Carotid Pulse Wave Velocity Measurements Using Accelerated High Temporal Resolution MRI

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Purpose

Arterial stiffness is one of the major biomarkers of early atherosclerotic disease[1]. A common method to assess vessel wall stiffness is by measuring the pulse wave velocity (PWV) of the pulse wave created by cardiac contraction[2]. Using phase-contrast MRI based flow measurements, PWV can be determined by measuring the time delay between the flow curves at two different slice locations. These measurements require sufficient spatial resolution for accurate flow quantification, as well as high temporal resolution with respect to the travel time of the pulse wave between the two slices. In the aorta, these measurements seem feasible using standard imaging protocols. However, in case of the carotid artery, more sophisticated acquisition strategies are needed to deal with the small lumen diameter (4-6 mm) and shorter imaging coverage of dedicated carotid coils. Here, we present a new MRI method for carotid PWV assessment, where we combine retrospective triggering and compressed sensing (CS) reconstruction, resulting in flow measurements with in-plane spatial resolution of 0.85 mm and temporal resolution of 200 frames/cardiac cycle.

Methods

MRI measurements were performed on a whole-body 3T MR scanner. A fast field echo (FFE) phase contrast MR sequence with unidirectional velocity encoding (VENC = 120 cm/s) was used with the following parameters: TE/TR/FA = 3.28 ms/10.58 ms/20^o; slice thickness = 3mm; FOV = 136 mm and acquisition matrix of 160x160 resulting in a spatial resolution of 0.85 mm. We first validated the method using phantom measurements by acquiring PC MRI data for a silicon carotid model of a healthy volunteer, where a flow waveform mimicking carotid arterial blood flow pattern was applied. The fully-sampled cartesian kspace was acquired 25 times. All 25 dynamics were acquired and the klines were retrospectively binned into 200 fully-sampled frames[3]. Unlike prospective triggering, where the temporal resolution is limited by TR, retrospective triggering enables reconstructions with higher temporal resolutions. This is because the data is acquired asynchronously with the heartbeat. Additionally, a variety of undersampled random acquisition schemes were simulated by subsampling the fully-sampled data. Undersampled kt-space sampling patterns were generated using computer simulations. We aimed to achieve a 3 minute scan time per slice, and for efficient kspace sampling, half Fourier factor of 30% was used. In the simulation process random weighted sampling with different Gaussian distributions was emphasized as shown in Fig.1. Assessment of all trajectories leads to one optimum trajectory, which was used to acquire undersampled kt-space data in vivo.

In the in vivo experiments, the optimal variable density scheme is implemented on the scanner. Measurements were performed on 4 volunteers. Two axial slices were positioned to cover the common and internal carotid arteries. The resulting phase contrast data have been acquired multiple times in order to assess reproducibility of our technique. The resulting data was then subjected to a three-dimensional (2D + time) compressed sensing reconstruction[4]. Flow curves were created for each vessel and, finally, PWV analysis is performed by calculating the time-shift in flow curves between the vessels in the two axial slices. The time-shift between the curves, **t**, was determined by the maximum cross-correlation between the (time-shifted) curves. The PWV is then given by **PWV=d/t**, where **d** is distance traveled between the two slices.

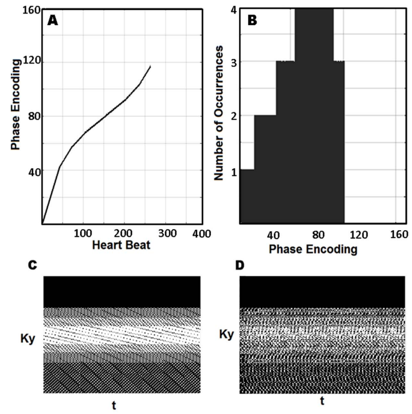

Figure 1: A) The phase encoding step as a function of time (heart beat), and the corresponding B) histogram. C, D) The simulated acquired kt spaces assuming constant heart rate and varying heart rate (5%). It can be seen small variation in heart rate shows that random weighted undersampled acquisition is achieved.

