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A Comparative Study to Analyse the Pull-Out Strength of Cortical and Cancellous Screws: FE Analysis

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Abstract—*Implant serves as a stress shielding agent, it helps to protect the bone from sudden impact loads on it and screw were used to fix the numerous variety of implant to the bone. The key focus of this paper mainly emphasize on the strength of screw in the bone fixation system and its behavioural impact change with respect to gradual changes incorporated with density variations of bone. The Computed Tomography(CT) Scans medico-analysis is been done with advanced tools of visualising the results such as materialise MIMICS version 17.0,Simulation tool ABAQUS version 6.13 and the virtual part drawing created with Solid works. Moreover, the present study is add on extension to the pull out strength test which agreed to pre-existing literature. Two screws are employed with pitch of 1.75mm and 2.75mm respectively for which it shows a far reliable results with displacement of 1.5mm under force (load).*

Keywords: *CT scan, MIMICS, ABAQUS, Pull-out test*

1. INTRODUCTION

An implant is a medical device manufactured to replace a missing biological structure, support a damaged biological structure, or enhance an existing biological structure. The surface of implants that contact the body are made up of a biocompatible material such as titanium, silicone or cobalt-chromium, SS-316L[1]. Screws serve as a bonding agent used to fix various implants to the human bone. They plays a vital role in fixation system of bone fractures. A good quality screw alleviates the risk of plate loosening and fracture failure.

Worldwide, Approximately 100 million bone screws are used each year. With a failure rate of at least 1%, this leads to around 1 million screws failing with each potentially leading to further surgery[2]. The stable fixation of an osteosynthesis system is necessary for the bone healing process and the clinical success of the implant. Manufacturers worldwide developed various methods to offer maximum intraoperative flexibility (e.g. polyaxial screws) and stable screw-plate connection (e.g. angular stable fixations)[3,4]. The functionality of the mentioned fixation methods has been demonstrated in several experimental studies[5]. Nevertheless, experimental testing is often time-consuming, cost-intensive and accurate results are to be extracted with extensive equipment.

A typical screw is composed of several parts (Fig.1). The outer diameter (OD) of the screw is the distance between the tips of the thread crest on either side. The inner diameter (ID), also known as root diameter is the distance between inner portions of thread crest. The distance between threads is called the pitch[6].

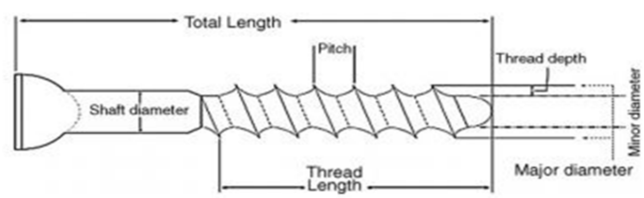


Fig. 1: Parts of a typical Screw[6]

Conventionally, the pulls out strength tests are performed on animal bones. But in FE analysis, CAD model of bone taken from CT scan data is used instead of real bone. Besides experimental testing, finite element analysis (FEA) has grown to a powerful tool in order to analyze stresses and strains within structures during static and dynamic load situations. Moreover, it offers detailed information which cannot be determined with experimental methods. Due to the capability to analyze the influence of various parameters on implant components during the preclinical testing without prototype production, the FEA has become an irreplaceable tool with various applicability. Therefore, it is a common method in mechanical engineering and has considerable influence in biomechanics also. Biomechanical studies do analyze the pull-out strengths of fixation screw for improving the bone-screw interface strength, a correlation was investigated between insertional torque and pull-out strength of three different pedicle screw designs, with different insertional torque characteristics. The concept of screw pull-out failure is based on the shear failure of an interface between the screw and the bone where the screw will shear bone, carrying material between the threads[7]. They hypothesized that a significant increase in insertional torque would indicate a commensurate increase in pull-out strength. Factors affecting the Pull-out Strength of bone screw depends upon relationship between Pull-out Strength, Thread Geometry, and Material Shear Strength. Comparison of Pull-out Strengths of different screws were also discussed[8].

