4D Pressure Mapping with time-resolved PC VIPR

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Abstract

We present a method for obtaining dynamic pressure gradient maps in clinically feasible scan times using time-resolved PC VIPR velocity data. This method allows for accurate measurements across vessels with complicated geometry and relatively small cross-sectional areas. Results show accurate pressure modeling across a 50% stenotic vessel.

Introduction

The pressure drop across stenotic vessels is a key factor in determining treatment; however, clinical measurements currently require catheterization. Fluid dynamical relationships have been previously used to create relative pressure maps from phase contrast velocity data, but have been limited to 2D or lengthy 3D Cartesian sequences. The recently developed time-resolved Phase-Contrast Vastly Undersampled Isotropic Projection (PC VIPR) sequence allows for high spatial resolution imaging with short acquisition times [1]. VIPR utilizes 3D isotropic projection under sampling to accelerate imaging by up to 60x, as compared to 3D PC. This acceleration factor is defined as the product of the ratios of spatial resolution, acquisition speed, and imaged volume [3].

With the addition of ECG gating, PC VIPR allows for the use of the full Navier-Stokes equations to determine relative dynamic pressure measurements. This requires the assumption that the fluid is both Newtonian and incompressible; which, for all practical purposes holds true for blood. Under these assumptions, the pressure gradient can be determined solely from the velocity field.

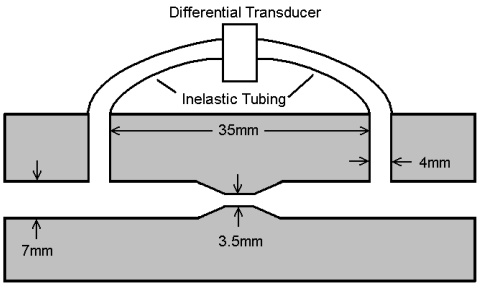

Figure 1. Stenotic phantom with pressure transducer setup. .

Methods

Straight tube and 50% stenosis phantoms were constructed from acrylic blocks to model 7mm artery, with varying levels of stenosis. The setup is portrayed as in figure 1, with a differential pressure transducer mounted across the stenosis. Glycerol with a dynamic viscosity of 3.8 cp and a density of 1261 kg/m^3 was used in a displacement pump with ecg triggering and programmable flow rates. For this preliminary study, the peak flow rate was set at 10 ml/s for both phantoms, with a time varying flow waveform meant to mimic that found typically in a common carotid at 71 beats/min.

All data were acquired using a retrospectively gated PC VIPR sequence, which allowed individual VENCs to be set for each time frame and spatial direction. 15000 total projections were acquired allowing for 10 binned time frames with ~1500 projections each. Each scan lasted ~10min depending on the VENC selection. Velocity and complex difference images were reconstructed offline using a Fourier regridding technique. An ROI was cropped and interpolated via Fourier domain zero filling.. From a composite complex difference image, a mask was generated by a variable threshold method, which varied the threshold depending on the spatial proximity to local maxima, followed by an anti-island filter. The pressure gradient was determined using the Navier-Stokes relationship for points contained in the mask. An initial pressure map was generated using a seed point integration method, which was iteratively refined until convergence using the method described by Tyska et. Al [2].

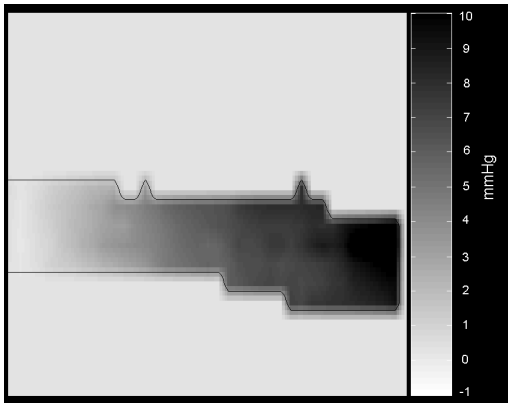

Figure 2. An average pressure map of the 50% stenosis at the peak pressure difference.

Results

Relative pressure waveforms were created from 4D pressure fields and compared to the pressure transducer measurements. VENC selection for the stenotic phantom proved difficult, due to the large spatial variations in the maximum velocity. As the number of iterations to convergence is dependent on the noise of the MR signal and the turbulence in the velocity field, the convergence of the field required significantly more iterations in the stenotic phantom. 2D projection average pressure images were created as shown for the 50% stenotic phantom in Figure 2 as well as pressure difference waveforms (figure 3). Pressure measurements across the phantom show strong agreement with the transducer-measured values, with a correlation coefficient of 0.93.

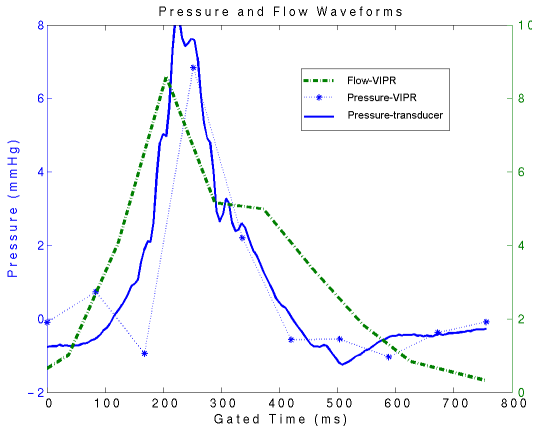

Figure 3. Pressure and flow waveforms derived from the data, compared to the pressure transducer measurement.

Discussion

Accurate pressure maps were created using a non-contrast enhanced PC VIPR sequence; however, anatomical boundaries were modified by thresholding. Better overlay method with the complex difference image should allow for a better diagnostic image. Low SNR is most likely the largest source of error, which can be increased using careful VENC selection and contrast injection (clinical time-resolved PC VIPR studies are normally done following contrast enhanced MRA examinations). In more severe stenosis, turbulent flow and post stenotic jets further decrease the SNR, and pressure mapping with higher stenosis and small vessel diameters will need to be evaluated using PC VIPR.

References

[1] Barger et al, MRM 2000, 48:397
[2] Tyska et al, JMRI 2000, 12:321
[2] Gu Tl et al, Proc. MRA Club 2004