# Volume Tracking - a novel method for visualization and quantification of cardiac blood flow

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## Introduction

The detailed interactions between blood, myocardium, valves and vessels are not completely understood. Three-dimensional time resolved Phase Contratst MRI (PC-MRI) promises greater insights into cardiac dynamics, as a complete description of the blood flow can be acquired [1,2]. However, understanding unsteady three-dimensional flow is difficult, and no single solution to the visualization problem exists [3]. Also, clinical methods for quantification of blood flow are currently limited to two-dimensional flows in valves and vessels. Here we propose a novel method for visualization and quantification of cardiac blood flow, called Volume Tracking.

## Purpose

The purpose of this study was to develop a novel visualization method, Volume Tracking, and to evaluate and validate its performance for three-dimensional PC-MRI measurements of cardiac blood flow. A specific goal was to enable the measurement of physical parameters such as kinetic energy in visualized volumes.

## Methods

Volume Tracking is a novel field formulation of previously used particle methods. A volume is first defined by an isosurface of a function $f(x,y,z)$ of the spatial coordinates. Then a linear advection partial differential equation (PDE) is used to transport the coordinates along the flow. The same function $f$ is then used on the transported coordinates (x',y',z'), which gives the original surface transported along the flow as an isosurface of $f(x',y',z')$. The PDE is solved with CLAWPACK, a freely available solver.

To test the method, an artificial swirling flow in an equilateral 1 m box was constructed so that in an exact solution, the coordinates are transported back to their respective starting positions after 0.5 s. The average path length in the flow is 0.71 m.

For demonstration of the method in real-life data, four healthy volunteers underwent acquisition of three-dimensional time resolved PC-MRI on a Philips Intera 3T MRI scanner with slice thickness 3 mm, in-plane resolution 2.7 x 2.7 mm, flip angle 8°, temporal resolution 30 ms and VENC 100 cm/s.

## Results

In the artificial test case a solution was obtained with mean absolute error of 3.7 mm, which amounts to 0.5% of the average path length or 0.2 voxels. Figure 1 shows an example visualization of cardiac blood flow. The method also facilitates measurement of physical parameters such as kinetic energy E in the visualized volume, as shown in the lower left corner of the images in Figure 1.

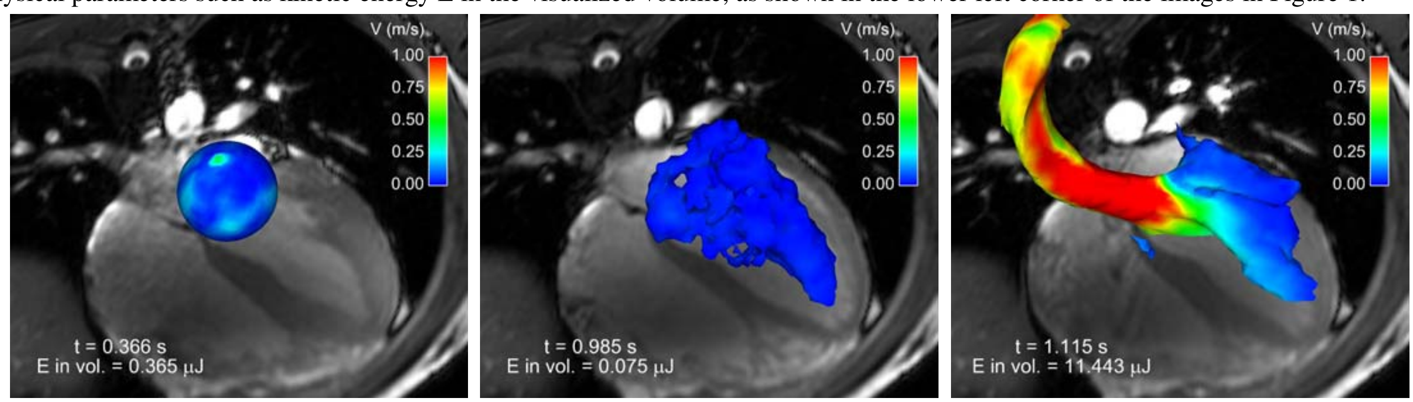


**Figure 1:** Volume Tracking visualization of cardiac blood flow. Surfaces are colored by local velocity. Time $t$ from start of systole and kinetic energy $E$ in the volume are indicated in the lower left corner of every frame. Left: Early diastole. A spherical volume of blood near the mitral annulus. Middle: Late diastole. The volume has deformed and moved into the left ventricle. Right: Early Systole. Additional deformation as the volume is ejected into the aorta.

## Conclusions

A novel method, Volume Tracking, has been developed and validated. In a test case with known solution, the underlying mathematical model is solved with high accuracy. The method produces intuitive visualizations of cardiac blood flow, as well as enabling quantification of physical variables such as kinetic energy. This new visualization and quantification method may bring additional physiological insights into cardiac blood flow.

## References

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