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A Comparative Analysis of Influence of Three Different Implant Thread Designs on Stress Distribution with Different Insertion Angles in Anterior and Posterior Mandibular Bone – A Three-Dimensional Finite Element Analysis

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KEYWORDS

Stress Distribution, Finite Element Analysis

ABSTRACT:

Aim - To evaluate the effect of three different implant thread designs on stress distribution in anterior and posterior mandibular bone by FEA & to evaluate the effect of different implant insertion angles (0°, 10°,15°, 20°) on stress distribution in anterior and posterior mandibular bone by FEA.

Material and method - This experimental dissertation evaluates stress concentration on cortical, cancellous, implant fixture, crown, and abutment beyond zero degrees using four placement angulations. The study also subjected models to 100N of force, choosing the mandibular canine region and the posterior first molar region due to their high peripheral areas for implant insertion.

Result – Stress distributions increased with insertion angulation, with the D3 region having greater stress distributions than the D2 region. No significant stress differences were found across thread patterns, and stress activity was higher on the implant fixture as insertion angle increased

Conclusion - According to the study's findings, whether a bone is D2 or D3 in kind, zero-degree angulation is always the most advantageous for an operator. Less angulation is preferable in any sort of bone type in order to reduce the greatest amount of stress placed on the bone.

INTRODUCTION

Modern implant dentistry has undergone a revolution because to implant-supported fixed dental prosthesis (FDPs), which provide a dependable and efficient means of rehabilitating patients who are partially or completely edentulous. By using dental implants as anchorage to support a fixed prosthesis that mimics the form and function of the natural dentition, these prostheses offer a stable and useful alternative [1] [2]. The direction or tilting of the implant device with respect to the underlying bone and neighbouring teeth is referred to as implant angulation [3]. It is essential for figuring out how stress is distributed at the implant-bone contact, which can have a big impact on how long implant-supported FDPs survive and how successful they are overall [4]. Variations in implant angulation have the potential to impact the intricate biomechanical relationships among the implant, underlying bone, and prosthetic components. This could result in biomechanical problems, implant failure, and poor treatment outcomes [5]. Optimising implant design, insertion methods, and treatment planning techniques require a thorough understanding of how implant angulation affects stress distribution [6]. An angled abutment has the following benefits: stability even with little bone volume with the benefit of enhanced bone-implant contact and less demand for vertical bone augmentation, longer implants can be utilised with the least amount of bone volume. Excellent clinical outcomes. removes the requirement for a bone transplant, which is aggressive and may have unanticipated effects. This procedure can be performed on individuals who are not a good fit for bone grafting due to a variety of systemic problems [7]. Implant placement that avoids anatomical structures is possible with angled implants. Using tilted distal implants rather than distal cantilever units offers the advantage of reducing the length of the cantilevers without the need for sinus lifting or bone grafting [8]. When it comes to the biomechanical optimisation of dental implants,

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thread geometry and form are crucial. Threads are employed to increase the implant's external area, enhance initial stability, optimise initial contact, and promote interfacial stress dissipation. Clinical success can be increased by optimising the thread design of dental implants [9,10,11].The ideal thread design will meet the following criteria: maximum surface area, best initial bone-implant contact (BIC), greatest initial stability, and best ability to dissipate stresses [7,9]. This study aimed to evaluate the influence of three different implant thread designs on stress distribution with different insertion angle in anterior and posterior mandibular bone through a three-dimensional finite element analysis. Dental implants' mechanical and thermal behaviours in their natural environments can be accurately predicted using finite element analysis (FEA). Through this examination, researchers can learn more about the type of biting pressure and the stress and strain that the dental implant as well as surrounding bone are subjected to. With the advantages of finite element analysis, custom dental implants' biomechanics are assessed and the mechanical aspects of their design are optimised [12,13]. This study aimed to evaluate the influence of three different implant thread designs on stress distribution with different insertion angle in anterior and posterior mandibular bone through a three-dimensional finite element analysis.

