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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, intigrates 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 drains into the sinusoids, which is the capillary system of the liver. Here, in the sinusoids, blood from the portal vein joins with blood flow from end-arterial branches of the hepatic artery. Once passed through the sinusoids, blood enters the collecting branch of the central vein, and 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.

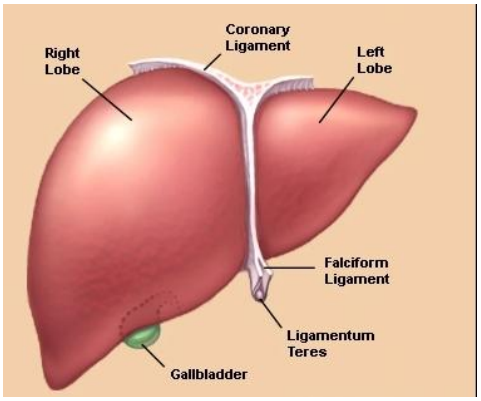

Figure 1: Liver Architecture

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 trunc, 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 images displaying a density map of the sample. Stacking these images creates a 3D representation of the scanned area.. This is computationally and a memory intensive process but within the capabilities of many computer modeling programs. Differentiation of tissue in CT scans is accomplished through contrast segmentation, the grayscale value of each voxel determined solely by tissue density. As such, CT is inferior to both MRI and optical microscopy in differentiating soft tissues of similar density.

2.2 Imaging Process and Three-Dimensional Reconstruction (3DR)

The CT images are integrated using 2D segmentation and 3D region growth and this volumetric image data extracts more meaningful, derivative images via three-dimensional anatomic view. These three-dimensional images lead to the generation of anatomic modeling. 2D segmentation is extraction of the geometry of the CT scan data set. Each slice is processed independently leading to the detection of the inner and outer contours of the living tissue. The contours are stacked in 3D and used as reference to create a solid model. A realistic tissue model is desirable for virtual reality surgery training simulators, mechanical tool design and controller design for safe and effective tissue manipulation. The anatomic tissue modeling should result in efficient and realistic estimation of tissue behavior and interaction forces. The construction of anatomic modeling by either Contour based method or 3D shaded surface extraction.

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.

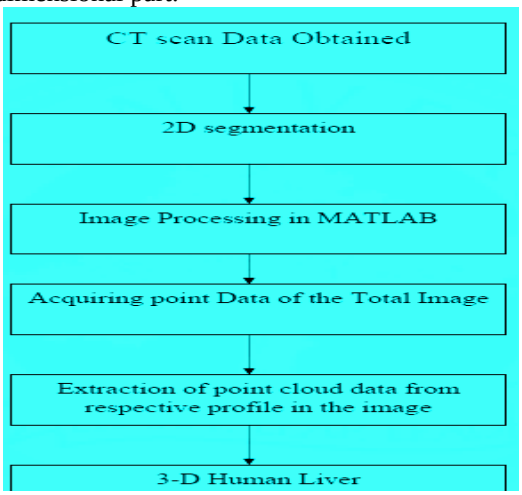

Figure 2: Process Flow

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. .

Table 3.1: List of operations and commands

Operation	Command
Create and display image object	image
To read the image	imread
To display an image	imshow
To change the size of the image	imresize
To rotate the image	imrotate
To extract a rectangular part of an image	imcrop
To brighten the image	imadd
Scale data and display as image	imagesc
Read a DICOM image	dicomread
Write a DICOM image	dicomwrite
Convert image array to double precision	im2double
Convert image array to 8-bit integer	im2unit8
Display histogram of image data	imhist
Reshape array	reshape
Adjust image intensity value	imadjust
Multidimensional image filtering	imfilter

