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To Evaluate the Influence of Different Implant Thread Designs on Stress Distribution of Osseointegrated Implant: A Three-Dimensional Finite-Element Analysis Study–An In Vitro Study

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Abstract

Introduction Dental implants are common treatment modality for tooth loss which leads to unaesthetic appearance and may also cause deterioration of mastication and speech. The aim of implant therapy in dentistry is to restore tissue contour, function, comfort, aesthetic, and speech. Dental implant role is to transfer the mechanical force created during chewing to the supporting osseous tissues within the mandible and maxilla. The importance of biomechanical factors such as the bone-implant interface, implant thread design, the length and diameter of implants, type of loading, the quality and quantity of surrounding bone have been strained by various authors. The selection of implant thread design plays an important role in the outcome of the treatment. This study was done to evaluate the influence of different thread designs on stress distribution of osseointegrated implant using three-dimensional (3D) finite-element analysis.

Materials and Methods Three implants with different thread designs, namely V-thread, buttress, and reverse buttress thread designs were considered and dimensions were standardized. The site considered was the mandibular molar region with cortical and cancellous bone assuming to be isotropic and homogeneous. The implant modeling was done with the ANSYS 18.1 software. Axial load (100N) and buccolingual load (50N) were applied. The stresses were calculated as Von Mises stress criterion.

Results Minimum von mises Stress concentration was seen for tapered implant body with reverse buttress thread design under axial load 100N and tapered implant body with V-thread under buccolingual load of 50N at cortical bone which signifies bone preservation. Stress levels were observed maximum at implant and minimum at the cancellous bone.

Conclusion Hence, within the limitations of this study the results obtained can be applied clinically for appropriate selection of implant thread design for a predictable success of implant therapy.

Keywords
- dental implant
- FEA study
- implant thread
- stress analysis
- von mises stress

Introduction

Success of implant is evaluated from the mechanical and aesthetic perspectives. These both factors depend on the degree and reliability of the bond formed between the implant and the surrounding bone. Implant design is an important factor effecting implant primary stability and ability of implant to sustain loading during and after osseointegeration. Two major categories of implant designs are Macro design and Micro design. Macro design includes body shape and thread design

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e.g., thread geometry, face angle, thread pitch, thread depth. Micro design includes surface morphology implant materials, and surface coating.[1] Factor that play direct role in treatment outcome related to bone preservation is implant design in the form of body shape, thread design, surface texture, and drill protocol during preparation of osteotomy site and it also affects primary Implant stability. In low density bone primary stability increases by tapered design and surface modifications. As this factor directly influence the biomechanics in the bone so this is a point of dispute among researchers and manufactureres.[2] There is strong impact of biomechanics on long term maintenance of interface between implant and bone. So understanding of bone quality and quantity is very important to increase success rate. This also affects primary stability. Mandible shows thick cortex and dense trebaculation as compare with maxilla.[3]

The classification for bone quality (type i to iv) proposed by Lekholm and Zarb has been generally applied by clinicians in evaluating patient's bone for implant placement. Since the bone around implant must react to stresses and strains generated by occlusal loads, bone with poor quality could more easily fail to withstand these loads.[4]

FEA has become an increasingly useful tool for the prediction of effects of stress in the implant and its surrounding bone loads which are transferred from implants to surrounding bone depends on various factors like bone implant interface, type of loading, implant design, the shape and characteristics of implant surface, prosthesis type, quantity and quality of surrounding bone. FEA is a method in which instead of seeking a solution function for entire domain, one formulates the solution functions for each finite element and combines them properly to obtain a solution to the whole body. Components of implant and bone are extremely complex so suitable tool for analysis is FEA. Most difficult part is simulating the mechanical behavior of dental implants and preparation of human bone tissue model and its response to applied force. For that certain assumptions need to be made to make the modelling and solving process possible.[5] This study was done to evaluate the influence of different thread designs on stress distribution of osseointegrated implant using 3 Dimensional finite element analyses.

The aim of the article is to analyze the stress in peri-implant area by different implant thread designs in the molar region of mandible.

Materials and Methods

Materials

1) MIS Implant-Implant technology Ltd., Germany.
2) Dried specimen of human partially edentulous mandible (with missing first Molars) used for Coordinate measuring machine scanning.
3) Finite Element Software ANSYS v 18.1 (CADD CENTRE, S.C.O. 198- 200,4th floor, Sector -34-A, Chandigarh, India.

Methodology

Three implants with different thread designs namely V-thread, Buttress thread, and Reverse buttress thread designs with similar dimensions were considered. The dimensions standardized were implant length being 11.5 mm, diameter 3.75 mm, thread pitch 1.2 mm, thread depth 0.42 mm as depicted in (►**Fig. 1**). The site considered was the mandibular molar region with cortical and trabecular bone assuming to be isotropic and homogeneous and implants were inserted into this site (►**Fig. 2**). ANSYS program was used to solve the stress analysis problems.

