Evaluation of Stress Distribution in Platform Switch Short Dental Placed at Different Depths in D1 bone – An in Vitro 3D FEM Study

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Abstracts: Context: FEA has been extensively used in implant dentistry to predict the biomechanical behavior of various dental implant designs, as well as the effect of clinical factors for predicting clinical success. Stress patterns in implant components and surrounding bone are well studied. Objective: To investigate the pattern of stress distribution in terms of equicrestal and subcrestal implant placement at various depths using short platform switching dental implants. Materials and Methods: 3D FEM of the mandibular anterior area was modelled with a uniformly cortical bone of 0.5 mm with an inner core of cancellous bone (FEM) using ANYSIS soft wear. Four implant modes were used with the following dimensions. Model 1. (6x4.6x3.5mm), models 2 (7.5x4.6x3.5mm), 3 (6x5.8x4.5mm), and 4 (7.5x5.8x4.5mm). For a realistic simulation, 100N and 200N of force were applied in axial and oblique directions (0°, 15°, and 30°, respectively). At different depths, both cancellous and cortical bone is evaluated for von Mises stress. Ten-noded tetrahedron components with three degrees of freedom per node are used to interpret translations on the x, y, and z axes. Results: Based on bone shape, force direction, and depth of implant placement, each of the five positions of platform-switched short osseointegrated implants examined by FEM simulations had a unique stress-based biomechanical behavior. Conclusions: Axial forces were less harmful than oblique forces. The cortical and cancellous bone experienced less stress because of the implantation of subcrestal implants. According to recent research, platform-switched short subcrestal implant models result in improved stress distribution around peri implant areas in D1 bone and the conservation of marginal bone loss.

Keywords: Eqicrestal, Finite Element Model, Platform Switched Implants, Short Dental Implants, Subcrestal Implants Position, Von Mises Stress, D1 Bone.

1. INTRODUCTION

Periodontitis is the most common cause of tooth loss, but other factors include dental caries, injuries, developmental abnormalities, and genetic disorders.[1] Replacement of missing teeth with dental implants has become an integral part of day-to-day dental practice. As a result, endosseous dental implants have gained widespread acceptance as a treatment option for replacing missing teeth in many clinical cases due to their practicality and high success rate. This rise in popularity has triggered a never-ending evolution, necessitating the use of implants in more difficult forms than previously thought possible.[2]

Due to recent technological innovations, the dental profession has undergone revolutionary changes.[3] Over the years, several clinical and systematic evaluations have noted a high success rate for endosseous dental implants. As a natural alternative to dentures, dental implants have a considerable positive impact on a person's general health.[4] On the other hand, a number of factors might favour implant failure, with site-related issues being the greatest risk to implant insertion and success.[5,6] Crestal bone loss for two-piece dental implants is considered suitable at 1.5 mm in the first few days and 0.2 mm in the following years. The preservation of crestal bone levels is necessary for the defence of gingival margins and interdental papillae, as well as the ensuing success of the implant-supported prosthetic restoration.[7,8] Clinicians and academics from all over the world became interested in this failure rate, which sparked a hunt for novel methods and procedures that would increase implant success. Utilizing short dental implants was one such effort.

The literature lists several initiatives to preserve marginal bone levels surrounding implants. Newer implant designs, surfaces, and time load strategies have reduced the risk of bone resorption.[9] Platform switch short, wider-diameter implants and subcrestal implant placement techniques have both been utilized to reduce crestal bone loss. Platform switching, which involves moving the micro gap site away from the bone crest using an abutment that is smaller than the implant neck, has been shown to reduce early MBL.[10,11.]

