# Multi-dimensional Velocity Field Reconstruction from Sparsely Sampled 3D Phase Contrast MRI

**K. S. Sundareswaran[1], D. H. Frakes[1], M. Fogel[2], O. Skrinjar[1], and A. P. Yoganathan[1]**

[1]Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA, United States, [2]Children's Hospital of Philadelphia, Philadelphia, PA, United States

## INTRODUCTION

Phase Contrast MRI has been used extensively for the reconstruction and visualization of blood flow velocity fields in pediatric applications. However, due to imaging time constraints most of the scans are limited to single plane, 3 component PC MRI acquisitions. In the case of patients born with single ventricle congenital heart defects, the ability to visualize *in vivo* velocity fields in the total cavopulmonary connection (TCPC) in 4D (3D + time) is critical for identifying how well the connection is performing clinically. In this paper a new method for velocity field reconstruction is presented that utilizes blood flow incompressibility as a property for estimating a continuous flow field representation in the TCPC from a stack of contiguous PC MRI.

## METHODS

Since blood behaves like an incompressible fluid (divergence of velocity field is zero) in large vessels, this property can be used for reconstructing 3D velocity fields. In order to accomplish this, the following are required: a.) a 3D representation of the vessel anatomy; b.) measurements of all 3 components of velocities inside the vessel; c.) a model for zero divergence interpolation of the measured 3D velocities onto the 3D anatomy. For a), an axial stack of static free breathing steady state free precession sequence with a matrix size of 256 x 168 pixels, a pixel size of 1.0 x 1.0 mm2, and slice thickness is 3 mm was employed for reconstructing the anatomy. An in house segmentation method was used for reconstructing the vessel anatomy and for identifying the nodes in the vessel of interest. Each node was then transformed to the MRI co-ordinate system for registration purposes. For b), a stack of 3D retrospectively triggered PC MRI slices in the coronal direction with a matrix size of 320 x 230 pixels, a resolution of 1.25 mm2, slice thickness of 6 mm, and 20 cardiac phases were acquired. All scans were performed in the Siemens 1.5T Avanto scanner at the Children's Hospital of Philadelphia. Using the segmentation from a) the velocity measurements inside the vessel of interest were retained, and the rest were discarded. For c) a divergence free matrix valued radial basis function of the form shown in Equation set 1, is initialized, where V(x) is the velocity field expressed as a function of the location inside the flow domain. Φ (x) is a matrix valued radial basis function which is expressed as a distance function of x from a set of chosen control points, cj is the vector valued interpolation coefficient that is determined using the least squares method, and α is a scaling parameter that is dependent on the spacing between the control points. It can be shown, that the divergence of V(x) is mathematically 0. To enforce the no-slip condition, the nodes on the vessel surface are used as measurement nodes and are set to 0. Once the value of $c_j$ for each control point was determined, the velocity at any point inside the vessel lumen can be calculated.

**Equation Set 1**

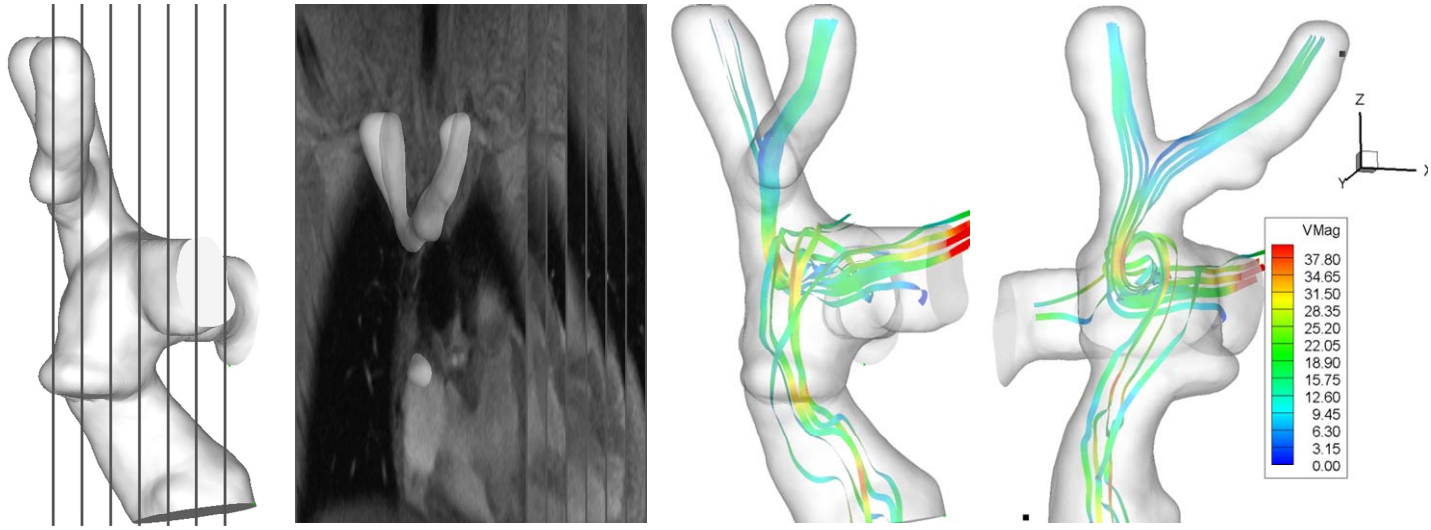
$$V(\vec{x}) = \sum_{j=1}^{p} \Phi(|\vec{x} - \vec{x}_j|)\vec{c}_j$$

$$\Phi_\alpha(x) = \{-\Delta I + \nabla\nabla^T\}\varphi_\alpha(x)$$

$$\varphi_\alpha(x) = e^{-\alpha\|x\|^2}$$

## RESULTS

The methodology has been tested on fifteen *in vivo* datasets. Shown below in the figure is the PC MRI slicing direction, and stream traces color coded by velocity magnitudes inside an intra-atrial TCPC. Complex flow structures are evident in the form of vortices in the region of confluence of the superior and inferior vena cava.




## CONCLUSIONS

A new method for velocity field reconstruction is presented that is truly 3D and takes into account the properties of blood in addition to PC MRI velocity measurements. The new technique now allows for improved visualization of blood flow fields from sparsely acquired PC MRI data, while at the same time providing an analytical expression for the velocity field to perform higher order analysis.