International Journal Dental and Medical Sciences Research
Volume 3, Issue 4, July-Aug 2021 pp 517-523 www.ijdmsrjournal.com ISSN: 2582-6018

Assessment of Optimal Dental Implant Length and Diameter in Differentqualities of Bone Using 3 Dimensional Fintte Element Analysis

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Submitted: 30-07-2021 Revised: 05-08-2021 Accepted: 08-08-2021

ABSTRACT: Dental implants are a breakthrough in the rehabilitation of missing teeth in edentulous patients. Dental prosthesis supported by osseointegrated implants have become an integral part of restorative therapy for both completely and partially edentulous patients. The success of Dental implants depends on various factors and the key factor being the quality of the surrounding bone as well dimensions of implants.

Despite the high success rates reported by a vast number of literature, time dependent marginal bone resorption around implants is still unavoidable. Clinical studies have reported significant marginal bone loss around the implant neck inducing the implant to fail, bone loss occurrence was often attributed to oral hygiene and biomechanical factors. The biomechanical aspects can be related mostly to the implant design (namely- diameter, shape and material property) where implant diameter and length are accepted as key factors and to the patient physiological condition (namely- bone density, occlusal force and medicalcondition).

Owing to the limitations in studying the biomechanical behavior of implants in experimental and clinical studies, Finite element analysis can be used to virtually study the three Dimensional stress propagation. Finite element analysis can used to simulate the different qualities of bone and assess the optimum length and diameter of implants under masticatory loads. Virtual simulation can thus help us in understanding the biomechanics of implants in different qualities of maxillary or mandibularbone.

In this study, a 3D finite element model of the mandible was created using CT scan data. All complexities of the mandible and implant were simulated using ABAQUS software. Implants were then subjected to axial and bucco-lingual loadings. Multiple clinical scenarios with regard to the bone type and various lengths and diameters werechosen to determine the ideal choice.

The maximum Von Mises stresses (maximum equivalent stress, abbreviated Max EQV stress) in the mandible and in implant-abutment complex were evaluated and analyzed, thus assessing the success or failure of implants on simulated loading conditions.

Results from the analysis can be used to choose optimal (preferred) length and diameter of implant in different qualities of bone.

KEYWORDS: Finite Element Analysis, Nobel Active Implants, Bone quality.

I. INTRODUCTION

Dental implantology, a specialized field of dentistry deals with the rehabilitation of the damaged masticatory apparatus due to loss of the natural teeth and is currently the most intensively

International Journal Dental and Medical Sciences Research
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developing field of dentistry. The survival rate for dental implants is over 90%. In posterior jaw regions with bones of poor texture, the survival rate is much lower, ranging from 50 to 80%. It is difficult to estimate the optimal primary stability in the posterior jaw region, which leads to higher implant failure rates. Success of dental implants depends on the type of bone, implant design and mostimportantly on length and diameter of implants. Even after several years of research and literature being available, the effects of dental implant diameter and lengthon stress distribution and implant stability in this region still remains unclear rendering the definition of optimal range of implant diameter and length difficult to predict or arbitrary.[1] It is hence necessary to understand the role of implant diameter and length in regions with all types of qualities of bones. Unfortunately,there have been insufficient studies focusing on the mechanical interrelations between the implant type (length and diameter) and bone quality. Literature indicates that experimental approaches or clinical observations could not provideenough information to determine the biomechanics for complicated multi-parameter investigation.

Over the recent years, biomedical engineering has gained much attention in dental implantology, particularly in terms of design optimisation and also has widened the dentists view on diagnosis, treatment planning, and rehabilitation in patient care.[2] Biomechanics as a discipline deals with the analysis of biologic structures to various mechanical conditions to which it is subjected in a living environment as well as the various prosthetic restorations which coexist with them by utilising engineering principles.[3,4,5]

Hence in this study, the finite element method[6,7,8] was chosen to evaluate stresses in an implant with varying length and diameter supported with mandibular crown in four different bone types and subjected to different offset loadings. Multiple clinical scenarios with regard to the Bone type and various diameters of the Implants were chosen in this study to help determine the ideal choice for an Implant to be placed in a specificarea

II. MATERIALS ANDMETHODS

3D model design

A posterior mandible segment with an implant and a superstructure were modeled on a computer, using a 3D Program. A cross-section of a mandible in the first molar region was used as the basis for a solid model, and then the cross-sectional image was extruded to create a 3D mandible segment (Figure1).

