Modeling and Analysis of Human Liver by Using Finite Element Analysis

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Abstract: This work is focused on the construction of BIO-CAD modeling and analysis of human liver to satisfy the mechanical and biological characteristics. Developing the CAD model by using the data extracted from the CT scans. The 3D model of the human liver will be taken out from the CT scan data's using modeling tool CATIA. The 3DR concept can be applied for construction of profiles of human liver. The objective of this study is to develop robust finite element models of the liver. The organs are modeled for the first time as hyper viscoelastic materials and with individual constituents of each (viz. the capsule and veins). To validate these models in vitro dynamic tests on porcine kidneys were performed, whereas dynamic impact test data from the literature on human liver were used. The optimize model of the human liver may attained by the way of interfacing CAD modeling tools and visual basic software. The FEM analysis will be carried out and verify the biological and mechanical characteristics using ANSYS.

Keywords: CAD, Bio-CAD, CATIA, ANSYS and FEM

1. Introduction

1.1 Bio-CAD

CAD has been traditionally used to assist in engineering design and modeling for representation, analysis and manufacturing. Recent advances in computing technologies both in terms of hardware and software have helped in the advancement of CAD in applications beyond that of traditional design and analysis. CAD is now being used extensively in biomedical engineering in applications ranging from clinical medicine, customized medical implant design to tissue engineering. Using data derived from these images, computer models of human joints for stress analysis, dynamic force analysis and simulation; design of implants. This effort to model human body parts in a CAD based virtual environment is also referred to as Bio-CAD modeling. Bio-CAD is a multidisciplinary field involving biology, medicine, and engineering. It has largely been made possible due to developments made in imaging technologies and reverse engineering techniques supported equally by both hardware and software technology advancements. Image-based Bio-CAD modeling in which the imaging modality must be capable of producing three-dimensional views of anatomy.

1.2 Computer Aided Tissue Engineering

Tissue Engineering, the science and engineering of creating functional tissues and organs for transplantation, engenders a variety of scientific and engineering disciplines to produce physiologic “replacement parts for the development of viable substitutes which restore, maintain or improve the function of human tissues. Utilization of computer-aided technologies in tissue engineering research and development has evolved a development of a new field of Computer-Aided Tissue Engineering (CATE).

Tissue engineering research includes biomaterials, cells, biomolecules, engineering design aspects, biomechanical aspects of design, informatics to support tissue engineering. Computer-Aided Tissue Engineering, the methodology of reconstruction of 3D Bio-CAD models from non-invasive medical imaging, imaging process and 3D reverse engineering reconstruction and preparing CAD model. Image based bio-CAD modeling process involves following three major steps:

1) Non-invasive image acquisition.
2) Imaging process and three-dimensional reconstruction (3DR).
3) Construction of CAD-based model.

1.3 Basic Liver Architecture

The major blood vessels, portal vein and hepatic artery, lymphatics, nerves and hepatic bile duct communicate with the liver at a common site, the hilus. From the hilus, they branch and rebranch within the liver to form a system that travels together in a conduit structure, the portal canal. From this portal canal, after numerous branching, the portal vein finally leaves the liver via the hepatic vein. The hexagonal structure with, in most cases, three portal canals in its corners draining into one central vein, is defined as a lobule. The lobule largely consists of hepatocytes (liver cells) which are arranged as interconnected plates, usually one or two hepatocytes thick. The space between the plates forms the sinusoid. A more functional unit of the liver forms the acinus. In the acinus, the portal canal forms the center and the central veins the corners. The functional acinus can be divided into three zones:

1) The periportal zone, which is the circular zone directly around the portal canal
2) The central zone, the circular area around the central vein, and
3) A midzonal area, which is the zone between the periportal and pericentral zone.
1.4 Pressure Distribution

Blood pressure in afferent vessels and pressure distribution inside the liver is essentially similar for most species. Pressure in the hepatic artery, originating from the descending aorta and the celiac trunk, is considered to be the same as aortic pressure. This includes a high pulsatile pressure between 120 and 80 mmHg with a frequency equal to the heart rate. Vessel compliance causes a gradual decrease in pulsation as the hepatic artery branches and rebranches inside the liver. Once at the sinusoidal level, pulsation amplitude decreases to virtually zero and pressure drops to approximately 2-5 mmHg. On the other hand, pressure in the portal vein, originating from capillaries of the digestive tract, has no pulsation and a pressure of 10-12 mmHg. In the sinusoids, both portal venous and hepatic arterial pressure is 3-5 mmHg. Consequently, the pressure drop inside the liver is much less in the portal venous system than in the arterial system. The pressure drop from the collecting central veins to the vena cava is then approximately 1-3 mmHg, fluctuating slightly with respiration.

2. Process for Modeling the Human Liver

2.1 Non-invasive Image Acquisition

The primary imaging modalities used in tissue modeling is CT, MRI, and optical microscopy, each with its own advantages and limitations. CT scans require exposure of a sample to small quantities of ionizing radiation, the absorption of which is detected and imaged. This results in a series of 2D grey value images, where each image contains all geometrical information of one planar slice through the measured object. In the current case the image slices had a slice distance of 0.5 mm between consecutive images. To obtain a CAD description from the CT images, commercially available tools can be used to get a tessellated surface description, also called a polygonized point cloud, which is well known in CAD. The point data is used to create non-uniform B-Splines (NURBS). The splines are used to create surfaces and the surfaces are used to create solids. The NURBS were collected into a surface definition and the surfaces were prepared on to create the resulting three dimensional part.