The geometric models of mathematical mandible and implants were created. A graphic preprocessing software ANSYS version 18.1 was used for creating geometric configuration of the mandibular model and implant nodes and elements for a finite element analysis. The assembled finite element model of inserted implant in bone then imported into ANSYS 18.1 (ANSYS 18.1, Inc, USA) software for analysis (►**Figs. 3**–**5**). The material properties of implant and bone were entered in the preprocessing stage. The applied force and boundary conditions were applied in the solution stage. Post-processing the results and capturing the von Mises stress contours of each individual section in the system was done. Pre-processing, solving, and post-processing are three separate stages in the ANSYS software.

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The elastic properties of bone model were obtained from the literature as shown in (►**Table 1**) and the implant from MIS (►**Table 2**).

Elements and Nodes

The models were meshed with 10-node-tetrahedron. A finer mesh was generated around the implant-bone interface. Models were composed of 152255 elements and 190661 nodes.

Constraints and Loads

Forces of 100 N and 50 N were applied axially and buccolingually. The maximum and minimum von Mises equivalent stresses contour at cortical bone, cancellous bone and implants were calculated.

Observations and Results

The present study was aimed to evaluate the amount of stress field developing at implant and bone with implant with different thread designs Buttress, V and Reverse buttress in mandibular first molar region under axial load of 100N and buccolingual load of 50N. A color scale showing von Mises stress distribution with stress values was used to evaluate quantitatively the stress distribution in the bone and the implant. The scale for stress ranged from 0MPa (blue) to the highest stress values (red). Red indicates areas with highest stress; blue indicates areas with the lowest stress. The maximum von Mises stress values obtained from scale in cortical and cancellous bone and on implant were recorded and compared with the help of (►**Tables 3**–**5**) and (►**Figs. 6**–**8**).

The maximum Von Mises Stress values with axial force on implants with tapered body were observed to be 19.40 Mpa