MATERIALS AND METHODS

An analysis of the scenario was conducted using a three-dimensional finite element research to generate models featuring varying implant inclinations and thread designs. In order to calculate the stress and strain around those dental implants on the anterior and posterior mandibular bones, finite element analysis has been used. Bone Model - Two forms of bone, D2 and D3, have been chosen for this investigation. The most prevalent bone type, D2, is present in the majority of the anterior mandible's regions (Table-1). Two specific positions in the mandible-the canine region and the first molar region-have been chosen for this study. The width of the bone is 7 mm at the canine area. and the height of the bones overall is 29 mm. In the molar region, bone width is 11mm and height is 26 mm. For D2 bone type 2mm cortical thickness and D3 bone 1 mm cortical thickness has been maintained [14,15,16] (Figure-1,2). Implant Models - Three distinct brands are chosen to provide standardised models implanting with square threads (ADIN,TouaregCloseFitTM ,Israel) , with buttress thread (StraumannNeodentBasel Switzerland), with reverse buttress thread (Straumann Standard Plus, Basel Switzerland) which is 4.1 mm in diameter. Pitch of thread is 1.25 mm.; implant is 8 mm in length (Figure-3).

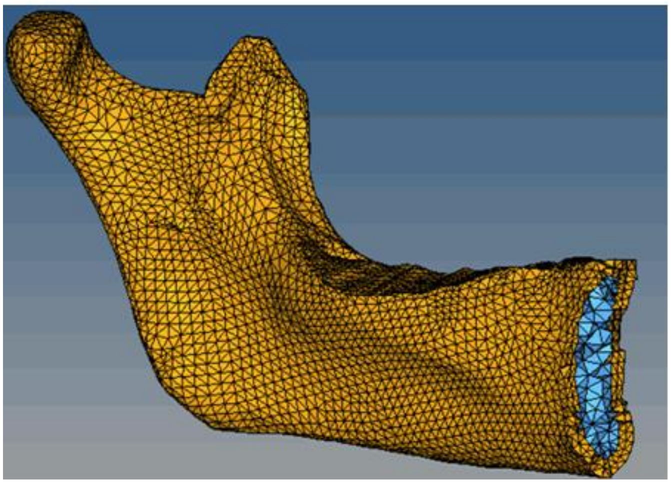

FIGURE 1: mesh structure of the D2 bone type in the canine region

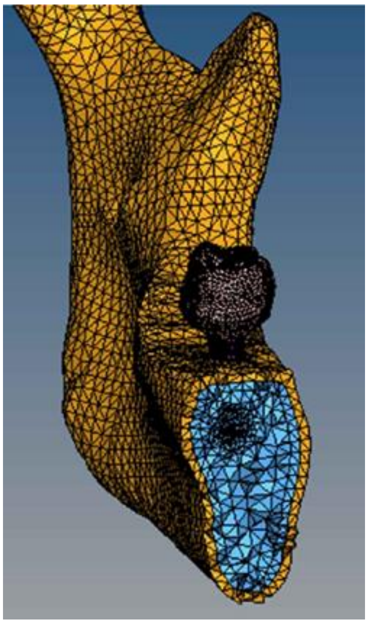

FIGURE 2: Mesh structure of D3 type of bone in molar region

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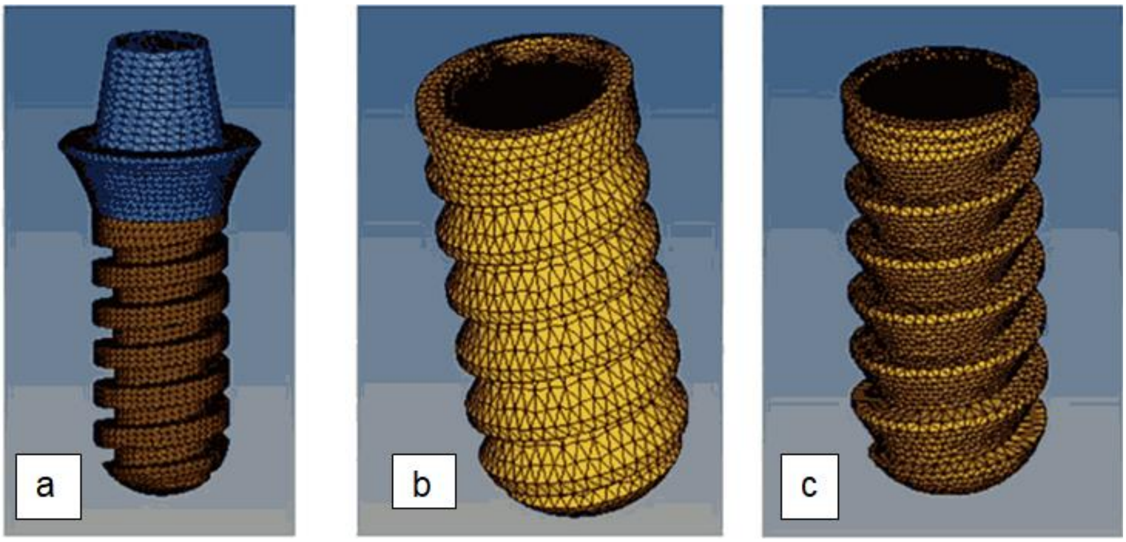

