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CAD MODEL OF PATIENT SPECIFIC PORTAL VEIN FOR ANALYSIS OF LIVER DISORDER

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Abstract— Recent days Computer-aided design and image processing techniques are one of the most emerging useful tools for analysis of models in various medical, industrial and research areas. In medical field for the diagnosis of various diseases in vivo techniques including biochemical test, enzymatic tests are needed for continuous monitoring of patients. These diagnosis procedures are time consuming and inconvenient for patients. Therefore Computer assisted designing and image processing techniques are most promising non invasive tools for faster diagnosis and useful tool for designing of biomedical implants. In this paper portal vein was segmented from patient's Liver computed tomography (CT) image by dedicated software. A Liver's CT image of 38 year old Indian male patient's was collected and by using imaged based software MIMICS (Materialise's Interactive Medical Image Control System, Belgium) 3D model of HPV (hepatic portal vein) was obtained and Solid Work Professional (Dassault Systems Solid Works Corporation, USA) software was used for designing of normal portal vein's 3D model and various portal vein diseased models including minor right portal vein thrombosis (19-20% reduction in medial region of vein), severe right portal vein thrombosis (20-22% reduction in medial and distal region of vein), minor left portal vein thrombosis (19-20% reduction in medial region of vein, severe right portal vein thrombosis(20-22% reduction in medial and distal region of vein), left aneurysm (150-200 % increase of medial region).These models can be used for designing for implants and analysis of portal vein's disorder like portal thrombosis, and portal aneurysm which are main cause of portal hypertension and also useful for surgeon for planning surgery and also helpful for understanding of portal vein hemodynamic (pressure, velocity, wall shear force).

Keywords-MIMICS, CT image, HPV, Portal Thrombosis, CAD, Solid Work Professional;

I. INTRODUCTION

Modern quantitative computational analysis of two dimensional (2D) and three dimensional (3D) biomedical vasculatures images is currently most effective non-invasive method for diagnosis of disease in various medical areas [1-2]. The liver is the biggest digestive gland and plays a vital role in circulatory system containing three important vasculatures, including hepatic portal vein (HPV), hepatic vein (HV) and hepatic artery (HA). The HPV is the functional organ providing about 70%-80% of the liver blood. Therefore, the analysis of HPV is crucial for not only diagnosis of liver diseases but also important for planning of surgery [3-5].

Portal hypertension (PH) is a sustained increase in the portal vein pressure, usually as a result from obstruction of the blood flow within the portal circulation. Portal hypertension is characterized by a gradient of greater than 5 mm Hg between the portal venous and central venous pressures [6]. Portal hypertension is the commonest cause of upper gastrointestinal bleeding in children and up to 30% of cases with upper gastrointestinal hemorrhage can be fatal. Extra hepatic portal

venous obstruction (EHPVO) is the commonest cause of portal hypertension in children and adults not only in India but also distributed worldwide. EHPVO is a common cause of portal hypertension in the developing countries (30-55% of all variceal bleeders) and other liver infections like cirrhosis (up to 5-13%). Literature from different parts of India indicated that in children EHPVO is responsible for 54% of portal hypertension [7-8]. Most (85-92%) of the upper gastrointestinal bleeding in Indian children was result of portal hypertension due to EHPVO [9]. It is the most common liver disorders, which includes portal vein thrombosis, liver cirrhosis, tumors, surgical trauma, infections and atrial pressure rise in heart, esophageal and stomach varices and pregnancy. Diagnosis of PH can be done by various imaging techniques includes ultrasound, computed tomography (CT), angiography and magnetic resonance imaging (MRI). Now different surgical procedures are used by surgeon to treat Portal hypertension includes i). Transjugular Intrahepatic Stent Shunt (TIPS); ii).Portocaval shunt; and iii).Mesocaval shunt.

