A Demonstration of Errors in Relative Pressure Calculations from MR Velocity Data

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Introduction Relative pressure maps may be calculated from MRI velocity images on a voxel-by-voxel basis using the Navier-Stokes equation [1] to calculate the pressure gradient and numerical integration to generate a relative pressure map [3]. We show the accuracy of the derived pressure maps to be very sensitive to imaging noise and partial volume effects, both of which undermine the fluid dynamical assumptions associated with the Navier-Stokes formulation. We present here the results of numerical simulations of these error sources in a simple hydrodynamic system and suggest a method for reducing the impact of partial volume effects on the derived pressure map.

Methods MR phase contrast velocity images [2] of steady flow within a finite section of a rigid, infinite cylinder (Poiseuille flow) were simulated. The simulations included the point-spread function due to conventional Fourier MR imaging and uncorrelated noise in the complex MR velocity data. Relative pressure images were calculated from these synthetic velocity images using the Navier-Stokes equation and an iterative refinement scheme similar to that used by Yang *et al.* [3].

In an attempt to reduce partial volume errors in the derived pressure map, an intermediate velocity dataset was also calculated in which the velocity was extrapolated smoothly beyond the cylinder boundary. In this case, the extrapolation was simply the extension of the theoretical Poiseuille flow profile for radii greater than the cylinder radius. The pressure map was similarly calculated from the extrapolated velocity dataset.

Results First, noise in the MR velocity images is amplified by the pressure gradient calculation and leads to pressure inaccuracies several times the correct pressure (Fig. 1A). Second, partial volume effects also introduce significant errors into both the calculation that produces the pressure gradient and the integration that calculates pressure. These errors can be many times the magnitude of the correct pressure gradient or pressure. Fig. 1B shows theoretical pressure as a reference for Fig. 1C, which shows calculated pressure with errors due to partial volume effects. The velocity images for this example had no added noise. The partial volume errors are most pronounced at vessel boundaries, where the velocity derivatives, pressure gradient, and pressure are discontinuous and cannot be accurately represented by a sampled image. Extrapolation of the velocity profile beyond the boundaries of the cylinder greatly reduces errors in the derived pressure map due to partial volume effects(Fig. 1D).

Conclusions We have demonstrated that, for a very simple theoretical flow, the errors in calculated pressure due to image noise in MR velocity images are significant. Errors due to partial-volume effects in MR velocity images are also significant. For this simple case, the partial-volume induced errors can be virtually eliminated by removing the velocity derivative discontinuity at vessel boundaries.

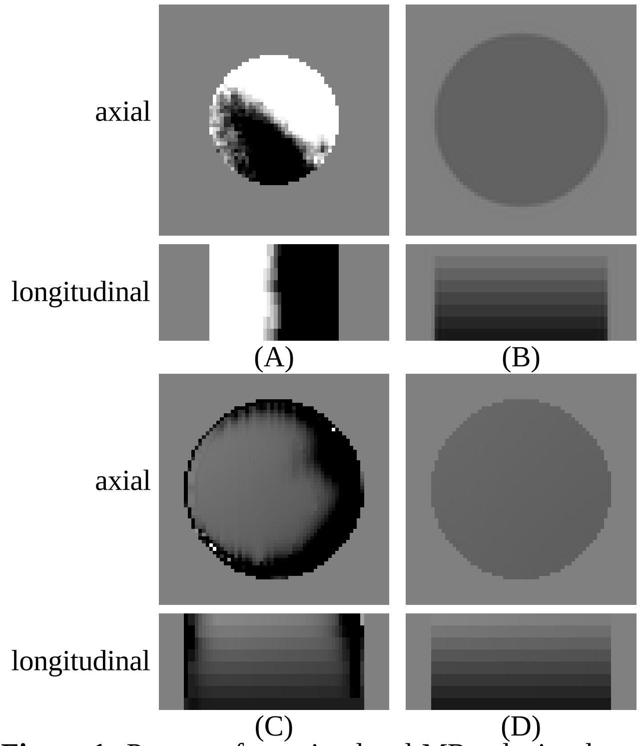

Figure 1: Pressure from simulated MR velocity data of constant flow in a cylinder (Poiseuille flow). (A) shows pressure calculated from simulated MR velocity data with partial volume effects and SNR of 64 in each velocity component. Pressure should be constant in axial sections and linear longitudinally. Peak longitudinal velocity was 0.11 m/s, tube radius 12.5 mm, image resolution 64x64x8 in 4 temporal phases; white and black correspond to +0.25 Pa and -0.25 Pa respectively. (B) shows ideal pressure as a reference for (C) and (D). (C) shows pressure calculated from velocity data with partial volume effects, but no added noise. Pressure errors are many times the correct value, particularly near the boundaries of the cylinder. (D) shows pressure calculated from velocity data extrapolated smoothly outside the cylinder boundaries. Note that errors are virtually eliminated. For (B), (C) and (D) peak longitudinal velocity was 1 m/s, tube radius 12 mm, image resolution 64x64x8 in 4 temporal phases; medium gray is zero, white and black are +8 Pa and -8 Pa respectively.

References

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