2.3 Construction of CAD-based model

Measuring by computed tomography typically results in a large series of 2D grey value images, where each image contains all geometrical information of one planar slice through the measured object. In the current case the image slices had a slice distance of 0.5 mm between consecutive images. To obtain a CAD description from the CT images, commercially available tools can be used to get a tessellated surface description, also called a polygonized point cloud, which is well known in CAD. The point data is used to create non-uniform B-Splines (NURBS). The splines are used to create surfaces and the surfaces are used to create solids. The NURBS were collected into a surface definition and the surfaces were prepared on to create the resulting three dimensional part.

3. Modeling and Analysis of Human Liver

3.1 MATLAB

MATLAB is an abbreviation of Matrix Laboratory and it is a data analysis and visualization tool that has been design with powerful support for matrices and matrix operations. Here we are using the image processing tool box for extraction of geometrical data from the scanned images. 
1. Image processing generally involves extraction of useful information from an image. 
2. Images can be conveniently represented as matrices in Matlab.
3. One can open an image as a matrix using imread command.
4. The matrix may simply be m x n form or it may be 3D arrays or it may be an indexed matrix, depending upon image type.
5. The image processing may be done simply by matrix calculation or matrix manipulation.
6. Image may be displayed with imshow command.

### 3.3 Profile Points Extracted From the MAT File

In MATLAB image processing tool box we read the scanned image and scaling that image to extract the points. From there we get the point cloud data of the particular image through this data extract the coordinate points of each profile with slice thickness of 30mm.

#### Table 3.1: Coordinates of normal liver Profile

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### 3.2 Scanned image of Human Liver

#### Figure 3.1: CT scanned image of liver

#### Figure 3.2: Point cloud data of the image of Human Liver

### 3.4 Modeling

CATIA is multiplatform CAD/CAM/CAE commercial software developed by the French company and marketed worldwide by IBM. Model the three dimensional human liver by using CATIA V5. By taking profile coordinate points from ct scans and then draw the profiles in parallel planes. Loft that profiles and filleting the edges with the edge fillet option for smooth and curved surfaces.

#### Figure 3.3: Three Dimensional Cad Model of Normal Human Liver

### 4. Finite Element Analysis

Finite element analysis is a process, which can predict deflection, and stress on a structure. Finite element modeling divides the structure into a grid of elements, which form a model of a real structure. Each of the elements is a simple shape for which the finite element program has information to write the governing equations in the form of a stiffness matrix. The unknowns for each element are the displacements at the node points, which are the points at

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which the elements are connected. The finite element program will assemble the stiffness matrix for the entire model. This stiffness matrix is solved for the unknown forces and the boundary conditions. From the displacements at the nodes, in stresses in each element can then be calculated.

Even though the unknowns are at discrete degrees of freedom, the internal equations were written for strain functions that represent a continuum. This means that even though the finite element model has a discrete number of equations, if the right elements are chosen, it is possible to coverage on the correct answer with a less than infinite number of nodes and elements. A finite element model is a complete idealization of the entire structural problem, including the node locations. The elements, physical and material properties, loads and boundary conditions.

4.1 Mesh Generation

After the specifications of element attributes, and control, the mesh has been generated automatically by picking the volumes or areas, which is going to mesh. The following figure shows the meshed model of human liver. The meshing is done in ANSYS Software where all the contours are read and meshed properly.

![Meshed model of the human liver](image)

Figure 4.1: Meshed model of the human liver

![Deformation of normal liver at 70Pa pressure](image)

Figure 4.2: Deformation of normal liver at 70Pa pressure

![Stress of normal liver at 70Pa pressure](image)

Figure 4.3: Stress of normal liver at 70Pa pressure

4.2 Results and Discussion

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of person</th>
<th>Pressure (Pa)</th>
<th>Stress (N/mm²)</th>
<th>Strain (mm)</th>
<th>Deformation (mm)</th>
<th>Stiffness (N/m)</th>
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</table>

4.2 Results and Discussion

After modeling analysis has been done to calculate the stiffness values by applying different pressures. The above figure shows the deformations and stresses at different pressures.

From the graph we infer that for a normal liver there is a slight variation in its stiffness however increased pressure applied on it. In the case of the other two fat and thin livers, when a pressure of 75 and 80Pa are applied the stiffness variations are more. Hence it is to be concluded that normal liver is better under the applications of increasing pressures. The values in the above table support the discussion.

5. Conclusion

The original translation of anatomical knowledge into geometrical data for modeling the human liver is successfully taken from CT scans. By using MATLAB image processing tool we got the point cloud data and it is used to continue further operation to convert that data to...
model the three dimensional human liver in CAD package. Interface the model with visual programming language for the geometrical changes. After modeling analysis has been done using ANSYS to find out stiffness by applying different pressures. Based on stiffness we have to determine which is better one.

6. Future Scope of this Project

Because of the small number of specimens that were successfully analyzed for determination of the stiffness for different pressures, if we consider the other age groups with more number of specimens also then much more accurate results will be obtained. This can be also improved by considering other biological elements.

References


Author Profile

N. Kishore Kumar received his Bachelor of Technology degree in Mechanical Engineering from Annamacharya Institute of Technology & Sciences, Rajampet in the year 2009 and his Master of Technology degree in CAD/CAM specialization in Mechanical Engineering from the same institute during the academic year 2010-2012. Now he is working as a Assistant Professor, in the Department of Mechanical Engineering, A.I.T.S, Rajampet.

K. Ashok Kumar Raju received his Bachelor of Technology degree in Mechanical Engineering from Vaishnavi Institute of Technology & Sciences, Rajampet in the year 2013 and pursuing his Master of Technology degree in CAD/CAM specialization in Mechanical Engineering from the Annamacharya Institute of Technology & Sciences, Rajampet, during the academic year 2013-2015. He published two international journals in the areas of CAE and Heat Exchangers in the field of Mechanical Engineering.