Results

In Fig.2, the top row shows the difference between linear and CS reconstructions for one of the time frames. Clearly, CS reconstruction cleans up the aliasing artifacts and better image quality with good delineation of the carotids is achieved as shown in Fig.2D. By using a retrospective triggering scheme, detailed flow curves could be estimated from the reconstructed Cine as shown in Fig.2E. In Fig.3A the normalized blood flow curves of the carotid artery of a representative case for the 2 slices are shown. Cross correlation with a dense temporal resolution scale between the two curves is calculated to estimate the time shift that yield the highest correlation value as shown in Fig3B. Repeated scans for the four volunteers have been conducted. Fig.3C shows the estimated PWV in the 2 scans of the 4 volunteers with a coefficient of variance (CV) of 16%.

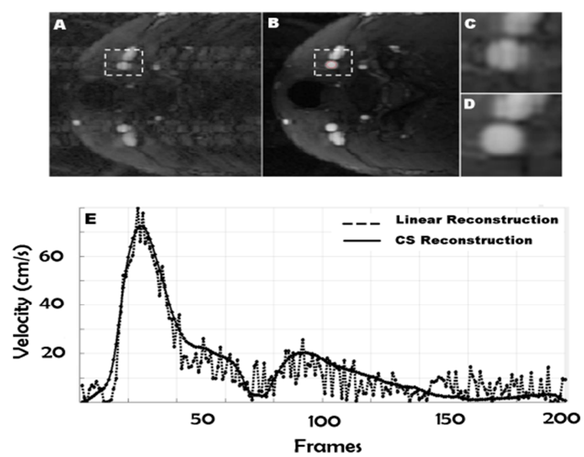

Figure 2: The difference between(A) linear and (B) CS reconstructions for a time frame. The zoomed images, C and D, show better delineation of the carotid wall for the CS reconstruction. E) The estimated flow curves for the linear and CS reconstructions.

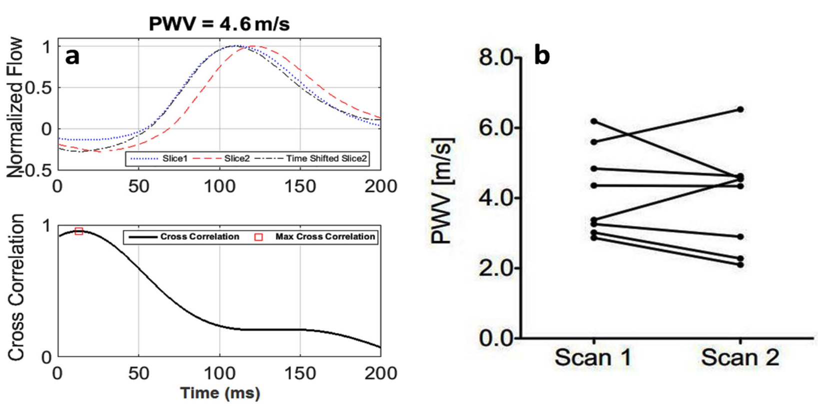

Figure 3: A) Normalized blood flow curves in the left carotid artery for the 2 slices and shifted flow curve that gives the highest correlation. B) Cross correlation between the two curves for the time difference that yields the highest correlation is calculated. By estimating the shift and by knowing the distance between the two slices, the PWV could be calculated. C) Repeated measurement for the 4 volunteers.

Conclusion

In conclusion, we showed in this abstract that by combining retrospective triggering and compressed sensing reconstruction, measuring the carotid pulse wave velocity becomes possible. Given this high temporal measurements, translation of this technique to patient and elderly people, who are expected to have higher PWV, also seems feasible

References

1. Ben-Schlomo et al. J Am Coll Cardiol 2014; 2. Wentland et al. Cardiovasc Diagn Ther 2014; 3. Coolen et al. Magn Reson Med 69:648–65 4. Motaal et al. J. Cardio Vasc. Imag. 2014