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Implant Angulations Effect on Bone Stresses: Clinical and FEA Study.

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ABSTRACT

Although, dental implants are excellent prosthetic treatment option, implant complications do occur. To evaluate the effect of different implant angulations on the displacements and stress distributions on the implants, surrounding bone and its clinical consequences. Twenty-seven implants were placed in twelve patients. Cone Beam CT was used preoperatively to plan implant placement and post operatively to evaluate the actual implants positions. Finite element analysis was achieved using standard implant for a parametric study. A load of 100 N was applied at four different angulations relative to the long axis of the implant. Implant angulation discrepancies ranged from 0.7 - 32.6 degrees with mean value of 9.0 degrees. Axial displacement at loading angles zero-30 was; implants 4.02 - 4.6 micron, spongy bone 2.67 - 4.03 microns, compact bone 2.56 - 4.46 microns. While compressive stress in spongy bone increased from 2.2 to 4.2 MPa, and similar trend was observed for the other stress types in implant, cortical and spongy bone. The increase of stresses was directly proportional to the increase in implant angulations. Also, loading angulations may increase lateral displacement of implant which may explain the bone resorption in more angulated implants

Key words: Implants, Finite Element Analysis, CBCT.

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INTRODUCTION

Dental implants are an effective, safe and reliable solution for patients who have lost their teeth due to various reasons. Despite implants high success rate when they are correctly designed, manufactured and inserted in adequate bone quality and quantity, implant failures do occur, especially in compromised sites and/or patients [1]. The implant surface quality is believed to be a combination of physical, chemical, mechanical and morphologic factors [2].

In Implantology, it is essential to have adequate diagnostic methods to accurately assess the alveolar ridge resorption pattern, the bone quality, location of various vital structures and any bone pathology if present [3]. Osseointegration, which is histologically defined as direct implant-to-bone contact, is believed to provide rigid fixation of a dental implant within the alveolar bone and promote its long-term success rate [4].

Masticatory forces acting on dental implants may result in undesirable stresses within the bone surrounding the implant, leading to its resorption and subsequent implant failure. In order to produce accurate predictable behavior of the implant bone interface, it is essential to determine the realistic loading magnitudes and directions [2]. Furthermore, recent imaging techniques, such as digital radiography, computed tomography (CT), and cone beam ct (CBCT become mandatory in the jaw bone assessment, offering preoperative evaluation of the proposed treatment effectiveness and decreasing the recovery period.

Meanwhile, CT scan has revolutionized the bone analysis and treatment planning using a single scan and a low radiation dosage where both bone and soft tissues images can be analyzed. CT creates a three-dimensional reconstruction of the patient’s skull or of any maxillofacial region. The dental CBCT is recommended for: assessment of bone support for implants placement, TMJ’s analysis, examination of teeth and facial structures, viewing wisdom teeth proximity to mandibular canal prior extractions, diagnosis of cysts, tumors or infections of the teeth and/or the jaw bones [6].

Nevertheless, the bone quantity varies considerably because of edentulous regions undergoing bone resorption due to disuse atrophy. This can considerably affect the alveolar ridge height and/or thickness. Furthermore, patients must also be evaluated carefully to determine the exact location of the mandibular canal (neurovascular bundle), maxillary sinuses incisive foramen. Violation or damage to these vital structures can cause serious complications [7].

FEA has been used extensively to predict the biomechanical performance of various dental implant designs as well as the effect of various clinical factors on the success of implantation. The principal difficulty in simulating the mechanical behavior of dental implants is the modeling of the living human bone tissue and its response to applied mechanical forces. Research has been conducted on the design philosophy, length, diameter, shape and angulation of implants as well as the bio-mechanical bond formed between the implant and the jawbone.

When an implant or implants are installed into the jawbone, the mechanical environment is greatly altered. According to Wolff’s law, bone rearranges its internal structure by remodeling in response to the implants’ installation and loading. Hence, the present study was designed to investigate the implant angulations effect on bone stresses based on a newly proposed bone remodeling algorithm [1].