On the other hand, there is debatable information on implants positioned subcrestally. To effectively preserve marginal bone levels, several writers suggested positioning the implant platform 1 or 2 mm below the alveolar crest.[12,13] Other investigations, however, found that compared to implants placed equicrestally, the deep location of the IAJ caused inflammatory infiltrates to spread more widely.[14,15] The condition of the bone also affects how successful implant therapy is over the long term, with poor bone quality resulting in lower success rates. When evaluating a patient's bone for implant placement, clinicians frequently utilize the Lekholm and Zarb categorization for bone composition (types I through IV bone).[12] By referencing radiographic appearance in 1990, Misch suggested a taxonomy of various bone densities. Misch divided the bone consistency into four parts based on the measured bone density (D-1 to D-4).[16]

Platform-switched implants with conical connections implanted subcrestally, up to 15 months after implant insertion, may be affected by certain variables. From a biomechanical perspective, the basic interplay between ordered living bone and dental implants determines whether any implant type or design will be successful or unsuccessful.[17] The construction of finite element models (FEMs) in vitro aids in the understanding of principles for clinical application.[18,19] These models clearly offer additional benefits without involving any animals or people, but they also deliver information on stress, strain, and implant structures using in vivo techniques. But it also evaluates any biomechanical issues in advance.[10,11,20] FEM has recently evolved into a useful technique in implant dentistry for assessing stress distribution patterns. The scientific rationale for the use of short dental implants is based on the concept of functional surface area (FSA). Increased implant length increases the implant’s total surface area and improves primary stability by increasing the implant’s contact with the bone (BIC). However, the FSA, which transfers compressive and tensile loads to the bone, is limited to the crestal of 5-7 mm. This cannot be changed by lengthening the implant, while a short implant with a wider diameter offers both enhanced primary stability and increased FSA.[21] Advantages of short dental implants include avoiding more invasive procedures thereby reducing morbidity and healing time.

Two implant techniques have been proposed for preserving the degree of crestal bone surrounding implants: platform switching and subcrestal location.[22-24] The assumption is that when an implant is placed into the alveolar bone, there will be an unanticipated absence of bone surrounding it, which is hard to predict in advance, despite all the research and developments in implant design. Even now, people still cite the seminal work on crestal bone loss in the first and following years.[25]

1.1. Objectives of the Study

Research hypothesis – platform switch short dental implants: whether has any significant effect on crestal bone changes. Also, the research question is whether different forces at varying angulations have any significant effect on different bone types. Based on this research question the following are the objectives of our research.

1. To study the influences of von Mises stress in the D1 cortical and cancellous bone.

2. To evaluate bone stress in platform-switched implants when different forces are applied (100N, 200N) in D1 bone.

3. To compare stress distributions in D1 bone concerning angulation of load applied (0°, 15°, 30°)

4. To evaluate peri-implant bone stress distribution for platform-switched implants placed at different depths relative to the bone types D1.

5. To evaluate stress in D1 cortical and cancellous bone according to implant diameter and length.

2. MATERIAL AND METHODS

In this study, we utilized partial mode. Specific areas such as the mandibular anterior segment were constructed. A mandibular anterior segment with implants and superstructure was modeled on a personal computer (PC- HP 22-C0020NE), using a finite element program (ANSYS 14.5, Pittsburgh USA). D1 models were created with an inner cancellous core surrounded by a 2mm thick outer cortical layer as shown in figure 1. A total of four titanium platform switch short implant models were created according to the length and diameter of the implant used. Model 1 was designed with a 6mm implant length, 4.6mm implant diameter, and 3.5mm abutment (6x4.6x3.5mm). Similarly, model 2 (7.5x4.6x3.5mm), model 3 (6x5.8x4.5mm), and model 4 (7.5x5.8x4.5mm) were designed with the help of ANSYS workbench software. (Figure 1,2).

All the materials employed in the models were homogenous, linearly elastic, and isotropic. Anisotropic materials only have Young's modulus and Poisson's ratio as discrete material constants since their characteristics are the same in both directions. The literature was used to determine the elastic characteristics. (Table1) Most FEA models were deemed to have good bone-implant interfaces that accurately represented 100% osseointegration. In this study, the implant was surrounded by a thick cortex, simulating full osseointegration and avoiding slippage and separating at the implant-bone interface.