In this paper, the main focus was given on analyzing the holding capabilities of screw in fixation system. For this purpose the pull-out strength was simulated on screw bone assembly. The analysis included displacement of screw to pull it out of the bone and required forces were obtained.

2. MATERIALS AND METHODS

Three dimensional (3D) model of femur bone was constructed from computer tomography (CT) scan images of human with MIMICS software which is an ideal toolbox for visualization and segmentation of CT images and 3D rendering of objects. The Computer Tomography images were stored in Diacom format and imported in MIMICS to create 3d femur model. The bone material was considered as a linearly elastic, homogeneous and isotropic material. The CAD model of cortical and cancellous screws was designed by using Solidworks software and both were exported in STL format to 3 Matic a module of MIMICS. The screw is of 1.75 mm and 2.75 mm pitch. A hole was created in bone for screw insertion for which material was removed by Boolean subtraction. Now volume mesh was created for both the bone and screw model with tetrahedral volume mesh and C3D10M as material type. The number of elements and nodes in bone and screws were shown in table.1. Both models were exported to ABAQUS software for further analysis.

Table 1: Number of elements and nodes

Part	Cortical Screw and bone assembly	Cancellous Screw and bone assembly
Number of Elements	245664	241786
Number of Nodes	1051312	1037232
Element Type	C3D10M	C3D10M
Mesh Type	Tetrahedral	Tetrahedral

The bone was modelled as linearly elastic and isotropic material with homogenous material distribution. The homogeneity of bone was derived from CT scan data. The elastic constraints were taken from literature with young's modulus of 20 GPa and Poisson ratio was assumed to be 0.3[9]. Material properties for screws of titanium alloy were derived from literature with young's modulus106GPa and Poisson ratio 0.3 as shown in table.2.

Table 2: Material Properties of bone and screw

Material	Screw	Bone
Young's Modulus (GPA)	106	20
Density(kg/m3)	4700	2000
Possion Ratio	0.3	0.3

3. LOADS AND BOUNDARY CONDITIONS

The FE model of bone and screw were imported into the analysis software and interaction properties were defined between bone and screw interface as shown in Fig.2. For pull out test, the bone surface was encastered to fix all the degrees of freedom completely so that bone do not move in any direction and a displacement of 1.5mm was given to the screw to pull it out of the bone.

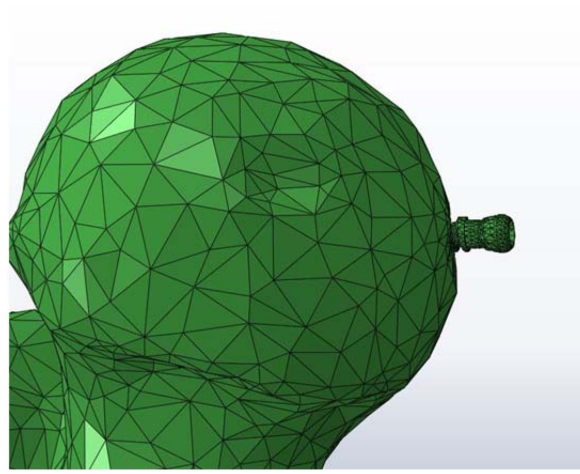
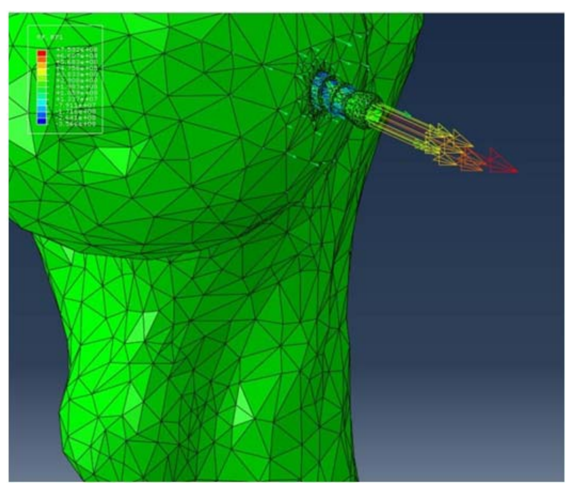


Fig. 2: Assembly of screw and bone

4. RESULTS

The pull out test was completed successfully with screw displacement 1.5mm and the reaction forces came out in the direction of cortical and cancellous screws were 5.5KNand 6.8KN respectively as shown in Fig.3.