MATERIALS AND METHODS

Patients

All patients were recruited from the National Research Center (NRC) –dental clinic in Egypt. Participant shared in this study only after written informed consent was signed. The study protocol was approved by the Ethics Committee at NRC.

For all subjects, personal data were collected by interview. Both sexes were analyzed. All subjects were partial edentulous. Twenty-seven implants (Osseo link, USA) were placed in twelve patients. Pre-operative routine CBCT (I-CAT Cone Beam 3D Dental Imaging System) was made to plan the implant placement while post-operative CBCT was made to evaluate the actual positions of the installed implants (sample from pre/postoperative CT is presented in Fig. (1)

Finite element model

Four 3D FEA models were developed, representing a segment of the human mandible. The bone protrudes slightly beyond the implant. The models were constructed based on CT scan images measurements. The models were designed that the implant to be placed inside two co-axial cylinders [8, 9]; the outer layer represented cortical bone of 2 mm thickness. Each model consists of three parts: spongy bone (modulus of elasticity 1,370 Mpa, poisson's ratio 0.3), cortical bone (modulus of elasticity 14,500 Mpa, poisson's ratio 0.323), and implant (modulus of elasticity 110,000 Mpa, poisson's ratio 0.3) [10].

The interfaces between the (spongy and cortical bones), and the implant / abutment are assumed to be perfectly bonded [11]. Considering the distances of these section planes to either the loaded implant or bone, the sectioned planes of bone are kinematically clamped for the sake of simplification, simulating the segmented bone model being connected to the rest part of the mandible [12].

The solid modeling and finite element analysis were performed on a personal computer Intel Pentium IV, processor 2.8 GHz, 1.0 GB RAM. The meshing software was ANSYS version 9.0 and the used element in meshing all three-dimensional models is 8 nodes Brick element (SOLID 45), which has three degrees of freedom (translations in the global directions) [13].

Boundary condition was just supporting the bottom level of the cortical bone cylinder. Linear static analysis was performed with vertical load of 100 N applied on implant placed at angles zero, ten, twenty and thirty degrees.

RESULTS

Twenty-seven implants with different lengths and diameters were placed in twelve patients, according to individual patient's needs (as listed in Table 1). Angulations of the implants in relation to the buccal bone were measured from post-operative Cone Beam CT images. The difference range was 0.7- 32.6 degrees with mean value of 9.0 degrees. Lateral displacement at loading angles zero – 30 was; implants 0.08 - 14.3 microns, spongy bone 0.27 – 9.2 microns, compact bone 0.57 – 10.7 microns. Axial displacement at loading angles zero – 30 was; implants 4.02 – 4.6 micron, spongy bone 2.67- 4.03 microns, compact bone 2.56- 4.46 microns. Angulations of the implants in relation to the buccal bone were measured from post-operative Cone Beam CT images. The difference range was 0.7 – 32.6 degrees with mean value of 9.0 degrees.

Lateral displacement at loading angles zero – 30 was; implants 0.08 – 14.3 microns, spongy bone 0.27 – 9.2 microns, cortical bone 0.57 – 10.7 microns.

Axial displacement at loading angles zero – 30 was; implants 4.02 – 4.6 micron, spongy bone 2.67 – 4.03 microns, cortical bone 2.56 – 4.46 microns.

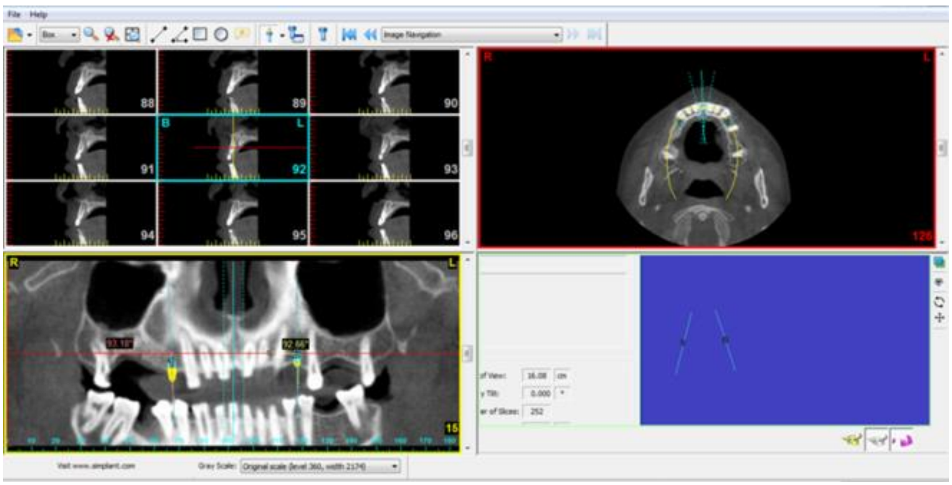
The finite element analysis results of this study were collected and tabulated in Table 2, while Fig. 2 and 3 give samples and graphical comparison between different parts of the FEA model. Demonstrating results will lead to the following findings;