Svetla petkova et al (2003) used computational model to analyzed the portal hypertension by constructing 3D computer aided design (CAD) model

of hepatic portal vein with thrombosis and without thrombosis condition and hemodynamic of blood flow was examined in normal and diseased condition[10]. C.C. Botar et al (2010) proposed mathematical modeling of the blood flow in the portal vein by CAD model of hepatic portal vein and analyzed the portal hypertension by computational fluid dynamic (CFD) technique and validated the result by using in vivo Echo-Doppler method [11].

This paper presents a novel approach for designing of 3D model of portal vein by using patient specific CT image by MIMICS (Materialise’s Interactive Medical Image Control System, Belgium) software and CAD model of normal and diseased conditions. Information’s in CT image are extracted by 3MATIC software by measuring dimension of portal vein (length, angle, and diameter) and these values are used for designing CAD model. In future these CAD model can be used for designing implants (stent), portal blood flow dynamic analysis (CFD) and will helpful for surgeons for planning of surgery.

II. AIM AND OBJECTIVES

The aim of this study was to create patient specific CAD models of normal- as well as diseased-hepatic portal vein (HPV) from the standard CT image of liver of an individual using dedicated image processing softwares.

The objectives are as follows: i).to create patient specific 3D model of normal HPV using image analysis software; ii). to measure geometry of different regions of HPV model with accuracy; iii). to create patient specific CAD model of normal HPV by measured geometry values by image analysis software; and iv). to create the following patient’s specific diseased CAD models of HPV: a). right side- and left side- minor and severe PV thrombosis; and b). left side PV aneurysm using a software.

III. MATERIAL

CT Image of Portal Vein

A 38 years old Indian male patient’s liver CT image was collected from one of the private scanning Centre, Chennai, India. It was in DICOM (Digital Imaging and Communications in Medicine) format, which was described as follows:

- Number of slices: 419
- Slice thickness: 0.8 mm
- Resolution: 512 x 512 pixels

IV. METHODS

A. Schematic of the Study

The various steps involved in the digital image analysis of CT image are given as in Figure. 1.

B. Softwares Used in the Image Analysis

The softwares used in the digital image analysis were:

- MIMICS, version-14.4 (Materialise NV, Belgium);
- 3-Matic (Materialise NV, Belgium);
- Solid Work Professional, version-10.0 (Dassault Systems, France);

C. Image Analysis Using MIMICS Software

The following tools of the software were used in creating a 3D model of HPV:

- Opening the project
- Windowing
- Thresholding
- Region growing
- Edit masking
- Creating a 3D representation

i). Opening the project

After opening the MIMICS file (mcs format) from the working directory will open an already existing file and for new study, import images by selecting ‘file’ option in MIMICS working directory and then choose ‘import image’, opens an ‘import project wizard’ [13].

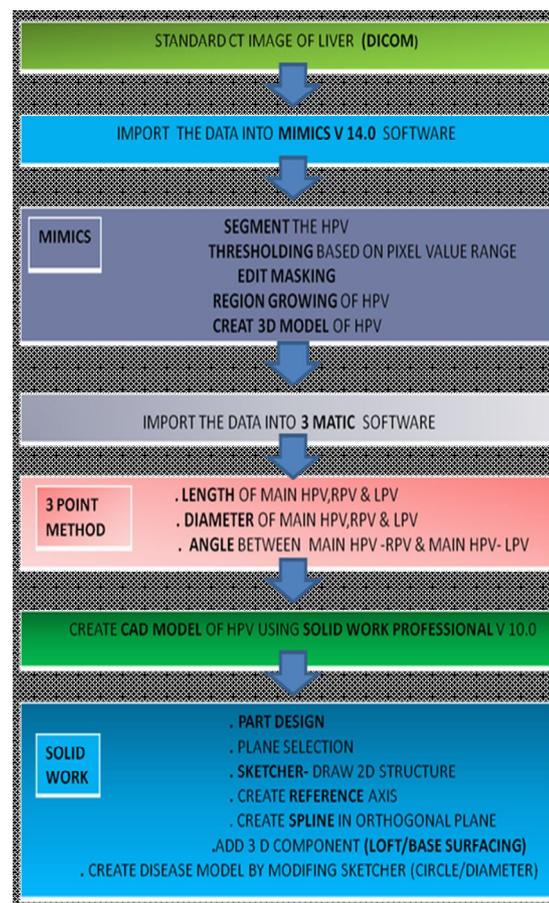


Fig. 1: Flow diagram of CAD model of HPV and different HPV diseased conditions.

