A Finite Element Study on the Characterization of the Loading Effect on the Stress-Strain Distribution of the MIS 7 Dental Implant

Razel Cada, Carlos Cruz and Homer Co*
Department of Manufacturing Engineering & Management
De La Salle University - Manila
homer.co@dlsu.edu.ph

Abstract: Nowadays, dental implants have been the most commonly used system for solving the problem of tooth loss because they are inert, alloplastic materials usually implanted in the maxilla and/or mandible. (Chang, et Al 2013) Dental implantologists say that osseointegration is basically the major factor that they look into for determining the success of the orthodontic treatment of which the success of the process relies on the bone quality and occlusal overloading. Characterizing the loading effect on stress-strain distribution of a dental implant will help dental implantologists to understand how functional loads are transferred to the bone-implant surface under a fully osseointegrated condition. The researchers have assigned three different loading forces (35 N, 67.5 N, 100 N) focused on three different angles for each load (30, 45, 60). Adding material properties to the 3D model which closely resemble the material properties of the exact model will provide near accurate results. The researchers successfully achieved the purpose of the study with the use of CATIA V5 R16 for 3D modelling, simulation, and finite element analysis. As a result from the experiment, higher applied loads also bear increasing Von Mises Stress and Translational Displacement. Meanwhile, increasing angles show decreasing Von Mises Stress. An increasing angle results in a decreasing/increasing Translational Displacement for Ø3.75mm and Ø4.20mm models respectively.

Key Words: finite element; loading effect; stress-strain distribution; dental implant

1. INTRODUCTION

Despite the abundant use of dental implant systems in tooth replacement and tooth restoration, loss of osseointegration still occurs. Some of the key factors that affect the long-term success of osseointegration of dental implants are bone quality and occlusal overloading. Poor bone quality determines occurrence of greatest failure rates because it denotes lack of capability to react accordingly to stresses produced in occlusal loads. Meanwhile, occlusal overloading arises due to absence of periodontal ligament in dental implants as compared to natural teeth (Chang, et Al, 2013). The main function of the periodontal ligament is to control tooth movement. Since dental implants lack the naturally existing ligament, there is a higher probability that occlusal overloading will happen and that will result to peri-implant bone loss and implant failure. [4]

According to ASM International (1998), characterization describes the features of composition and structure (including defects) of a material that are significant for a particular preparation, study of properties, or use, and sufficient for reproduction of the material. Characterizing the loading effect on stress-strain distribution of a dental implant will help dental implantologists to understand how functional loads are transferred to the bone-implant surface under a fully osseointegrated condition. It will provide a data that will help resolve the problems encountered in the orthodontic treatment like loss of osseointegration and explain how occlusal overloading occurs. Countermeasure development through more detailed prediction of the performance of the dental implant will also be provided.

Today, there are plenty of techniques being used today in order to evaluate the performance of a dental implant. Some of these are photo elasticity, strain gages, two- or three-dimensional finite element analysis (FEA). (Tiossi, et Al, 2013) However, no single experimental technique meets all the requirements for completely showing the extensive physiological interactions involved, while numerical techniques require validation by experiments. [7] A study on characterizing the loading effect using three-dimensional finite element analysis is planned. Parameters that can be controlled such as direction of forces, type of forces involved, the design of the implant, and the bone quality (studied without involving an actual in vivo experiment) will be used.

2. MATERIALS AND METHODS

Ten (10) finite element models were built and analysed with the use of CATIA V5 R16 (Dassault Systemes). Each set of model is limited to the implant screw only without the crown and abutment.

1.1 Implant System

The implant system modelled in this study was the MIS Seven dental implant. There are three (3) platforms for MIS Seven implant, namely, narrow, standard, and wide. For this study, the researchers focused on the standard platform of MIS Seven dental implant. Presented in Table 1 are the MIS Seven dental implants screw type implant ranges for standard platform only.

Table 1. Standard Platform MIS Seven Dental Implant Size

Diameter	Length (mm)				
	8	10	11.50	13	16
Ø3.75mm					
Ø4.20mm					
Ø4.20mm					

1.2 Material Properties

The materials used in this study were considered to be homogenous, isotropic, and linearly elastic. The physical properties of different components modelled in this study are illustrated in Table 2. Two types of bone density were modelled by varying the elastic modulus of compact bone and cancellous bone (with high density) with elastic moduli of 13.0 GPa, 1.37 GPa, respectively.