3.2 Scanned image of Human Liver

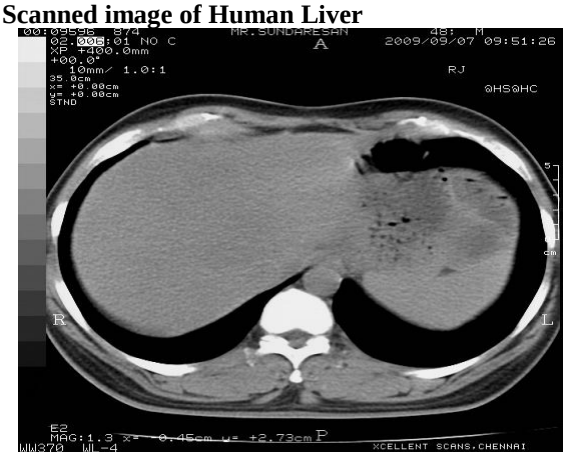

Figure 3.1: CT scanned image of liver

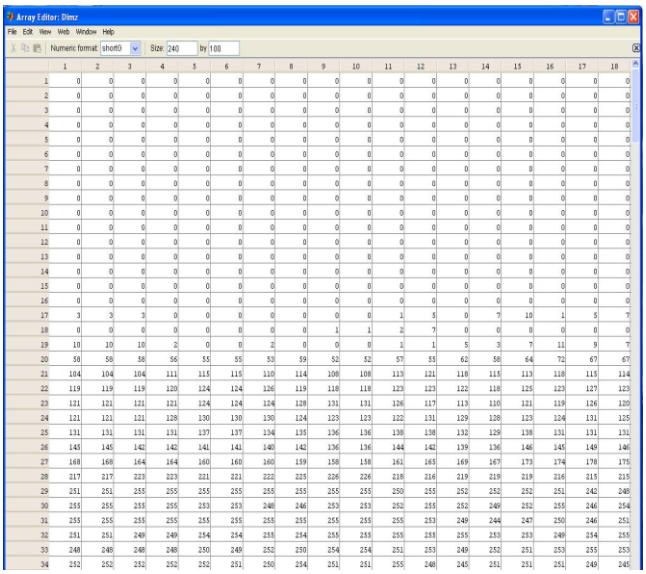

Figure 3.2: Point cloud data of the image of Human Liver

3.3 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

S.No	X-Coordinate	Y-Coordinate
1	-30.216755	29.999302
2	-40.358696	8.309019
3	-38.140146	-17.24392
4	-35.60466	-39.52846
5	-28.632076	-52.0078
6	-8.031258	-39.52846
7	7.49859	-29.12901
8	28.73328	-17.24392
9	43.312319	-13.97552
10	60.74378	0
11	72.153465	11.874545
12	72.153465	29.999302
13	46.164739	37.427483
14	28.73328	35.941845
15	13.203432	40.101627
16	-10.883678	40.101627
17	-30.216755	29.999302

3.4 Modeling

CATIA is multiplatform CAD/CAM/CAE commercial software developed by the French company and marketed world wide 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.

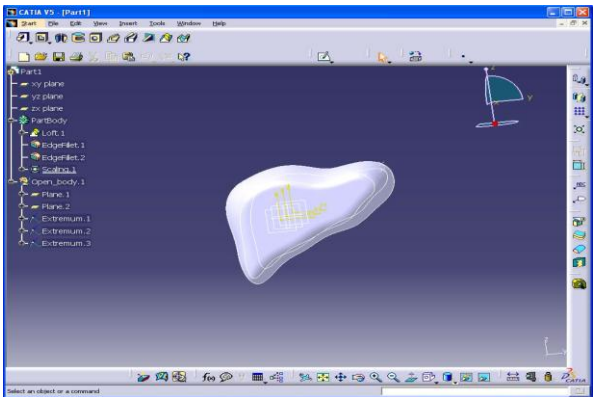

Figure 3.3: Three Dimensional Cad Model of Normal Human Liver

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, whish 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

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.