The meshing was accomplished by issuing a meshing order. Models meshed with ten-node tetrahedron elements. 3D FEM geometric models are messed with by Hypermesh software (ANSYS version 14.5). Translations were interpreted on the x, y, and z-axis with ten nodded tetrahedron elements with 3° of freedom per node. The total number of elements and nodes for cortical bone, cancellous bone, implant, and abutment that were used in this study are as mentioned in Table 2.

In the current study, we used the vertical and oblique forces of 100 N and 200N applied at the center of the occlusal surface at 0°, 15°, and 30° angulation. Forces of 100N, and 200N were chosen because this force is widely accepted in the literature as compared to the average magnitude of the occlusal force. A platform-switched implant was placed at 0mm (equicrestal), 0.2mm, 0.4mm, 0.6mm, and 0.8mm to 1mm subcrestal positions. Models were analyzed under axial and non-axial loads in static conditions. Von Mises stresses (in Mega Pascal’s) were obtained. The values thus obtained are tabulated and graphically presented. Ethical approval for this study was provided by the Institution Ethical Committee.

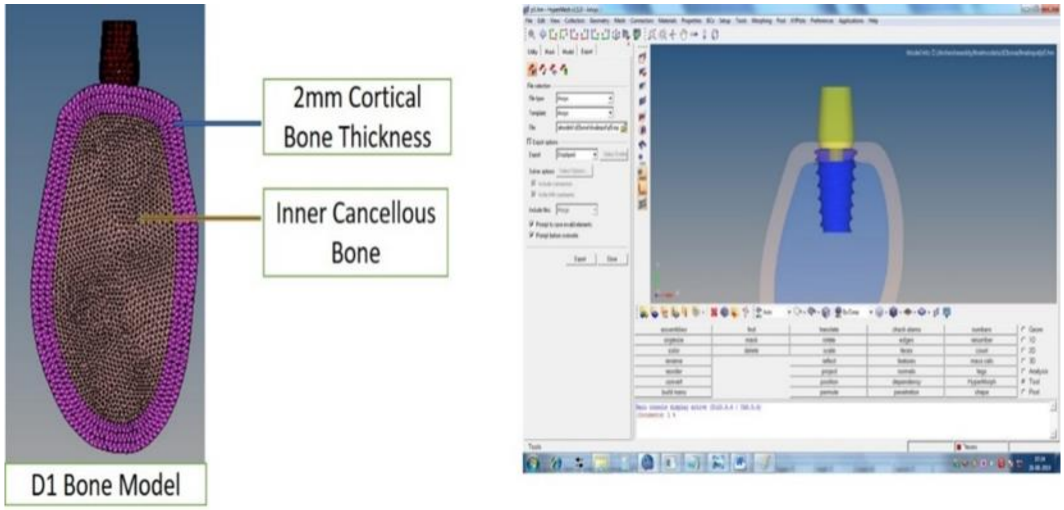

Figure 1: D1 Bone Model Meshed with Implants:

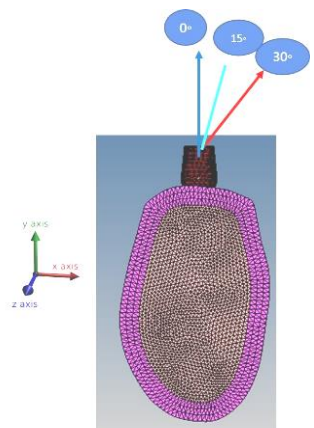

Figure 2: 100N, 200N Forces Applied in Vertical and Oblique Directions.

Table1: Elastic properties used in FEM model analysis.

