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Fatigue Analysis and Stress Transfer by Different Diameter Short Implants in Posterior Edentulous Area: A 3D Finite Element Analysis

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Abstract

Objectives: The aim of this study was to compare the stresses transferred to the implant-abutment interface and bone by different diameter short implants when used for prosthetic rehabilitation in the region of reduced bone height in posterior edentulous maxilla.

Material and Methods: Four 3D finite element models for a two implant supported three unit fixed dental prosthesis were fabricated. Standard and short implants with varying diameter were used. Model M1 had both standard implants (4x10mm). M2 had one standard implant (4x10mm) and one short wide implant (5x6mm). M3 had one standard implant (4x10mm) with one short regular diameter implant (4x6mm). M4 model had both short-wider implants (5x6mm). Stress was then applied in the vertical (300N), horizontal (60N) and oblique (150N) directions and the stresses transferred to the implant-abutment interface and bone were calculated. Fatigue life of the prosthesis under dynamic load was then tested.

Result: Stresses at the implant-abutment interface and bone were minimum for M4 model. Stresses on the implant-abutment interface were maximum for M3, followed by M1 and M2. Stresses on the bone were comparable for M1, M2 and M3. M2 showed the most favourable fatigue life followed by M1, M4 and M3.

Conclusion: Under the limitations of the study it was concluded that a distal short-wide implant can be used effectively in patients with atrophic posterior maxilla. Two short-wide implants can be a viable option in patient with better bone width. Short-regular diameter implants should be used sparingly.

Keywords: Dental Implant, Dental Implant-Abutment Interface, Dental Prosthesis, Implant-Supported, Finite Element Analysis, Maxillary Sinus, Short Implant, Wide Implant.

Introduction

Posterior edentulous ridges impose challenges for the prosthetic and surgical rehabilitation of the jaw due to the close proximity of vital structures and reduced alveolar ridge height. Alveolar ridge resorption is rapid in the posterior edentulous area. Due to the presence of underlying vital structures such as the maxillary sinus and inferior alveolar canal, the amount of bone available for rehabilitation is limited in the posterior region as compared to the anterior region.(1) Various surgical techniques have been proposed in the literature for bone augmentation in such atrophic regions of the mouth including bone grafting using onlay grafts, sinus augmentation, distraction osteogenesis and guided bone regeneration.(1) These techniques facilitate the placement of standard dimensions implant however they increase the treatment time, are technique sensitive and may be contraindicated in some patients due to the medical conditions or other relative contraindications. Such cases can be managed effectively by modifications in the implant size and placement configurations.

Use of short implants has proven to be an effective method for rehabilitation of atrophic posterior edentulous areas. (2) Available literature pertains to stresses generated in the bone around an implant supported prosthesis wherein three short implants are used to replace three missing teeth in posterior edentulous area. (3) Such placement modality tends to increase the cost of treatment. Situations where the available bone is compromised in both length and width can be managed by the use of short-regular diameter implant. There is lack of studies comparing the stresses transferred to the bone and on the implant-prosthesis assembly under both static and dynamic loading conditions when two implants are used for replacing missing teeth with the help of a three-unit implant supported fixed dental prosthesis. (4-7)

Stresses transferred to the bone and on the implant-prosthesis assembly was evaluated and compared in the present FEA (Finite Element Analysis). Different diameters of short implants were used alone or in combination with standard implant to replace three missing teeth in posterior edentulous maxilla. The study focused on determining the stresses transferred to the implant-abutment interface and bone by a short-wide and short-narrow diameter implant assemblies when used in atrophic posterior maxilla where available bone is limited. Fatigue analysis was also done to determine the log life of each model under cyclic loading.

Material and Methods

3D model of the patient's edentulous jaw was obtained using a computed tomography scan data of a patient which was imported in the 3-Matic module of Mimics software. The bone comprised of an outer cortical bone and an inner cancellous core.