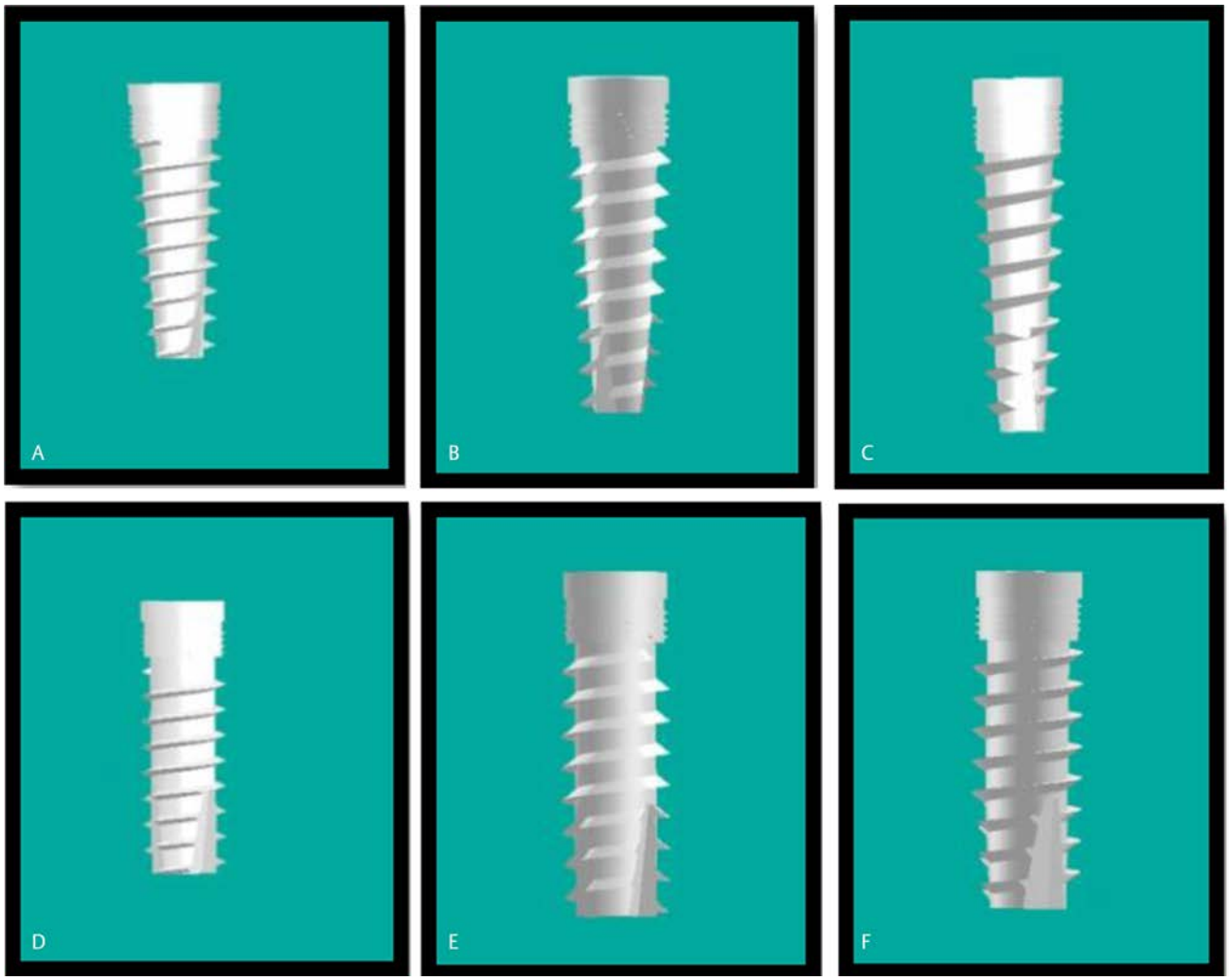

Fig. 1 (**A-C**) Cylindrical implant with different thread design. (**D-F**) Tapered implant with different thread design.

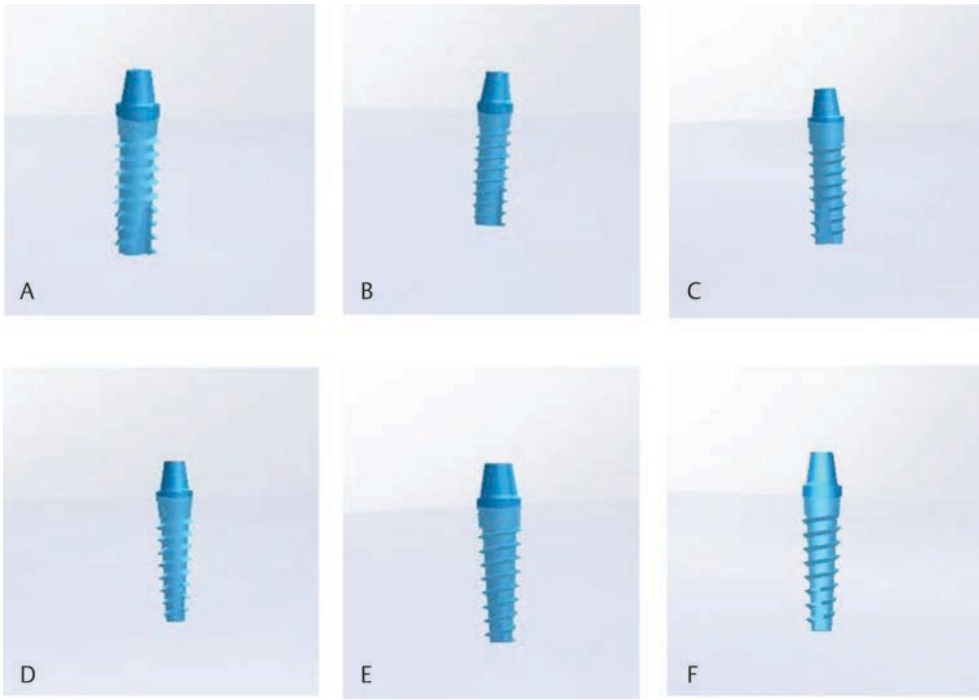

Fig. 2 (**A-C**) Cylindrical implant with different thread design in bone. (**D-F**) Tapered implant with different thread design in bone.