Table 2. Physical Properties of the Different Components Used in this Study.

Component	Elastic Modulus	Poisson ratio	Source
Cortical bone	13.0 GPa	0.3	Chang, H.S. et. Al.
Cancellous bone			
High Density	1.37GPa	0.3	
Titanium	113.8GPa	0.342	ASM International

1.3 Implant Model Design and Boundary Conditions

Each set of the implant screw model received loads of varying magnitude. The rough surface of the testing fixtures about 10mm long were totally embedded in the bone and the interface conditions between the bone and the implant were assumed to be fully osseointegrated. Blocks were used to represent the cortical and cancellous bones with each side of the inner block in surface contact with the inner walls of the outer block. The implant model was used to bore hole right through the connected blocks and had surface contact to the walls of the hole. This was done to achieve the condition of a fully osseointegrated implant.

1.4 Bone Model Structure and Geometry

The bone model was simplified to a cuboid form (23mm x 23mm x 20mm) and was classified as type II or type IV bone; type II bone consisted of a layer of cortical bone with a cuboid dimension same as the entire bone model, (23mm x 23mm x 20mm), while the type IV bone consisted of a thin layer cortical bone with a cuboid dimension of (20mm x 17mm x 20mm). Figure 8 shows a 2-dimensional measurement of the model from the YZ-plane.

1.5 Experimental Design: CATIA

The software used in this study is CATIA V5R16. It is capable to creating 3-dimensional objects used for various researches. The researchers made use of the software's capability to calculate for the stress-strain distribution. Along with this analysis, it is also able to show the displacement once the load has been placed. Shown in Table 3 are the resultant forces applied on the bone-implant model.

Table 3. Resultant Forces Applied on the Bone-Implant Model.

	35N	67.5N	100N
30°	y = -30.31N z = -17.5N	y = -58.46N z = -33.75N	y = -86.6N z = -50N
45°	y = -24. 75N z = -24.75N	y = -47.73N z = -47.73N	y = -70.71N z = -70.71N
60°	y = -17.5N z = -30.31N	y = -33.75N z = -58.46N	y = -50N z = -86.8N

1.6 Analytical Method: Finite Elemental Analysis

Various values were used on the materials of the model to simulate the same properties a real bone or titanium implant would possess. Shown in Table 4 are the material properties used by the researchers for FEA.

Table 4. Material Properties of the Bone-Implant Model

	MIS 7 Dental Implant	Cortical	Cancellous
Elastic Modulus	113.8 GPa	13 GPa	1.37 GPa
Poisson's Ratio	0.342	0.3	0.3
Yield Strength	880 MPa	133 MPa	2 MPa

3. RESULTS

1.1 Von-Mises Stress

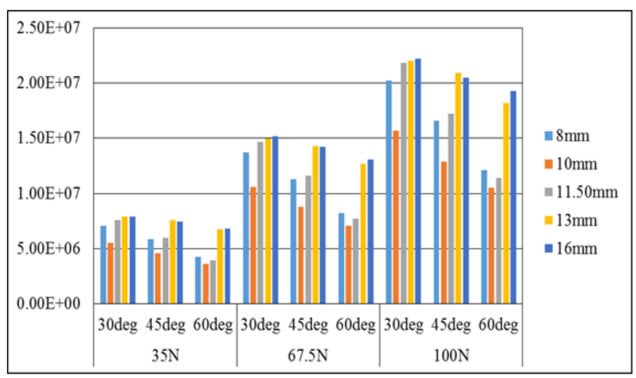

Fig 1. Summary of the Stress Distribution for Ø3.75mm MIS 7 (All Lengths)

As shown in Figure 1, the resulting Von Mises stress between the applied force and the angle it was projected to has an inverse relationship. The Von Mises stress decreases when the angle of the applied load is higher. Also, as the load increases, the resulting Von Mises stress also increases. On the other hand, the relationship between the resulting Von Mises stress and the length of the dental implant has no linear relationship. The resulting Von Mises stress varies as the length of the dental implant increased or decreased. These relations were also identified for the 4.20mm diameter MIS 7 dental implant as shown in Figure 2 below.

