STRESS DISTRIBUTION ANALYSIS OF INTACT AND IMPLANT MODEL OF HUMERUS

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ABSTRACT

Bone is a composite material which is made of a substance which behaves both homogenous and in-homogenously at places. The project is aimed at creating a 3 dimensional model of the humerus which makes contact with the glenoidal joint in the shoulder region of the human body using image processing and modeling techniques. Further, upon creating the 3-dimensional structure, the model is analyzed for the stress distribution to check out the place where the concentration of the stress is more. Later the model is inserted with implant humerus heads with varying stem lengths and the reconstructed model is analyzed in the same way and optimum stem length which mimics the intact model to a certain extent is identified.

Key words: image processing, intact and implant model, stress distribution analysis.


1. INTRODUCTION

The humerus is the largest bone in the human upper limb and it essentially performs various movements in the daily activities. It has a head region termed humeral head in the top part of the humerus, a central region known as the shaft and the lower end. The head region is covered with hyaline cartilage that articulates with the joint it has made with glenoid cavity. Due to osteoporosis, it undergoes fracture upon aging. Humeral part connects the parts named ulna and radius of the lower part of the arm with the shoulder part scapula which is a complex system and it consists of four articulations, three bones and three joints and a number of tendons, ligaments, and muscles. These parts all together act to make stabilized movements and a wide range of motions. The shoulder has glenohumeral joint and a socket ball joint. Upon failure of the bone structure the upper humeral head is cut replaced with the implant made which is biocompatible. The humeral region head is cut with a plane specified in surgical procedure and the implant is placed with high accuracy so as to maintain lower stress shielding.

Bone is made up of organic and inorganic matter which provides strength and rigidity to the bone. The organic matter resists tensile forces acting on the structure and provides elastic and viscoelastic properties to the bone. This makes the bone a composite structure. Further on
looking into the bone structure it has an outer cortical layer which is highly dense and the inner part of the bone is termed as cancellous bone which is more of an inhomogeneous structure where it comprises a medullary cavity.

Osteoporosis is a disease which occurs on bone causing it to get reduced in its density by increasing the porosity. These structured bone has the ability to withstand the loads acting on it during various activities. Upon osteoporosis the bone gets fractured on excessive loading conditions, in such cases remodeling of bone is done with placing the implant in it. Humeral fractures also occur due to trauma which can be both direct and indirect.

2. METHODOLOGY

Replicating the original shape of the bone is necessary to compare the results obtained from in silico study with the in vitro results. For which the mimic of the bone with original dimensions is taken out using computed tomographic images. The X-ray beam is made to move in a circle around the body part, thus the different views of the part are recorded and the sum is displayed in a two-dimensional form. This provides more detailed information about the tissues and the bone structure, a typical CT scan image of limb consists of several cross-sectional images of the structure. These images are stored in DICOM (Digital imaging and communication in medicine.) format which collectively stores the information as .img and .hdr file which carries the image data and header data containing the patient and scan specific information.

2.1. Collection of CT Scan Images

The X-ray beam is passed through the human body and the cross-sectional images of the bone are captured in suitable DICOM format. These images are imported into the image processing software, mimics. Here these images are processed to obtain a surface geometry of the region of our interest which can further be analyzed.

This is interface screen of the image processing software which takes the cross-sectional images and creates the whole 3-dimensional view of the imported part. The necessary regions are to be cut out to model a bone geometry with calculated dimensions. There are tools in mimics software, those are used to complete the exact modeling. Here manual thresholding is used to extract the bone details out the images. Obtaining this bony information is followed by creating and editing mask over the regions which gives out the surface of the model. The surface model is then segmented where those segments connect the set of contours extracted from the image. Threshold values are used to control the separation of bone parts and region growing tool splits the segmentation into several objects to remove floating pixels. The output file is taken out as a surface model for discretization and analysis. The surface model is further imported into solid modeling software, SolidWorks where the surface errors are removed and a complete solid geometry is created.
2.2. Image Processing flowchart