This section had a thick layer of cortical bone surrounding dense cancellous bone, that is, type D/1, D/2, D/3, D/4 bone according to the Lekholm and Zarb classification.[9] A tapered implant and a 5-mm high solid abutment were also modeled and simplified to one unit.

A porcelain superstructure with 2-mm occlusal thickness was applied over the titanium abutment (Figure 2). The diameter of implant (D) and length of implant (L) were set as the input variables. D ranged from 3.0 to 5.5 mm, and L ranged from 7.0 to 18.0 mm. All models were meshed by ABAQUS
6.14 software.

Material properties

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic [10,11,12]. The elastic properties were taken from the literature (Table 1)

Interface conditions

The implant was rigidly anchored in the bone model along its entire interface. The same type of contact was provided at the prosthesis–abutment interface.[13]

Elements and nodes

Models were composed of an average of elements 1670834 and total nodes used were 282133.

Constraints and loads

Models were constrained in all directions at the nodes on the mesial and distal bones. As this study aimed at investigating bone effects to loads within the physiological limits, forces of 100 N and 400 N were applied axially (AX) and buccolingually (BL), respectively, to the middle point in the center of the superstructure. The analysis of each load was performed by means of the ABAQUS software program. The maximum von Mises stresses (maximum equivalent stress, or “Max EQV stress”) in the cortical and cancellous bones and maximum displacement (abbreviated Max displacement) in implant-abutment complex were set as output variables to evaluate the effect of different designs on the mandible. (Figure 3,4)

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III. RESULTS

For the successful insertion of a biocompatible material into living tissue the implants should anchor to the bone to withstand functional loading. Even a slight micromotion between the implant and bone surface leads to failure of implants and the amount of force required to create this micromotion depends on the bone quality, insertion torque, functional loading and implant length and diameter,collectively

which effects the initial stability of the implant. Therefore, the success of implants not only depends on the ability of implants to carry and sustain the dynamic and static loads that it is subjected to but also on the quality of bone to which it is osseointegrated and as well as on the implant design. This study aimed in assessing the optimal implant length and diameter in different qualities of bone and displacement in the implant abutment complex. Four groups were formed, to each group 35 models were assigned in combination with various implant lengths and diameters (L- 7mm, 8.5mm, 10mm, 11.5mm, 13mm, 15mm, 18mm and D- 3.0mm, 3.5mm, 4.3mm, 5.0mm, 5.5mm). Therefore, in total 140 models were prepared. The stress distribution in maximum implant- abutment displacement complex is shown in figure 5,6 . The results indicated that minimum implant-abutment displacement values were seen as the diameter and length of the implant were increased. The maximum displacement was found near the implant neck and abutment region. Figure 5,6 shows 5.0 mm diameter of the implant and 13mm length, the implant abutment displacement value is 2.22, 2.4, 2.7, 2.9 in 100N force and 45, 48.9, 60.8, 68.7 in 400N force in D/1, D/2, D/3, D/4 bone, which subsequently decreases with further increase in length of the implant as well as diameter of theimplant.

IV. DISCUSSION

Clinical studies have reported significant marginal bone loss around the implant neck inducing the implant to fail, bone loss occurrence was often attributed to oral hygiene and biomechanical factors. The biomechanical aspects can be related mostly to the implant design (example- diameter, shape and material property) where implant diameter and length are accepted as key factors and to the patient physiological condition (example- bone density, occlusal force and medical condition- chronic periodontitis, systemic diseases, smoking, unresolved caries or infection, advanced age). Apart from this, parafunctional habits and absence/loss of implant integration with the hard and soft tissues, inappropriate prosthesis design may also contribute to implantfailure.

The effects of implant diameter and length on stress distribution and implant stability in this region remain unclear making the optimal range of implant diameter and length difficult to define. It isnecessary to understand the role of implant diameter and length in regions with all types of qualities of bones. To study these stress distribution by various designs of implants, three dimensional finite element analysis (FEA) were carried out which gave us a pre-operative idea regarding the success rate of implant design. For 100N masticatory force in the mandible with type I density, the minimum implant dimension required may be 3x11.5mm, 3.5x13mm, 4.3x18mm, 5x13mm, 5.5x13mm; for type II density 3x11.5mm, 3.5x13mm, 4.3x18mm, 5x13mm, 5.5x13mm; for type III density, 3x10mm, 3x11.5mm, 3.5x18mm, 4x18mm, 5x11.5mm, 5.5x11.5mm; for type IV density, 3x10mm, 3x11.5mm, 3.5x15mm, 4.3x18mm, 5x13mm, 5.5x13mm based on availability of clinical length and width and for 400N masticatory force the minimum implant dimension for type I required may be 3x10mm, 3.5x8.5mm, 4.3x18mm, 5x13mm, 5.5x13mm; for type II density, 3x10mm, 3.5x8.5mm, 4.3x10mm, 5x13mm, 5.5x13mm; for typeIII density, 3x10mm, 3x11.5mm, 3.5x8.5mm, 4.3x11.5mm, 5x13mm, 5.5x13mm; for type IV density, 3x7mm, 3.5x8.5mm, 4.3x11.5mm, 5x13mm, 5.5x13mm based on available clinical height and width. However, depending upon the clinical scenario, the available mesio-distal, bucco-lingual dimensions and the length of mandible and approximity to vital structures, the appropriate dimensions of the implant should be choosen. (Table 2).

