Computational Analysis of Flow in the Portal Vein of Normal Subjects and Patients Using MRI and CFD

S. M. George[1], D. R. Martin[2], and D. P. Giddens[1]
[1]Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, Atlanta, GA, United States, [2]Department of Radiology, Emory University School of Medicine, Atlanta, GA, United States

Introduction: Chronic liver disease, a leading cause of death in the United States, can result in several vascular complications including hypertension, ascites and varices. In efforts to quantitatively describe the flow in the portal venous system, previous studies have used a variety of imaging methods most commonly Doppler ultrasound (1-4). Magnetic resonance imaging (MRI) supplemented by phase contrast (PC) MRI offers a noninvasive methodology to obtain both anatomical and hemodynamic information in patients with liver disease. These data can then be used to create a computational fluid dynamics (CFD) model of the portal venous system providing further information on the detailed flow within the portal vein. To explore possibilities of improving clinical evaluation of chronic liver disease (CLD) and to determine feasibility of CFD modeling of liver blood flow, we have employed MRI, PC-MRI and CFD to examine four patients who presented with moderate to severe stages of CLD.

Methods: To date this study includes 7 normal subjects and 4 patients diagnosed with cirrhosis. The portal vein (PV), splenic vein (SV), superior mesenteric vein (SMV), right portal vein (RPV) and left portal vein (LPV) were imaged using a steady state free precession technique (SSFP) on either a Philips 1.5T Intera or a Siemans 1.5T Avanto MRI scanner both equipped with a body phased array coil. The scans were breathheld contiguous slices 3mm thick with a resolution of 1.56x1.56mm. Velocity data were also obtained using breath-hold cardiac gated PC-MRI with a segment gradient echo sequence. Scan parameters were as follows: slice thickness 6-8mm, resolution 1.17x1.17mm, TR 24.2, TE8, number of phases 16-20 and Venc 30-60cm/s. Image registration and segmentation techniques were applied to the data sets as described in Yang *et al* (5). Image post-processing of the PC-MR data was completed using an in house MATLAB program based on threshold criteria. Computational models were developed for one normal subject and one patient. The geometry was used to create a computational mesh which was then imported into FLUENT to solve this 3D laminar flow field. The inlet boundary conditions include matching the cardiac cycle average SMV and SV flow measured using PC-MR. For the outflow conditions the flow split was prescribed based on the measured PC-MR flow in the portal vein branches. The results were visualized using TECPLOT.

Results: Both anatomy and flow were variable among the patients as well as among our normal population. Typically, the cross-sectional area of the PV was larger in the patients than in normal patients which is consistent with published reports (1-4). In comparing the PC-MR data the PV cross-sectional average velocity was lower in patients and the PV cross-sectional average velocity per liver volume was significantly lower. The PV velocity variance was also significantly lower in patients. These values can be found in Table 1. In two of the patients, there was marked spleen enlargement with a concomitant elevated SV flow, while in the other two patients, SV flow was reduced and there was relatively little spleen enlargement. In one patient with the severe spleen enlargement the PV flow rate was increased; this would suggest little to no varices, which was the case. In addition, one patient had no SV and therefore low PV flow. The computational analyses revealed more complicated flow patterns with increased secondary flow in our patient. A comparison of stream-traces can be seen in Figure 1.

Table 1: Portal Vein PC-MR Measured Parameters

Cross Sectional Measurements	Normal (n=6)	Patients (n=4)
Average Area (cm^3)	0.97 +/- 0.08	1.75 +/-3.03
Average Velocity (cm/s)	12.74 +/-3.17	8.74 +/-3.09
Velocity Variance	4.4 +/-1.7	1.93 +/-1
Average Velocity/Liver Volume	0.01 +/-0.0025	0.0058 +/-0.0017

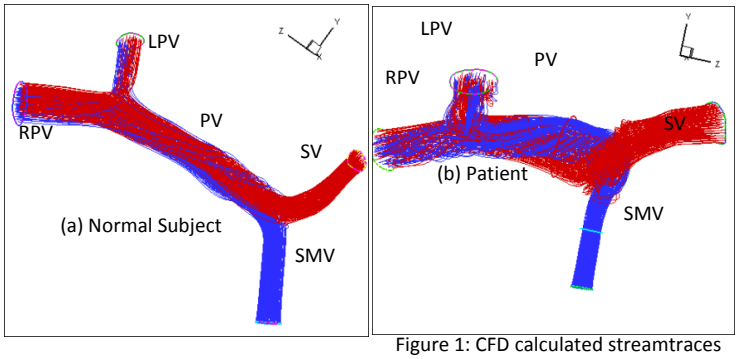

Figure 1: CFD calculated streamtraces in (a) Normal Subject and (b) Patient. Notice increase in secondary flow and enlarged PV and SV.

Conclusions: These results demonstrate the feasibility for using MRI combined with PC-MRI and CFD to provide detailed vascular characterizations of altered flow parameters in CLD. Evaluation of a larger number of patients may yield new insights into clinically significant characteristic flow changes related to stages of CLD and/or patterns related to specific complications such as bleeding varices or ascites.

References: 1. Kayacetin E *et al, Journal of Gastroenterology,* 2004 2. Kutlu, R *et al, Journal of Clinical Ultrasound,* 2002 3. Vyas K *et al, Indian Journal of Gastroenterology,*2002 4. Yin, XY *et al, Journal of Clinical Ultrasound,* 2001 5. Yang, Y *et al*, *In Proceedings of IEEE EMBS Annual International Conference*, 2006.