- Tensile stress in implant increased from 104.1 MPa to 132.9 MPa with increasing angulation from zero to 30°. While, in spongy and cortical bone it increased from 1.5 MPa to 1.8 MPa, and from 12.8 MPa to 13.1 MPa respectively.
- Compression stress in spongy bone increased from 2.2 MPa to 4.2 MPa as implant angulation increased from zero to 30°. Similar trend was found in cortical bone that it increased from 7.7 Mpa to 12.2 Mpa. On the other hand, compression stresses in implant decreased from 141.9 MPa at zero degree angulations' to 132.9 MPa 30° angle.

- Shear stresses in implant increased from 39.7 MPa at zero degree angle to 46.5 MPa at 30° angle. Similarly in spongy and cortical bone shear stress, was increased from 0.7 MPa to 1.41 MPa and from 4.4 MPa to 8.5 MPa respectively, with increasing the implant angulation from zero to 30°.
- Von Mises stress in implant, spongy and cortical bone increased with increasing implant angulation from zero to 30° as; 70.4 MPa to 80.5 MPa and from 1.3 MPa to 2.6 MPa, and from 7.9 MPa to 15.5 MPa respectively.

Table (1): of different implants angulations for all patients

	Implant no.	code	Implant	Bone	Angle in Degrees
1st patient	1	1A	77.03	83.65	6.62
	2	2A	63.55	79.8	16.25
2nd patient	1	1B	18.97	14.75	4.22
	2	2B	64.94	69.96	5.02
	3	3B	80.57	77.1	3.47
	4	4B	33.44	32.48	0.96
	5	5B	68.44	70.41	1.97
	6	6B	8.84	-4.15	12.99
3rd patient	1	1C	3.77	0	3.77
4th patient	1	1D	6.25	-22.4	28.65
5th patient	1	1E	85.26	79.12	6.14
6th patient	1	1F	2.85	-17.07	19.92
	2	2F	5.78	-14.88	20.66
7th patient	1	1G	60.49	58.05	2.44
	2	2G	71.65	79.07	7.42
8th patient	1	1H	130.45	126.3	4.15
	2	2H	50.86	56.32	5.46
	3	3H	44.24	49.55	5.31
	4	4H	40.96	42.47	1.51
9th patient	1	1I	5.92	-7.19	13.11
	2	2I	0.62	1.3	0.68
10th patient	1	1J	23.67	-8.96	32.63
	2	2J	12.23	-1.8	14.03
	3	3J	5.5	-5.92	11.42
	4	4J	7.84	8.93	1.09
11th patient	1	1K	6.26	3.69	2.57
12th patient	1	1L	50.94	61	10.06
				Average	9.0
				Max	32.6
				Min	0.7
				std dev	8.5