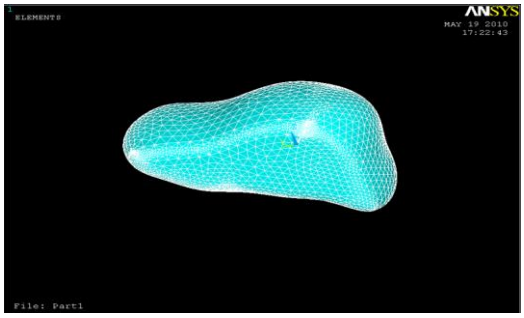

Figure 4.1: Meshed model of the human liver

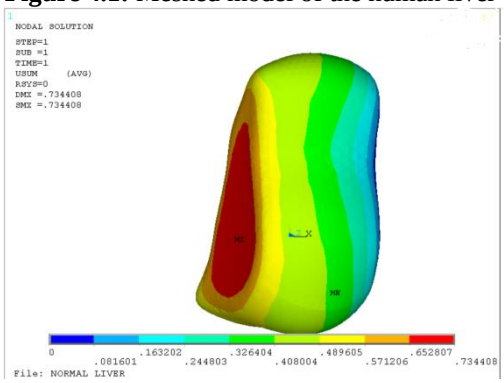

Figure 4.2: Deformation of normal liver at 70Pa pressure

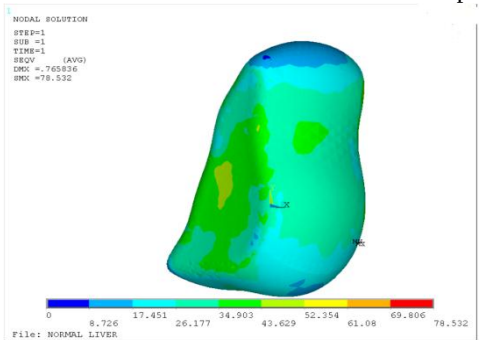

Figure 4.3: Stress of normal liver at 70Pa pressure

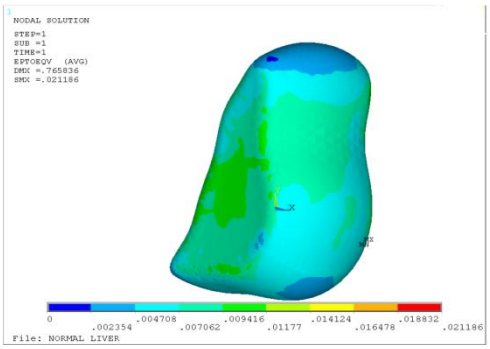

Figure 4.4: Strain of normal liver at 70Pa pressure

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.

4.2 Results and Discussion

Table 4.1: Results

S.No	*Type of person*	*Pressure (Pa)*	*Stress (N/mm2)*	*Strain*	*Deformation (mm)*	*Stiffness (N/m)*
1	Fat	80	97.915	0.0254	0.8354	0.710
		75	92.56	0.0256	0.7819	0.703
		70	84.86	0.0234	0.7725	0.664
2	Normal	80	95.391	0.0267	0.8845	0.671
		75	88.898	0.0235	0.7658	0.675
		70	78.532	0.0211	0.7344	0.657
3	thin	80	92.975	0.0243	0.7904	0.634
		75	91.082	0.0268	0.7899	0.595
		70	78.926	0.0214	0.7013	0.625

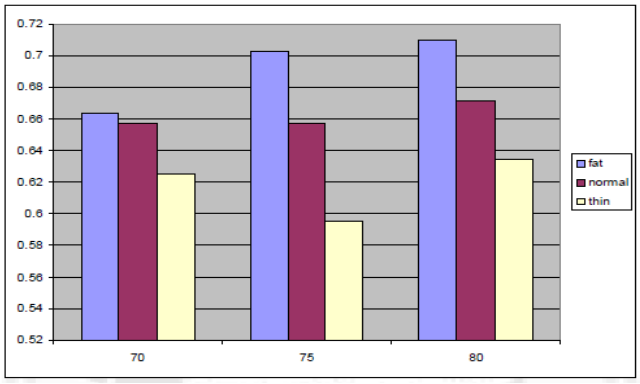

Figure 4.5: Pressure (Pa) vs stiffness (N/m) graph

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.

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