ii). Windowing

To adjust the contrast of the imported images displayed in the different views like axial, saggital and coronal, a tool 'contrast' is used for selecting parts with different intensities and according to patient specific image contrast is adjusted for bone, soft tissue and fatty tissue. The gray values or Hounsfield units (HU) below the start point and end point is displayed by black and white color. The gray values below the start point of the line will be displayed in black and all gray values above the end point of the line will be displayed in white. The gray values in between the window will be mapped on a shade of gray. The window size can be changed by clicking on the line and dragging it to its new position [14].

iii). Thresholding

It segments the region of interest based on the HU of interest, containing all pixels of the image between an upper and lower threshold specified thus area of interest is separated from image by setting fixed pixel value Range (-20 to 130) [15].

iv). Region growing

The region growing tool splits the segmentation created by thresholding into several objects and to remove floating pixels. In region growing the area of interest is grown by assigning different mask color to threshold pixel values range [16].

v). Edit masking

Edit masking is important tool for further filtering of area of interest where undesired regions are eliminated by assigning different color masking [17].

vi). Calculate 3D

3D model was created by selecting assigned active color mask field to area of interest listed along with their respective threshold and by clicking on the 'calculate' button from Dialog box appearing in the Project Management tool bar [18].

D. Image Analysis Using 3-Matic Software

The created 3D model of HPV using MIMICS software was imported to 3-Matic software (Materialise N.V., Belgium). The software offers a wide range of tools for geometry analysis, dedicated for anatomical data and the same is used for optimize design of its structure [19].

i). Import formats:

The import format of the file in the software is given as follows:

- IGES (Initial graphics exchange specification)
- STL (Stereo lithography)
- Solid work
- CATIA
- UniGraphics
- Pro-Engineer
- Step

ii). Geometrical Measurements:

The created 3D model of HPV was used to measure various geometrical measurements of its parts with good accuracy.

a). *Measurement of length:* The length of main portal vein (MPV), right-side portal vein (RPV) and left-side portal vein (LPV) were measured by selecting the starting- and end- points of the line between two points in each vein.

b). *Measurement of diameter:* The 3-point method was used to measure diameter of MPV, RPV and LPV. First arc was defined by selecting the first 2 points namely, the beginning- and end- point of the arc. The third point selected defined radius of HPV, RPV and LPV.

c). *Measurement of angle:* The angle between two sets of planes of the following HPV were measured: i). HPV and RPV; and ii). HPV & LPV.

TABLE I
MEASURED GEOMETRY VALUES OF HPV
USING 3-MATIC SOFTWARE

Parameter *	Measured Values
Angle HPV - RPV	48.23 deg
Angle HPA - LPV	52.73 deg
Diameter of MPV	10.52 mm
Diameter of RPV	7.43mm
Diameter of LPV	8.53 mm
Length of MPV	45.36 mm
Length of RPV	27.15 mm
Length of LPV	29.6 mm

E. Image Analysis Using Solid Work Software

This CAD software has the following features: i). Creating base, boss, and cut features from sketches; ii). adding fillets to smooth edges; iii). creating a circular pattern, adding drawing views, adding centerlines, center marks, and dimensions to the drawing [20]. Solid Work Professional V 10.0 (Dassault Systems, USA) software was used in this project for creating CAD model of normal HPV and different diseased models.

