Can We Detect Carotid Artery Stenosis From Skin Vibrations: A Computational Investigation of High-Frequent Flow Under Physiological Varying Flow Conditions.

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Abstract

Introduction
Carotid artery stenoses are a major cause of stroke with a prevalence of 4.2% in the population[1] and are often asymptomatic. Therefore, it is a need for a quick and portable screening method. A newly suggested method for screening is using a laser Doppler vibrometer, which can detect skin vibrations induced by a high-frequent post-stenotic flow. However, we do not know if all stenoses harbor such instabilities. The aim of this study was to investigate how high-frequent flow instabilities vary with the degree of stenosis, inlet flow rate, and outlet flow split.

Methods
A computed tomography image of a 76 % stenosed internal carotid artery (ICA) was segmented and then altered to obtain models ranging from a mild stenosis to almost complete occlusion: 56%, 66%, 86%, and 96%, as illustrated in Fig1A. The inlet flow rates, with a physiologically plausible waveform[2], and outflow splits were varied with mean plus/minus one and two standard deviations[3,4], respectively, see Fig1C-D. Furthermore, since flow rates and splits vary with the degree of stenosis, we also changed these alongside with the degree of stenosis, see Fig1B. We assumed blood to behave as a Newtonian fluid with kinematic viscosity $\nu=3.3\cdot10^{-6}m^2/s$ and used our kinetic energy preserving and minimally dissipative, second order solver *Oasis*[5] to simulate for two cardiac cycles and reported the velocity magnitude from the latter measured in point P, see Fig1A. We used 20.000 time steps per cycle and meshes with ~15 million linear elements, resulting in an average cell length of $\Delta x_{mean}=1.92\cdot10^{-4}m$.

Results
Fig1E shows the qualitative results from varying the degree of stenosis, and we can observe that the models with a stenosis severity less than 70 % harbored high-frequent fluctuations. Fig1F-G shows the results from varying the flow rate and split, respectively, and both exhibited similar trends; increased ICA flow rate enlarged the fluctuations.

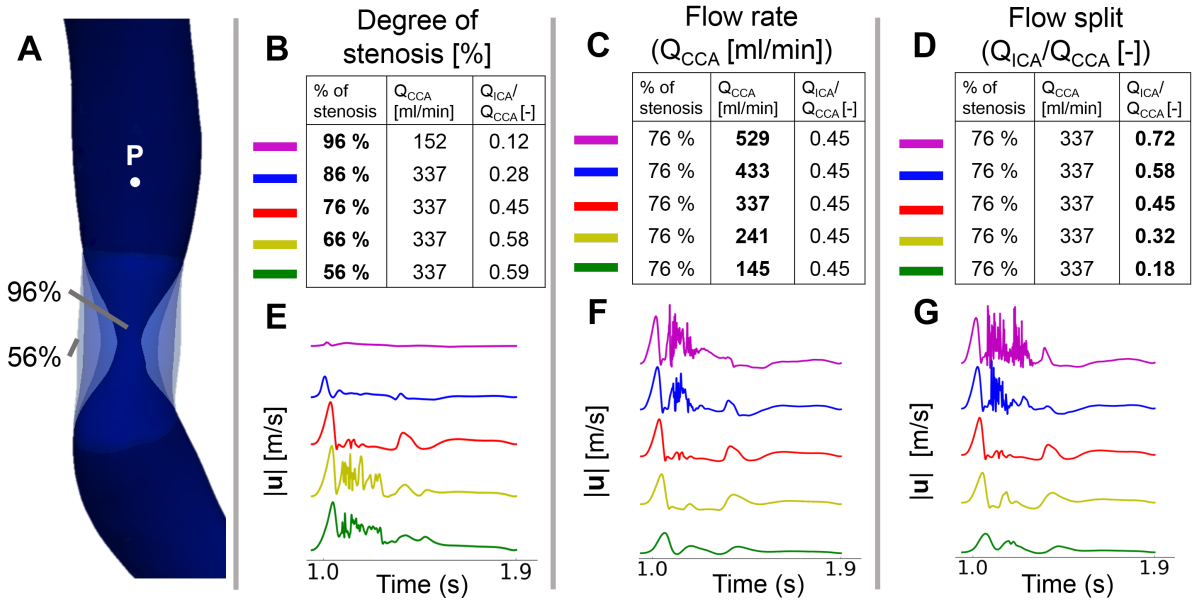

Fig1 **A**: Variable degree of stenoses in the internal carotid artery, and a point P located 1 diameter downstream of the stenosis. **B**, **C,** and **D**: List of simulations, with varying degree of stenosis, flow rate, and flow split, respectively. **E**, **F**, and **G**: Velocity magnitude (|**u**|) in point P of the corresponding list simulations in **B**, **C**, and **D**, respectively.

Discussion

We only observed fluctuations in moderate (< 70 %) stenosis models, which can physiologically be explained by a reduction in flow rate due to an increased pressure drop over the stenosis. If the simulated results reflect physiology, and not modeling assumptions, the LDV is promising for detecting early-stage carotid artery stenosis. In future work, we will investigate flow fluctuations in healthy subjects to understand the risk of false positives.

Acknowledgments

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