S.No	Material	Young's Modules (MPa)	Poisson's Ratio
1	Cortical bone	13.700(GPa)	0.30
2	Cancellous bone	1.10(GPa)	0.30
3	Pure Titanium	110000 (MPa)	0.33
4	Titanium alloy	114000 (MPa)	0.30

Table 2: Total number of elements and nodes for cortical bone, cancellous bone, implant, and abutment used in the FEM model.

Model 4.6 -6mm length	Elements	Nodes	Model 4.6 -7.5mm length	Elements	Nodes	Model 5.8 -6mm length	Elements	Nodes	Model 5.8 -7.5mm length	Elements	Nodes
Cortical Bone	102149	164995	Cortical Bone	101285	163693	Cortical Bone	101783	161652	Cortical Bone	101929	163582
Cancellous Bone	132893	198911	Cancellous Bone	135324	202274	Cancellous Bone	131879	197528	Cancellous Bone	134232	199288
Implant	14230	24046	Implant	16238	26829	Implant	16238	28762	Implant	17239	29776
Abutment	9867	15719	Abutment	10281	16282	Abutment	9965	16128	Abutment	10192	17289

Table 3: Descriptive Statistics of Stress in D1 Cortical Bone in 4.6 diameter implant.

		D1 Cortical Bone (6x4.6x3.5mm)					D1 Cortical Bone (7.5x4.6x3.5mm)				
		Implant position									
	Angulation	Equicrestal	0.5mm	1mm	1.5mm	2mm	Equicrestal	0.5mm	1mm	1.5mm	2mm
Force of 100N	0c	8.29	9.64	10.59	12.51	15.94	9.49	9.03	9.66	11.87	14.9
	15c	18.42	17.71	19.22	18.28	23.88	16.8	16.93	18.15	17.57	22.83
	30c	25.36	24.73	26.94	13.02	14.74	23.02	23.85	25.46	12.09	12.82
Force of 200N	0c	17.41	19.53	22.98	31.2	38.81	19.91	18.21	21.23	29.54	35.99
	15c	38.94	35.23	37.25	42.81	54.49	35.76	34.01	35.99	40.97	50.69
	30c	54.04	49.15	39.89	16.2	19.02	49.41	47.81	38.31	13.09	13.78

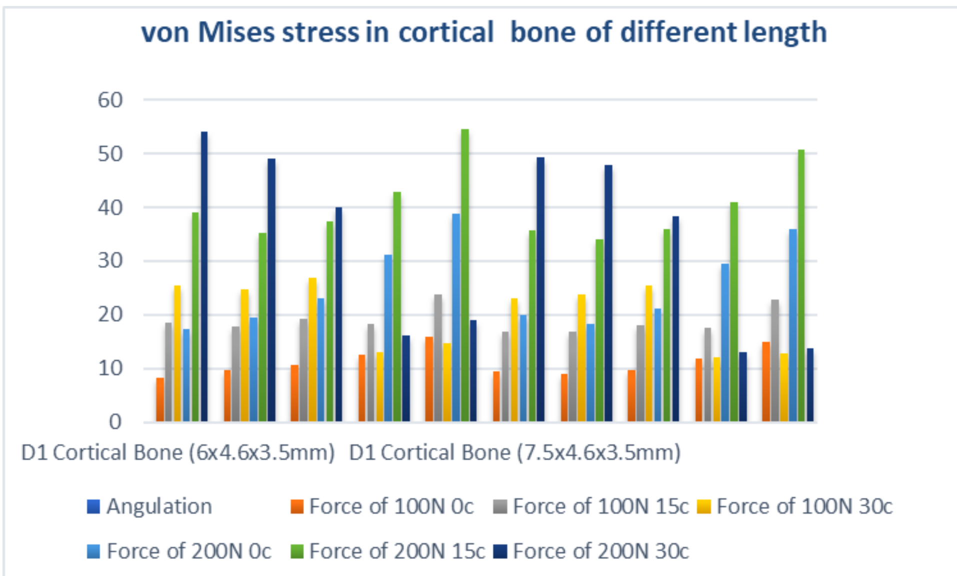

Figure 3: Graphic representation of von Mises forces in D1 Cortical Bone in 4.6 diameter implant.