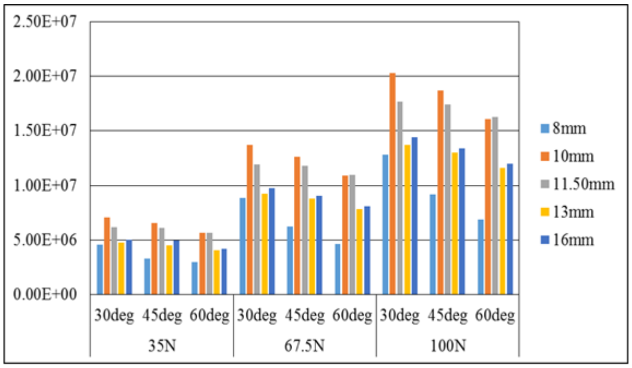

Fig 2. Summary of the Stress Distribution for Ø4.20mm MIS 7 (All Lengths)

1.2 Translational Displacement

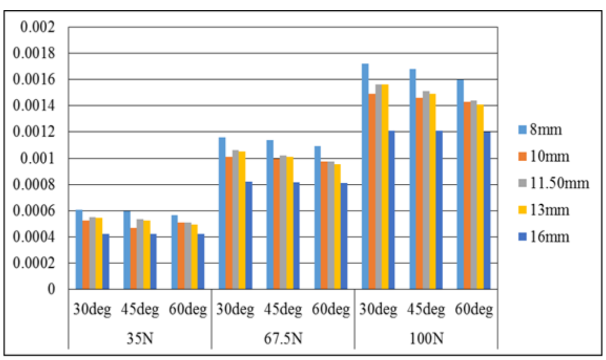

Fig 3. Summary of the Strain Distribution for Ø3.75mm MIS 7 (All Lengths)

As shown in Figure 3, the resulting translational displacement produced by the applied force shows a linear relationship. As the load increases, the resulting translational displacement also increases. On the case of the translational displacement between the force and the angle, the resulting translational displacement shows an inverse relationship. As the angle increases, the resulting translational displacement decreases. The translational displacement and the length of the dental implant have no linear relationship.

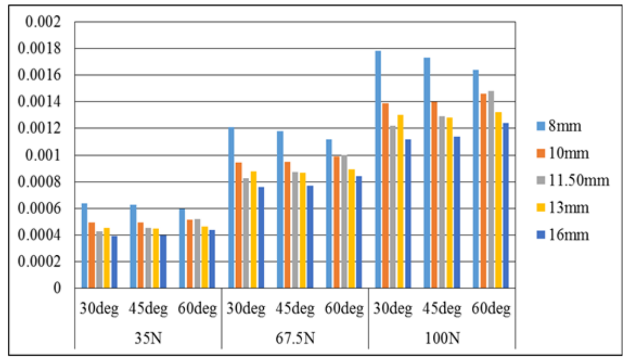

Fig 4. Summary of the Strain Distribution for Ø4.20mm MIS 7 (All Lengths)

As shown in Figure 4, the resulting translational displacement produced by the applied force shows a linear relationship. As the load increases, the resulting translational displacement also increases. However, on the case of the translational displacement between the force and the angle, the resulting translational displacement shows a direct relationship. As the angle increases, the resulting translational displacement also increases. The translational displacement and the length of the dental implant have no linear relationship.

4. CONCLUSIONS

The purpose of this research study was to characterize the loading effect on the stress-strain distribution of the MIS 7 Dental Implant using finite element analysis. The researchers were able to characterize the stress-strain distribution by varying the different parameters (load, angle, length). Within the limitations of this study, the following conclusions were drawn:

- As the applied load increases, the Von Mises stress and translational displacement also increases for all MIS 7 dental implant.
- As the angle of the load increases, the Von Mises stress decreases for all MIS 7 dental implant. On the other hand, as the angle of the load increases for Ø3.75mm MIS 7, the translational displacement decreases while as the angle of the load increases for Ø4.20mm, the translational displacement also increases.
- The relationship between an Ø3.75mm and Ø4.20mm with regards to the translational displacement is opposite because of the difference between their interface. The

Ø3.75mm implant has a straight-cut top while the Ø4.20mm diameter implant has an angled-cut top.

- The implant submerges onto the bone with respect to the direction of the applied load.
- As the length of the dental implant is either increased or decreased, the resulting Von Mises stress and translational displacement has no linear relationship.

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