loading was strained at the crestal bone that demonstrated by biomechanical studies. On the other hand, the real behavior of stresses analyzing in the peri-implant bone could differ along with morphological and prosthetic features [30]. To avoid injury of the inferior alveolar nerve, these studies recommend that wide diameter should be favored for using short implants [31]. According to the bone accessibility for implant insertion, it might be inadequate by anatomical structures, for example, the inferior alveolar nerve and the maxillary sinus. Therefore, recently, the issues are insertion a metallic implant in the resorped maxilla/mandible because the narrow bone, with more hazarders of destructive vital morphological components [32].

Tufekcioglu *et al*. [28] reported postoperative neurosensory complications of 314 patients with total number of 474 implants placed posterior to mental foramen area, and concluded that 2 mm is safe distance from the IAC. This finding matched the finite element analysis results obtained in this study and any minor or negligible differences might be referred to implant complex design and or bone properties simplifications (isotropic and linear elastic) used in analyses.

There is a limitation on implant length (gap distance point of view), that gap distance should not be precise to ensure safety of nerve (no pain, i.e., patient satisfaction).

A large number of surgical operations are planned to overwhelm the measurements limits with resorbed mandible or maxilla, containing, additional new sites of bone to fix implants sinus floor augmentation, adding bone block substitutes, and for any abnormality in bone or soft tissues [33]. Regardless of the good results of methods, for example, a new bone fixing, which recommends more treatment phase and charge, more complications after surgery and risk of difficulties of dentist-sensitive methods [34], [35]. Furthermore, the augmentation of sinus floor, the expectedness of these processes is uncommon [36]. Therefore, the evaluation of every case before the surgical procedure for implant insertion, must be taking in consideration the special characteristics of each patient [37].

In case of sever resorbed alveolar bone, there is an alternative therapy with simple and less aggressive processes, using short dental implants as they may require less intervention, as a shorter time of treatment, reduced costs, and lower patient morbidity [38], [39]. In addition, “Macro and micro-geometry, prosthesis design, and biomechanics of overdentures with the use of short dental implants” were considered the factors of success [40]. Furthermore, the macro/micro intention of short metallic dental implants must stand minimized for improvement the achievement rate and actual stability in different stages [41].

In general, increasing gap distance will decrease deformations and stresses around mandibular canal. Two and half millimeters can be considered as the optimal gap distance to have acceptable level of deformations and stresses around mandibular canal. While increasing the gap distance (more than 2.5 mm) will also decrease stresses and deformations around canal, but causes more complications due to reducing implant length. The obtained results of perpendicular loading through uniform loading in both sides besides balanced muscle movement with maximum teeth closure in the good mandibular situation as the lateral movement for the posterior teeth were controlled. Individual changes in the material properties of the soft tissue may affect the real distribution of occlusal forces. Moreover, the lateral movement of the mandible during mastication, was simulated by the lateral load, was not considered. Furthermore, the study examined the biomechanical feature of the shortened dental arch using dental implants. The role and life quality of patients with shortened dental arch, and the occlusal force of every tooth and implant, including analysis of bone strain, would be examined in future researches [2].

Conclusions

It is found that:

1. Cortical bone, implant complex, cement layer, and crown seem not affected by variation of gap distance between implant tip and mental foramen
2. Increasing gap distance reduces stresses and deformation around canal.

Gap distance of order 2.5 mm may be sufficient to reduce stresses and deformations around IAC, and more gap distance will not be beneficial as complications of using short implants will arise if the bone geometry enable using long implants, managing gap distance of more than 2.5 mm may be preferred.

Acknowledgment

Many thanks to King Khalid University for their support and encouragements.

Ethical Approval

This research does not require ethical approval and followed the Helsinki Declaration.