Table 4: Descriptive statistics of stress in D1 Cancellous Bone in 5.8 diameter implant.

		D1 Cortical Bone (6x5.8x4.5mm)					D1 Cortical Bone (7.5x5.8x4.5mm)				
		Implant position									
	Angulation	Equicrestal	0.5mm	1mm	1.5mm	2mm	Equicrestal	0.5mm	1mm	1.5mm	2mm
Force of 100N	0c	7.29	7.15	7.9	9.53	10.98	7.27	6.74	7.59	9.91	10.55
	15c	13.18	13.69	15.72	14.03	17.34	13.35	13.13	15.1	14.64	16.72
	30c	18.27	19.53	22.53	11.38	11.99	18.62	18.87	21.79	19.62	22.5
Force of 200N	0c	15.19	15.31	17.74	22.39	26.28	14.61	14.45	17.79	23.15	25.56
	15c	28.86	29.96	31.03	30.42	37.44	28.26	28.57	30.7	31.7	36.7
	30c	40.85	42.86	36.02	13.31	13.23	40.26	41.15	43.58	39.24	45

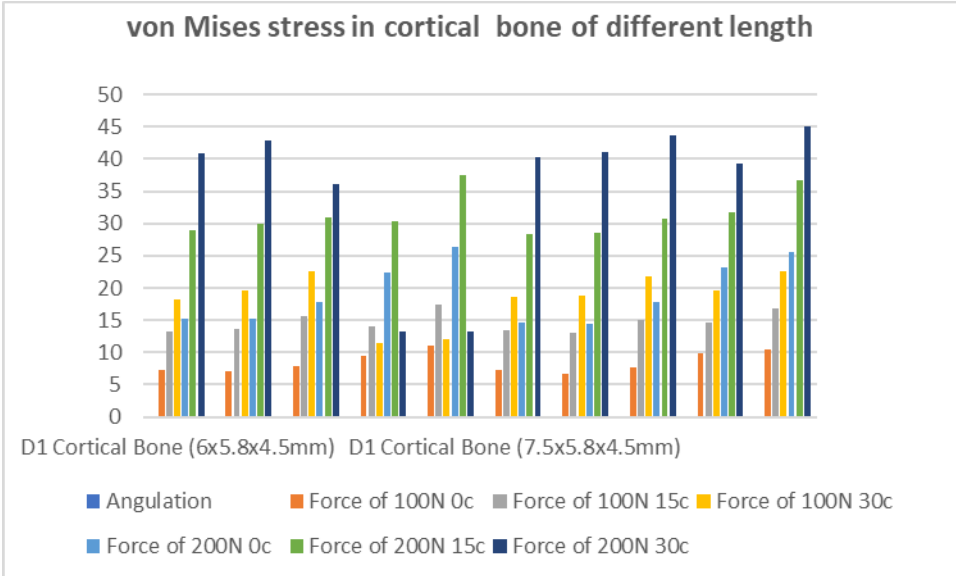

Figure 4: Graphic representation of von Mises forces in D1 Cortical Bone in 5.8 diameter implant.

Table 5: Descriptive Statistics of Stress in D1 Cancellous Bone in 4.6 diameter implant.