V. CLINICALIMPLICATIONS

As this is an in-vitro study, the exact bite forces cannot be replicated which varies from individual to individual. Hence an average of forces were applied on the recreated models. Success of implants not only depends upon on the selection of ideal implant length and diameter but also upon long term maintenance of the health of the peri-implant hard and soft tissues. Review of patients, evaluation of their oral hygiene and implant stability plays an important role in preventingperi-implantitis.

VI. STUDYLIMITATIONS

This study had a few limitations, first, modelling has its own set of limitations. The models can produce results as accurate as the set of assumptions that were used to create it, including boundary conditions, load conditions and material

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properties. Therefore, caution should be taken while extrapolating in vitro results to the clinical implication as the bone is made of combination of anisotropic materials and bone as such responds differently to the forces that are applied to the mandible. Secondly only mandibular first molar site was used to simulate a patient to which two loading forces were applied 100N and 400N but the loading forces also varies from authors to authors. There were no validation or verification of these models.

VII. CONCLUSIONS

The results of the study indicated that wider and longer implants shows favorable stress distribution in bone with minimal implant-abutment displacement values and provides a wear accurate estimate of the ideal dimension that may be chosen for bone with different densities. However, further studies correlating thisstudy along with a clinical will bolster the claims of thisstudy.

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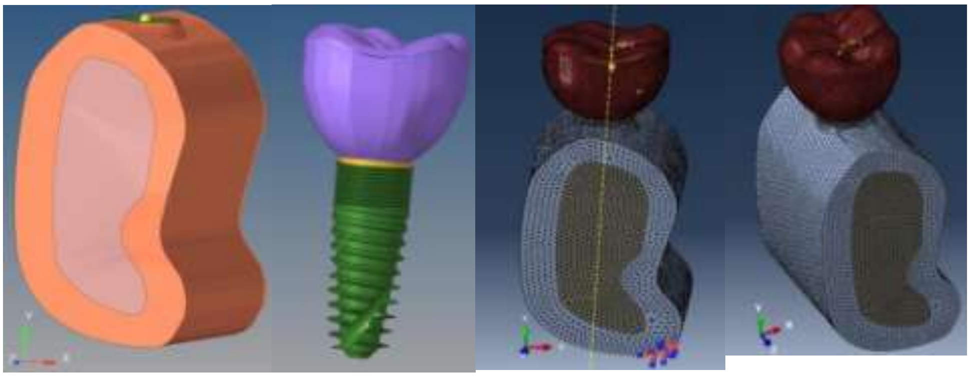
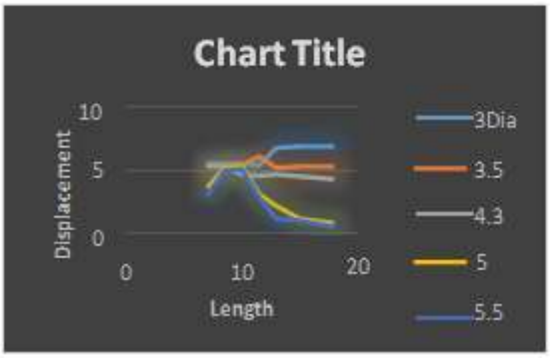


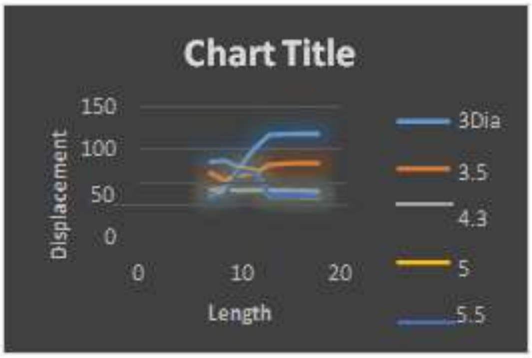
Figure 1:Modelling of inner cancellous and outer cortical bone.
Figure 2: Modelling of implant and crown
Figure 3: 100N Axial load
Figure 4: 400N Bucco- lingual load