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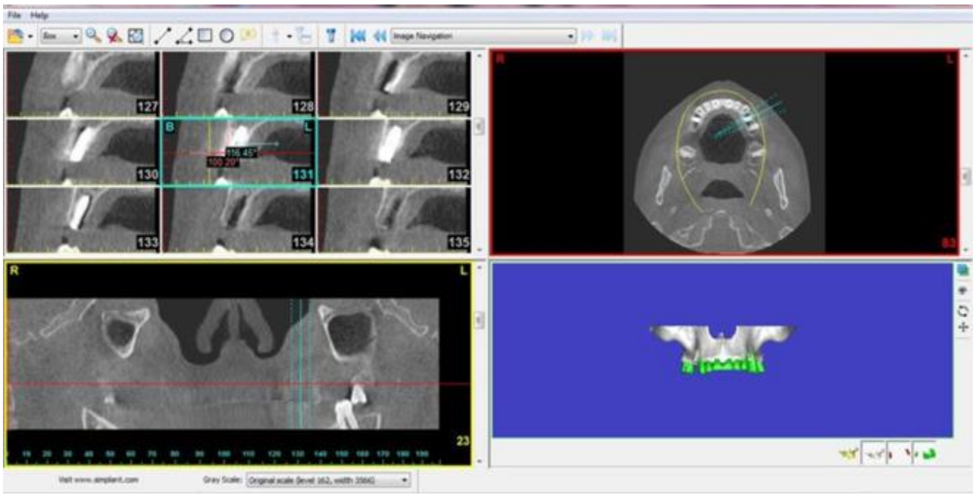

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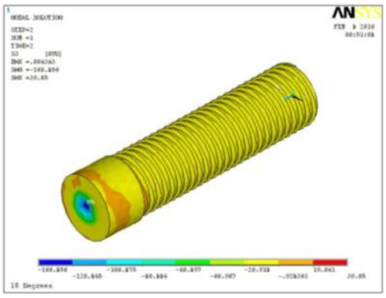
(Fig 1) a. Pre-operative CBCT before implant placement, b. Post-operative CBCT after implant placement and measurement implant angulation.

Table (2): stresses and displacements results at all different degree angles

	Implant Angle	0°	10°	20°	30°
Implant	**Lateral Displacement**	0.086	4.979	9.030	14.300
	Axial Displacement	4.026	3.961	4.1520	4.700
	Max. Tensile S1	104.105	119.506	131.287	139.075
	Max. compressive S3	141.917	140.854	137.949	132.936
	Shear stress	39.682	40.228	44.025	46.485
	Von Mises	70.372	69.689	76.265	80.521
	Implant Angle	0°	10°	20°	30°
Spongy	**Lateral Displacement**	0.274	3.440	6.700	9.020
	Axial Displacement	2.671	3.116	3.630	4.030
	Max. Tensile S1	1.490	1.500	1.660	1.770
	Max. compressive S3	2.209	2.725	3.390	4.194
	Shear stress	0.724	0.836	1.139	1.409
	Von Mises	1.305	1.531	2.093	2.591
	Implant Angle	0°	10°	20°	30°
Cortical	**Lateral Displacement**	0.570	4.064	7.440	10.700
	Axial Displacement	2.559	3.277	3.920	4.456
	Max. Tensile S1	12.842	12.895	12.689	13.089
	Max. compressive S3	7.743	8.493	9.453	12.196
	Shear stress	4.369	4.965	6.828	8.490
	Von Mises	7.869	8.960	12.414	15.500



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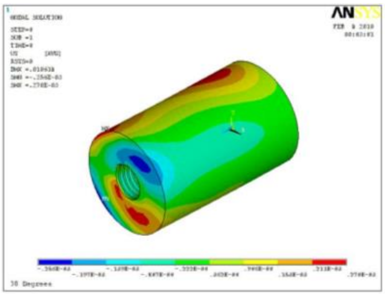

