Age-related changes of regional pulse wave velocity in the descending aorta using Fourier velocity encoded MR M-mode

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Introduction

Central arteries, like the aorta, play a crucial role in buffering and attenuating the pulsatile nature of blood flow. Aging is the most important process involved in altering arterial compliance. Over time, stiffening of the aorta reduces its buffering function, with adverse consequences on the left ventricle [1] and more peripheral arteries [2]. Although aortic stiffening with age has been extensively documented [3], the interplay between aging and regional arterial compliance is still a debated question, with major implications for therapeutic interventions.

Previous MR studies have addressed the problem of quantifying regional arterial compliance either by direct measurement of arterial distensibility [4] or by pulse wave velocity (PWV) measurement using cine phase contrast (CPC) with through-plane velocity encoding [5]. Direct measurements of arterial distensibility are limited by the fact that local pulse pressure is difficult to evaluate. The accuracy of PWV measurements by PC with through-plane velocity encoding can be degraded when short arterial segments are considered. Fourier velocity encoded (FVE) M-mode can produce time-velocity profiles with high temporal and spatial resolution along a relatively straight arterial segment [6]. The aim of this work was to measure regional PWV in the descending aorta using FVE M-mode in a large cohort of healthy subjects and to investigate the interplay between regional aortic stiffening and age.

Methods

Fifty-six healthy subjects (age range: 25-76 years, mean age: 53.1 years) participated in the study after providing written informed consent. All subjects were normotensive and free from cardiovascular disease and medication. Images were acquired on a 1.5T whole-body imaging system (Signa HDx, GE Healthcare, Waukesha, WI) using an 8-channel abdo-torso phased-array surface coil.

An ECG-triggered, oblique-sagittal double inversion recovery prepared fast spin-echo (FSE) sequence was used to localize the descending aorta (Figure 1a). The FVE M-mode sequence consisted of a cylindrical excitation pulse, followed by a bipolar velocity-encoding gradient and a readout gradient applied along the axis of the cylinder (pencil) [6]. The sequence was gated to the cardiac R-wave and executed 32 times per heart cycle with the bipolar gradient amplitude stepped to a new value on each new trigger. To increase the effective temporal resolution to 3.5ms, four interleaves were acquired, with the ECG trigger delay incremented by 3.5ms each time, resulting in 128 time frames covering the first 450ms of the cardiac cycle. Thirty-two velocity-encoding steps were used, yielding a true velocity resolution of 9.4cm/s, which resulted in aliasing of velocities greater than 150cm/s. A 24cm readout field of view (matrix size = 256×32) and a 2cm diameter cylindrical excitation pulse were prescribed. Cylindrical excitation was achieved through an 8-cycle spiral trajectory which resulted in an inner aliasing ring diameter of 28.5cm.

FVE M-mode images (Figure 1b) were reformatted to yield Doppler-like time-velocity images (Figure 1c) along the length of the pencil [7]. An automatic line detector was used to extract the velocity profile as a function of time from each of the time-velocity images. The velocity profiles extracted from the time-velocity images at different spatial positions were visualized as a velocity surface, each point of which represented velocity at a given time and position. Bilinear interpolation and the gradient-based regularization technique, implemented in the Matlab (The Mathworks, Inc., Natick, MA) function *gridfit* [8], were used to smooth the obtained velocity surface, with the smoothing parameter chosen for each subject on the basis of visual comparison with the original data points. The foot of the velocity wave was defined at each spatial location as the intersection between a line fitted to the early systolic upslope (10% to 40% of peak velocity) and the zero velocity line.

Four planes, orthogonal to the descending aorta, were defined on the FSE scout image: 1) 2cm distal to the aortic valve; 2) at the level of the diaphragm; 3) midway between location 2) and a location 3cm proximal to the aortic bifurcation; 4) 3cm above the aortic bifurcation (Figure 1a). PWV was computed over the entire length of the pencil and for the three segments delimited by these planes, by linear regression of the foot of the wave at each position along the vessel as a function of the corresponding location along the aorta (Figure 1d). Repeatability of segmental PWV was evaluated on a smaller cohort of 10 volunteers over two visits, a week apart.

