Reconstruction of 3D PCMR Velocity Data for Clinical Fluid Dynamics Analysis Applications

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Introduction

The tradeoff between voxel volume and signal to noise ratio (SNR) inherent to magnetic resonance (MR) imaging prohibits isotropic velocity data volumes from being acquired in most phase contrast MR (PCMR) applications. Accordingly post-processing remains an important issue for many applications. Here we present a methodology for the reconstruction of 3D PCMR data in the context of carotid artery fluid dynamics analysis. The aim of this study, comprising MR, computational fluid dynamics (CFD), and ultrasound components, is to demonstrate the ability of the proposed technique to provide high-quality isotropic velocity data volumes for clinical fluid dynamics analysis applications.

Methods

3D PCMR scans were conducted on five healthy volunteers. Approximately ten contiguous transverse 5mm thick slices with all three velocity components were acquired for each volunteer with a Philips Intera scanner using the following parameters: TR=27ms, TE=11ms, flip angle=35^{o}, phases=14-20, encodings=192, FOV=180mm, matrix=256x256, AP/RL VENC=40cm/s, SI VENC=120cm/s. Velocity data sets were reconstructed to isotropy with in house code implementing a novel image processing technique, adaptive control grid interpolation (ACGI), as well as segmentation, surface fitting, and meshing functions. ACGI is a progressive interpolation algorithm uniquely suited for velocity data, which has been shown to perform with superior quality in comparison to alternatives for *in vitro* data [1].

Morphological reconstructions, like that in Fig. 1, were used in conjunction with velocity profiles from MR as input for steady flow CFD simulations conducted in FIDAP (Fluent, Inc., Lebanon, NH). An inlet boundary condition was prescribed from PCMR data at end diastole, no-slip wall boundary conditions were applied, and a volumetric outflow ratio was imposed.

Results

The entire velocity field within the carotid artery was reconstructed to isotropy with ACGI, tri-cubic, and spline methods. Each was then mapped to the reconstructed fluid domain geometry and compared to 3D CFD results to evaluate accuracy. Tri-cubic interpolation will be focused upon comparatively here as it performed better than the spline model. Qualitatively, ACGI-reconstructed PCMR data displayed far greater correlation with CFD results than velocity data interpolated with the current standard in multi-planar reconstruction applications, tri-cubic interpolation, as shown at the carotid center planes in Fig. 2. For these planes the peak common carotid artery (CCA) velocity for the ACGI-reconstructed data varied an average of 6% or less from simulated CFD data, while the conventionally interpolated data varied an average of 28%. Both interpolation techniques underestimated velocity in comparison to CFD. On average the RMS error for all center plane nodes was 39% greater for tri-cubic interpolation than for ACGI reconstruction when compared to CFD. In terms of mass conservation, the ACGI-reconstructed data was also in stronger agreement as indicated by the plots in Fig. 2 where local divergence values at each center plane node are color-coded by magnitude. In two cases for which ultrasound data was available, the peak CCA velocity value was overestimated by approximately 8% for ACGI data, while the tri-cubically interpolated data underestimated the parameter by more than 15%. Reconstructed and CFD simulated data compared well qualitatively in terms of shear stress as well.

Discussion and Conclusions

Our results suggest that the new methodology performs better than alternative state-of-the-art techniques for reconstructing isotropic volumes of velocity information from 3D PCMR data. The proposed technique outperformed conventional interpolation methods in this study and provided data that agreed well with CFD simulations based on multiple fluid dynamics parameters. The new method provides an improved starting point for advanced clinical applications that demand high-quality 3D velocity information.

In the context of the carotid artery the current chain of care employs ultrasound to evaluate ratios comparing peak flow velocities in order to identify stenotic conditions. As ultrasound can gather only the component of velocity moving towards or away from the probe, it is unlikely that these ratios are always characterized accurately. Accordingly, the fact that reconstructed MR data estimated larger velocity values in the CCA than ultrasound is not surprising.

Furthermore, shear stress in the carotid region is known to relate directly to plaque formation and as such a methodology to quantify the parameter based directly on patient MR data would be a valuable clinical tool [2]. Efforts along these lines continue to be hindered by resolution issues, but the reconstruction of 3D PCMR data into accurate isotropic volumes of flow information is a step in the right direction. The proposed technique addresses the out-of-plane resolution issue well, allowing scan time to be focused on acquiring the detailed in-plane data needed to enable advanced fluid dynamics applications.

References

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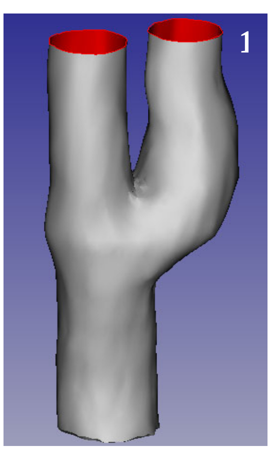

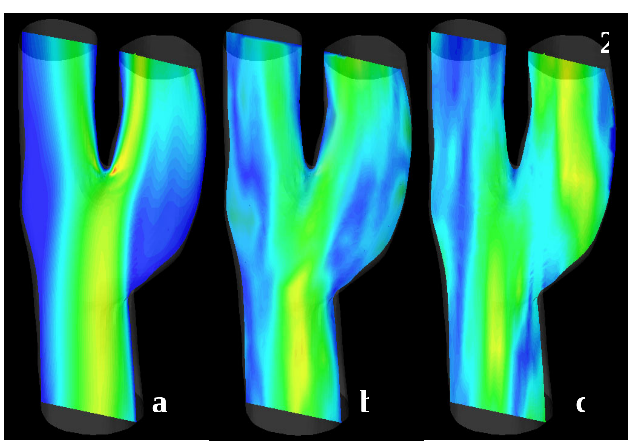

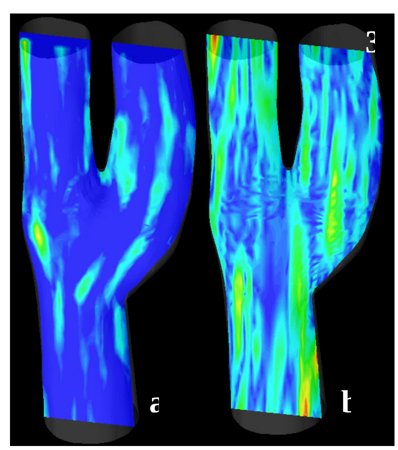

Fig. 1. Example of morphological reconstruction from MR data. Fig. 2. Carotid artery center plane velocity magnitude contour plots from (a) CFD, (b) ACGI reconstruction, and (c) tri-cubic interpolation. Fig. 3. Carotid artery center plane velocity divergence plots from (a) ACGI reconstruction and (b) tri-cubic interpolation.