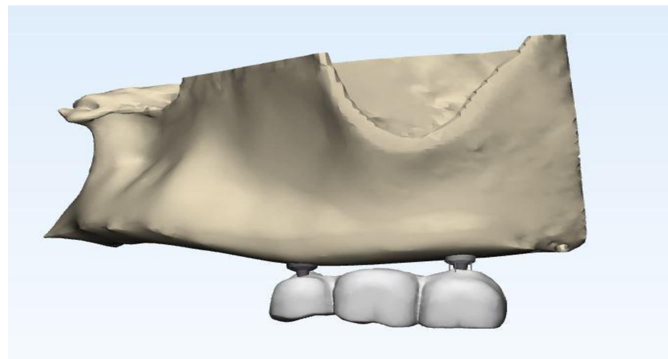
Modelling and material properties

3-Matic software was used to design standard, short regular diameter and short wide diameter implants of dimension 4x10mm, 4x6mm and 5x6mm respectively. Three-unit implant supported prosthesis was then scanned using a 3D scanner and the data was imported in the 3-Matic software which was then used to design the models (Fig 1). In finite element studies, the model is broken down into small elements to evaluate the effect of force on the smallest portion of model. These small elements comprise the mesh framework. Mesh regeneration for the models was done using 3-Matic software using Tet 10 element. Ten noded elements were used to maximize the sensitivity of the analysis. The total numbers of elements in M1 model were 160458, M2 were 158657, M3 were 167281 and M4 were 159283. The material used for the implants was titanium while that for the framework was cobalt-chromium as it is the most commonly used material in the clinical practice. All the structures in the study were considered isotropic, homogenous and linearly elastic. The mechanical properties of the materials in study were taken from the data available in the literature (Table 1) (8).

Table 1: Mechanical properties of different materials used in the model

Material		Youngs Modulus (Gpa)	Poisson Ratio
Bone	Cancellous	0.69	0.3
	Cortical	13.7	0.3
Titanium		110	0.3
Cobalt chromium		210	0.3

Fig 1: Model generated using 3-MATIC software.



Boundary and Loading conditions

The average biting force of 300N has been advocated in the literature hence a static vertical load of 300N was applied on the occlusal surface of the prosthesis. However, as the biting force is not always vertical, static oblique load of 150N was applied on the buccal inclines of palatal cusps of the prosthesis at an angle of 30˚ to the vertical. A static horizontal load of 60N was on the occlusal surface of the prosthesis in the mesiodistal direction to mimic the parafunctional jaw movement. (9) Von Mises stress values in the bone and on the implant-prosthesis assembly for all the models was then calculated under these 3 loading conditions. Movement of the nodes was constrained in all the areas simulating the attachment of maxilla to the cranium i.e. when load was applied, movement took place at the level of prosthesis. Osseointegration between the implant bone interfaces was assumed to be 100% hence restricting any movement at the interface.

Models

Four models were designed for the study:

Model 1 (M1) – Maxillary bone with standard implants (4x10mm) placed in a conventional manner for a three unit fixed dental prosthesis i.e. in the second premolar and second molar region.

Model 2 (M2) - Maxillary bone with standard implant (4x10mm) placed in the second premolar region and a short wider implant (5x6mm) placed in the second molar area for a three unit fixed dental prosthesis.

Model 3 (M3) - Maxillary bone with standard implant (4x10mm) placed in the second premolar region and a short regular diameter implant (4x6mm) placed in the second molar area for a three unit fixed dental prosthesis.

Model 4 (M4) - Maxillary bone with short wide implants (5x6mm) placed in a conventional manner for a three unit fixed dental prosthesis i.e. in the second premolar and second molar region.

Von Mises stresses were evaluated in the bone around the implants and on the implant-prosthesis assembly using the ABAQUS software. Data was obtained in the form of a coloured scale that represented the maximum and minimum stress values in the model. Comparative evaluation of the location and amount of stress generated by each model was done.

Fatigue analysis

The masticatory cycle and hence the masticatory forces are dynamic in nature so after performing the FEA under static loading condition, fatigue analysis using FESAFE software under dynamic loading conditions was performed for each model. Fatigue analysis helps in predicting the log life of the implant and the implant prosthesis assembly before crack propagation begins.

Brown-Miller strain configuration was used to design algorithms in FESAFE software. (10) The input file for the software was output file obtained using ABAQUS thus the models were tested under similar loading conditions. The cycles of dynamic loading were such that a maximum load of 300N and a minimum load of 0N was applied for vertical load; 150N, 0N for oblique load and 60N, 0N for horizontal loading condition. The applied load was repeated at a frequency of 5Hz i.e. five times in each second till any deformation began.

Result

Tables 2 and 3 depict the von Mises stresses transferred to the bone and on the implant-abutment interface for all the models. Stresses are depicted in the form of a coloured scale that helps in better visualization of the areas of maximum and minimum stress transfer.