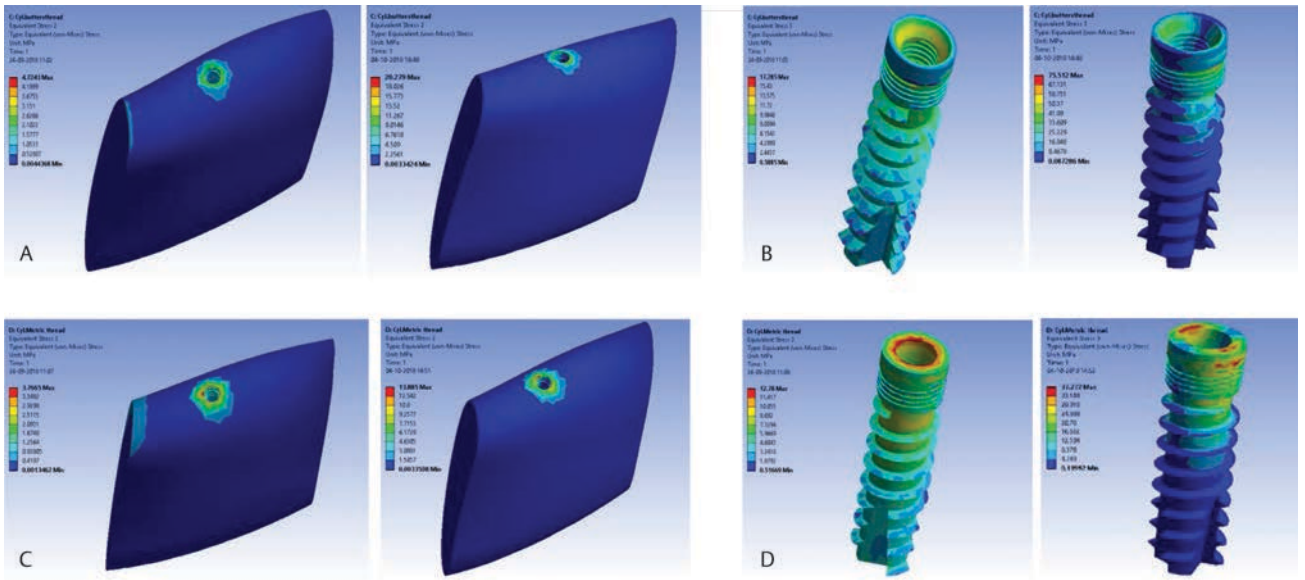

Fig. 3 (**A, B**) Bone model and cylindrical buttress thread implant. (**C, D**) Bone model and cylindrical V-thread implant.

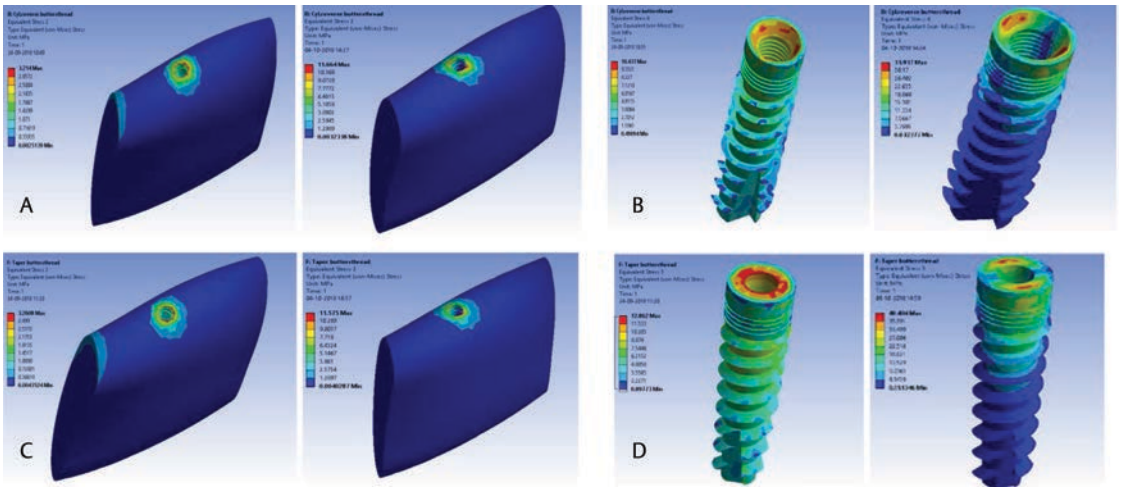

Fig. 4 (**A, B**) Bone model and cylindrical reverse buttress thread implant. (**C, D**) Bone model and tapered buttress thread implant.

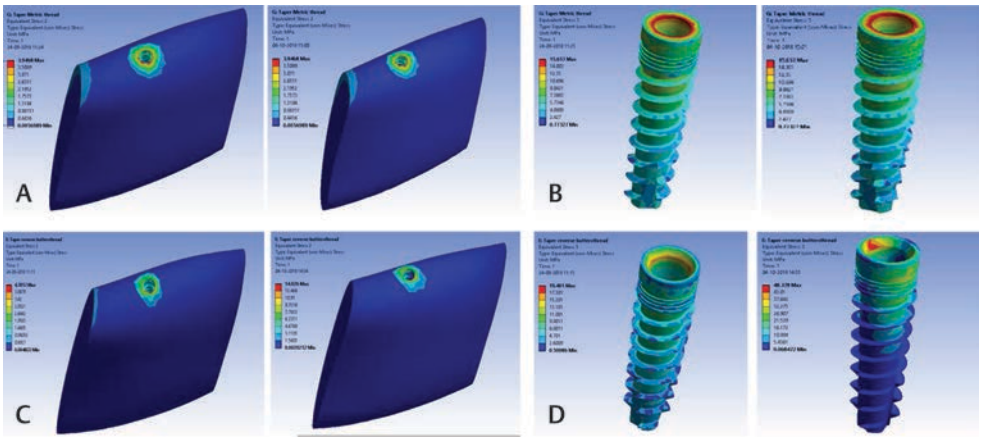

Fig. 5 (**A, B**) Bone model and tapered V-thread implant. (**C, D**) Bone model and tapered reverse buttress thread implant.

for Reverse Buttress thread and for cylindrical body were observed to be 17.28 Mpa for Buttress thread. The maximum Von Mises Stress values with buccolingual force on implants with tapered body were observed to be 48.37 Mpa for Reverse buttress thread and for cylindrical body were observed to be 75.51 Mpa for Buttress thread (►**Table 3**, ►**Fig. 6**).