References

1. Nokar S, Jalali H, Nozari F, Arshad M. Finite element analysis of stress in bone and abutment-implant interface under static and cyclic loadings. Front Dent. 2020;17(21):1-8. https://doi.org/10.18502/fid.v17i21.4315
PMid:33615298
2. Yoshitani M, Takayama Y, Yokoyama A. Significance of mandibular molar replacement with a dental implant: A theoretical study with nonlinear finite element analysis. Int J Implant Dent. 2018;4(1):4. https://doi.org/10.1186/s40729-018-0117-7
PMid:29484524
3. Schwiedrzik JJ, Wolfram U, Zysset PK. Ageneralized anisotropic quadric yield criterion and its application to bone tissue at multiple length scales. Biomech Model Mechanobiol. 2013;12(6):1155-68. https://doi.org/10.1007/s10237-013-0472-5
PMid:23412886
4. Prados-Privado M, Bea JA, Rojo R, Gehrke SA, Calvo-Guirado JL, Prados-Frutos JC. A new model to study fatigue in dental implants based on probabilistic finite elements and cumulative damage model. Appl Bionics Biomech. 2017;2017:3726361. https://doi.org/10.1155/2017/3726361
PMid:28757795
5. Elias CN. Factors affecting the Success of Dental Implants. Rijeka: InTech. Available from: http://www.intechopen.com/books/implant-dentistry-a-rapidly-evolving-practice/factors-affecting-the-success-of-dental-implants. [Last accessed on 2021 Jan 25]. https://doi.org/10.5772/18746
6. Seth S, Kalra P. Effect of dental implant parameters on stress distribution at bone-implant interface. Int J Sci Res. 2013;2:121-4.
7. Gehrke SA, Frugis VL, Shibli JA, Fernandez MP, Sánchez de Val JE, Girardo JL, *et al*. Influence of implant design (cylindrical and conical) in the load transfer surrounding long (13 mm) and short (7 mm) length implants: A photoelastic analysis. Open Dent J. 2016;10(1):522-30. https://doi.org/10.2174/1874210601610010522
PMid:27843505
8. Rokaya D, Srimaneepong V, Wisitrasameewon W, Humagain M, Thunyakitpisal P. Peri-implantitis update: Risk indicators, diagnosis, and treatment. Eur J Dent. 2020;14(4):672-82. https://doi.org/10.1055/s-0040-1715779
PMid:32882741
9. Mandhane SS, More AP. A review: Evaluation of design parameters of dental implant abutment. Inter J Emerg Sci Eng. 2014;2:64-7.
10. Syed AU, Rokaya D, Shahrbaf S, Martin N. Three-dimensional finite element analysis of stress distribution in a tooth restored with full coverage machined polymer crown. Appl Sci. 2021;11(3):1220. https://doi.org/10.3390/app11031220
11. Gaviria L, Salcido JP, Guda T, Ong JL. Current trends in dental implants. J Korean Assoc Oral Maxillofac Surg. 2014;40(2):50-60. https://doi.org/10.5125/jkaoms.2014.40.2.50
PMid:24868501
12. Prados-Privado M, Gehrke S, Rojo R, Prados-Frutos J. Probability of failure of internal hexagon and morse taper implants with different bone levels: A mechanical test and probabilistic fatigue. Int J Oral Maxillofac Implant. 2018;33(6):1266-73. https://doi.org/10.11607/jomi.6426
PMid:30427957
13. Available from: https://www.straumann.com/en/dental-professionals/services/download- center/catalogs.html. [Last accessed on 2021 Jan 25].
14. Al Qahtani WM, Yousief SA, El-Anwar MI. Recent advances in material and geometrical modelling in dental applications. Open Access Maced J Med Sci. 2018;6(6):1138-44. https://doi.org/10.3889/oamjms.2018.254
PMid:29983817
15. Kinoshita H, Nakahara K, Matsunaga S, Usami A, Yoshinari M,

Takano N, *et al*. Association between the peri-implant bone structure and stress distribution around the mandibular canal: A three-dimensional finite element analysis. Dent Mater J. 2013;32(4):637-42. https://doi.org/10.4012/dmj.2012-175

PMid:23903647

16. Wazeh AM, El-Anwar MI, Atia RM, Mahjari RM, Linga SA, Al-Pakistani LM, *et al*. 3D FEA study on implant threading role on selection of implant and crown materials. Open Access Maced J Med Sci. 2018;6(9):1702-6. https://doi.org/10.3889/oamjms.2018.331