FIGURE 3: Three types of implant thread design (from the left side) (a. square thread , b. reverse buttress thread , c. buttress thread)

The following configurations were the subjects of the construction of three-dimensional finite element models (Table-2).

System Configuration Analysis software used was Ansys V18.1, Meshing Software used was HypermeshV11, SolidEdge V19 used as modelling software. Processor of Intel® Core TM i5-3GHZ had been used for this study as a hardware with 16GB RAM and 1TB hard disk.

Statistical analysis

It is not applicable as the tests are done once under ideal conditions; the result will be same irrespective of the repeating the tests.

TABLE 1: Material properties

S. no.	Materials	Elastic modulus (MPa)	Poisons ratio
1.	Titanium implant	105	0.33
2.	Cancellous bone	1.37	0.3
3.	Cortical bone	13.7	0.3
4.	Metal	190	0.3
5.	Crown	693	0.27

TABLE 2: These are the 24 samples has been selected for this study

Model Number	Implant Type	Position	Inclination
1	Square thread	Canine (D2)	0
2			10
3			15
4			20
5		Molar (D3)	0
6			10
7			15
8			20
9	Buttress thread	Canine (D2)	0
10			10
11			15
12			20
13		Molar (D3)	0
14			10
15			15
16			20
17	Reverse Buttress thread	Canine (D2)	0
18			10
19			15
20			20
21		Molar (D3)	0
22			10
23			15
24			20

RESULTS

The present study evaluated the stress distribution of 24 finite element models which are groups into 3different categories - Group I which refers to a group of models or samples being tested. A force of 100N is applied along the axis of the implant. This is a standard way to simulate the forces that implants might experience in real-life situations such as chewing or biting. The implants have a square type thread design. Thread design can impact the stability and performance of dental implants, affecting factors such as stress distribution. Implants with varying angulations (0°, 10°,

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15°, 20°) are being tested. Angulation can affect the distribution of forces and stress on the implant fixture, implant abutment, prosthesis and surrounding bone tissue. Two types of bone are being simulated: D2 (canine region) and D3 (molar region) bone types. Bone density and quality can influence the stability and success of dental implants. D2 bone is denser and stronger than D3 bone, so implants may behave differently in each type (Table -3). Group II appears to be another set of models being tested. Unlike the square type thread design in Group I, Group II utilizes a buttress type thread design. Unlike the square type thread design in Group I, Group II utilizes a buttress type thread design. Two types of bone are simulated: D2 (canine region) and D3 (molar region) bone types. The bone quality impacts the stability and success of implants, with D2 being denser and stronger than D3. Just like in Group I, a force of 100N is applied. Similar to Group I, implants with varying angulations (0°, 10°, 15°, 20°) are being tested. The angle of the implant can influence stress distribution and load-bearing capacity (Table -4). Group III is the third group of models being tested in the experiment. Unlike the square type and buttress type thread designs in Groups I and II respectively, Group III utilizes a reverse buttress type thread design. As in the previous groups, implants with varying angulations (0°, 10°, 15°, 20°) are being tested. The angle of the implant affects the stress distribution. Two types of bone are simulated: D2 (canine region) and D3(molar region) bone types. Similar to the previous groups, a force of 100N is applied (Table - 5). Here the graphical representation of stress distribution of cortical bone, cancellous bone, implant fixture in different aspect such as D2 (canine region) and D3 (molar region). Here X-axis depicts different angulation and implant position, thread design and Y-axis depicts stress distribution (Figure-4) (Figure-5) (Figure-6).