Material	**Young's modulus(GPa)**	**Poisson ratio**
Cortical bone	110	0.30
Cancellous bone	Type 1-9.5 Type 2-5.5 Type 3-1.6 Type 4- 0.69	0.30
Titanium	14.8	0.35
Porcelain	68.9	0.38

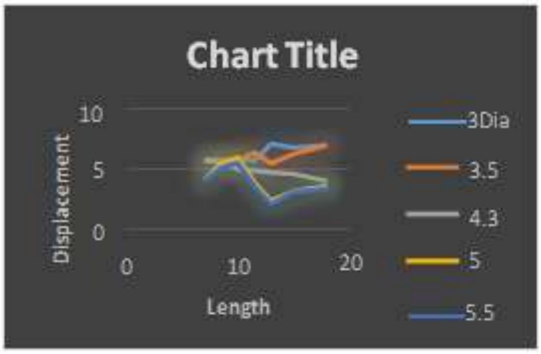
Table 1

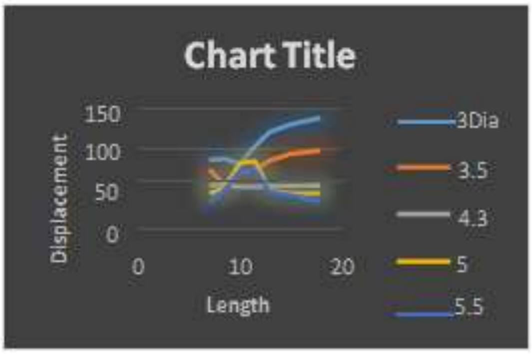
TYPE – I (100N and 400N)



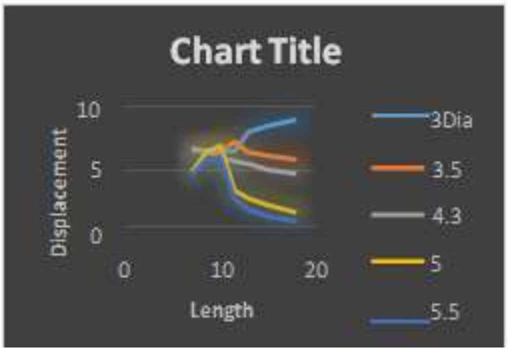


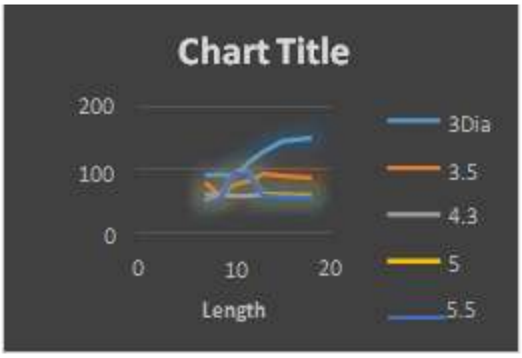
TYPE – II (100N and 400N)





TYPE – III (100N and 400N)





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Volume 3, Issue 4, July-Aug 2021 pp 517-523 www.ijdmsrjournal.com ISSN: 2582-6018

TYPE – IV (100N and 400N)

