MEASUREMENT OF PRESSURE DROP IN ARTERIAL STENOSIS WITH COLOR DOPPLER IMAGING

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Introduction

Vascular stenosis is a condition in which a vessel narrows, reducing blood flow to the tissues it supplies. Assessing the severity of vascular stenosis is critical to making therapeutic decisions. A standard method is to scan the narrowed area with ultrasound and measure geometric indices, providing limited information about the hemodynamic function. An alternative is to measure the pressure drop induced by the stenosis. It can be assessed by catheterization, an invasive medical procedure with some risk of complications, in which a pressure wire is inserted into the bloodstream. To limit cost and clinical side effects, non-invasive methods based on ultrasound imaging of blood flow would be more appropriate [1]. In this study, we present an original non-invasive method for estimating transtenotic pressure drop using clinical vascular color Doppler ultrasound.

Methods

Color flow imaging provides only the velocity projection along the ultrasound propagation axes. The innovative non-invasive method is based on 1) recovering the 2-D velocity vector field from this scalar Doppler velocity field by solving a zero-divergence optimization problem, and 2) deriving the relative pressures by integrating the Navier-Stokes equation. We validated our approach using multiphysics simulations and *in vito* experiments covering different physiological conditions (mild and moderate severity, low to high flow).

Simulations – We performed computational fluid dynamics CFD simulations of axisymmetric transtenotic turbulent flows. After adding virtual seeding particles, we simulated color Doppler images generated by a linear ultrasound probe using the open-source simulator SIMUS [2, 3].

In vitro – Blood-mimicking fluid flowed into homemade carotid stenosis phantoms. Doppler velocities were acquired with a clinical ultrasound scanner (GE Vivid iq). Upstream and downstream pressures were measured with pressure guidewires (Philips ComboWire) to obtain the ground-truth pressure drops.

From color Doppler to pressure drops – To recover the velocity vector fields from the Doppler scalar fields, we minimized a regularized cost function that ensures the preservation of the Doppler velocities under the mass conservation constraint [4]. The pressure drops were then estimated by solving the Navier-Stokes equation using a finite difference method.

Results

Pressure drops estimated by color Doppler ranged from 0.5 to 28 mmHg for flow rates between 0.2 and 1 L/min. Considering both *in silico* and *in vitro* data ($N = 26$), we observed a very good agreement between Doppler-based and reference pressure drops ($y = x - 0.04, r^2 = 0.97$).

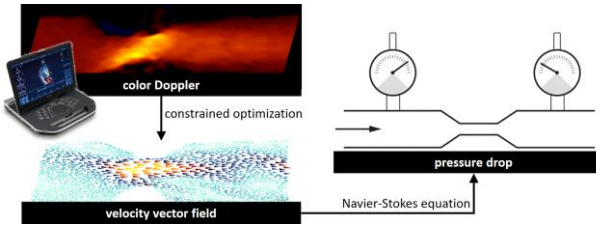

Figure 1: Methodological flowchart of the proposed method: from color Doppler to pressure loss estimation.

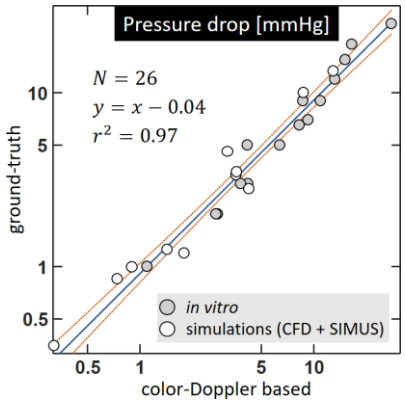

Figure 2: In silico and in vitro results: estimated vs. ground-truth pressure drops (logarithmic scale).

Discussion

In contrast to other studies [1], our results show that it is possible to estimate turbulent pressure losses in arterial stenoses using conventional color Doppler ultrasound. The next step will be to generalize our method to asymmetric stenoses. Once generalized, it will be tested in patients with carotid stenosis.

References

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