The maximum Von Mises Stress values with axial force on bone when implants of tapered and cylindrical body with different thread designs inserted in bone were observed to be 3.41 Mpa for cortical bone in cylindrical body with buttress thread and 0.79 Mpa for cancellous bone in cylindrical body with buttress thread. The maximum Von Mises Stress values with buccolingual force on bone when implants of tapered and cylindrical body with different thread designs inserted in bone were observed to be 13.52 Mpa for cortical bone in cylindrical body in Buttress thread and 2.25 Mpa for cancellous bone in cylindrical body with Buttress thread (►**Table 4**, ►**Fig. 7**).

The maximum Von Mises Stress values with axial force on implant with tapered body with Reverse buttress thread were observed to be 15.20 Mpa for cervical level, 11.01 Mpa for middle level and 3.65 Mpa for apical level. The maximum Von Mises Stress values with buccolingual force on implant with cylindrical body with Buttress thread were observed to be 37.79 Mpa for cervical level, 21.04 Mpa for middle level and 8.46 Mpa for apical level (►**Table 5**, ►**Fig. 8**).

Table 1 Material properties of the structures and materials of interest

Materials	Young's modulus (MPa)	Poisson's ratio
Titanium	110,000	0.30
Cortical bone	13,700	0.30
Cancellous bone	1370	0.30

Table 2 Material properties of implant MIS (Make It Simple) Implants Technologies Limited (Global), Germany

Mechanical properties	SI units
Tensile strength	1035 MPA
Yield strength	905 MPA
Elastic modulus	102 GPA
Poisson's ratio	0.34
Elongation	22%
Implant length	11.5 mm
Implant diameter	3.75 mm

Table 3 Comparison of maximum Von Mises stress on tapered and cylindrical implant body with different thread designs under axial load (100N) and buccolingual load (50N)

Implant thread design	Axial load (100N)		Buccolingual load (50N)	
Buttress thread	12.86	17.28	40.48	75.51
V-thread	15.65	12.78	15.65	37.27
Reverse buttress thread	19.40	10.43	48.37	33.93
	Tapered	**Cylindrical**	**Tapered**	**Cylindrical**

Discussion

Threads are designed to maximize initial contact, enhance surface area, and facilitate dissipation of stresses at the bone implant interface. Thread shapes in dental implant design include V-shape, Buttress and Reverse buttress. In conventional engineering applications, the V thread design is called a "fixture" and is primarily used for fixating metals parts together, not load transfer. Krupp[6] has design reverse buttress thread initially to control pull out load. Buttress and reverse buttress thread design help to transfer single stress areas into disconnected areas near thread tip. This leads to discontinuity and stress shielding effect.

Stress shielding effect is increasing nonlinear stress on implant surface as more stresses in valley between thread pitch as compare with those at the tip of the thread.

Table 4 Comparison of maximum Von Mises stress on cortical and cancellous bone when tapered and cylindrical implant body with different thread designs inserted in bone under axial load (100N) and buccolingual load (50N)

Implant thread design	Axial load (100N)			
	Cortical	Cancellous	Cortical	Cancellous
Buttress Thread	2.89	0.54	3.41	0.79
V-Thread	3.071	0.66	3.13	0.62
Reverse Buttress	2.44	0.49	2.67	0.53
Implant thread design	Tapered		Cylindrical	
	Buccolingual load (50N)			
	Cortical	Cancellous	Cortical	Cancellous
Buttress Thread	7.718	1.91	13.52	2.25
V-Thread	3.28	0.66	10.8	1.54
Reverse Buttress	10.13	2.33	9.072	1.29
	Tapered		Cylindrical	

Table 5 Comparison of maximum Von Mises stress on tapered and cylindrical implant body with different thread designs at different levels of implant body under axial load (100N) and buccolingual load (50N)

