Towards At-Home Applications of Pulse Wave Imaging (PWI): Investigating Optimal Sampling Parameters for Real-Time Pulse Wave Velocity (PWV) Estimation

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Introduction: Pulse wave imaging (PWI) is a noninvasive, high-frame-rate, ultrasound imaging technique that tracks the pulse wave-induced arterial wall motion. PWI has been demonstrated to provide estimates of central arterial mechanics (carotid, aorta), including pulse wave velocity (PWV) at end-diastole (PWV_{ED}) and end-systole (PWV_{ES}), compliance, and pulse pressure (PP)[1-2]. Quantification of central arterial properties could improve the characterization, monitoring, and prediction of cardiovascular diseases like hypertension, diabetes, and Alzheimer's. Recent advancements in piezoelectric micromachined ultrasound technology (PMUT) has enabled the development of wearable applications of ultrasound imaging[3], which could be utilized to translate PWI to at-home settings. While the current PWI technique provides reliable results, PWI requireS offline processing, manual intervention, ~15-18 minutes of run-time, and GPU-based computing. Since at-home applications of PWI will require real-time PWV and PP estimation, it is necessary to reduce the data size and computational complexity of PWI. This study focuses on investigating the optimal, minimum number of lateral positions required for accurate PWV estimation.

Methods: A retrospective study was conducted on data from the left and right common carotid arteries (CCA) of 6 young, healthy, normotensive patients (28±3 y.o.; 3 M, 3 F). Two acquisitions were taken at the same location by both the standard L7-4 transducer and the PMUT array. After rejection of erroneous data, nine carotids were utilized for further analyze. Ultimately, 39 samples for PWV_{ED} estimates and 34 samples for PWV_{ES} were gathered from the L7-4; 35 and 31 samples for PWV_{ED} and PWV_{ES}, respectively, were gathered from the PMUT array. The sampling analysis investigated how the PWV and PWV % error values changed as the number of lateral positions utilized for estimation decreased. PWV estimation using fewer lateral positions (L7-4: n≤13; PMUT: n≤7) employed cluster-random sampling while utilization of a greater number of lateral positions employed stratified-random sampling. One position is randomly selected per zone and the new sample is used to estimate the PWV. It is assumed that the PWV value calculated from utilizing all lateral positions is the most accurate, gold-standard PWV estimate. This process was repeated for 100 realizations for each cardiac cycle, and PWV% error was averaged and compared between transducer types and subjects.

Results: The mean PWV% error across all 9 carotid subjects was 2.78±1.42% when using 20% of lateral positions (26 positions) from the L7-4 acquisition at end-diastole. At end-systole, the mean error was 2.69±2.23% when utilizing 15% of lateral positions (20 positions). For the PMUT array, the mean error at 50% of lateral positions (32 positions) was found to be 2.51±1.14% at end-diastole and 1.84±0.96% at end-systole.

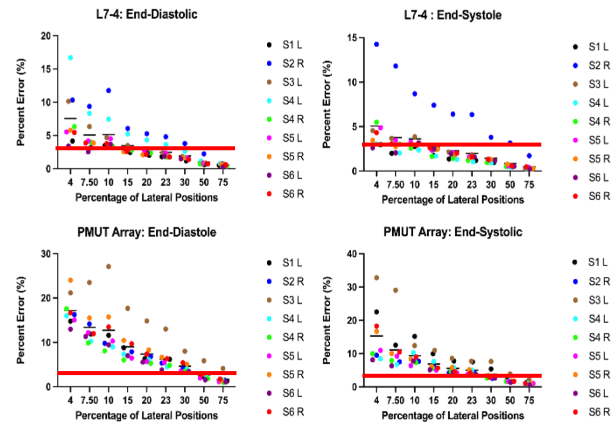

Figure 1. a-d.) The PWV% errors were averaged per subject and lateral positions utilized. The black bars represent the mean PWV% error across all subjects for each percentage group of lateral positions utilized for PWV estimation. Red lines are located at 3% error.

Conclusions: For young, non-stenosed CCAs, to achieve a PWV% error below 3% with the L7-4, around 26-30 lateral positions should be utilized for PWI to estimate PWV_{ED} and 20-30 for PWV_{ES}. To achieve a PWV % error below 3% when using the PMUT Array, at least 50% of lateral positions (32 positions) should be utilized to estimate PWV_{ED} and PWV_{ES}, which is comparable to the results from L7-4. For future work, we aim to increase patient population and capture variability with subjects in various disease states. We also hope to work on the development of live quality standards to improve the selection of lateral positions in cluster-bands as well as optimization of the PWI pipeline to reduce time and hardware costs.

References:

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