PMid:30337994

17. El-Anwar MI, El-Mofty MS, Awad AH, El-Sheikh SA, El-Zawahry MM. The effect of using different crown and implant materials on bone stress distribution: A finite element study. Egypt J Oral Maxillofac Surg. 2014;5(2):58-64. https://doi.org/10.1097/01.omx.0000444266.10130.4c

18. Bosshardt DD, Chappuis V, Buser D. Osseointegration of titanium, titanium alloy and zirconia dental implants: Current knowledge and open questions. Periodontol 2000. 2017;73(1):22-40. https://doi.org/10.1111/prd.12179

PMid:28000277.

19. Prados-Privado M, Martínez-Martínez C, Gehrke SA, Prados-Frutos JC. Influence of bone definition and finite element parameters in bone and dental implants stress: A literature review. Biology. 2020;9(8):224. https://doi.org/10.3390/biology9080224

20. Hou PJ, Ou KL, Wang CC, Huang CF, Ruslin M, Sugiatno E, *et al*. Hybrid micro/nanostructural surface offering improved stress distribution and enhanced osseointegration properties of the biomedical titanium implant. J Mech Behav Biomed Mater. 2018;79:173-80. https://doi.org/10.1016/j.jmbbm.2017.11.042

PMid:29306080

21. Fretwurst T, Nack C, Al-Ghrairi M, Raguse D, Stricker A, Schmelzeisen R, *et al*. Long-term retrospective evaluation of the peri-implant bone level in onlay grafted patients with iliac bone from the anterior superior iliac crest. J Craniomaxillofac Surg. 2015;43(6):956-60. https://doi.org/10.1016/j.jcms.2015.03.037

PMid:25964006

22. Schincaglia GP, Thoma DS, Haas R, Tutak M, Garcia A, Taylor TD, *et al*. Randomized controlled multicenter study comparing short dental implants (6 mm) versus longer dental implants (11-15 mm) in combination with sinus floor elevation procedures. Part 2: Clinical and radiographic outcomes at 1 year of loading. J Clin Periodontol. 2015;42(11):1042-51. https://doi.org/10.1111/jcpe.12465

PMid:26425812

23. Srinivasan M, Vazquez L, Rieder P, Moraguez O, Bernard JP, Belser UC. Survival rates of short (6 mm) micro-rough surface implants: A review of literature and meta-analysis. Clin Oral Implants Res. 2014;25(5):539-45. https://doi.org/10.1111/clr.12125

PMid:23413956

24. Hentschel A, Herrmann J, Glauche I, Vollmer A, Schlegel KA, Lutz R. Survival and patient satisfaction of short implants during the first 2 years of function: A retrospective cohort study with 694 implants in 416 patients. Clin Oral Implants Res. 2016;27(5):591-6. https://doi.org/10.1111/clr.12626

PMid:26096052

25. Anitua E, Pinas L, Escuer-Artero V, Fernandez RS, Alkhraisat MH. Short dental implants in patients with oral lichen planus: A long-term follow-up. Br J Oral Maxillofac Surg. 2018;56(3):216-20. https://doi.org/10.1016/j.bjoms.2018.02.003

PMid:29502938

26. Ngyen TT, Eo MY, Cho YJ, Myoung H, Kim SM. 7-mm-long dental implants: Retrospective clinical outcome in medically compromised patients. J Korean Assoc Oral Maxillofac Surg. 2019;45(5):260-66. https://doi.org/10.5125/jkaoms.2019.45.5.260

PMid:31728333

27. El-Anwar MI, El-Zawahry MM, Ibraheem EM, Nassani MZ, ElGabry H. New dental implant selection criterion based on implant design. Eur J Dent. 2017;11(2):186-91. https://doi.org/10.4103/1305-7456.208432

PMid:28729790

28. Tufekcioglu S, Delilbasi C, Gurler G, Dilaver E, Ozer N. Is 2 mm a safe distance from the inferior alveolar canal to avoid neurosensory complications in implant surgery? Niger J Clin Pract. 2017;20(3):274-7. https://doi.org/10.4103/1119-3077.183240