TABLE 3: Square thread implant type (group I) stress distribution

Model Number	Implant Type	Position	Inclination	Overall deformation	Cortical stress (MPa)	Cancellous Stress (MPa)	Implant Stress MPa	Abutment Stress	Crown Stress
1	Square Group-I	Canine (D2)	0	1.36331	8.33249	2.13877	14.5925	14.6118	4.2676
2			10	1.2532	13.4676	1.942	16.9501	17.9216	4.2623
3			15	1.1943	17.3569	1.74062	19.6996	20.5123	4.34545
4			20	1.16783	20.3651	1.73109	27.2644	28.6694	4.48959
5		Molar (D3)	0	1.192593	13.3435	1.21159	17.1729	16.1024	5.62748
6			10	1.04036	17.5604	1.9123	22.5669	25.809	5.65527
7			15	1.01761	22.8659	2.90972	27.4945	33.3586	5.62181
8			20	0.995043	24.6573	3.20391	35.0936	34.4445	5.58132

TABLE 4: Buttress thread implant type (group II) stress distribution result

Model Number	Implant Type	Position	Inclination	Overall deformation	Cortical stress (MPa)	Cancellous Stress (MPa)	Implant Stress MPa	Abutment Stress	Crown Stress
9	Buttress	Canine (Anterior) (D2)	0	1.36331	9.5388	2.60566	13.3192	13.5212	4.26546
10			10	1.20529	16.6163	2.03104	19.5231	17.3953	4.2348
11			15	1.19429	17.4176	2.01992	20.9391	19.2505	4.34529
12			20	1.16781	19.6219	1.5964	22.6922	26.2872	4.49108
13		Molar (Posterior)	0	1.08919	14.8343	1.82964	16.7786	18.503	5.18651

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14	Group-II	(D3)	10	1.060016	16.5958	1.89833	25.6756	21.9811	5.6369
15			15	1.01752	19.9317	1.97455	30.1844	27.02	5.6113
16			20	0.995001	25.6732	2.41406	41.9422	31.6076	5.57314

TABLE 5: Stress distribution in reverse buttress thread type implant fixture

Model Number	Implant Type	Position	Inclination	Overall deformation	Cortical stress (MPa)	Cancellous Stress (MPa)	Implant Stress MPa	Abutment Stress	Crown Stress
17	Reverse Buttress Group-III	Canine (Anterior) (D2)	0	1.36354	11.9989	2.34072	19.5877	11.9204	4.25787
18			10	1.2057	15.8127	2.15895	21.6521	13.2336	4.19325
19			15	1.19429	17.2046	2.05303	26.5506	18.668	4.34568
20			20	1.16781	22.4332	1.55316	26.7071	28.4751	4.49171
21		Molar (Posterior) (D3)	0	1.08917	20.957	1.76302	28.617	15.8461	5.01955
22			10	1.07559	23.364	1.96372	29.3477	22.6861	5.62996
23			15	1.01755	26.0719	2.05867	37.8523	30.628	5.61053
24			20	0.995036	32.7559	2.61607	46.3978	32.0555	5.58288

FIGURE 4: Representational bar diagram of cortical stress in different aspect.
MPa - Megapascal

