

Estimation of local aortic pulse wave velocity in a single heartbeat

M. C. Langham¹, J. Magland¹, and F. W. Wehrli¹

¹Radiology, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Introduction

The aorta represents 60 – 70 % of the systemic compliance [1]. Loss of aortic compliance leads to increased pulse wave velocity (PWV), the propagation velocity of the blood motion (in contrast to blood flow velocity). Further, greater mismatch in the vascular impedance will result at the level of the arterioles, which is the predominant reflection site. Consequently, the reflected pulse wave will arrive sooner and with greater amplitude. Early arrival of PWV will increase the cardiac afterload and systolic pressure while reducing diastolic pressure, when coronary perfusion takes place [2]. Aortic stiffness has been shown to correlate with aging [3], presence of atherosclerotic alterations and is a strong predictor of cardiovascular risk [4]. We present an MRI technique to estimate, in principle, aortic PWV within a single heartbeat.

Methods

At the early systolic phase (first 60 - 80 ms after the ventricular ejection [5]) it is assumed that the pulse wave is unidirectional and reflectionless [6]. From this assumption PWV can be expressed as $PWV = \Delta Q / \Delta A$ [7], where ΔQ and ΔA represent temporal changes in the blood flow rate and cross-sectional area of the aorta. To time-resolve flow and diameter simultaneously a velocity-compensated reference image (Figure 1a) with Cartesian scan is first acquired, followed by scanning of two-step velocity-encoded $k_y = 0$ lines. From the complex reference image the artery of interest (aorta) is masked out (Figure 1b) and Fourier transformed (FT) back to k-space (Figure 1c). The center k-space line is then subtracted from the velocity-encoded acquisitions. Time-resolved estimation of the aortic diameter and average blood velocity is obtained by computing $|Z_+Z_-^*|$ (Figure 2a) and $\angle(Z_+Z_-^*)$ (Figure 2b), respectively, where Z_{\pm} are the velocity-encoded projections with positive or negative first moment. The temporal resolution is equal to 2TR. All experiments were performed on a 3T Siemens Trio and axial images of the thoracic aorta were acquired using a body matrix coil. The following imaging parameters were used: FOV=256 x 256 mm², voxel size = 1 x 1 x 5 mm³, TE/TR = 5.4/10 ms, dwell time = 15 μ s, flip angle = 20°, VENC = 150 cm/s and total scan time ~ 15 s (~ 6 heartbeats total). The pulse sequence was programmed using SequenceTreeTM [8], a custom-designed pulse-sequence design and editing tool.

Results and Discussion

Figure 2a shows the time-course of $|Z_+Z_-^*|$ of the aorta in a 36-year old male during a single heartbeat. The lengths of the red vertical lines represent the “diameter” of the aorta at three time points during systole. The corresponding average blood velocity map ($v_{map} = VENC \cdot \angle(Z_+Z_-^*) / \pi$) is shown in Figure 3a (red circles). The PWV is equal to the slope of area vs. flow rate plot in Figure 3b; the derived PWV = 2.5 m/s, which is somewhat lower than those found in [7].

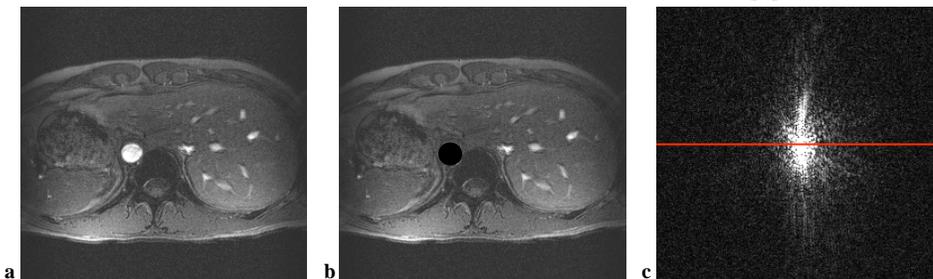


Figure 1 a) Axial reference image of a thoracic aorta. b) The reference image where the aorta is removed and is FT back to k-space, c).

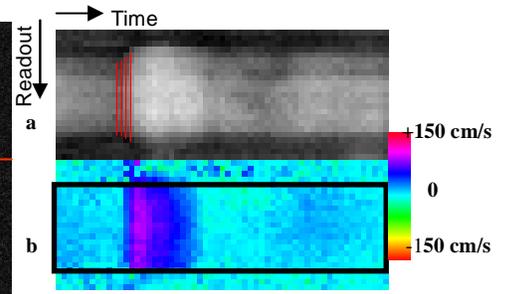


Figure 2 a) Magnitude of time-resolved projections and b) the corresponding velocity map.

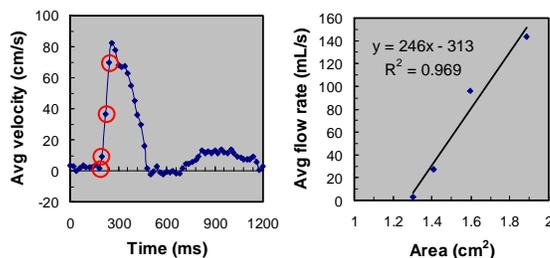


Figure 3 a) Average blood velocity during a single heartbeat; b) flow plotted vs. area.

Conclusion

Arrhythmia is a major source of error for flow and area estimation with most methods that require data from multiple heart beats. The proposed method is not affected by irregular heart rhythm (which is normal) since PWV is estimated during a single heartbeat. From the PWV, local aortic compliance can be estimated [7]. Sources of error are deviations of aortic circularity. The method needs validation and comparison with established techniques.

References [1] Stergiopoulos et al., Am J Physiol 1999;276: H424–H428; [2] Sutton-Tyrrell et al., Circulation 2005;111:3384–3390; [3] Mohiaddin et al., J. Appl. Physiol. 1993; 74:492–497; [4] Blacher et al., Hypertension 1999;33:1111–1117; [5] Li, J., Dynamics of the Vascular System. New Jersey: World Scientific; 2004, p.97; [6] Berger et al., Am J Physiol

1994;266:H1626–H1642; [7] Vulliemoz et al., MRM 2002; 47:649–654; [8] Magland et al. Seattle, WA. Proc. ISMRM.2006, p 578.

Acknowledgement: NIH Grants T32 EB000814 and R21-HL0881