The steps involved in creation of CAD models normal as well as different diseased models of HPV are listed as follows:

- *Step-(i):* Open 'part design' from file menu of the software.
- *Step-(ii):* Select appropriate planes from available xy (top), yz (side) and zx (front) planes.
- *Step-(iii):* Open 'Sketcher' window and draw the 2D sketches namely line and point as per the dimensions of 3D model and circle were drawn on the desired point namely inlet, medial and distal and exit the sketcher.

- *Step-(iv)*: Create an axis in orthogonal plane for tracing the shape of the model.
- *Step-(v)*: Joint all constructed geometry by spline option available in tool bar at reference plane for a particular plane of interest.
- *Step-(vi)*: Use 'Loft' option for construction of 3D model by selecting geometry and directions and 3D CAD model was created.
- *Step (vii)*: By modifying measured normal sketcher's diameter values of LPV and RPV, thrombosis and aneurysm models were created at preferred location.

F. Designed diseased CAD model Using Solid Work Software

a).Minor right portal vein thrombosis model:

It was created by (20-22) % reduction in diameter of medial part of RPV, compared to its corresponding normal value.

b).Severe right portal vein thrombosis model:

It was created by (20-22) % reduction in diameter of medial and distal parts of RPV, compared to its corresponding normal value.

c).Minor left portal vein thrombosis model:

It was created by (19-22) % reduction in diameter of medial part of LPV, compared to its corresponding normal value.

d).Severe left portal vein thrombosis model:

It was created by (19-22) % reduction in diameter of medial and distal parts of LPV, compared to its corresponding normal value.

e). Left portal vein aneurysm model:

It was created by (150-200) % increase in diameter of medial and distal parts of LPV, compared to its corresponding normal value.

V. RESULTS

A. 3D Model of portal vein

Figure-2 denotes the created 3D model of hepatic portal vein (HPV) using MIMICS software indicates the axial, coronal, sagittal and 3D views of the HPV respectively starting clock-wise from top left corner of the output window. Figure-3 indicates the created 3D model of the HPV after segmenting and thresholding the hepatic portal vein with threshold values ranging from -20 to 130 HU, and thus 3D model of portal vein is created.

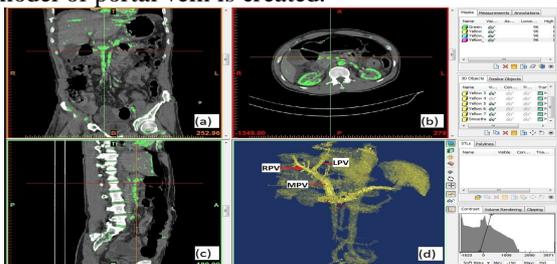


Fig.2 Created 3D model of human portal vein (HPV): a).axial view, b).coronal view, c).sagittal view, and d).3D view where RPV and LPV stands for right and left portal vein respectively.

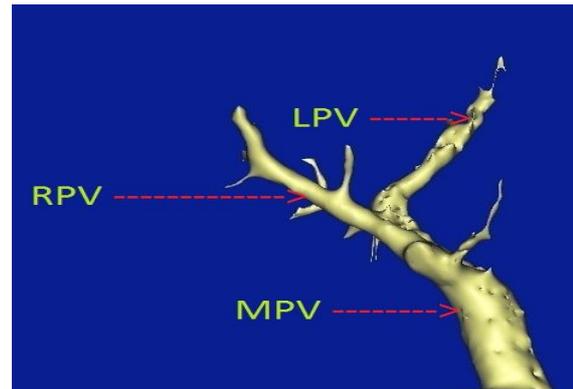


Fig. 3 shows 3D model of Hepatic Portal Vein (HPV) where MPV, LPV and RPV indicates main portal vein, left portal vein and right portal vein respectively.