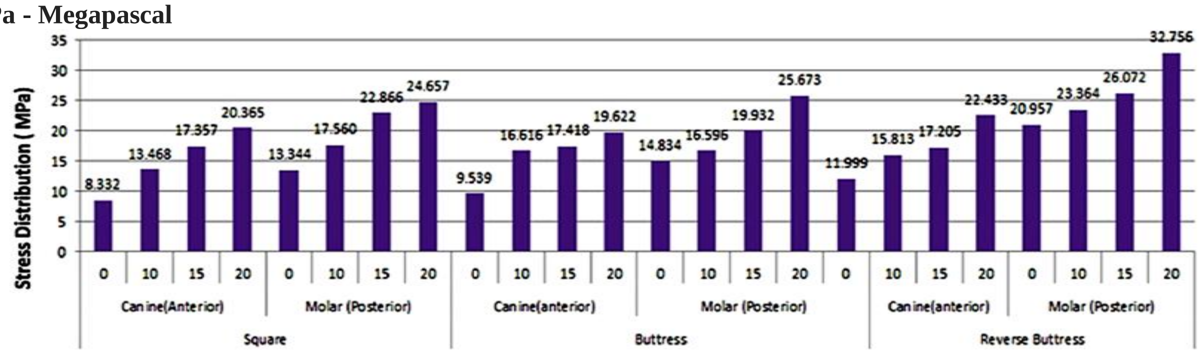

FIGURE 5: Representational bar diagram of cancellous stress in different aspect
MPa - Megapascal

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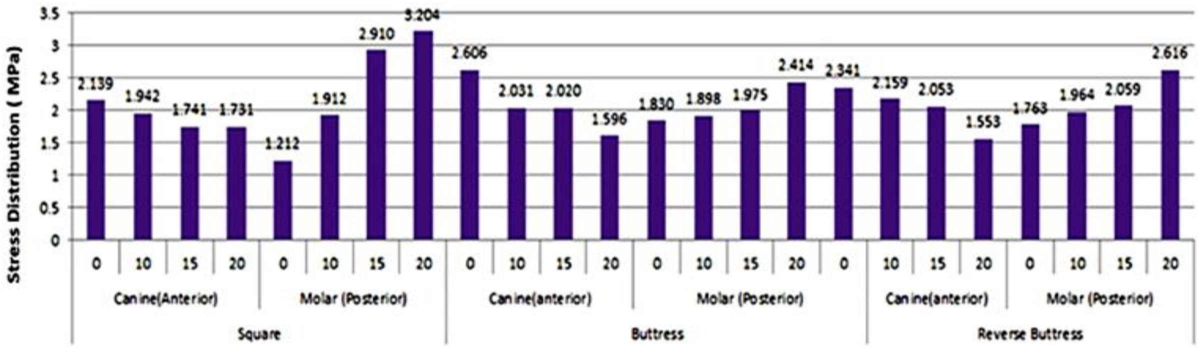
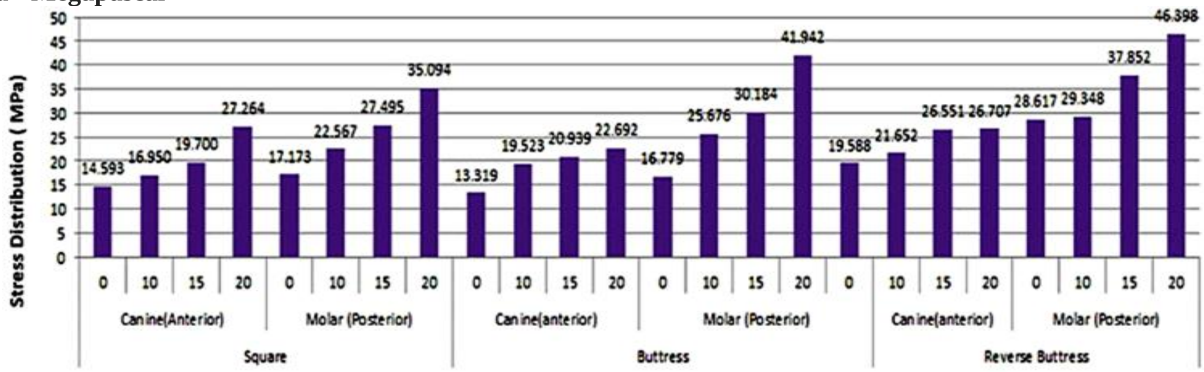


FIGURE 6: Representational bar diagram of stress on implant fixture in different aspect.
MPa - Megapascal