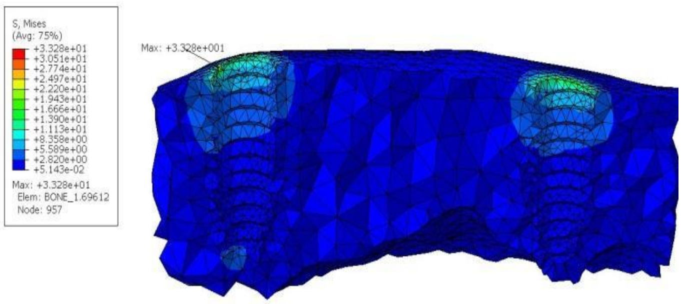
Von Mises stresses in the bone (Table 2, Fig 2)

Minimum von Mises stresses in the bone were observed in M4 model under all loading conditions followed by M2, M3 and M1. However, under oblique loading condition, M3 showed higher stress values as compared to M1. The pattern of load distribution was similar in all models and was concentrated at the bone crest under all loading conditions. Under horizontal load, maximum stress was observed at the mesial and distal aspect of the implants. Under vertical load, stress was observed at the buccal and palatal aspect of the implant while under oblique load, maximum stress was observed at the palatal aspect of the implant.

Table 2: Stresses on the bone

Model	Horizontal (MPa)	Vertical (MPa)	Oblique (MPa)
M1	28.1	33.28	49.51
M2	7.53	17.17	24.7
M3	9.8	28.2	54.9
M4	6	13.8	19.5

Fig 2: Von Mises stresses in the bone.



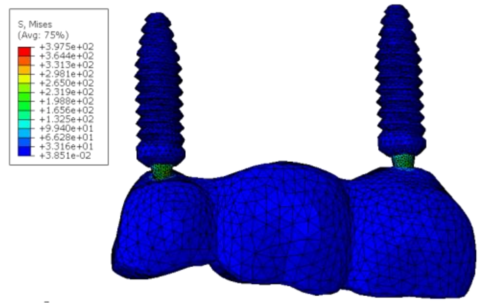
Von Mises stresses on the implant-abutment interface (Table 3, Fig 3)

On the implant-abutment interface, minimum stresses were observed in M4 model under all loading conditions followed by M2, M1 and M3. However, under vertical and oblique loads, the stresses on the implant-abutment interface were much higher for M3. The load was distributed equally on both the mesial and distal implants for all models irrespective of the loading condition.

Table 3: Stresses on the implant and prosthesis assembly

Model	Horizontal (MPa)	Vertical (MPa)	Oblique (MPa)
M1	397	457	1486
M2	154	545	608
M3	478	1840	2638
M4	118	428	815

Fig 3: Von Mises stresses on the implant-abutment interface.



Fatigue analysis (Table 4)

The fatigue life of the prosthesis before crack propagation began was predicted with the help of fatigue analysis hence the maximum and minimum log life of each model was assessed. Under horizontal loading condition, M2 and M4 showed similar log life followed by M1 and M3. Under vertical loading condition, M1 showed the maximum log life followed by M2, M4 while M3 showed the least log life. Under oblique loading condition, M2 showed the maximum log life followed by M4, M1 and M3.

The results of the study depicted that though the stresses transferred to the bone and on the implant-abutment interface were minimum for M4. Under static loading conditions, M3 assembly showed poorer log life under dynamic loading when compared to M1 and M2.

Table 4: Log life of each model (in cycles) under cyclic loading

	Horizontal		Vertical		Oblique	
Model	Minimum Log life	Maximum Log life	Minimum Log life	Maximum Log life	Minimum Log life	Maximum Log life
M1	$10^{6.7}$	10^{9}	$10^{8.6}$	10^{9}	10^{3}	10^{9}
M2	$10^{8.6}$	10^{9}	$10^{8.2}$	10^{9}	$10^{6.9}$	10^{9}
M3	$10^{4.6}$	10^{9}	$10^{1.8}$	10^{9}	$10^{1.2}$	10^{9}
M4	$10^{8.6}$	10^{9}	$10^{5.8}$	10^{9}	$10^{5.3}$	10^{9}

