ORIGINAL RESEARCH

A Prospective Study to Evaluation of Design Parameters of Short Dental Implants on Stress Distribution in D2 Bone Quality Under Immediate Loading-A 3D FEA

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ABSTRACT
Background: Implant stability is influenced by a combination of surface topography and macroscopic levels of implant design. In reduced bone height situations, short implants are often considered a viable alternative to long implants, which often require additional augmentation procedures. The objective of this finite element study was to evaluate the peri-implant Von Mises stresses, strains and micro movements distribution in D2 bone quality around short implants of 6mm length with varying diameters of 4mm, 5mm and 6mm and different thread designs under immediate loading.
Materials& Methods: The study was conducted to evaluate the Von Mises stress, strain and micro movements distribution in D2 bone quality under immediate loading at department of periodontis at Rajasthan Dental College & Hospital, Jaipur, Rajasthan. 3D FEM were developed to simulate mandibular molar crown, supported by an implant of 6mm length with variation of different diameter and thread designs. The material properties were derived from other studies 32 and assigned to the models. The modeling analyses were accomplished using a software program SPSS version 22.0.
Results: When all the three diameters were compared wide diameter i.e. 6mm diameter implants had the least values of peri-implant von mises stresses, strains and micro movements around them. When thread shapes were taken into consideration the buttress thread created the most favourable stress parameters around them with minimum values of stress, strains and micro movements.
Conclusion: Short implants combined with a wide diameter and platform switching can be used in atrophic ridges or when there is a need of extensive surgery to prepare the implant site. Further randomized clinical trials are required to validate the results of this study.
Keywords: Bone Density, Thread, Width, Short Implant, Bone Quality, 3D.

INTRODUCTION
Dental implant serves as a load bearing device that not only sustain smasticatory forces, but also transfers load to peri implant bone.[1] A major contraindication to the placement of dental implants is inadequate volume and integrity of bone at the chosen site. Atrophy of alveolar

bone ridge occurs frequently in patients as a consequence of periodontitis, tooth extractions and craniofacialtraumas.[2]It was assumed at the time of introduction of dental implants that longer implants would be more beneficial in clinical use than their shorter counterpart due to improved crown to implant ratio & greater implant surface for osseointegration. However, with recent technological advances in the design & surface characteristics of dental implant, shorter implants are equally successful.[1]

Implant success is evaluated from the esthetic and mechanical perspectives. Both depend on the degree and integrity of the bond created between the implant and the surrounding bone. Many factors have been found to influence this interfacial bonding between the implant and bone and thus the success of implants.[3]Albrektsson et al. (1981) reported factors such as, surgical technique, host bed, implant design, implant surface, material biocompatibility and loading conditions to affect implant osseointegration.[4]

The advantage of short implants over regenerative techniques with conventional implants is low cost, shorter treatment span, simplicity and lesser risk ofcomplications.[5] The successful outcome of any implant procedure requires a series of patient-related and procedure-dependent parameters.[6] The volume and quality of the bone, which determine the type of surgical procedure and the type of the implant, are associated with the success of dental implant surgery.[7] Because mechanical behavior of the bone is an important factor in the successful osseointegration, several classification methods were suggested for assessing the bone quality.[8,9]However,many studies have included the evaluation of bone quality either at the time of osteotomy preparation or subsequent to implant insertion.[10,11]

Primary implant stability has an essential role in successful osseointegration.[12]Primary stability is a function of local bone quality, and bone quantity, the geometry of an implant (i.e. length, diameter and type), and the placement technique used (relation between drill size and implant size, whether a pre-tapped or self-tapped implant was used).[13] Secondary stability results after formation of secondary bone contact of woven and lamellar bone.[14]

Bone quality is one of the significant factors in determining the implantselection, primary stability and loading time. To understand the biomechanics of oral implants, it is important to understand the behaviour of bone around the implants, especially the volume and the density/quality, which reflects the structure of the bone. For the osseointegration of endosteal implant to occur, not only is adequate bone quantity (height, width, shape) required, but adequate density is also needed. Zarb and Schmitt stated that bone structure is the most important factor in selecting the most favourable treatment option in implant dentistry. Bone density of available bone in an edentulous site is a determining factor in treatment planning, implant design, surgical approach, healing time and initial progressive bone loading during prostheticreconstruction.[15-17]

Stress analysis of dental structures has been a topic of interest in recent years with an objective of determining stresses in the dental structures and improvement ofthe mechanical strength of these structures. Finite Element Analysis (FEA) is a modern tool for numerical stress analysis, with an advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties. Such numerical techniques may yield an improved understanding of the reactions and interactions of individual tissues.[18,19] It involves a series of computational procedures to calculate the stress and strain in each element. This makes it possible to adequately model the tooth and periodontal structure by dividing the problem domain into a collection of much smaller and simpler domains. The field variables can be interpolated with the use of shape functions for scientific checking and validating the clinical assumptions.[20] The structure is discretized into so called “elements” connected through nodes. When choosing the appropriate mathematical model, element type and degree of discretization are important to obtain accurate as well as time and cost effective solutions.

