Aortic Compliance Evaluation: Comparison of Time Delay Algorithms

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Aortic pulse wave velocity (PWV), a measurement of the flow pulse traveling along aorta as a surrogate for aortic compliance (AC), can be assessed using a single breath-hold through-plane phase contrast 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, including measuring the intervals between flow onset points, between maximal flow points, and between parallel upslopes after least squares fittings. We compared five automated approaches for time delay detection and evaluated their effects on aortic compliance and their relationship to age in 186 normal volunteers.

MATERIAL AND METHODS

186 healthy volunteers with informed consent (age: 58.6±14.4, 104 females) 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 phase contrast imaging performed, VENC = 150 cm/s, TR/TE/FA = 98ms/2.9ms/15° on a 1.5T MRI scanner. The distance between ascending and descending aorta, ΔD, was determined as the centerline in the 'candy cane' image. For Δt assessment, 5 algorithms were used:

(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 (t1) and then identified the time at which the same relative flow occurred in the descending aorta (t2). Δt is the difference between t1 and t2. **(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 MS method. **(5).** 5-point Maximum (5M): The true peak of each curve is determined by a least-squares 2nd order fitting of the peak and the 2 neighboring time points on both sides.

We then calculated $PWV=\Delta D/\Delta t$ and aortic compliance as $AC=1/(\rho * PWV^2)$, where blood density ρ=1057kg/m. Spearman correlation coefficient was used to determine the relationships between AC and age. To determine the optimal algorithm for measuring PWV, a Cronbach Coefficient α was computed for all five methods. This approach assumes that each method is an unbiased measure of the *true* PWV and the error introduced by each method is random noise. In that case, the mean of all five methods is the closest to the true PWV.

RESULTS

All 5 algorithms worked well on all cases without any user interaction. As illustrated in the box and whisker plot (**Figure),** the aortic compliance results from 5 methods varied significantly. The mean±sd of AC were $(4.02\pm6.18)*10^{-5}$/Pa for MS, $(3.73\pm4.37)*10^{-5}$/Pa for CC, $(4.08\pm6.55)*10^{-5}$/Pa for SF, $(3.49\pm4.04)*10^{-5}$/Pa for XI, and $(4.10\pm5.09)*10^{-5}$/Pa for 5M, respectively. CC and SF methods showed smaller variability among subjects. Correlation between AC and age had an R of -0.52 for MS, -0.67 for CC, -0.56 for SF, -0.46 for XI, and -0.46 for 5M respectively, all $p<.0001$. The age versus AC results showed stronger correlation in females than in males. The standardized Cronbach α was 0.90. The deletion of the CC method decreases the Cronbach α more than any other method. The superiority of CC over the other four methods is consistent with the observation that cc had the highest correlation with the mean of all five methods. In a multiple regression model predicting age using the five methods as predictors, only cc was a statistically significant predictor of age, after controlling for the other four methods ($p<0.001$).

CONCLUSION

Aortic compliance in normal volunteers using the through-plane phase contrast 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 cross correlation method of AC determination seems consistent and to provide the greatest sensitivity to age effects.

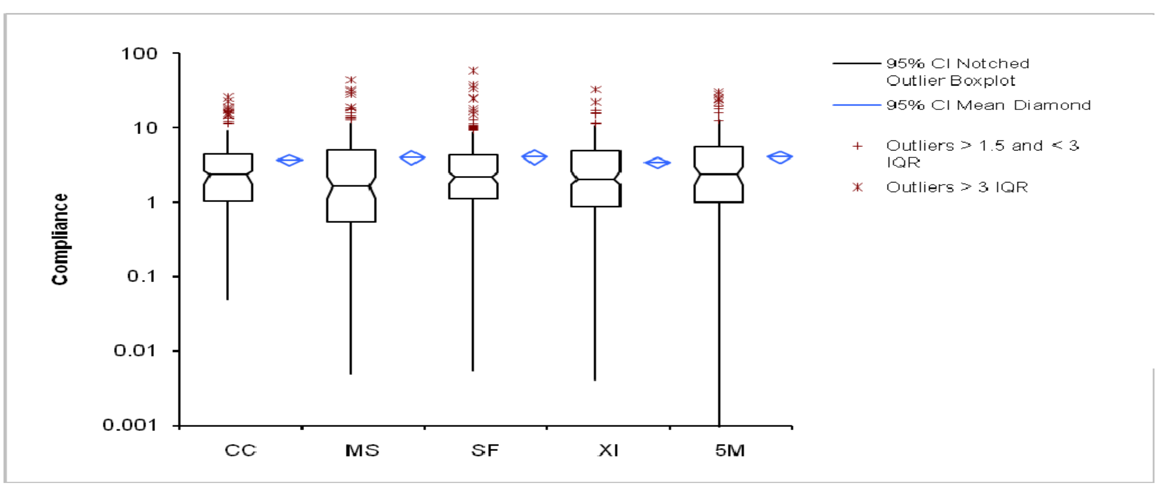

Figure Box-and-whisker plots of aortic compliances from 5 methods: the central box represents the values from the lower to upper quartile (25 to 75 percentile). The middle line represents the median.