DISCUSSION

This experimental dissertation evaluates stress concentration on cortical bone, cancellous bone, implant fixture, crown, and abutment beyond zero degrees using four distinct placement angulations, demonstrating overall deviation. The study selected the mandibular canine and first molar bone types for implant insertion due to their high perineal areas and proximity to the dental arc's turning point, despite being subjected to 100N of force. Hence, it has been calculated that stress in the square thread type implant fixture on the D3 bone (molar region) is greater than that on the D2 bone (canine region) as the inclination of the implant fixture increases from zero to twenty degrees. Additionally, it has been determined that in the D2 and D3 sections, the stress differential between 10, 15, and 20 degrees corresponds to zero degrees. Arun Kumar G et al. [17] conducted a study comparing straight and angulated abutments on different bone types. They found that stress concentration increased with angle increments, similar to Elsyad M et al. [18] recommendation for parallel implant placement. The study also used von Mises stress calculation. In a 3D finite element analysis Las Casas EB et al. [19] stated that the straight implant showed a smooth distribution throughout the body and a large compressive peak the concentration of stress on one side of the neck under vertical load. The use of finite element analysis (FEA) in implant dentistry, particularly the assessment of distribution of stresses in prostheses supported by implants, is covered in another literature review [20]. The significance of taking into account implant angulation and additional variables that could affect the distribution of stress and implant performance is emphasised by the authors.Under vertical load, the stress distribution for the angled implant was quite similar. While the highest compressive stresses happened on the cervical line at the lingual side, the largest tensile stresses happened at the wider curvature zone (buccolingual line) close to the cervical area. The study evaluated D2 and D3 bone types, finding D3 more stress in square, buttress, and reverse buttress threads with increased angulation, but less stress in cancellous buttress threads. In one FEA study [21] three distinct clinical scenarios were simulated by implant placement into the bone block: i. healed bone-delayed loading; ii. healed bone-immediate loading; and iii. instantaneous implant-immediate loading.In every case, there was a rise in the stress values in the abutment, implant, and bone as the abutment angle went from 5 to 10 degrees.Arun Kumar G et al. [17] evaluated bone quality ranging from D1 to D4, revealing that straight and tilted abutments increased pressures on the facial side of the cortical bone, while angled abutments reduced stress values in

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D2, D3, and D4 bone types. In another literature review [22] four investigations, two found that the square thread design had the least amount of stress distribution throughout all osseointegration degrees, and the other two found that the V-shaped thread design had the least amount of stress. Because of smaller sample sizes, variations in the implant system employed for the study, and a range of groups compared, some studies are unable to draw firm conclusions. Different implant thread designs and osseointegration circumstances had little effect on the stress distribution pattern.Nam et al. [23] studied stress dissipation properties of four implant thread designs using 100 N applied to the implant axis and implant abutment. They found that the V-shaped thread's stress dissipation properties were in the middle of the four threads, aiming to identify the least tension on the bone underneath.

Limitations of The Study

Finite element analysis is a precise method for analyzing structures, but it should not be used solely. Living structures are not reducible to predetermined parameters, and biology is not a calculable field. Experimental methods and clinical trials are needed to determine the true nature of biologic systems. The study assumed linearly elastic and homogeneous bone, but subjective variability cannot be completely eradicated due to model blending.

CONCLUSIONS

It is possible to conclude, within the parameters of the current investigation, it has been found that stress distributions increased according to increase in insertion angulation, when stress is measured using the same type of thread design and insertion angle, the D3 region has greater stressdistributions than the D2 region, after analysing all the data, it was determined that there were no appreciable stress differences across the various thread patterns, the conclusion reached after analysing all of the comparisons of stress distribution in these models is that, while stress activity is relatively low in the crown and cancellous region, it is higher on the implant fixture as the insertion angle increases. Comparedto other methods of stress analysis, computer modelling-such as the finite element method-offers several advantages. It is imperative to identify the assumptions and limits of the methodology. As per the conclusions from this study, whenever possible as an operator zero-degree angulation is the most favourable either it is D2 type of bone or D3 type of bone. To decrease the maximum stress on bone and as a present ofas much as less angulation is more favourable in any kind of bone type.

Conflicts of interest- The study, unbiased and not funded by dental implant manufacturers, chose Adin and Straumann due to their commercially available and widely used thread designs.

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