Implant thread design	Axial load (100N)					
	Cervical	Middle	Apical	Cervical	Middle	Apical
Buttress thread	11.53	8.874	2.60	13.57	10.76	3.365
V-thread	14.03	9.042	3.25	11.41	8.04	3.24
Reverse buttress	15.20	11.01	3.65	9.33	6.645	2.145
	Tapered			Cylindrical		
Implant thread design	Buccolingual load (50N)					
	Cervical	Middle	Apical	Cervical	Middle	Apical
Buttress thread	27	9.03	4.543	37.79	21.038	8.46
V-thread	10.28	6.28	3.25	18.696	12.50	4.24
Reverse buttress	28.68	10.8	5.43	16.98	9.45	3.799
	Tapered			Cylindrical		

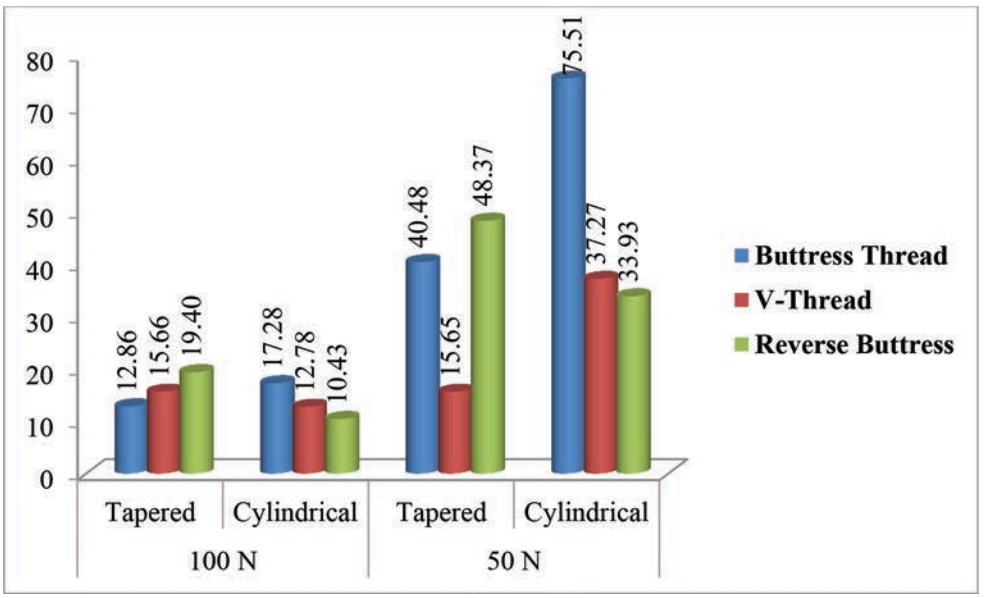

Fig. 6 Comparison of maximum Von Mises stress on tapered and cylindrical implant body with different thread designs under axial load (100 N) and buccolingual load (50 N).

Comparison of Tapered and Cylindrical Implant Body with Different Thread Designs

The maximum von mises stress was observed at tapered implant body with reverse buttress thread (19.401 Mpa) and cylindrical implant body with buttress thread (17.285 Mpa) under axial load (100 N). The maximum von mises stress was observed at tapered implant body with reverse buttress thread (48.37 Mpa) and cylindrical implant body with buttress thread (75.51 Mpa) under buccolingual force (50 N). Due to shielding effect there is less transfer of load to the bone near the interface which improves osseointegeration (►**Table 3**, ►**Fig. 6**).

Comparison of Cortical and Cancellous Bone when Tapered and Cylindrical Implant Body with Different Thread Designs Inserted in Bone

In this study maximum stresses were seen at the cortical bone compared with the cancellous bone. Stress levels were maximum at implant than bone suggested that stresses which were transferred more to the implant than to the bone promote bone preservation observed by Amasil et al.[7] On axial loading (100 N), minimum von mises stress was seen at Tapered body with Reverse buttress Buttress thread design within the cortical bone (2.44 Mpa) and within cancellous bone minimum von mises stress was seen (0.49 Mpa). On buccolingual loading (50 N), minimum von mises stress was seen at tapered body with V- thread design within the cortical bone (3.28 Mpa) and within cancellous bone minimum von mises stress was seen (0.66 Mpa). In accordance with Oswal M study, in this study also on axial loading maximum von mises stress was observed on tapered body with reverse buttress thread implant with minimum von mises stress observed on bone which promotes bone preservation as maximum stress was observed on implant and minimum on bone (►**Table 4**, ►**Fig. 7**).