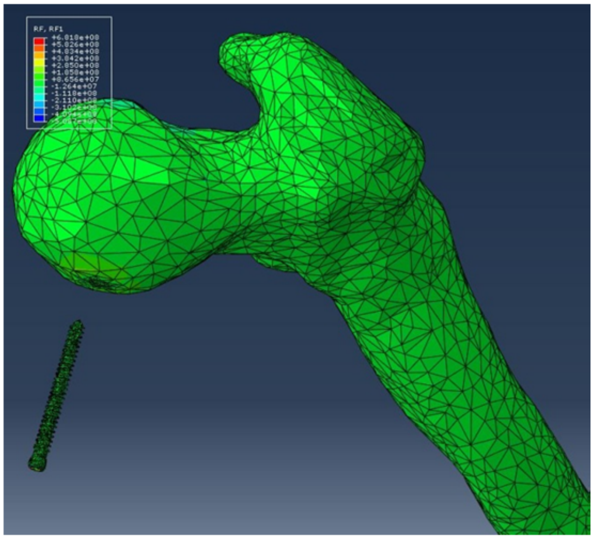


Fig. 3: Pull out test results

This is the force which was required to extract the screw out of the bone. Various steps involved in this analysis are shown in Fig.4.

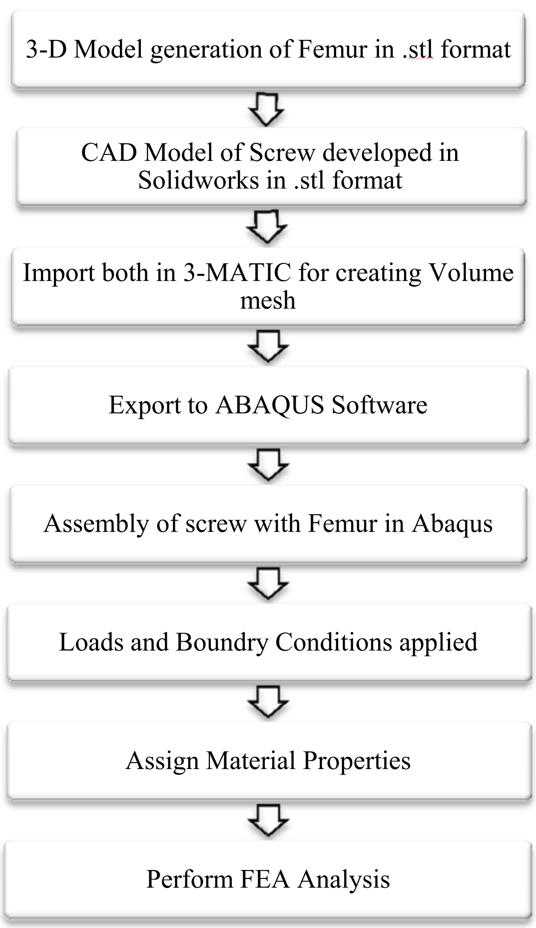


Fig. 4: Flow process of analysis

5. CONCLUSION

Obtaining adequate fixation of a screw in fragile bone, as that of an osteoporotic patient, has been proven to be an ongoing challenge. The pull out test revealed better results for specimens under study as force required to displace it by 1.5mm comes out to be 5.5 KN and 6.8 KN respectively. This result shows that huge forces are required to pull out the screw from the bone which is impossible from human body motions. Hence it is evident that screw will not loosen under the normal forcing conditions it will endure normal human body loading.

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