Results

Repeated regional PWVs were in good agreement (mean difference=0.19±0.82cm/s). A significant nonlinear relationship between overall PWV and age was found (2nd order polynomial regression: r^2=0.73, p<0.001) (Figure 2), confirming previous results [3]. Overall PWV was found to decrease along the aorta (PWV_1=6.4±2.1m/s; PWV_2=6.0±1.9m/s; PWV_3=5.2±1.5m/s), with PWV_3 significantly lower than both PWV_1 and PWV_2 (p<0.05). Two-way ANOVA showed a significant interplay between age and position (p<0.01) (Figure 3). The distal thoracic aorta was found to stiffen the most with age (Seg1, PWV_1(20-40ys)=4.7±1.1m/s; PWV_1(60-80ys)=7.9±1.5m/s), followed by the proximal (Seg2, PWV_1(20-40ys)=4.9±1.3m/s; PWV_1(60-80ys)=7.4±1.9m/s) and distal abdominal aorta (Seg3, PWV_1(20-40ys)=4.8±1.4m/s; PWV_1(60-80ys)=5.7±1.4m/s).

Discussion

Although peripheral arteries have been found to be stiffer than central arteries [9], the existing data concerning the descending part of the aorta are contradictory, probably due to the small sample size and the different techniques used. Our results are in agreement with the two major MR studies conducted to date [4,5] and support the well-known hypothesis of age-related degradation of elastin [10], mainly found in the thoracic aorta, as the major determinant of vascular stiffening.

In conclusion, we used the high spatial and temporal resolutions achievable with FVE M-mode to evaluate regional PWV in a large cohort of healthy subjects. We found a nonlinear relationship between overall PWV and age and a preferential stiffening of the thoracic aorta with age.

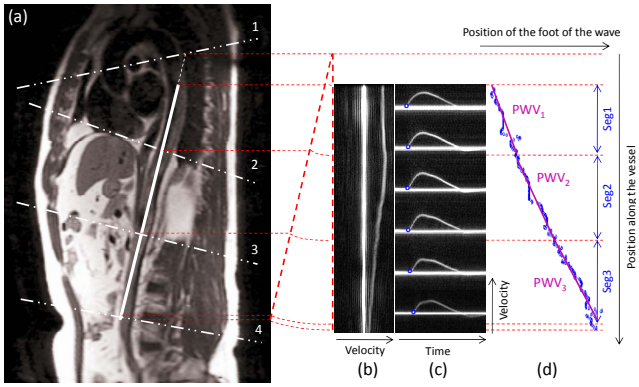

Figure 1

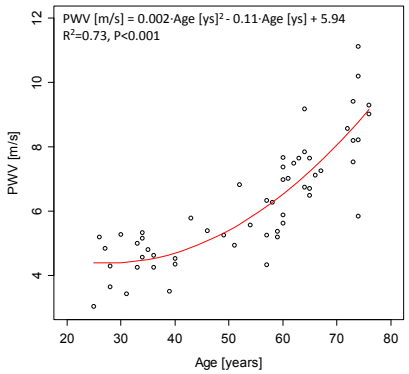

Figure 2

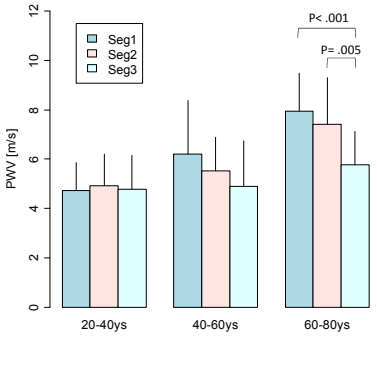

Figure 3

References

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