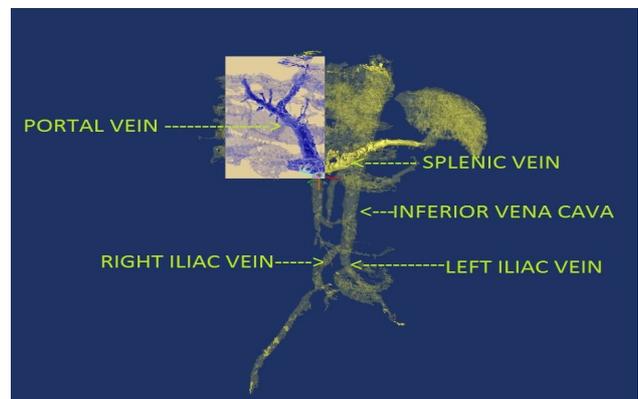


Fig. 4 shows 3D model of segmented lower abdomen veins including portal vein, splenic vein, inferior vena cava and iliac vein.

B. Measured Geometry Values of Hepatic Portal Vein

Figure-5 describes the geometrical measurements made at different regions of hepatic portal vein using 3-Matic software. Measured geometry values are already listed in the Table-1.

C. Creation of CAD Model of Hepatic Portal Vein

a). Normal HPV model

Figures 6 indicate the CAD model of normal HPV; created in the yz (side) plane of CAD user interface.

b). Diseased HPV models

Figures 7a,7b,8a,8b and 9 indicate the diseased CAD model of hepatic portal vein (HPV);minor right portal vein thrombosis, severe right portal vein thrombosis, minor left portal vein thrombosis, severe left portal vein thrombosis, left portal vein aneurysm respectively, created in the yz (side) plane of CAD user interface.

i) CAD model of right portal vein thrombosis

a) Minor right portal vein thrombosis:

Figure 7a shows minor thrombosis of right portal vein. It was created by (20-22)% reduction in diameter of medial region of right-side portal vein, compared to its corresponding normal value.

b) Severe right portal vein thrombosis:

Figure 7b shows severe thrombosis of right portal vein. It was created by 20-22 percent reduction in diameter of medial and distal region of right portal vein branch of normal portal vein CAD model. Reduction in medial and distal region increased the severity of thrombosis in right portal vein.

ii) CAD model of left portal vein thrombosis

a) Minor left portal vein thrombosis:

Figure 8a shows minor thrombosis of left portal vein. It was created by 19-22 percent reduction in diameter of medial region of left portal vein branch of normal portal vein CAD model.

b) Severe left portal vein thrombosis:

Figure 8b shows severe thrombosis of left portal vein. It was created by 19-22 percent reduction in diameter of medial and distal region of left portal vein branch of normal portal vein CAD model.

iii) Left portal vein aneurysm

Figure 9 shows aneurysm of left portal vein. It was created by 2-2.5 folds increase in diameter of medial and distal region of left portal vein branch of normal portal vein CAD model

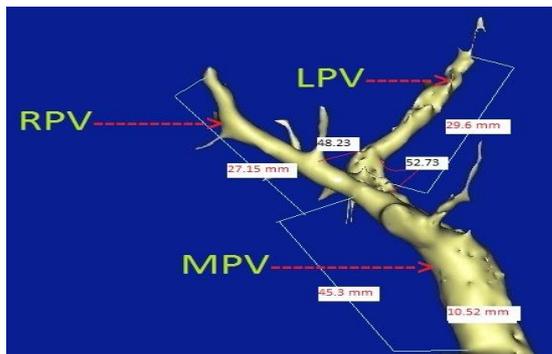


Fig. 5 shows 3D model of Hepatic Portal Vein with its measured geometrical details where MPV,RPV and LPV denotes main portal vein, right portal vein and left portal vein respectively.

