Detecting carotid stenosis from skin vibrations: proof-of-principle from hydraulic bench tests on a compliant stenotic carotid bifurcation model.

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Abstract

Introduction

Within the CARDIS project, we are exploring the use of a multi-beam laser Doppler vibrometer (LDV) to detect asymptomatic carotid stenosis from measurement of skin vibrations on the neck of affected patients. This method is based on the hypothesis that flow instabilities induced by the stenosis will propagate as mechanical waves through the soft tissues of the neck to the skin. As a first proof-of-principle, we report measurements on hydraulic bench models to assess the sensitivity of LDV to detect vibrations arising from flow instabilities.

Methods

A compliant model of the carotid bifurcation with internal carotid artery (ICA) 76% area-stenosis was created in silicone rubber. It was then mounted in an open-topped Perspex box and surrounded by an aqueous hydrogel to mimic the neck’s soft tissues. A skin-like layer was then applied over the gel surface. To ensure adequate reflection of the laser light (wavelength 1540 nm), small patches of retro-reflective tape were attached to the skin layer. LDV measurements were acquired 1diameter (0.8 cm) downstream from the stenosis. For reference, intra-arterial pressure measurements were performed at the same location (see Fig1A). We set the flow ratio between the branches to physiological values [1,2], while the nature and the level of the inflow were adjusted in order to match multiple flow conditions such as constant flow with 1) volumetric flow rate VFR=130ml/min, 2) pulsatile flow with VFR=340ml/min and pulse pressure PP=20 mmHg, and 3) pulsatile flow with VFR=800ml/min and PP=40mmHg. Water was used for the experiments. Signals were sampled at 20KHz (Powerlab 16/35) and Fast Fourier Transform frequency spectra were computed in LabChart with 8K points, Hann windowing and 50% overlap. The spectra of the LDV and pressure signals were then normalized against the no-flow condition and plotted in Fig1B and Fig1C, respectively.

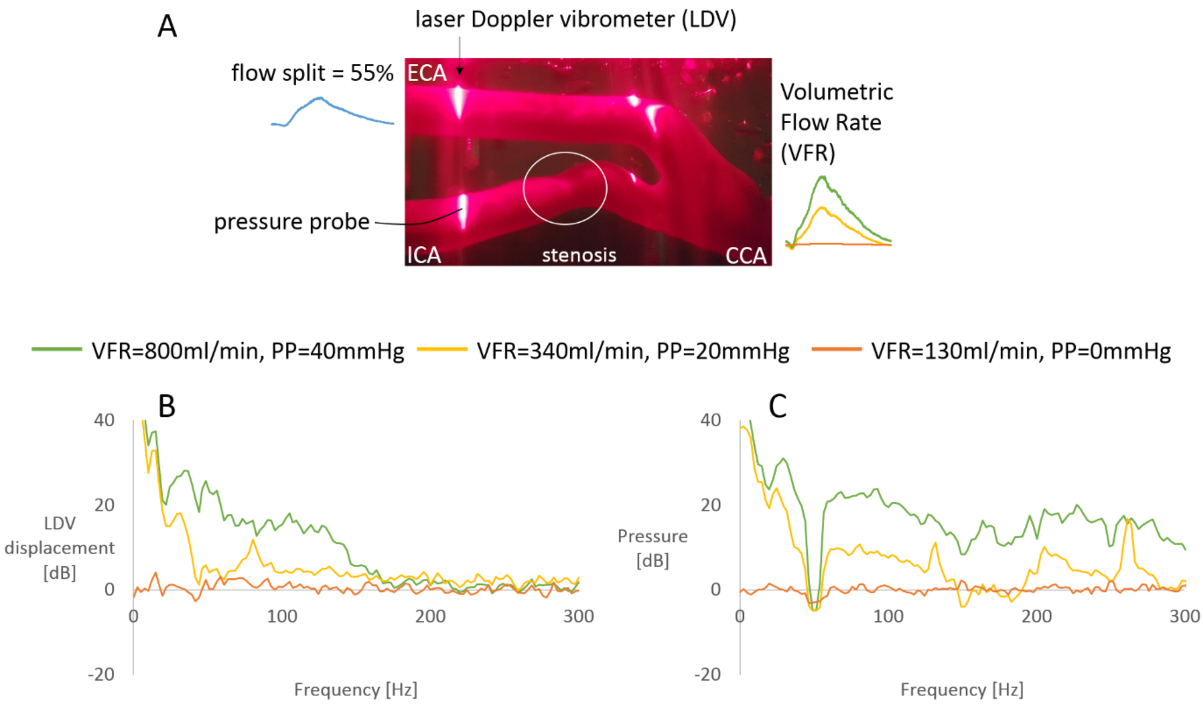

Fig1. Panel A: the pressure probe was positioned in the internal carotid artery (ICA) 0.8 cm downstream of the stenosis. The laser Doppler vibrometer (LDV) was positioned on the surface directly above the pressure probe. The volumetric flow rate (VFR) was adjusted giving rise to multiple pulse pressures (PP) while the division of flow between the two carotid branches was maintained as 55% : 45% = ECA : ICA. Panel B: spectra of displacement signal produced by the LDV. Panel C: spectra of the pressure signal recorded within the ICA.

Results

Peaks in the pressure spectra were absent for the lowest flow rate (130ml/min, steady flow), while their width and amplitude increased when the PP matched more physiological values. No peaks were found in the LDV spectrum at the lowest flow rate while a narrow 70-90Hz peak in the PP=20mmHg became a wider 100-150Hz when PP=40mmHg.

Discussion

The absence of peaks at the lowest flow rate was due by the absence of stenosis-induced-flow instabilities. Once the VFR was high enough to trigger disturbed flow, both pressure and displacement signals showed peaks in the low frequency range. The difference in frequency range could be due to wave propagation mechanisms which form the basis of a second set of experimental tests investigating shear wave propagation in soft tissues.

Acknowledgments

Funded by H2020 ICT-26-2014 CARDIS.

References

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