Discussion

The conventional implant assembly with one mesial and one distal implant is the most widely accepted configuration for the replacement of posterior three missing teeth. However, often in clinical practice, we encounter situations where due to the pneumatisation of the maxillary sinus and continued bone loss, the space available for implant placement is limited which precludes the placement of an implant with regular length (>8mm). Such situations can be effectively managed with the help of short implants, that allow prosthetic rehabilitation of the atrophic area which decreases the cost and morbidity for the patient. (4) Most commonly the posterior maxilla presents with a loss of vertical bone height but with adequate bone width. In these situations, wider distal implant can be placed along with a standard mesial implant however, there may be a situation where the bone width is also limited, and such situations can be managed with a shorter regular diameter implant. Literature suggests acceptable survival and success rate of three regular diameter (4mm) short implants (≤7mm) in supporting three crowns. (7) Present study compared the regular diameter short implant (4x6mm) and wide diameter short implant (5x6mm) with standard diameter implant (4x10mm) when used in posterior atrophic maxilla. (7)

All the materials in the study were assumed to be homogenous, isotropic and linearly elastic with 100% bone implant contact. (11) Stresses were applied on all the models in the ratio of 1:5:2.5 for horizontal, vertical and oblique stresses as seen by Graf. (12) These stresses represented the masticatory and parafunctional load on the assemblies. The study design was made for comparative evaluation of the stresses hence the simplifications made in the study was justified.

Stresses in bone

Stresses were observed around buccal and lingual aspect of the implants in all the models as depicted by Akca et al. (13) Stresses were minimum for M4 model under all loading conditions. This may be due to the larger diameter of the mesial and distal implants hence increasing the bone-implant contact. A study by Kang et al reported that von Mises stresses in the bone decrease with increase in implant diameter. (14) Stresses were distributed to a larger area for wider implants however, for regular diameter implants, stress concentration was observed near the bone crest around the implant. Various studies have demonstrated the increase in bone implant contact with increasing diameter and length of the implant. (15) It has been seen that an increase of 1mm in the diameter increases the bone implant contact by 35% whereas for a similar result, length of the implant should be increased by 3mm. (16) Hence the M4 model showed minimum stress distribution to the surrounding bone under all loading conditions. Regular diameter of the distal implant in M3 model along with the shorter length led to increased force transfer (54.9MPa) to the surrounding bone in M3 model. Under oblique loading condition but this was in a comparable range with conventional M1 (49.51MPa) model.

Stress on the implant-abutment interface

Stresses were concentrated at the implant abutment interface for all the models under all loading conditions. Under horizontal loading condition, stresses were concentrated near the distal implant abutment connection for all models. M4 showed the minimum stress values followed by M2, M1 while M3 showed the maximum stress values. This may be due to the wider diameter of the distal implant in models M4 and M2 hence, increasing the bone implant contact and reducing the bucco-lingual cantilever of the prosthesis. Under vertical loading condition, the stresses were distributed along the length of the implant hence, M3 showed maximum stress concentration due to shorter and regular diameter distal implant leading to unfavourable force distribution.

M1, M2 and M4 showed almost comparable stress values due to similar stress distribution pattern and similar bone implant contact. Under oblique loading condition, M2 showed minimum stress values followed by M4, M1 and M3. This is due to the reduced bucco-lingual cantilever of the prosthesis for assemblies M2 and M4 leading to better stress distribution under oblique loading condition. Increased stresses on the M3 assembly under oblique load may be due to the shorter length of the distal implant and regular diameter of the implants making it an unpredictable alternative.

Fatigue analysis

The fatigue life of the prosthesis before crack propagation begins was observed under dynamic loading. This was done to predict the life of the prosthesis in function. One million masticatory cycles over a period of one year has been observed in humans in previous studies. (17) Under all loading conditions, M3 assembly failed under masticatory load before completing one million cycles while M2 showed the most favourable log life. The results of fatigue analysis depicted that a distal short wider implant along with a standard mesial implant can prove to be an effective alternative in areas of reduced bone height. In case of regular diameter bone with short length, two distal short regular diameter implants in a three implant configuration can be used.

Limitations of The Study

FEA has some inherent limitations as the loading conditions are applied to the virtual models using computerized tool which may not simulate the actual situation. Presence of defective elements may influence the results of the study however the study has the advantage of being repeatable and controllable. Further studies are required to validate the results.