For osseointegration of the implants to occur, adequate bone quality and density is needed. So, bone quality is the significant factor in determining the implant selection, primary stability & loading time. Till date no studies have been carried out comparing short platform switched implants with different diameters and thread designs, under immediate loading protocol, placed in D2 bone quality. So the aim of the present study is to evaluate the peri implant Von Mises stress, strain& micro-movements using short platform switched implants with variation of different diameters and thread designs in D2 bone quality under immediate loading protocol.

MATERIALS& METHODS

The study was conducted to evaluate the Von Mises stress, strain and micro movements distribution in D2 bone quality under immediate loading at department of periodontis at Rajasthan Dental College & Hospital, Jaipur, Rajasthan. 3D FEM were developed to simulate mandibular molar crown, supported by an implant of 6mm length with variation of different diameter and thread designs.

METHODS

3D models were meshed using tetrahedral and octahedral elements and modeled by identifying the exact location of nodes after mathematical calculation by considering the inclination of threads. Each implant design consisted of fixture of 6 mm length incorporating acme, square, buttress and triangle (V) thread with a thread width of 0.8mm and thread height of 0.4mm. All models were developed to support a first permanent mandibular molar in a bone block of 20x22mm dimension with a cortical bone thickness of 1.5mm. Cortical and cancellous anisotropic properties were applied to the bone. The crown dimensions were derived from average dimensions of mandibular first molar. The screw was tapered by 5º. The height of the abutment was 5mm with hexagonal internal connection. The models with 4mm diameter were 10% platform switched and 5mm and 6mm diameter were 20% platform switched. Each model was analyzed with a single force magnitude of 100 N and with the force applied on the central fossa in the vertical direction (90 degrees) and in oblique direction (45 degrees) to the long axis of the tooth under immediate loading conditions with a frictional co efficient of 0.6 applied at the bone implant interface. The material properties were derived from other studies32and assigned to the models. The modeling analyses were accomplished using a software program SPSS version 22.0.

RESULTS

The present study was conducted to evaluate and compare the peri implant Von Mises stresses, strains and micro movements, using a 3 dimensional finite element analyses around short platform switched implants of 6mm length, with different diameter and thread designs. The implant designs were developed to support a mandibular molar crown placed in D2 bone quality under immediate loading conditions. Each model was analysed with a single force magnitude of 100N and withthe force of direction applied in the vertical direction (90 degrees) and in oblique direction (45 degrees) to the long axis of the tooth. 6mm length implants with 4/3.6mm diameter, 5/4 mm diameter & 6/4.8 mm diameter was effect on VonMises stresses, strains and micromovements values at vertical loads & oblique load of 100N force under immediate loading was shown in table no. 1.

Table 1: 6mm length implants with 4/3.6mm diameter, 5/4 mm diameter & 6/4.8 mm diameter was effect on VonMises stresses, strains and micromovements values at vertical loads & oblique load of 100N force under immediate loading

Implant		Vertical loads of 100N				Oblique loads of 100N			
		ACME	Buttress	Square	Triangle	ACME	Buttress	Square	Triangle
4/3.6 mm	Stress (MPa)	77.27	17.2	18.70	21.13	131.4	109.2	164.3	146.5

diameter	**Strain (Ɛ)**	846.6	234.3	386.6	254.2	889.1	655.8	747.4	920.2
	Micromovements (µm)	2.65	0.823	0.822	0.83	3.8	2.2	3.8	3.8
5/4 mm diameter	**Stress (MPa)**	11.18	10.6	9.7	12.2	38.17	33.86	42.18	51.02
	Strain (Ɛ)	200.5	261.4	292.7	207.7	449.8	417.2	710.4	535.3
	Micromovements (µm)	0.71	0.72	0.72	0.73	2.3	2.1	3.4	3.5
6/4.8 mm diameter	**Stress (MPa)**	9.4	8.2	9.2	9.17	27.62	26.8	30.8	41.3
	Strain (Ɛ)	189.2	216.6	163.12	206.2	463.6	420.3	529.4	439.8
	Micromovements (µm)	0.6	0.64	0.64	0.65	2.3	2.05	3.4	3.4