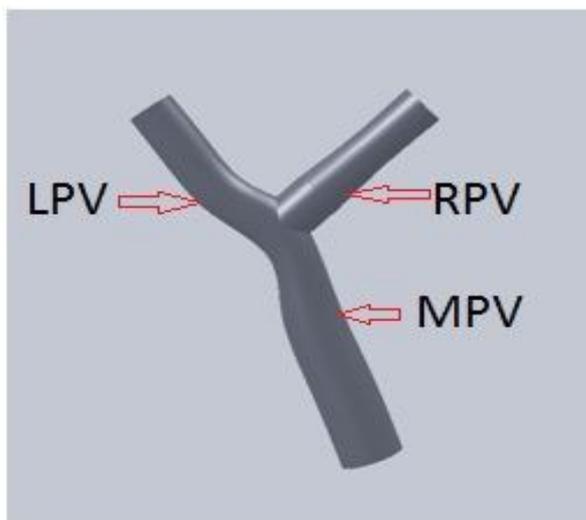


Fig. 6. CAD model of normal portal vein (HPV); LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

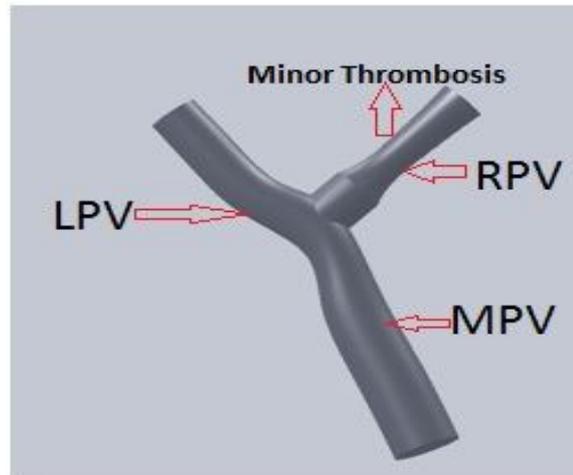


Fig.7a.CAD model of right portal vein's minor thrombosis; LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

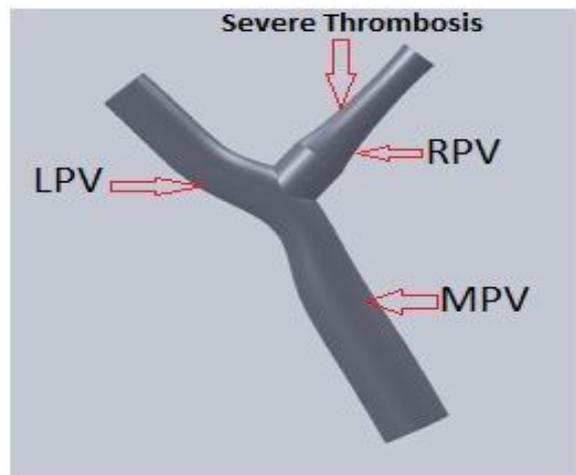


Fig. 7b.CAD model of right portal vein's severe thrombosis LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

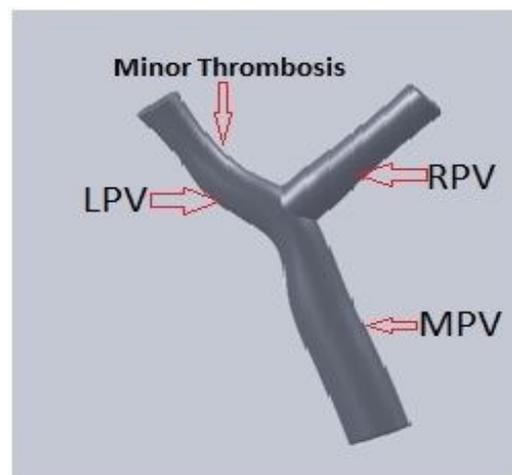


Fig. 8a.CAD model of left portal vein's minor thrombosis; LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