CT Images

Thresholding

Edit Mask

Segmentation

Region Growing

Calculate 3D

2.3. Model Generation

The region grown model is then imported into SolidWorks for creating solid geometry. The errors on the model like surface spikes are removed in the solid generation. The model is taken out in IGES format which contains cloud points of the image which enables additional processing of the model. The intact model which has no deformities is imported and processed, later the humeral head is cut with a specific plane angle for replacing it with a prosthetic model. The dimensions for creating prosthetic material are chosen and three such implants are created with varying stem lengths and a common head cap. These implants are then assembled into the head removed section of the intact bone model.
The stem lengths are modeled as 10mm, 20mm, 30mm for finding the optimal length which satisfies biocompatibility and shear shielding effects. The material properties are assigned based on suitability of necessary conditions on shear shielding. The placement of the implant in the bone should recreate the surgical placement, thus in SolidWorks mates were used to perform such recreation. The bone cut surface and the circle fitted to cut surface were mated additionally to ensure the centering the bone and implant axis were made collinear having made the implant head concentric with the circle on the cut surface.

2.4. Discretization
The material domain of a model is to be processed and converted into an analytical model that suits analysis, this conversion process is termed as discretization. For structural analysis node element model is generated where elements are given as lines and those connect the individual nodes. Later the physical behavior of the model which is discretized into elements is described by the material properties assigned to them. For meshing after sizing and positioning of the implant, all intact and reconstructed bone geometry are transferred from SolidWorks to hyper mesh. The intact model is discretized here with the element size of 1mm and with total elements of about 8000 giving tetrahedral mesh type. Solid 45 element type is described for the whole model and components are created for application of boundary and loading conditions.

These created meshes are finer and accurate which gives stress, strain, and deformation in all critical areas. The same process is carried out for all other model generated by placing implants. Thus similar mesh on the models helps in better comparison of stress distribution at certain nodes.

2.5. Loading and Boundary Conditions
The intact and reconstructed models that are discretized in a similar manner are given certain boundary condition and similar loading is done on all the models to analyze the result. On looking at bone anatomy the humeral head makes a constant contact with the glenohumeral region that connects the scapula and the humerus part of the arm, it provides a loose joint capsule thus the interface between the two is limited and serves as the most mobile joint.
A ring of cartilaginous fiber is attached to the joint cavity, for a load to be acting tensile to the bone axis the contact at this joint is fixed so as to restrict the geometry. While discretizing the model, a pivot point is created on the distal end of the bone, so that a load applied to the point will get distributed equally to the end surface which mimics the actual load which acts on it while carrying certain load mechanically. The load can either be compressive or tensile upon the condition that is taken for consideration. The flexion angle is fixed in this case as the condition is tested only for load carrying capabilities. The abduction angle can further be varied where certain other conditions can also be analyzed to obtain the result for varying position of the arm on carrying a load. The specimens are given varying load conditions and the stress distribution on the model is analyzed and compared to observe the model which better mimic the anatomical structure while under load carrying condition by which suitable prosthesis material shall be recommended for a further surgical process.

3. RESULTS AND DISCUSSION

3.1. Stress Distribution Analysis

A major factor which is to be considered for predicting the survivability of prosthesis is the implant design. Thus different stem lengths that are designed are placed for analysis and the results were studied in certain nodes where the failure of material tends to occur. The stress distribution in the intact model is compared with other studies and the values are found to be satisfactorily validated.

Figure 4 Intact model with boundary conditions applied.

Figure 5 Stress distribution contour.
The other models were given the same loading conditions and the stress distribution at the same nodes as the intact model is compared for the closeness. The distribution of stresses is based on the shear shielding effect and material properties which distribute the stress according to the cortical and trabecular regions with the implant material placed in between the materials. The closeness in the values implies that the model with similar values will better mimic the intact model and can be suggested for surgical treatment of failure. The comparison of stress distribution between the four models was performed and the stress values of intact and model with implant length of 10mm were similar by which the model is considered to better mimic the anatomical structure of bone.

3.2. Tabulation of Equivalent Stress

Table 1

<table>
<thead>
<tr>
<th>LOAD (N)</th>
<th>NODES</th>
<th>INTACT MODEL</th>
<th>IMPLANT (30MM)</th>
<th>IMPLANT (20MM)</th>
<th>IMPLANT (10MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>5639</td>
<td>11.5738</td>
<td>112.5976</td>
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<td>16.2498</td>
<td>159.6587</td>
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<td>20.1587</td>
<td>206.7452</td>
<td>98.8974</td>
<td>31.7125</td>
</tr>
</tbody>
</table>

Figure 6 Comparison of stress distribution of different models.

REFERENCES


Stress Distribution Analysis of Intact and Implant Model of Humerus


