MRI Velocity Data Reconstruction for Power Loss Estimation

D. H. Frakes[1], H. Kitajima[1], M. J. Smith[2], A. P. Yoganathan[1]

[1]Wallace H. Coulter Dept. of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA, United States, [2]Dept. of Electrical and Computer Engineering, Purdue University, West Lafayette, IN, United States

Introduction

New applications for MRI flow data are emerging as the clinical relevance of those data becomes better understood. One example is the processing of phase encoded MR velocity images to quantify the power loss incurred as blood circulates through vascular structures. This application is of interest because power loss information relates directly to efficiency. In the context of cardiovascular surgery, modifications that result in efficient flows are sought after to enable or maintain effective cardiovascular function. Accordingly the post-operative evaluation of modified flows is important so that optimal surgical designs can be established.

Methods

Quantifying power loss in vivo with the viscous dissipation function necessitates velocity data describing flow conditions within an entire three-dimensional fluid structure [1]. Other methods for estimating power loss demand pressure data that is more difficult to obtain accurately and that requires invasive catheterization procedures. For these reasons the viscous dissipation approach is clinically attractive as in vivo velocity data can be acquired accurately and non-invasively with MRI. Unfortunately the standard MRI technology that is clinically available confines velocity data acquisition to planar image samples. Accordingly there is a need for technology to reconstruct these data into the three-dimensional information required for power loss estimation. Here a novel signal processing technique that makes use of adaptive control grid interpolation is used to accomplish data reconstruction [2]. In this formulation a modified form of optical flow is employed to establish motion fields linking correlated fluid structures in contiguous phase velocity maps. Interpolation along the vectors composing this motion field enables high quality data reconstruction.

The methodology described above was applied to data gathered from an in vitro glass model of surgically modified pediatric cardiac malformations (Fig. 1) in order to demonstrate proof of concept. The phantom was designed to mimic the total cavopulmonary connection created in the treatment of single ventricle congenital heart defects. Fluid was circulated within the model as in vivo, entering the two vertical conduits and departing from the horizontal ones. The flow split between the two horizontal conduits was varied for different total flow rates in order to simulate the range of conditions encountered in vivo. The model apparatus was scanned with a Philips Gyroscan 1.5T MRI unit and phase velocity maps were acquired axially at 5mm intervals for each component of velocity. These data were then reconstructed and analyzed with the viscous dissipation function for each of the different sets of flow parameters.

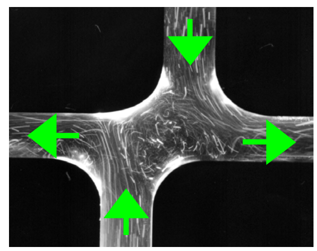

Fig. 1. In vitro flow model.

Results

Power losses in the phantom based on reconstructed velocity fields showed similar trends when compared to power loss values obtained using control volume analysis on experimental data and on data generated via computational fluid dynamics (CFD) simulation [3]. Specifically, the minimum power loss value for each different total flow rate was observed at a 50/50 flow split between the two horizontal conduits, and greater power losses were observed when this split was varied in either direction. The accuracy of the reconstructed velocity fields was also evaluated directly based on magnitude versus CFD results and particle image velocimetry (PIV) data. Comparisons among these data modes indicated that reconstructed MRI velocity data were of comparable quality to both CFD and PIV data based on a squared error measure. In addition to the in vitro studies, initial in vivo results will also be presented.

Discussion and Conclusions

The data presented here indicate that information describing power losses in vascular structures can be determined based on velocity values reconstructed from phase encoded MR images. This is significant for MRI as it is the only modality capable of acquiring in vivo velocity data with sufficient resolution and consistency to facilitate high-quality flow reconstruction. An example of a velocity-magnitude-color-coded flow field reconstruction from the aforementioned in vitro model is displayed in Fig. 2. Although presented here in the context of pediatric cardiac malformations, this power loss quantification technique is well suited for estimating power losses in any surgically modified vascular structure based on MRI data. Such technology is not clinically available at present and its advent would afford physicians valuable insight into the underlying factors that influence short and longer-term surgical outcomes.

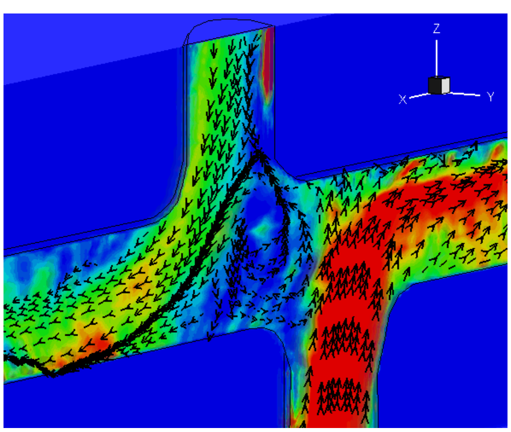

Fig. 2. Cutaway view of MRI-based in vitro flow reconstruction with vector streamtraces.

References

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