

Detection of Time Delay for Aortic Compliance Evaluation

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Aortic compliance (AC) can be evaluated noninvasively and its reduction with age in normals has been demonstrated with both MRI and Doppler echo methods. Aortic pulse wave velocity (PWV), a measurement of the flow pulse traveling along aorta as a surrogate for AC, can be assessed using a single plane breath-hold phase contrast (PC) imaging technique. Accurate determination of the time delay (Δt) between flows in ascending and descending aorta is critical in PWV assessment. Various approaches have been studied for Δt , including measuring the intervals between flow onset points, between maximal flow points, and between parallel upslopes after least squares fittings. We compared four automated approaches for time delay detection and evaluated their effects on aortic compliance and their relationship to age in normal volunteers.

MATERIAL AND METHODS

Eighty healthy volunteers with informed consent (age: 59.5 ± 13.9) were screened to exclude hypertension and cardiovascular disease. Using the 'candy cane' view of aorta, an axial plane through the ascending and descending aorta at the pulmonary artery level was prescribed and through-plane velocity encoded PC cine imaging performed with VENC of 150 cm/s, TR/TE/FA = 98ms/2.9ms/15° and voxel spatial resolution $1.3 \times 2 \times 6 \text{ mm}^3$ on a 1.5T MRI scanner. The distance traveled by the aortic pulse wave, ΔD , was determined as the distance along the centerline between ascending and descending aorta in the 'candy cane' image. For Δt assessment, four algorithms were used, as summarized below:

- 1). *Max Slope (MS)*: The Δt is the delay between the time of maximal flow velocity upslope in ascending and descending aortic flow curves. Flow upslope was calculated for each time point by taking flow values from neighboring time points using least square means. The maximal upslope was selected as the largest upslope among all time series.
- 2). *Cross Correlation (CC)*: The cross correlation between the first half of ascending and descending aortic flow curves was calculated by varying the relative time between them. The Δt was the time shift at the maximal correlation.
- 3). *Same Flow (SF)*: We first found the time of maximal upslope in the ascending aorta (t_1) and then identified the time at which the same relative flow occurred in the descending aorta (t_2). Δt is the difference between t_1 and t_2 .
- 4). *X-axis Intercepts (XI)*: The Δt is the difference between the x axis intercepts of the 2 lines that were determined by the times and maximal slopes as in 1).

We then calculated $PWV = \Delta D / \Delta t$ and aortic compliance as $AC = 1 / (\rho * PWV^2)$, where blood density $\rho = 1057 \text{ kg/m}^3$. Spearman correlation coefficient was used to determine the relationships between AC and age.

RESULTS

All 4 algorithms worked well on all cases without any user interaction. As illustrated in **Figure**, the aortic compliance results from 4 methods varied significantly. The mean \pm sd of AC were $(3.15 \pm 4.11) * 10^{-5} / \text{Pa}$ for MS, $(3.11 \pm 3.70) * 10^{-5} / \text{Pa}$ for CC, $(2.85 \pm 2.66) * 10^{-5} / \text{Pa}$ for SF and $(2.92 \pm 2.68) * 10^{-5} / \text{Pa}$ for XI, respectively. There was no outlier with the CC and SF methods and the SF method showed the least variability among subjects. Correlation between AC and age had an R of -0.50687 for MS, -0.62012 for CC, -0.66402 for SF and -0.55875 for XI, respectively, all $p < .0001$. The age versus AC results showed stronger correlation in females than in males (**Table**).

CONCLUSION

Aortic compliance in normal volunteers using the through-plane PC imaging technique showed a good correlation with age. This imaging technique permits evaluation of aortic compliance in a single breath-hold and has the potential to be an efficient clinical tool for assessment of vascular stiffness. The SF method of AC determination provides the greatest sensitivity to age effects.

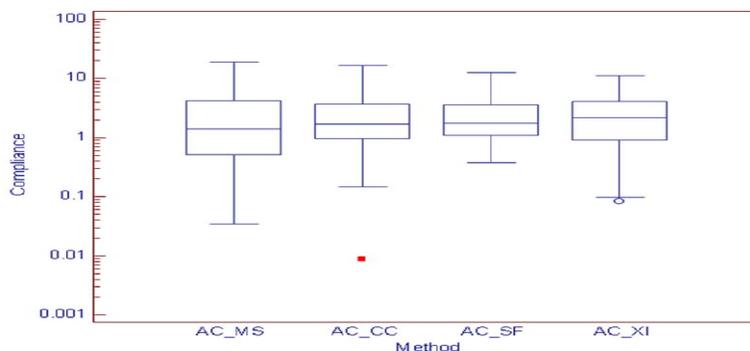


Figure Box-and-whisker plots of aortic compliances from 4 methods: the central box represents the values from the lower to upper quartile (25 to 75 percentile). The middle line represents the median. The horizontal line extends from the min to the max value, excluding *outside* and *far out* values which are displayed as separate points.

Spearman Correlation Coefficients, Prob > r under H0: Rho=0				
Age	AC_MS	AC_CC	AC_SF	AC_XI
Total P (N = 80)	-0.50687 <.0001	-0.62012 <.0001	-0.66402 <.0001	-0.55875 <.0001
Female P (N = 46)	-0.62312 <.0001	-0.59357 <.0001	-0.71828 <.0001	-0.60915 <.0001
Male P (N = 34)	-0.28049 0.1081	-0.47443 0.0046	-0.64427 <.0001	-0.49671 0.0028

Table. Correlation between compliance and age, for all subjects and by gender