		D1 Cancellous Bone (6x4.6x3.5mm)					**D Cancellous Bone (7.5x4.6x3.5mm)**				
	Angulation	Equicrestal	0.5mm	1mm	1.5mm	2mm	Equicrestal	0.5mm	1mm	1.5mm	2mm
Force of 100N	0c	2.16	1.86	2.12	2.65	2.2	1.7	1.35	1.46	2	1.55
	15c	2.64	2.29	2.2	3.29	2.56	1.9	1.53	1.6	2.31	1.72
	30c	3.16	2.6	2.48	2.12	2.56	2.11	1.64	1.7	1.84	1.44
Force of 200N	0c	4.11	3.61	4.38	5.7	4.85	2.99	2.69	3.42	4.22	3.3
	15c	4.73	4.35	5.33	6.97	5.63	3.23	3.01	3.9	4.84	3.59
	30c	5.44	4.86	4.36	3.51	2.92	3.43	3.17	3.51	3.53	3.79

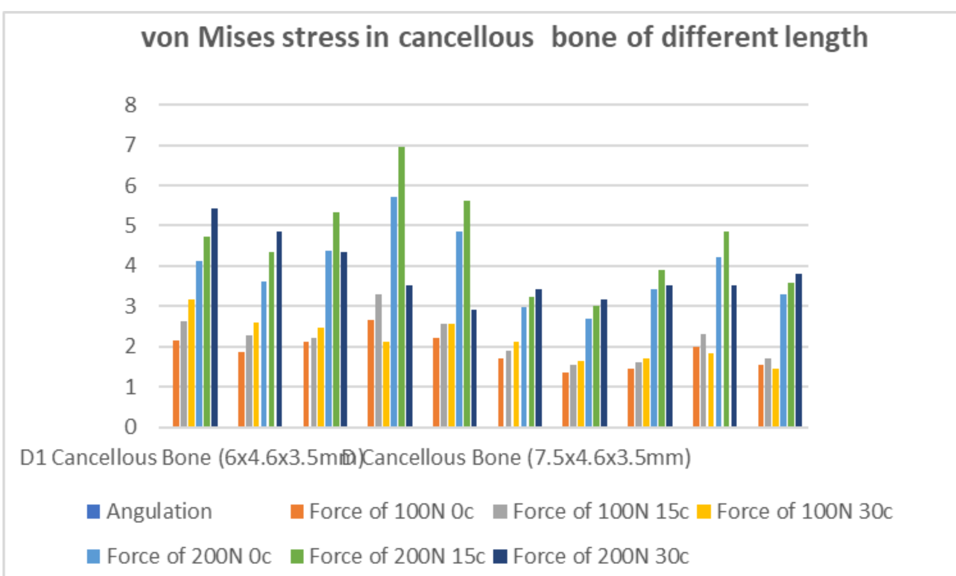

Figure 5: Graphic representation of von Mises forces in D1 Cortical Bone in 4.6 diameter implant.

Table 6: Descriptive Statistics of Stress in D1 Cancellous Bone in 5.8 diameter implant.

		D1 Cancellous Bone (6x5.8x4.5mm)					D1 Cancellous Bone (7.5x5.8x4.5mm)				
	Angulation	Equicrestal	0.5mm	1mm	1.5mm	2mm	Equicrestal	0.5mm	1mm	1.5mm	2mm
Force of 100N	0c	2.66	1.46	2.11	2.37	1.62	5.02	3.12	4.07	4.79	4
	15c	2.8	1.55	2.42	2.8	2.03	4.74	3.51	5.27	5.87	4.83
	30c	3.41	1.81	2.61	1.47	2.67	5.69	3.82	3.86	3.7	4.73
Force of 200N	0c	1.33	1.83	1.43	1.35	2.85	2.64	2.72	2.88	4.2	5.81
	15c	1.55	2.23	1.85	1.59	3.3	3.22	3.4	3.67	4.78	6.54
	30c	1.77	2.5	2.16	1.76	2.31	3.64	3.89	4.32	3.52	3.52

