Interactive Visualization and Analysis of Complex Flow Patterns in Congenital Heart Disease

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Introduction

Cardiac imaging is critical in patients with congenital heart defects (CHD) for delineating cardiovascular anatomy, therapeutic planning, and follow-up after therapy. Magnetic resonance imaging (MRI) has proven to be a robust imaging modality for imaging patients with CHD, including assessment of the anatomy of the heart and vasculature, quantification cardiac function, and determination of blood flow through the heart and vasculature. Typically this is done by acquiring cardiac cine bSSFP images for quantifying cardiac function, 2D phase contrast (PC) images for calculating hemodynamic parameters, and 3D contrast-enhanced magnetic resonance angiography to visualize the vasculature. A major limitation to this approach is the amount of time required to acquire all the images. Recently, a 3D phase contrast with vastly undersampled isotropic projection reconstruction (PC VIPR) technique with respiratory gating has become available. The respiratory gating permits acquisition of images of the chest within a reasonable scan time. The volumetric velocity information can not only be analyzed for jets and flow rates, but the volumetric coverage also allows for the derivation of additional hemodynamic parameters such as pressure gradients [2] and wall shear stress to evaluate the anatomy and flow patterns in patients with CHD.

Methods

PC VIPR data were acquired on 1.5T and 3T clinical systems (GE Healthcare, Waukesha, WI) after obtaining patient consent according to our IRB protocol in a total of 20 consecutive CHD patients with a variety of pathology including aortic coarctation, Scimitar syndrome, double inlet left ventricle, and atrial septal defects, among others. Typical scan parameters were: imaging volume = 320 x 320 x 320 mm3, readout = 256-320, $(1.0\text{-}1.25\ \text{mm})^3$ acquired isotropic spatial resolution, VENC of 50-100 cm/s (application specific). Respiratory gating was performed with an adaptive gating scheme based on bellows readings, resulting in a scan time of approx 10 min with 50% respiratory gating efficiency [3]. To reliably achieve high quality images, several correction schemes were applied to account for the effects of T1-saturation, trajectory errors, motion, and aliasing associated with undersampling. The PC VIPR data were reconstructed as magnitude images, velocity vector fields, and angiograms calculated similar to complex difference images and stored in a format specific to the engineering visualization software Ensight (CEI, Apex, NC). Processing steps were developed to allow for interactive cross-sectional analysis for velocities and flow rates in volumetric cine datasets, a feature currently unavailable in medical imaging software. In addition, streamline and particle tracing visualization approaches were explored to characterize complex flow patterns.

Results

A representative example is shown in Figure 1, from an 18 month old female with a history of a bidirectional Glenn for double inlet left ventricle. Analysis of streamlines through the superior vena cava show that flow from the right jugular vein and brachiocephalic vein have minimal mixing within the superior vena cava. In addition, turbulent flow as blood enters the pulmonary arteries is identified. The Ensight software was also used to quantify flow in the superior vena cava and the right and left pulmonary arteries. Because a 3D, volumetric scan was obtained, flow velocities and flow-time curves can be generated in any location and orientation a posteriori. In Figure 2, we show how a pressure map can be made from the PC VIPR dataset in a 2 year-old male with aortic coarctation, showing a pressure drop due to the aortic narrowing.

Conclusion

Comprehensive, volumetric hemodynamic flow analysis in patients with CHD is possible using PC VIPR. A commercially available software program, Ensight, was used to analyze and visualize complex vascular geometries and flow patterns in CHD in our study. In addition, this software can be used to quantify hemodynamic parameters a posteriori in any orientation. This has the potential to greatly simplify the workflow for cardiac MRI examinations in patients with CHD.

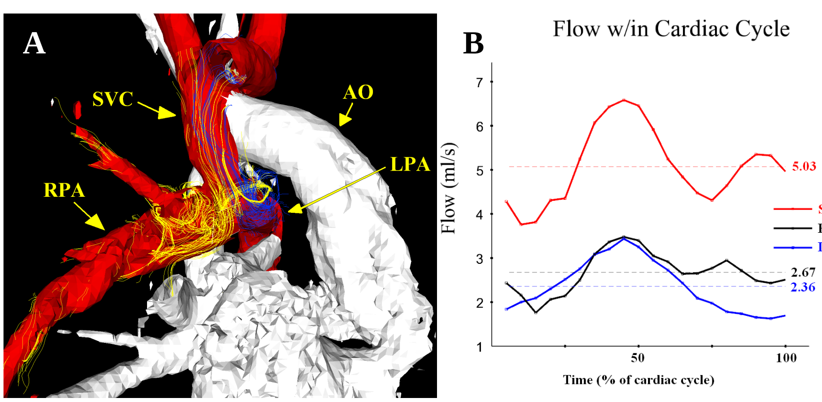

Figure 1. (A) Stream-lines show minimal mixing of flow from the right jugular vein (yellow lines) and brachiocephalic vein (blue line) in the superior vena cava (SVC). (B) Flow-time curves from the PC VIPR dataset show equal flow in the right (RPA) and left (LPA) pulmonary arteries. AO = aorta.

References

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[3] KM Johnson et al, PROC ISMRM, 733, 2008.

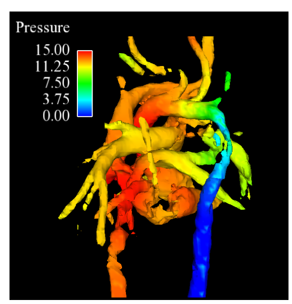

Figure 2. Pressure map in 2 year-old male with aortic coarctation. Red corresponds to high pressure values and blue corresponds to low pressure values.