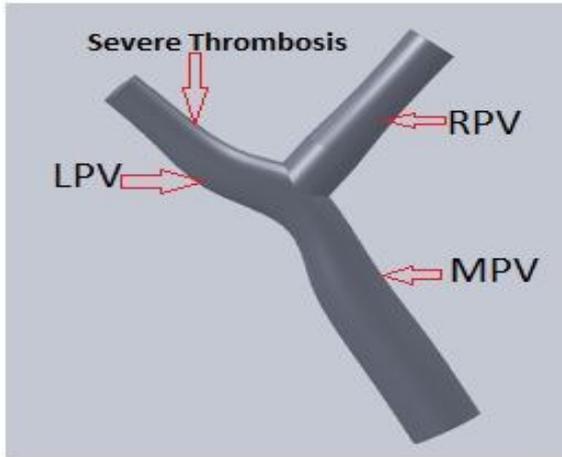


Fig. 8b. CAD model of left portal vein severe thrombosis; LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

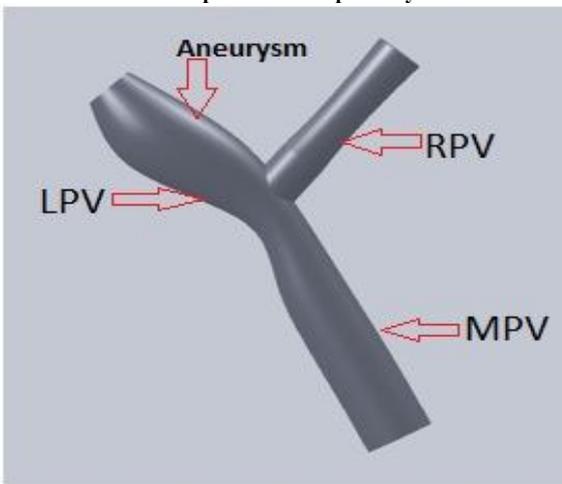


Fig. 9. CAD model of left portal vein aneurysm; LPV, RPV and MPV indicate left portal vein, right portal vein and main portal vein respectively.

VI. DISCUSSION

It was reported that portal hypertension is one of the major complication in different liver disorders and obstruction in portal vein is one of the main cause of portal hypertension. There was a significant increase of portal vein pressure near obstruction. C.C. Botara et al 2010 extracted hepatic portal vein geometrical information from a 3D TOF SPGR by using SmartPrep option based on bolus detection (gadolinium) technique by MRI image and constructed CAD model of portal vein for only normal portal vein not any diseased conditions. Svetla petkova et al 2003 designed CAD model of portal vein for normal and thrombosis condition but did not considered aneurysm condition. In this study thus designed 3D model was significantly effective for analysis of portal vein hemodynamic study and associated complication in different liver diseases. Geometrical measured values are matched with existing published data and exact angle between right and left portal vein were measured. For disease

diagnosis and treatment various invasive techniques were used for portal complication which includes biochemical assay analysis, microbiology assays. Color doppler ultrasonography, CT angiography, MRI based non invasive techniques has a lead over invasive technique and for evaluations of disease diagnosis and treatment. Three-dimensional (3D) reconstruction of portal-phase CT angiograms enhances the perception of the courses and anatomic relationships of varices. This information is valuable for surgical planning. Common varices include the left gastric vein, short gastric veins, paraumbilical veins, and splenic vein. Hence, in this study, patient specific CAD model of normal and disease hepatic portal vein was created and measured geometry values at different regions of portal vein from the created 3D model are matched with the published data of the same.

VII. FUTURE SCOPE

The designed CAD models of normal and diseased portal vein can be used to carry out CFD analysis of blood under different physiological conditions by dedicated software. Various hemodynamic parameters namely velocity, flow pattern (laminar or turbulent), pressure, wall shear stress (WSS), strain rate, turbulent kinetic energy, mass flow and momentum in vein can be quantified accurately. Also these models are useful for designing different bioimplant (stent) and planning of shunt based surgery.

VIII. CONCLUSION

This study describes technical parts of designing of patient specific 3 D model and computer aided design (CAD) models of normal hepatic portal vein (HPV) and disease portal vein using CT image analysis of liver. Measured anatomical data were accurate and matches with previously published data. The designed CAD models were created exactly with patient's mimicking conditions, and these can be used in the future for computation fluid dynamic (CFD) analysis of blood in portal vein normal and diseased condition.

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