

## 4-D Pulse Wave Imaging validated on stenotic PVA phantoms and carotid arteries of atherosclerotic human subjects

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### Background, Motivation and Objective

Tracking the pulse wave propagation locally through the arterial tree can serve as an important marker for assessing wall mechanical properties. Pulse Wave Imaging (PWI) can track these waves with 2D high frame rate ultrasound imaging and 4D (3D in time) without compounding. In this study, we report on use of 4D PWI (3D in time) with compounding that can overcome SNR and resolution limitations to estimate the pulse wave velocity (PWV) in stenotic PVA cylindrical channel phantoms with plaque inclusions and in three carotid plaque patients with low grade plaques (<40 % stenosis).

### Statement of Contributions/Methods

A 32x32 fully addressable matrix array probe operating at 3 MHz (Vermon SA, France) was used with four synchronous Vantage 256 systems (Verasonics) (Grondin et al. 2019) to perform sub aperture diverging wave coherent compounding at a pulse repetition frequency of 14 kHz with 9 virtual sources providing a volume rate of 1555 volumes/s. 3D PWI (2D+time) was also performed with a 128 element L7-4 transducer operating at 5 MHz and frame rate of 2890 frames/s using plane wave imaging. Three PVA phantoms all having 50% stenosis were built. Phantom 1 had one inclusion on the top wall, phantom 2 had two inclusions on top and bottom wall, and phantom 3 had a uniform thickening of the wall across the entire cross section. 4D and 3D PWI were performed on the three phantoms using a programmable physiological pump and also in three human patients in vivo.

### Result/Discussion

The pulse propagation on phantom 2 is presented in figure 1. In phantoms 1, 2, and 3 at the stenosis location, 4D PWI estimated longitudinal PWVs of 2.92 m/s, 2.78 m/s, and 2.06 m/s respectively. Corresponding 3D PWI estimated PWVs were 2.8 m/s, 2.96 m/s, and 1.55 m/s. Additionally, cross-sectional (CC) PWVs can be calculated using 4D PWI which are not available in 3D PWI. A high CC-PWV indicates normal coherent pulse. In the three phantoms CC-PWVs were 8.65 m/s, -5.857 m/s, and -4.19 m/s. Here, negative velocities indicate clockwise propagation direction and vice versa. In the three human subjects, 4D PWI estimated longitudinal PWV's of 30.6 m/s, 10.8 m/s, and 3.4 m/s and corresponding to 3D PWI values of 6.83 m/s, 10.13 m/s and 1.92 m/s at plaque locations. 4D and 3D PWI trended similarly but gave different PWV values in vivo since entire cross section as opposed to a slice with plaque was used in 4D and also exact values for very high PWV's observed in vivo tend to vary with frame rate limitations and noise. The CC-PWV's were 4.42 m/s, -11.4 m/s, and -1.12 m/s. Hence, 4D PWI was capable of providing a comprehensive picture of pulse propagation with additional information.

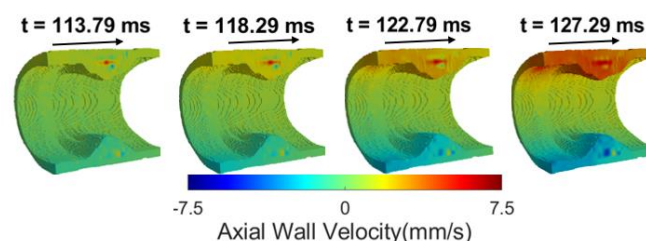


Figure 1: Pulse wave in experimental phantom with arrow denoting propagation direction