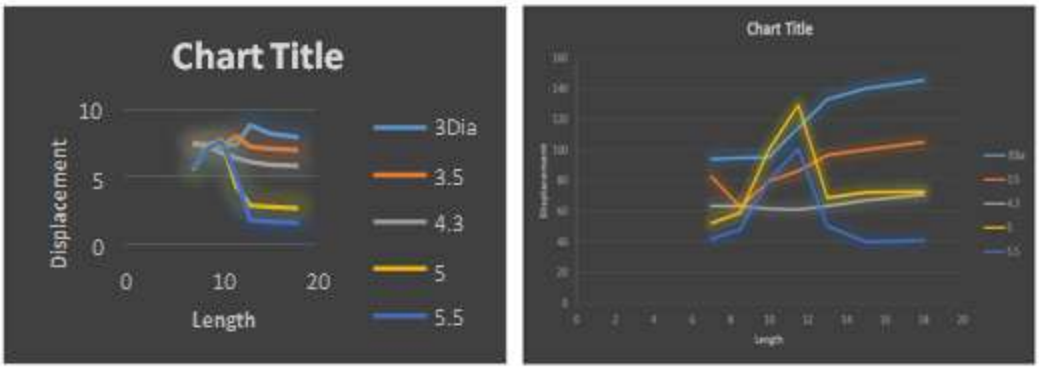
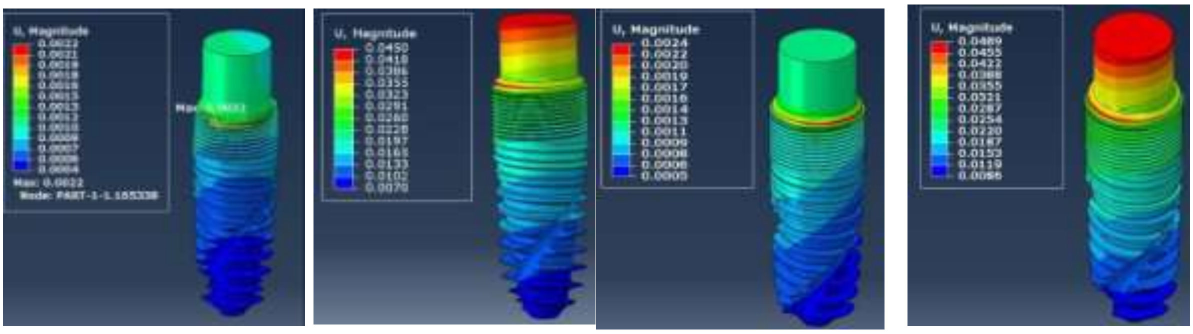
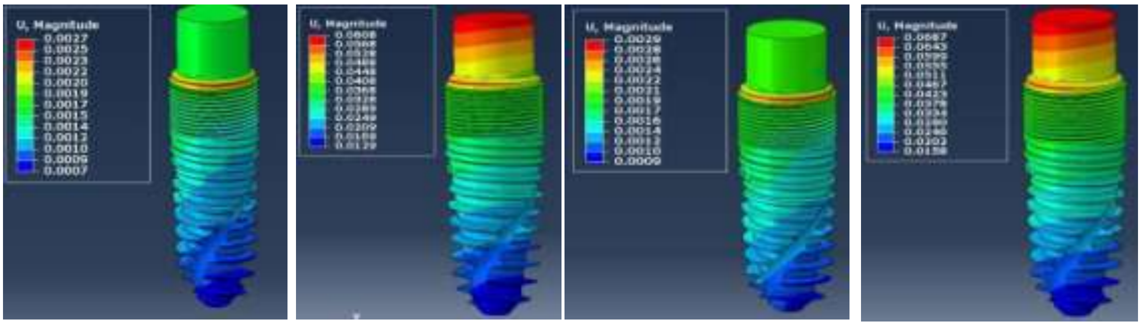


Figure-5 Max displacement in Implant-Abutment complex (µm)



(A) (B) (C) (D)



(E) (F) (G) (H)

Figure-6 Max displacement in Implant-Abutment complex (µm). A and B shows max displacement in Implant - Abutment complex in type I density in 100N and 400N. C and D shows in type II density in 100N and 400N, E and F in type III density in 100N and 400N, G and F shows in type IV density in 100N and 400N.

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TYPE - I	
100N (AX)	**400N(BL)**
3x11.5mm	3x10mm
3.5x13mm	3.5x8.5mm
4.3x18mm	4.3x18mm
5x13mm	5x13mm
5.5x13mm	5.5x13mm

TYPE-II	
100N (AX)	**400N(BL)**
3x11.5mm	3x10mm
3.5x13mm	3.5x8.5mm
4.3x18mm	4.3x10mm
5x13mm	5x13mm
5.5x13mm	5.5x13mm

TYPE-III	
100N (AX)	**400N(BL)**
3x10mm	3x10mm
3x11.5mm	3.5x8.5mm
3.5x18mm	4.3x10mm
4.3x18mm	5x13mm
5x11.5mm	5.5x13mm
5.5x11.5mm	

TYPE-IV	
100N (AX)	**400N(BL)**
3x10mm	3x7mm
3x11.5mm	3.5x8.5mm
3.5x15mm	4.3x11.5mm
4.3x18mm	5x13mm
5x13mm	5.5x13mm
5.5x13mm	

Table 2: Ideal dimensions in varying densities of bone