Free Breathing Fourier Velocity Encoded M-Mode MRI for Measurement of Aortic Distensibility

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Introduction

Repetitive cyclical stress to the arterial wall with aging leads to breakdown of elastin and a reduction in arterial wall compliance [1]. Excessive reduction in wall compliance or distensibility has been associated with a variety of diseases including diabetes, hypertension, atherosclerosis and heart failure [1-5]. A non-invasive method for the assessment of arterial wall stiffness would be a valuable diagnostic tool for the early detection and clinical management of these and other related cardiovascular diseases. Pulse wave velocity measurements can be used to determine aortic distensiblity without the need for local pressure or cross-sectional area measurements. ECG gated, Fourier-velocity-encoded (FVE) M-mode MRI has been shown to provide a fast, non-invasive measure of aortic distensibility [6]. In this technique, a movie of velocity distributions in the aorta is generated, in which the velocity wave can be seen propogating along the vessel. Interleaving the data acquistion can improve the effective temporal resolution [6]. However, the acquisition time is prolonged (order of 1 min.) making breath-holding impractical and resulting in respiratory artifacts. Furthermore, precise determination of the position of the foot of the velocity wave in each frame of the movie can be tedious and subject to error.

In order to improve the reliability and ease of pulse wave velocity measurements, we have implemented and tested a respiratory-gated, FVE M-mode sequence. Stronger gradients have been used with interleaved acquisitions to improve the temporal resolution, and hence the accuracy of this technique. An analysis tool has also been developed for accurate semi-automated calculation of pulse wave velocity.

Methods

After providing written informed consent, seven healthy adult volunteers (ages 25-65 years) participated in this study. All data were acquired on a 1.5 T GE CVi system using a 4 element phased array coil. Pulse-wave-velocity calculations were carried out using a tool developed in Interactive Data Language IDL (RSI, Colorado). An Ultra Sparc II workstation with realtime localization and visualization capabilities, networked to the scanner was used to drive the M-mode acquisition.

Following realtime localization on a left anterior oblique view ("candy cane") of the aorta, ECG gated M-mode MRI was performed. A cylindrical column of spins along the descending aorta was excited followed by a readout along the cylinder axis. The addition of an incremented bipolar flow encoding gradient pulse prior to readout yielded FVE M-mode images. A total of 16 velocity phase encoding steps was applied. High temporal resolution was achieved by interleaving the data acquisition. For each of the 16 velocity encoding steps, the start of acquisition was progressively delayed by 4 ms in 4 consecutive heartbeats, resulting in a 64 heart beat acqusition and an effective temporal resolution of 4 ms. A deliberately low venc value of 10 cm/s was used to improve the velocity resolution. 2D Fourier transformation of the data yields velocity distribution as a function of cardiac phase. A subset of the data frames was selected in which the propagation of the foot of the velocity wave was visible. These images were then filtered by taking the square of the image intensity, to suppress weaker signals. Any velocity aliasing was then unwrapped. The relative position of the foot of the velocity wave at each cardiac phase was determined automatically by a 1-D (spatial dimension) cross correlation of that frame with a chosen central frame. The pulse-wave velocity was then calculated by measuring the slope of the spatial position-time graph. Aortic distensibility A was computed using the formula $A = 1/\rho*c^2$, where ρ is the blood density and c, the pulse wave velocity.

Results

Figure 1 shows a few frames of a Fourier- velocity-encoded M-mode acquisition. The arrows point to the leading edge of the flow, whose propogation velocity is an index of aortic distensibility. Figure 2 shows the effect of breathing (a) on a frame of an interleaved FVE M-mode acquisition compared to that of a respiratory gated acquisition (b). The artifact-to-signal ratio reduced from 1.0 in (a) to 0.2 in (b). Figure 3 shows the IDL analysis tool depicting the filtering, cross-correlation and linear fitting operations. The estimated pulse wave velocities exhibited a linear increase with age (slope 4.4 ±1.3 cm/s/yr, r=0.83). The computed aortic distensibility values ranged from 20 to 60 µm-s^2/kg.

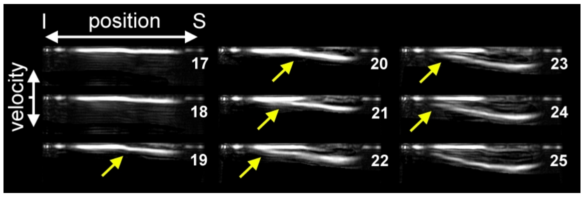


Figure 1. ECG gated fourier velocity m-mode images of the descending aorta

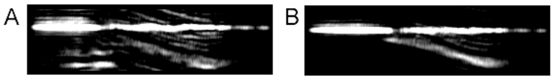
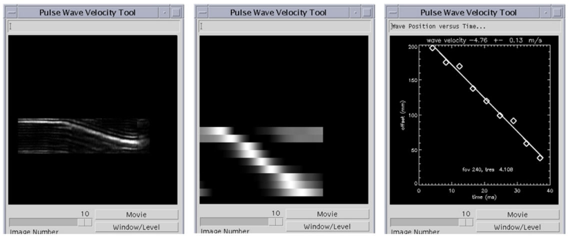


Figure 2. Comparison of one frame of free breathing (A) vs. respiratory gated (B) ECG-gated Velocity M-mode acquisition



Wave Position versus Time...

wave velocity -4.76 +- 0.13 m/s

fov 240, tres 4.108

Figure 3. Analysis tool depicting filtering, cross-correlation, and fitting operations.

Discussion

We have implemented a robust, high temporal resolution FVE M-mode MRI for non invasive estimation of aortic distensibility during free breathing. Respiratory gating is important for reducing respiratory artifacts in these long data acquisitions. The IDL tool developed can be used to extract the pulse wave velocity automatically from the acquisition, reducing the analysis times from 30 min. to 2 min. A clinical study of an atheroscerotic patient population is currently underway.

References

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