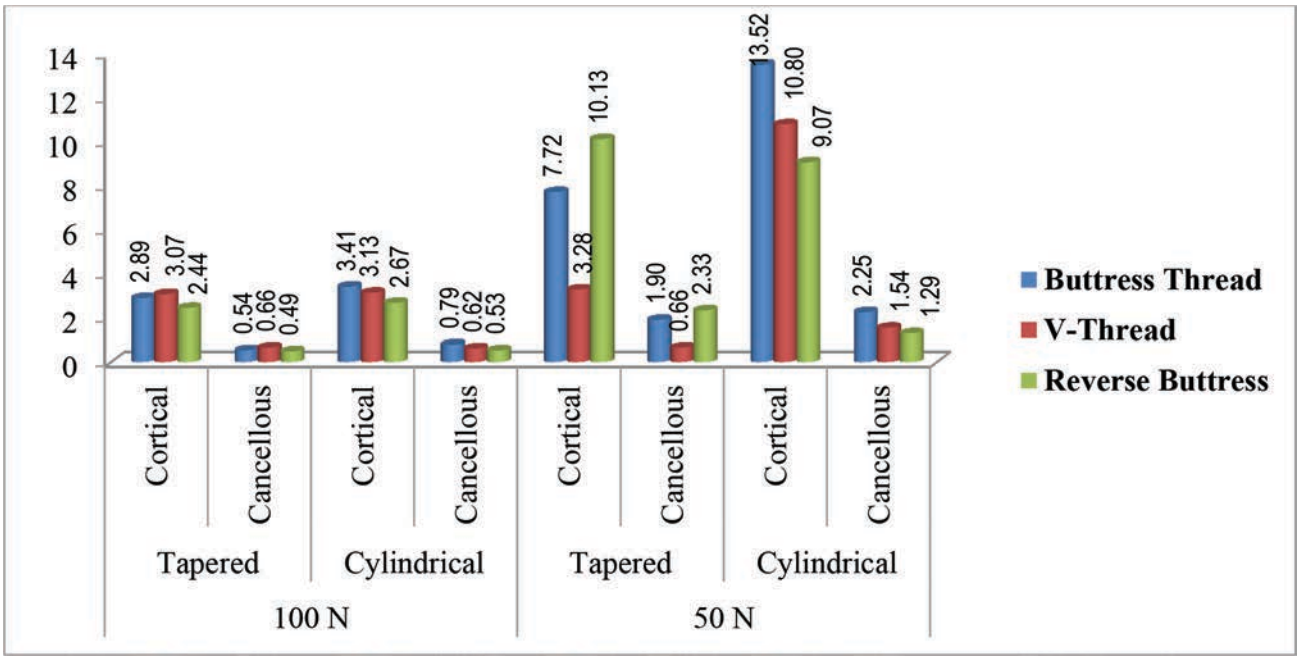

Fig. 7 Descriptive Von Mises stress values with buccolingual load (50N) on different levels of tapered and cylindrical implant body with different thread designs.