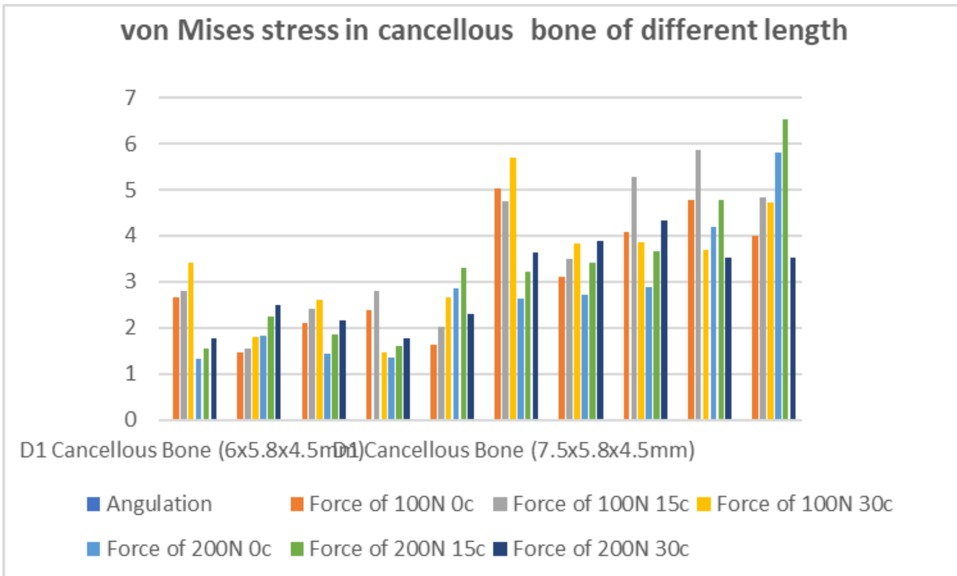

Figure 6: Graphic representation of von Mises forces in D1 Cortical Bone in 5.8 diameter implant.

3. RESULTS

A total of eight models were created and categorized into four groups. Stress was evaluated at the bone-implant interface with two different forces (100N, 200N) in D1 bone by using Ansys software, von Mises stress was evaluated with the help of color-coded bands. Each band of color signified a unique range of stress values, represented in Mega Pascal (MPa). In all models, cortical bone exhibited maximum stress greater than cancellous bone. [Figure 3] With regards to angulations of load, greater stress was observed in the axial direction of 30°, 15°, and at least at 0° irrespective of the amount of load applied. [Figure 3] An increase in implant length did not exhibit stress reduction at the equicrestal position but subcrestal placement exhibited maximum stress in model 1. However, both models 1 and 2 showed a decrease in von Mises stress as implant diameter increased, with 5.8 mm implants having the lowest von Mises stress. Figuring 4 Both cortical and cancellous bone displayed their maximum stress with a 200N axial force. Images 3 and 4 Regardless of the direction of the force applied, both bones experienced more stress as the force increased. However, the axial orientation (30°) of the 200N forces showed significant stress. Images 3 and 4 In both groups, subcrestal placement had a little lower stress level than equicrestal implantation [Table 3, Figure 3,4].

4. DISCUSSION

In comparison to natural teeth, stress destitution in implants will differ due to the absence of periodontal ligament. As a result, dental implants are more at risk due to excessive load leading to peri-implantitis.[26]

Comparison of von Mises stress between Cortical vs Cancellous: In line with earlier investigations, the present study showed that cortical bone had the highest peak stress, and that the trabecular area experienced the lowest.[27-30] Maximum stress was noticed as the primary area of contact in cortical bone, and in the case of cancellous bone, it has been noticed at the apex. This is because stress concentration in cortical bone is limited to the immediate region surrounding the implant; in cancellous bone, stress is distributed over a much wider area. It is because the cancellous bone is weaker than cortical bone and is less resistant to deformation and thicker than cortical bone (D1).[31,32]

Comparison of Forces and von Mises Stress: The current study revealed that the greater the force greater was stress in all bone models. The least stress was seen with a force of 100N and maximum stress with 200N force. (Figure 3,4, Table 3, 4) (Table 5,6). While there is no scientific proof of the amount of stress upon which remodeling of bone stops and reabsorption begins the greatest bone strength is the biological limit of the cortical bone.[33]