PMid:28256479

29. Sivolella S, Meggiorin S, Ferrarese N, Lupi A, Cavallin F, Fiorino A, *et al*. CT-based dentulous mandibular alveolar ridge measurements as predictors of crown-to-implant ratio for short and extra short dental implants. Sci Rep. 2020;10:16229. https://doi.org/10.1038/s41598-020-73180-3

30. Nunes M, Almeida RF, Felino AC, Malo P, de Araújo Nobre M. The influence of crown-to-implant ratio on short implant marginal bone loss. Int J Oral Maxillofac Implants. 2016;31(5):1156-63. https://doi.org/10.11607/jomi.4336

PMid:27632273

31. Reich W, Schweyen R, Hey J, Otto S, Eckert AW. Clinical performance of short expandable dental implants for oral rehabilitation in highly atrophic alveolar bone: 3-year results of a prospective single-center cohort study. Medicina (Kaunas). 2020;56(7):333. https://doi.org/10.3390/medicina56070333

PMid:32635173

32. Felice P, Barausse C, Pistilli R, Ippolito DR, Esposito M. Short implants versus longer implants in vertically augmented posterior mandibles: Result at 8 years after loading from a randomised controlled trial. Eur J Oral Implantol. 2018;11(4):385-95. https://doi.org/10.1111/clr.55_13356

PMid:30515480

33. García-Ochoa AP, Pérez-González F, Negrillo Moreno A, Sánchez-Labrador L, Cortés-Bretón Brinkmann J, Martínez-González JM, *et al*. Complications associated with inferior alveolar nerve reposition technique for simultaneous implant-based rehabilitation of atrophic mandibles. A systematic literature review. J Stomatol Oral Maxillofac Surg. 2020;121(4):390-6. https://doi.org/10.1016/j.jormas.2019.12.010

PMid:31904530

34. Papaspyridakos P, De Souza A, Vazouras K, Gholami H, Pagni S, Weber HP. Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: A meta-analysis. Clin Oral Implants Res. 2018;29(16):8-20. https://doi.org/10.1111/clr.13289

PMid:30328206

35. Saletta JM, Garcia JJ, Caramês JM, Schliephake H, da Silva Marques DN. Quality assessment of systematic reviews on vertical bone regeneration. Int J Oral Maxillofac Surg. 2019;48(3):364-72. https://doi.org/10.1016/j.ijom.2018.07.014

PMid:30139710

36. Ravidà A, Barootchi S, Askar H, Suárez-López del Amo F, Tavelli L, Wang HL. Long-term effectiveness of extra-short (6 mm) dental implants: A systematic review. Int J Oral Maxillofac Implant. 2019;34(1):68-84. https://doi.org/10.11607/jomi.6893

PMid:30695086

37. Anitua E, Alkhraisat MH. 15-year follow-up of short dental implants placed in the partially edentulous patient: Mandible Vs maxilla. Ann Anat. 2019;222:88-93. https://doi.org/10.1016/j.aanat.2018.11.003

PMid:30448466

38. Flanagan D. Stress related peri-implant bone loss. J Oral Implantol. 2010;36(4):325-7.

PMid:20545532

39. Triches DF, Alonso FR, Mezzomo LA, et al. Relation between insertion torque and tactile, visual, and rescaled gray value measures of bone quality: A cross-sectional clinical study with short implants. Int J Implant Dent. 2019;5(1):9. https://doi.org/10.1186/s40729-019-0158-6

PMid:30740630

40. Schwartz SR. Short implants: An answer to a challenging dilemma? Dent Clin North Am. 2020;64(2):279-90.

PMid:32111268

41. Reich W, Schweyen R, Heinzelmann C, Hey J, Al-Nawas B, Eckert AW. Novel expandable short dental implants in situations with reduced vertical bone height-technical note and first results. Int J Implant Dent. 2017;3(1):46. https://doi.org/10.1186/s40729-017-0107-1

PMid:29086193