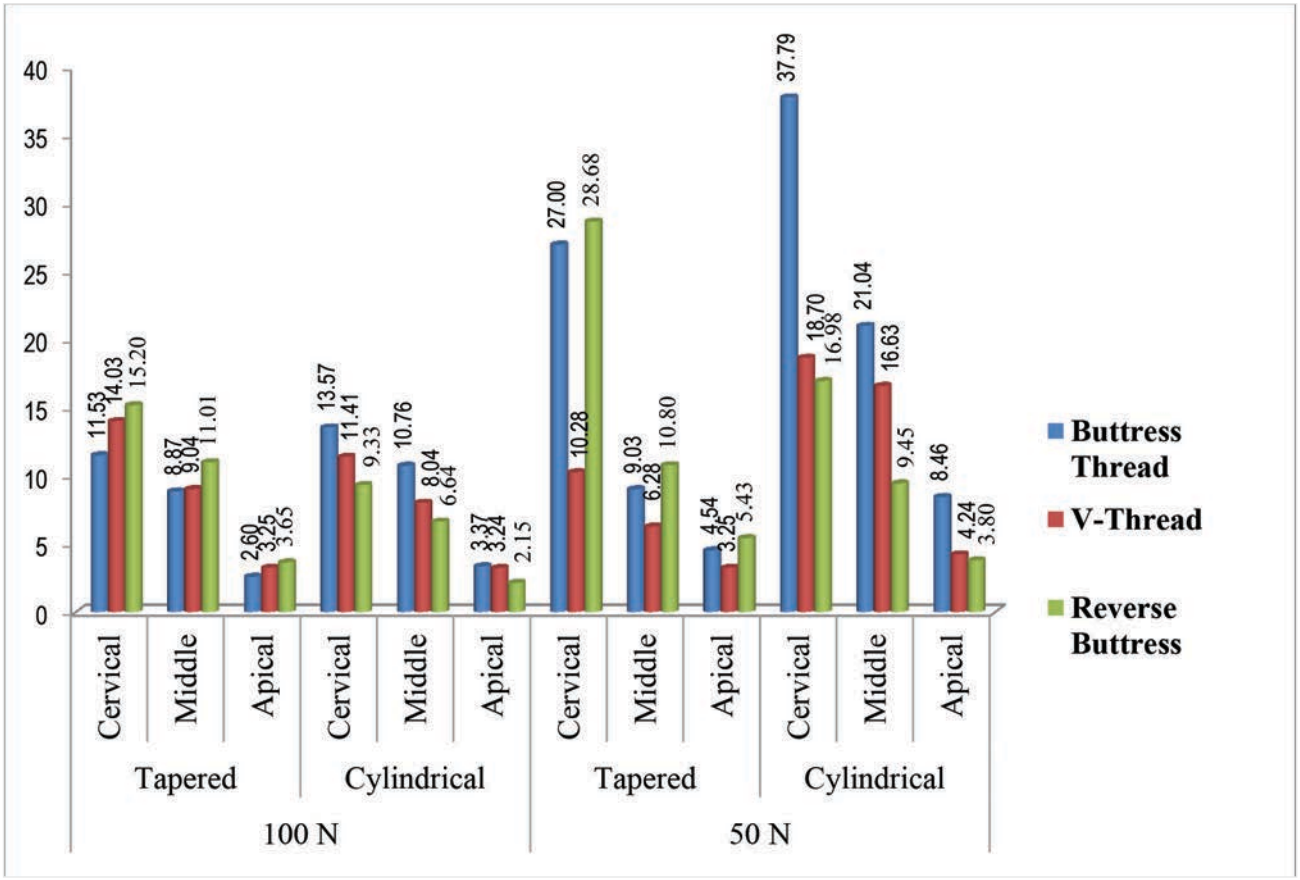

Fig. 8 Comparison of maximum Von Mises stress on tapered and cylindrical implant body with different thread designs at different levels of implant body under axial load (100 N) and buccolingual load (50 N).

Comparison of Maximum von Mises Stress on Tapered and Cylindrical Implant Body with Different Thread Designs at Different Level of Implant Body

The maximum stresses were located around the neck of the implant and distributed in the bone adjacent to the first six threads. In this study, the maximum stress was located up to the first thread and at the neck of the implant as stated by Anitua and Tapia.[8] In this study also maximum von mises stresses were also observed at cervical level of implant body in both tapered as well as cylindrical implants. The maximum von mises Stress values with axial force on implant with tapered body with Reverse buttress thread were observed to be 15.20 Mpa for cervical level, 11.01 Mpa for middle level and 3.65 pa for apical level. The maximum Von Mises Stress values with buccolingual force on implant with cylindrical body with Buttress thread were observed to be 37.79 Mpa for cervical level, 21.038 Mpa for middle level and 8.46 Mpa for apical level (►**Table 5**, ►**Fig. 8**).

Load concentrated on implant and bone was 100 N axial and 50 N oblique. Maximum Von mises stress was observed during oblique load. According to Zhang etal[9] this happened due to facts that vertical forces distributed uniformly all around the bone and threads of implant while lateral stresses generate shear force and bending effect in implant thus more stress in implant neck and bone interface.

Tapered implants exert higher stress on marginal bone, especially in thinner and shorter implants showed by Baggi et al.[10] Marginal bone loss around conical dental implants compared with parallel ones is higher showed by Kadkhodazadeh et al.[11] In this study under axial load tapered implants exert higher stresses while under buccolingual load cylindrical implants exert higher stresses.

Summary

In this study, mandibular first molar region was modeled on computer with the help of ANSYS 18.1 software. Implants of tapered and cylindrical body with different thread designs (buttress,v and reverse buttress) were modeled and virtually implanted into this bone of mandibular first molar region. Further axial load of 100 N and buccolingual load of 50 N were applied and stress patterns were observed. Under axial load of 100 N and buccolingual load of 50 N, maximum von mises stresses were observed on tapered body with reverse buttress thread and cylindrical body with buttress thread design. Under axial load of 100 N and buccolingual load of 50 N, maximum stresses were seen at the cortical bone compared with the cancellous bone. Under axial load of 100 N minimum von mises stresses on bone were observed for tapered and cylindrical implant body with reverse buttress thread when implant of different thread designs were inserted into bone. Under axial load of 50 N minimum von mises stresses on bone were observed at tapered body with V-thread and cylindrical body with Reverse buttress thread when implant of different thread designs were inserted into bone. Under axial and buccolingual load, maximum von mises stresses were observed at the cervical level of all implant designs.

Conclusion

Maximum stresses were seen at the cortical bone compared with the cancellous bone. Stresses which is transferred more to the implant than to the bone promoting bone preservation. Maximum von mises stresses were observed on tapered body implant with Reverse buttress thread and cylindrical body implant with Buttress thread. Minimum Von Mises stress concentration was seen for tapered implant body with reverse buttress thread design under axial load 100 N and tapered implant body with V-thread under buccolingual load of 50 N at cortical bone which signifies bone preservation. Stress levels were observed maximum at implant and minimum at the cancellous bone.

Funding

None.

Conflict of Interest

None declared.

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