Comparison of von Mises stress between Axial versus oblique load: In the current investigation, stress and the direction of applied force were most clearly observed in the cortical bone. Regardless of implant diameter, length, or depth (supracrestal / subcrestal) of placement, this investigation showed increased stress concentration in an oblique direction (30°) compared to an axial direction (0°). In comparison to axial forces, oblique forces are more damaging and cause more stress to build up near the peri-implant bone. Therefore, it is advised to prevent or minimize oblique pressures that concur with the work of the previous writers.[34] While there is no scientific proof of the amount of stress upon which remodeling of bone stops and reabsorption begins, the greatest bone strength is the biological limit of the cortical bone.[33] When the compressive stress in the cortical bone surpasses 100 to 130MPa, bone loss owing to overloading is predicted.[35]

Comparison of von Mises stress in Platform switch implants: Concerning implants that were repaired using the platform-switching idea, mixed results have been reported. By centralizing stress, platform-switched implants mechanically alter and realign stress, which ultimately affects marginal bone loss surrounding the peri-implant. According to the findings of the current investigation, shallow subcrestal implantation at 0.5mm caused the least stress in the cortical bone and at 2mm in the cancellous bone, which was consistent with the findings of other studies.[36,37]

Comparison Between Implant Length, Diameter, and von Mises Stress: Implant shape is one of the most important elements that influence load transmission at the bone-implant contact.[38] According to numerical statistics, implant diameter is more important than implant length in preventing crestal bone loss, which is consistent with our results.[39,40] Implants with 5.8mm diameter exhibited minimum stress in all bone models in comparison with 4.6mm diameter implants. (Figure 4,6)

Increased implant length increases the implant's overall surface area and improves primary integrity by improving bone-implant contact (BIC). However, the functional surface area (FSA), which shifts compressive and tensile loads to the bone, is limited to the crestal of 5-7 mm. Just by increasing implant length, FSA will not alter, while a short implant with a larger diameter has both better primary stability and increased FSA. Depending on the implant design, an increase of 1 mm in diameter will increase the surface area by 30-200 %.21 (Figure 3,4,56)

By comparison, there was a 3.5-fold crestal stress reduction upon improving the implant diameter on the contrary there was only a 1.65-fold in stress reduction by increasing implant length.[39] Long implants are therefore no longer necessary to enhance masticatory load distribution. Maximum stress is present at the principal point of contact in the primary interphase between the implant and bone. This phenomenon can be attributed to the "engineering principle" of composite beam analysis.[38,40.] Increasing the implant diameter has been shown in several FEM studies to reduce crestal bone strain. In addition, it has been suggested that the diameter of the implant is more essential than its length in terms of enhancing the stress distribution pattern.

Comparison of von Mises stress between equicrestal versus subcrestal plant placement: There are conflicting claims about the placement of subcrestal implants in the literature. Few studies have examined the idea of a platform switch and the implantation of short subcrestal implants under biomechanical circumstances. This investigation into D1 bone may be the first of its kind. Cortical bone stress considerably Thus, it is suggested that subcrestal implantation leads to less cortical bone stress. This condition is due to several biomechanical actions that subcrestal implants take when they do not engage the crestal cortical bone. Additionally, due to its elastic modulus, cancellous bone showed the least stress at the subcrestal position. It encourages better stress distribution as a result.[29,30] As the anterior mandible is the cosmetic zone, a marginal bone at the implant neck is essential for implant survival and aesthetics. (Figure 4,6)

CONCLUSIONS

The calculated results from the current study show that, for short implants, implant diameter is judged to be a more efficient design component than the length of the implant. This is to limit the danger of bone overloading and promote implant biomechanical stress-based efficacy. According to recent research, platform switch short subcrestal implant models result in improved stress distribution around peri implant areas in D1 bone and the conservation of marginal bone loss. Nevertheless, all the models examined for this study showed von Mises stress concentrations that were within a human cortical bone's biological range.

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