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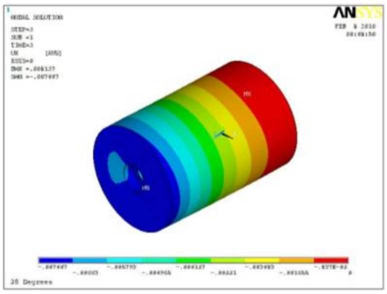
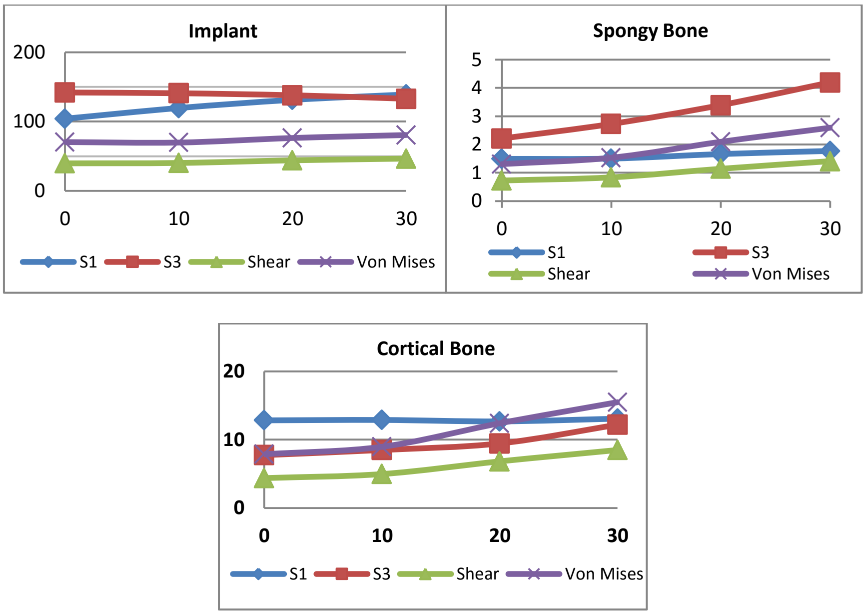
c. 

(Fig 2) Example of (a) compression stress on the implant at 10°, (b) displacement on the spongy bone at 30°, and (c) displacement on the cortical bone at 20°.



(Fig 3) Curves representing the induced stresses on Implant, Spongy and Cortical bone

DISCUSSION

The dentist-patient ethical attitude necessitates the presentation of the patient's morpho-functional dento-maxillofacial data and to offer suitable solutions of the recommended treatment, including dental implants placement. All these issues are solved by recommending a comprehensive pre-operative imaging analysis performed by CBCT. Radiation exposure used for CBCT, even if it is different from one unit to another, is less than the required values for CT. Furthermore, CBCT has also a superior spatial resolution and is compatible with dental implants simulation programs. However, due to the low-density resolution scanning techniques, soft tissue of the face and neck have a low contrast [14]. Meanwhile, it is evident that panoramic radiography cannot illustrate the bucco-lingual width of the alveolar ridge or the angle for the future dental implants installation and also distorts the images [7].

CT system using micro-focal spot X-ray sources and high resolution detectors, allow for projections rotated through multiple viewing directions to produce 3D reconstructed images of samples. These images represent spatial distribution maps of linear attenuation coefficients determined by the energy of the X-ray source and the material sample atomic composition. Since the imaging process is non-destructive, the internal features of the same sample may be examined many times and samples remain available after scanning for additional biological and mechanical testing [15].

Despite, the difficulty to establish an accurate and valid 3D finite element model using conventional modeling techniques as the jawbone and implants are very complicated structures[2]. Meanwhile, the method of the finite element model is frequently used in evaluating the design of dental implants [16, 17].

Furthermore, the bone has the ability to change its structure in response to the mechanical stress induced by loading an implant, within its defined physiological limits. While low strains at about 100 μ Strain in the spongy bone may lead to bone resorption, physiological loads from 100 to 3000 μ Strain result in bone modeling and remodeling, preserving and strengthening the bony structure. Nevertheless, hyper physiological loads above 3000 μ Strain can lead to fibrotic remodeling processes, which in turn can destroy the bone structure. Bone loading around an implant should thus be in the physiological range, and should not exceed it during regular chewing and swallowing processes [18].

The implant angulations are an important evaluation criterion during any analysis considering the implant's biomechanical influence on the surrounding jawbone. The stress distribution generated within the jawbone surrounding different dental implants was carefully analysed by means of the FEM. The results demonstrate that different implant angulations lead to significant variations in stress distributions in the jawbone [2].

CONCLUSION

Within the limitations of this study, the increase of stresses was found to be directly proportional to the increase in angulations between the implant and the long axis of the bone. It was evident that the angulations of loading may lead to large lateral displacement of the implant which may explain the fact that bone resorption in more in the angulated implants.

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