Among all the models developed, 6mm diameter threads had the least values of von mises stresses, strains and micromovements around them followed by 5mm diameter threads under vertical and oblique loading. All the values were the highest for 4mm diameter threads. Thus, wide diameter implants had the least amount of stresses and strains developed around them. Hence short implants will have favourable stresses if they are used with a wide diameter platform. Also, when the thread designs were compared, the buttress thread showed better stress distribution in case of 4mm and 6mm diameter implants, and buttress and square thread showed better results in case of 5mm diameter implants.

DISCUSSION

Primary implant stability is considered to play a fundamental role in obtaining successful osseointegration.[12] Implant configuration has been considered an essential requirement for implant success. Among the related implant parameters, diameter and length play key roles in implant success, since they directly influence the primary stability, placement and removal torque values.[21] Therefore to study the influence of diameter on peri implant bone loss we have evaluated short implants of different diameters ie4mm, 5mm and 6mm.

To accelerate osseointegration and to control the stresses in the bone, the most common approach is alteration of dental implant designs such as macro-design and micro-design (surface alterations).[22-25] An implant macro design includes thread, body shape, and thread design [e.g., thread geometry, face angle, thread pitch, thread depth (height), thickness (width), or thread helix angle]. Thread shape is determined by the thread thickness and thread face angle. Thread pitch refers to the distance from the center of the thread to the center of the next thread, measured parallel to the axis of a screw.[26] Implant threads should be designed to maximize the delivery of optimal favorable stresses while minimizing the amount of extreme adverse stresses to the bone–implant interface. In addition, implant threads should allow for better stability and more implant surface contact area.[27]Thread shapes in dental implant designs include square, V-shaped, acme and buttress. The acme thread form has a 29° thread angle with a thread height half of the pitch; the apex and valley are flat. This shape iseasier to machine (faster cutting, longer tool life) than is a square thread. The tooth shape also has a wider base which means it is stronger (thus, the screw can carry a greater load) than a similarly sized square thread. Acme screw threads were intended to replace square threads and a variety of threads of other forms used chiefly for the purpose of traversing motion on machines, tools, etc. Acme screw threads are now extensively used for a variety of purposes. Long length acme threads are used for controlled movements on machine tools, testing machines, jacks, aircraft flaps and conveyors. Short length threads are used on valve stems, hose connectors, bonnets on pressure cylinders, steering mechanisms and camera lens movement. They are best suited for applications that warrant large load bearing capacity and high accuracy.[28]Buttress thread shape is optimized for pull-out loads and has parallel major and minordiameter.[9] There are very few studies evaluating the use of acme thread as dental implant design. In this study we have used acme thread as one of the thread designs, other thread designs evaluated are buttress, square and triangle.

When applying FE analysis to dental implants, it is important to consider notonly axial loads and horizontal forces (moment-causing loads) but also a combined load (oblique occlusal force) because the latter represents more realistic occlusal directions and, for a given force, will result in localized stress in cortical bone.[29]Forthis reason, in this study, a force of 100 Newton was applied along the long axis of implants (axial load) and also separately a force of 100 Newton was applied at 45^0 to long axis of implants (oblique loads).

The results of our study were in accordance with the following studies. Chris M. ten Bruggenkate et al (1998)[30]assessedthe usage of short implants which were followed up for 1 to 7 years. The results of this study showed that quality of survival of short implants was comparable with the longer implants. Esposito M et al (2012)[31]inhisstudy comparedthe6 mmand10 mm-long implants placed in bone augmented with bone substitutes in posterior atrophic jaws, it was demonstrated that short implants might be a preferable choice to bone augmentation, since the treatment is faster, cheaper and associated with less morbidity. Maló P et al (2011)[32] reported that the outcome of 7 mm short implants in the rehabilitation of posterior areas of atrophic jaws. One year after loading, 7 mm short implants provided good success rates (95% at patient level and implant level) suggesting that the use of short implants is a viable concept. Telleman G et al (2012)[33]assessed the outcome of short implants (8.5mm) supplied with a conventional platform-matched implant-abutment connection or a platform-switched design. This study concluded that crestal bone resorption may be reduced by platform switching. Telleman G et al (2012)[34] assessed the effect of platform switching on peri implant bone remodeling around short implants placed in the resorbed posterior mandibular and maxillary region of partially edentulous patients. One year after loading, peri implant bone remodeling around test (8.5mm implant) was significantly less than around control. This study suggested that peri-implant bone remodeling is affected by platform switching. And one year after loading, inter proximal bone levels were better maintained at implants restored according to the platform switching concept.