Conclusion

Posterior edentulous area especially in the atrophic maxilla poses challenge to the clinicians with regards to the prosthetic rehabilitation. In situations where the augmentation procedures are contraindicated to decrease the morbidity and cost of the prosthesis, shorter implants can be used to effectively rehabilitate the area. The present study compared the stresses transferred by different implant diameter and length combinations. It was observed that a distal short-wide implant can be used effectively with a mesial standard implant to rehabilitate atrophic areas. Both mesial and distal short-wide implants can also be used effectively. However, considerations in the design of the prosthesis should be done depending on the opposing arch. A short regular diameter implant is best avoided in the posterior edentulous regions.

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References

1. Jivraj S, Chee W. Treatment Planning of Implants in Posterior Quadrants. Br Dent J. 2006;201:13-23.
2. Nisand D, Renouard F. Short Implant in Limited Bone Volume. Periodontology Periodontol 2000. 2014 Oct;66(1):72-96.
3. Karthikeyan I, Desai SR, Singh R. Short Implants: A Systematic Review. J Indian Soc Periodontol. 2012;16(3): 302–12.
4. Neves FD, Fones D, Bernardes SR, Prado CJ, Neto AJ. Short implants-an analysis of longitudinal studies. Int J Oral Maxillofac Implants. 2006;21:86-93.
5. Li T, Hu K, Cheng L, Ding L, Ding Y, Shao J, Kong L. Optimum Selection Of The Dental Implant Diameter And Length In The Posterior Mandible

With Poor Bone Quality – A 3D Finite Element Analysis. Applied Mathematical Modelling. 2011;35: 446–56.

6. Himmlova L, Dosta´Lova T, Ka´Covsky A, Konvicˇkova S. Influence of Implant Length and Diameter On Stress Distribution: A Finite Element Analysis. J Prosthet Dent. 2004; 91:20-25.
7. Renouard F, Nisand D. Impact of Implant Length and Diameter On Survival Rates. Clin. Oral Imp. Res. 17 (Suppl. 2). 2006; 35–51.
8. Meriç G, Erkmen E, Kurt A, Tunç Y, Eser A. Influence of Prosthesis Type and Material On the Stress Distribution in Bone Around Implants: A 3-Dimensional Finite Element Analysis. J Dent Sci. 2011;6(1):25–32.
9. Van Eijden TMGJ. Three-Dimensional Analyses of Human Bite-Force Magnitude and Moment. Arch Oral Biol. 1991;36(7):535–39.
10. Yu Z-Y, Zhu S-P, Liu Q, Liu Y. Multiaxial Fatigue Damage Parameter and Life Prediction Without Any Additional Material Constants. Materials. 2017;10(8):923.
11. Cochran D. The Scientific Basis for and Clinical Experiences with Straumann Implants Including The ITI® Dental Implant System: A Consensus Report. Clin Oral Impl Res. 2000;11: 33–58.
12. Graf H, Graseel H, Aeberhard HJ. A Method for The Measurement of Occlusal Forces in Three Direction. Helv Odont Acta. 1974; 18:7–11.
13. Akca K, Iplikcioglu H. Finite Element Stress Analysis of the Effect Of Short Implant Usage In Place Of Cantilever Extensions In Mandibular Posterior Edentulism. J Oral Rehabil. 2002;29(4):350–56.
14. Kang N, Wu Y, Gong P, Yue L, Ou G. A Study of Force Distribution of Loading Stresses On Implant–Bone Interface On Short Implant Length Using 3-Dimensional Finite Element Analysis. Oral Surg Oral Med Oral Pathol Oral Radiol. 2014;118(5):519–23.
15. Song H-Y, Huh Y-H, Park C-J, Cho L-R. A Two-Short-Implant-Supported Molar Restoration in Atrophic Posterior Maxilla: A Finite Element Analysis. J Adv Prosthodont. 2016;8(4):304.
16. Jui-Ting, Yu-Jen A, Fuh L, Huang H. Effects of Implant Length and 3D Bone-To Implant Contact On Initial Stabilities of Dental Implant: A Microcomputed Tomography Study. BMC Oral Health. 2017; 17:132-38.
17. Karl M, Graef F, Taylor TD, Heckmann SM. In Vitro Effect of Load Cycling On Metal-Ceramic Cement- And Screw-Retained Implant Restorations. J Prosthet Dent. 2007;97(3):137–40.