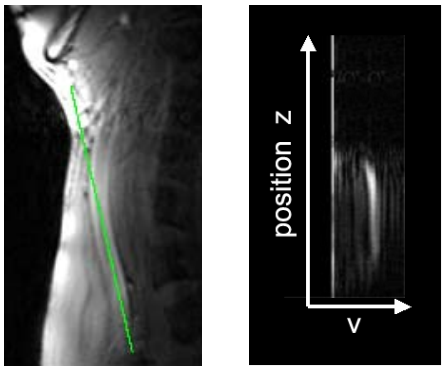
MRI Determination of Pulse Wave Velocity in the Carotid Arteries

C. J. Hardy[1], L. Marinelli[1], D. J. Blezek[1], and R. D. Darrow[1]
[1]GE Global Research, Niskayuna, NY, United States

Introduction: Reduced arterial distensibility has been associated with a variety of diseases including diabetes, hypertension, atherosclerosis and heart failure [1-4]. Pulse wave velocity (PWV) measurements can be used to determine arterial distensiblity without 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 [5]. In this technique, a movie of blood velocity distributions is generated, in which the velocity wave can be seen propogating along the artery.

A number of improvements have been made to this technique to allow its use in shorter segments of smaller vessels, such as the carotid arteries. For instance, a new semi-automated analysis method has been developed for more accurate calculation of PWV from the data. Pencil excitation pulses using more spiral turns and using stronger gradients have also been developed to reduce pencil diameters to 5 mm, to better exclude static-tissue contributions to the signal.



a b

Figure 1. a) Oblique sagittal image of right CCA of healthy volunteer. b) Time frame #32 of 128 from FVE M-mode dataset, acquired from pencil region denoted by line in a).

Methods: After providing written informed consent, three healthy adult volunteers (ages 25-50 years) participated in this study. All data were acquired on a 1.5 T GE CVi system using a 4-element carotid phased array coil. Following localization (Fig. 1a) of the common carotid artery (CCA), FVE M-mode MRI was performed. A 5 mm cylinder of spins along the vessel was excited with a 12-turn spiral excitation followed by a readout along the cylinder axis. An incremented bipolar flow encoding gradient pulse applied prior to readout yielded FVE M-mode images. A total of 16 velocity phase encoding steps was applied in 4 interleaves [5], resulting in a 64 heart-beat acquisition. 2D Fourier transformation of the data yields velocity distributions along the artery as a function of cardiac phase (Fig. 1b). This data set is then transformed to velocity-time-position coordinates, resulting in a series of Doppler-like traces characteristic of the CCA (Fig. 2). A best fit applied to the foot of each v-t waveform yields the timing of the foot (t-foot) at each position along the vessel, which can then be plotted against position (Fig. 3), with a spatial resolution of around 1 mm. The inverse slope yields the PWV, which was 6.4 m/s for this data set. Arterial distensibility D was computed using the formula $D = 1/(\rho\, c^2)$, where ρ is blood density, and c is PWV.

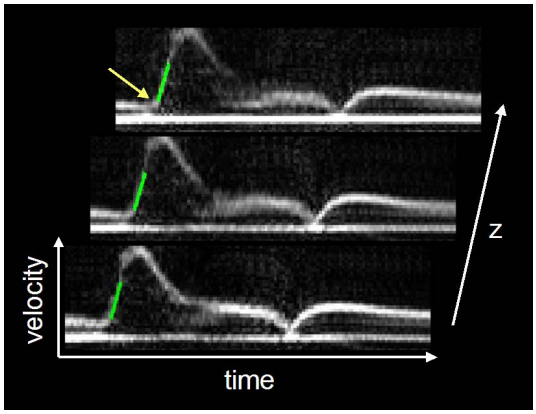


Figure 2. Remapping of Fig. 1b dataset into velocity-vs-time for each position z along vessel (3 of ~50 z positions shown). Best fits (green lines) to each foot (yellow arrow) of v-t waveform result in t-foot for each z location.

Results and Discussion: PWV was measured in the CCA of three volunteers to be 6.4 m/s, 5.7 m/s, and 7.4 m/s, corresponding to an average distensibiliy of 23×10^{-3} kPa^{-1}. This is consistent with the literature [6], and similar to values found in the normal aorta, an example of which is shown in Fig. 4.

We have implemented robust, high-time-resolution FVE M-mode MRI for non invasive estimation of carotid distensibility. Our analysis tool can be used to extract the PWV semi-automatically, yielding analysis times of ~2 min. Note that the precision with which t-foot can be established by this method is not limited to the inherent time resolution (4 ms) of the interleaved pulse sequence. Clinical trials are planned on an atherosclerotic patient population.

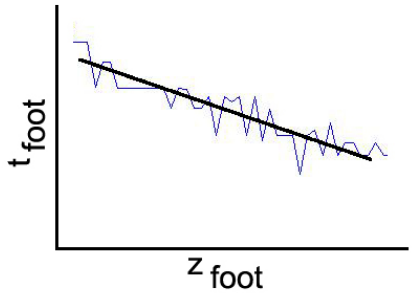


Figure 3. Plot of t-foot vs z-foot for dataset of Fig. 2. Inverse slope of best-fit line gives pulse wave velocity of 6.4 m/s.

References: 1) Avolio A, et al. Circulation 1985;71:202-210. 2) Farrar D et al. Circulation 1995;92:342-347. 3) Hirai T et al. Circulation 1989;80:78-86. 4) Salomaa V et al. Circulation 1995;91:1432 -1443. 5) Hardy CJ et al. Magn Reson Med. 1996;35: 814-819. 6) P. Angerer, et al. J Am Coll Cardiol 2000;36:1789-96.

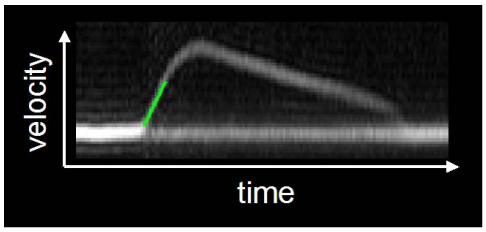


Figure 4. v-t waveform for descending aorta of volunteer. Here PWV = 5.8 m/s.