Determination of Age-Related Regional Pulse Wave Velocity with 4D Flow MRI

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TARGET AUDIENCE: People with an interest in vascular stiffness and/or the capabilities of 4D flow MRI.

PURPOSE: Current MR methods for pulse wave velocity (PWV) estimation primarily target global PWV values. However, vascular stiffness and thus PWV is known to vary regionally. This may be of particular interest with respect to focal diseases such as thoracic or abdominal aortic aneurysms. The purpose of the present study was to measure age-related differences in regional PWV using 4D flow MRI.

METHODS: 8 young (age: 23 ± 2 years) and 8 older (age: 58 ± 2 years) normotensive male volunteers were enrolled. Aortic 4D flow MRI velocity data were acquired on a 1.5T scanner (Philips Achieva) with a spatial resolution of 2.3-2.8 mm isotropic and a temporal resolution of 39-43 ms.

For each subject, a 3D segmentation of the aorta was generated for subsequent automated extraction of an aortic centerline and flow vs. time waveforms in a large number of planes perpendicular to the aorta. Travel-time was calculated between each plane and a reference location using the time-to-foot method, which tracks the point at which a line fitted to the upslope of the flow waveform crosses the base of the flow waveform. Travel distance was obtained from the aortic centerline. Global PWV in the suprarenal descending aorta (DAo) and regional PWV in three equally sized segments between the top of the aortic arch and the location of the renal arteries (proximal segment: PWV_{prox}, mid: PWV_{mid}, and distal: PWV_{dist}) were calculated by piecewise linear fitting of travel-time vs. travel-distance.

The interaction between age and location was assessed with two-way ANOVA. Paired two-tailed t-tests were used to assess the difference in global and site-specific PWV between the two age-groups. Additionally, the age-related differences in regional PWV were compared against previously published data [1-3]. Numerical results are reported as mean ± one standard deviation unless otherwise noted.

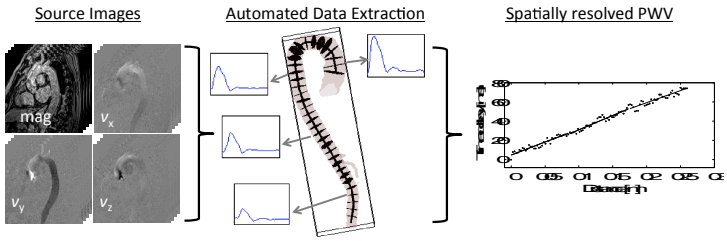

Figure 1. Semiautomatic estimation of regional PWV based on 4D flow MRI. Velocity and magnitude images are combined to generate a PC-MR angiogram that is used for segmentation of the aortic lumen. A centerline is extracted from the segmentation and the centerline is used to define planes for extraction of flow vs. time waveforms throughout the aorta. Calculation of the time-delay and distance between the analysis locations results in a graph of time-delay vs. distance that can be interrogated for regional PWV estimation.

RESULTS: The global PWV in the descending aorta was lower in the young compared to older volunteers: $PWV_{\_global\_young}$ = 3.6 ± 0.3 vs. $PWV_{\_global\_old}$ = 6.4 ± 1.7 ($p < 0.05$). Two-way ANOVA revealed a significant interaction between age and location. A profile plot of PWV versus location is shown in Figure 2. The age-related differences in PWV were significant for the proximal DAo ($PWV_{\_prox\_young}$ = 3.7 ± 0.4 vs. $PWV_{\_prox\_old}$ = 8.8 ± 3.5) and the mid DAo ($PWV_{\_mid\_young}$ = 3.3 ± 0.5 vs. $PWV_{\_mid\_old}$ = 7.0 ± 2.1), but did not reach significance for the distal DAo ($PWV_{\_dist\_young}$ = 4.5 ± 0.8 vs. $PWV_{\_dist\_old}$ = 5.2 ± 1.5). A comparison between the present study and previously reported regional PWV in the DAo is shown in Figure 3.

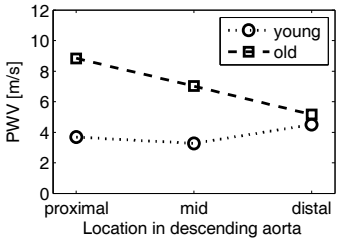

Figure 1. Profile plot of PWV vs. location in young (circles) and older (squares) subjects highlight interaction between age and location. Note that the PWV is homogenuous in the young subjects but markedly heterogeneous in the older subjects.

DISCUSSION: Previous studies have demonstrated the capability of 4D flow MRI for the assessment of PWV[4,5]. The present study extends those previous findings by showing that 4D flow MRI permits determination of regional PWV. Our results are well in line with those reported previously[1-3]. The age-related differences in regional PWV observed here suggest that the PWV in the proximal and mid segments of the DAo increase more rapidly with age than the PWV in the distal DAo. The fact that the elastin-to-collagen ratio decreases towards the distal aorta, in combination with the life-long fragmentation of elastin, may offer a structural explanation for the observation that the PWV in the distal aorta changes less with age when compared to proximal and mid segments[6,7].

CONCLUSION: 4D flow MRI permits determination of regional age-related PWV. The present findings support previous observations that the proximal descending aorta stiffens faster with age than the distal descending aorta.

REFERENCES: [1] Latham RD, et al. Circ 1985;72:1257-69. [2] Taviani V, et al. MRM 2011;65:261-8. [3] Rogers WJ, et al. JACC 2001;38:1123-9. [4] Markl M, et al. MRM 2010;63:1575-82. [5] Wentland AL, et al. JMRI 2012;37:853-9. [6]. Apter JT. Circ Res 1967;21:901-18. [7] Haskett D, et al. Biomech Model Mechan 2010;9:725-36

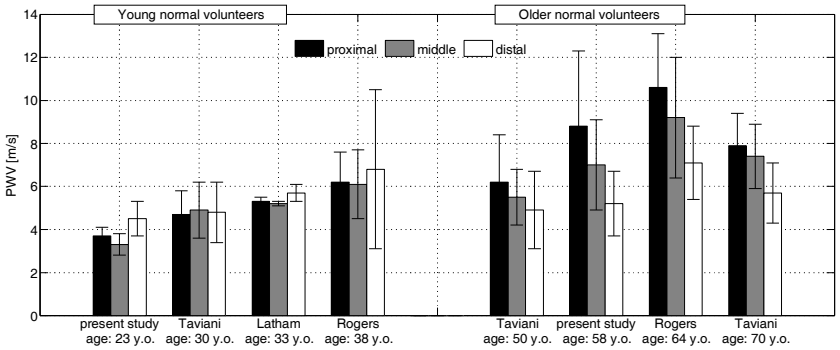

Figure 3*. Regional PWV in young (left) and older (right) subjects compared with data previously published by Latham et al, Rogers et al, and Taviani et al [1-3]. Each triplet of bars shows PWV data for the proximal (black), mid (gray) and distal (white) descending aorta in young subjects. Note that the definition of these anatomical regions differed between the studies. Note also that the age groups differ between the studies and that the presentation of data has been organized accordingly.*