Many studies have demonstrated the influence of implant diameter on peri implant stress reduction. . Xi Ding et al (2009)[35] in his finite element analysis studied implants ranging from 3.3mm to 4.8mm in diameter and length 6 to 14mm and he concluded that increasing both implant implant length and diameter resulted in reduction of crestal stresses, but the effect was more significant for the diameter factor. Similarly, Petrie et al (2005)[36] studied the influence of diameter and length in his FEA study and proved that increasing the implant diameter from 3.5mm to 6mm resulted in as muchas 3.5 fold reduction of crestal strain and increasing the length from 5.75mm to 23.5mm resulted in 1.65 fold reduction, clearly demonstrating an increase effect of the diameter on better stress and strain parameters. Himmlovaet al (2004)[37] in a FEA studied implants varying from lengths 8mm to 18mm and diameters ranging from2.9mm to 6.5mm. The decrease in stress was the greatest i.e 31.5% for implants with diameters ranging from 3.6mm to 4.2mm. After this the reduction of stresses was only 16.4%. The influence of implant length was also present but not that prominent as that of the diameter. He also concluded like previous authors that the implant diameter is a more influential factor for the reduction of masticatory stress around the implant. Vargas LC et al (2013)[38] evaluated the stress distribution of the peri-implant bone by simulating the biomechanical influence of implants with different diameters of regular or platform switched connections by means of 3-dimensional finite element analysis. It was concluded that, influence of platform switching was more evident for cortical bone than for trabecular bone and was mainly seen in large platform diameter reduction. Degidi M et al (2007)[39] evaluated the clinical outcome of wide diameter implants. Implant diameter and length ranged from 5.0 to 6.5 mm and from 8.0 to 15mm, respectively. Only five of 304 implants were lost (i.e., a survival rate of 98.4%) with reduced or no crestal bone resorption (CBR) which was considered as an indicator of success to evaluate the effect of several host, surgery, and implant related factors. The general linear model showed that distal teeth (i.e., premolars and molars), small implant diameter (i.e., 5.0 and 5.5 mm), and short implant length (i.e., <13 mm) correlated with a statistically significant lower CBR. It was concluded that use of WDIs is a viable treatment option, in posterior regions for long-term maintenance of various implant-supported prosthetic rehabilitations.

When comparing vertical and oblique loads, the results of our study demonstrated that the von mises stress, strains and micro movements were consistently higher for all threads and diameters under oblique loading as compared to the values under vertical loading. These findings were consistent with the following studies. Ding et al (2009)[35]studied, the effect of the diameter and length on the stress and strain distribution of the crestal bone around implants under immediate loading , and it was found that oblique loading would induce significantly higher interfacial stresses and strains than the vertical loading. Increasing the diameter and length of the implant decreased the stress and strain on the alveolar crest and the stress and strain values not ably increased under buccolingual loading as compared with vertical loading, but diameter had a more significant effect than length to relieve the crestal stress and strain concentration. Similarly another FEA study Kitamuraetal (2004,2005)[40,41] concluded that higher stresses were under buccolingual loading in both cancellous and cortical bone. This study also concluded that the increasing stresses in the cancellous bone and implant under lateral load may result in implant failure. This underlines the need for optimally designed implant t supra structures. During initial healing periods of an immediately loaded implant oblique forces can be avoided to prevent undue stresses and strains at bone implant interface.

In addition to the peri implant stresses and strains, displacement of implantbody occurs relative to the surrounding bone. Such movement or displacements arecalled as micro movements. Extensive micro motion may interfere with the implant’s osseointegration. For successful implant healing a threshold of 150µm should not becrossed.[42] All the models in our study had micro movements well within these limits. Negligible differences were recorded with the micro movements in all the models, and again buttress thread recorded minimal values except in case of 5 and 6mm diameter implants under vertical loading, in which case the acme thread have recorded the lowest values.

CONCLUSION

We concluded that short implants can be used since they offer a viable and successful alternative in patients who would otherwise require adjunctive treatment such as bone grafting prior to placement of a longer implant. Considering the results of the current FEA study, short platform switched implants with 6mm length and wide diameter incorporating buttress thread can yield favourable results.

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