Robust estimation of pulse wave transit time using group delay

Antonella Meloni[1], Heather Zymeski[2], Alessia Pepe[1], Massimo Lombardi[1], and John C Wood[2]

[1]CMR Unit, Fondazione G. Monasterio CNR-Regione Toscana and Institute of Clinical Physiology, Pisa, Italy, [2]Division of Cardiology, Children's Hospital Los Angeles, Los Angeles, California, United States

Introduction. Aortic pulse wave velocity (PWV) is considered as the "gold standard" measurement of arterial stiffness and is commonly calculated as the ratio between the distance separating two locations along the artery and the transit time (Δt) needed for the pressure or velocity wave to cover this distance [1]. PWV is increasingly assessed by means of cardiovascular magnetic resonance (CMR) [2,3]. Our goal was evaluate the efficiency of a novel method for Δt estimation, based on the principle of group delay (TT-GD method) [4].

Materials and methods. 30 patients with hemoglobinopathies (25.2±9.8 years) were scanned using a 1.5T scanner (GE Signa CVi; GE Healthcare, Waukesha, WI) with a phased array torso coil. Phase contrast (PC) data were acquired using a retrospectively ECG-gated breathhold GRE sequence providing phase-related pairs of modulus and velocity-encoded images (100 phases). Images were analyzed with the FLOW image analysis software (Medis, Leiden, the Netherlands) to extract ascending and descending aorta flow and velocity curves. The Δt was calculated from blood flow curves using a custom-built software platform developed in Matlab (The Mathworks, Natick, MA). The TT-GD method operates in the frequency domain and models the ascending aortic waveform as an input passing through a discrete-component "filter", producing the observed descending aortic waveform, so that the GD of that filter represents the average time-delay. This method was compared with two previously described time-domain methods: TT-point using the half-maximum of the curves [2,5] and TT-wave using cross correlation [6]. To study the effect of the temporal resolution on ΔT estimates, the flow curves were downsampled of a factor of 2, 3 and 4.

Results. Mean Δts obtained with the three methods were comparable (TT-GD: 28.18±5.36 ms, TT-point: 27.02±5.32 ms, TT-wave: 26.93±4.41; P=0.561).

The TT-GD method was the most reproducible (Table 1).

While the TT-GD as well as the TT-wave produced comparable results for velocity and flow waveforms (coefficient of variability or CoV: 4.81% and 5.04, respectively), the TT-point resulted in significant shorter Δt values when calculated from velocity waveforms (CoV=8.71%, mean difference: 1.78±2.73 ms).

The TT-GD method was the most robust to reduced temporal resolution (Table 2).

Table 1.

	TT-GD	TT-POINT	TT-FLOW
Intra-operator reproducibility			
CoV (%)	3.38	5.66	3.40
ICC	0.982	0.954	0.978
BA bias (ms)	0.04	-0.42	0.10
BA limits (ms)	-2.8 to 2.9	-4.7 to 3.8	-2.5 to 2.7
Inter-operator reproducibility			
CoV (%)	3.67	8.17	5.04
ICC	0.981	0.892	0.949
BA bias (ms)	0.06	-0.41	0.15
BA limits (ms)	-2.8 to 3.0	-6.6 to 5.8	-3.7 to 4.0

Table 2.

	Downsampling by 2	Downsampling by 3	Downsampling by 4
TT-GD			
Difference, mean ± SD (ms)	-0.08 ± 1.34	-0.10 ± 1.83	0.97 ± 2.52
P (paired test)	0.746	0.756	0.074
CoV (%)	3.33	4.52	6.57
ICC	0.985	0.970	0.937
Correlation, r (P-value)	0.970 (P<0.0001)	0.941 (P<0.0001)	0.893 (P<0.0001)
BA limits (ms)	-2.7 to 2.6	-3.7 to 3.5	-4.0 to 5.9
TT-POINT			
Difference, mean ± SD (ms)	-0.03 ± 4.63	-0.52 ± 5.28	1.74 ± 6.6
P (paired test)	0.971	0.597	0.159
CoV (%)	11.91	13.78	17.04
ICC	0.798	0.794	0.559
Correlation, r (P-value)	0.659 (P<0.0001)	0.683 (P<0.0001)	0.406 (P=0.026)
BA limits (ms)	-9.1 to 9.0	-10.9 to 9.8	-11.2 to 14.7
TT-FLOW			
Difference, mean ± SD (ms)	-0.61 ± 2.01	-0.13 ± 2.27	1.04 ± 2.66
P (paired test)	0.108	0.757	0.040
Correlation, r (P-value)	0.899 (P<0.0001)	0.876 (P<0.0001)	0.818 (P<0.0001)
CoV (%)	5.49	5.89	7.24
ICC	0.944	0.935	0.889
BA limits (ms)	-4.6 to 3.3	-4.6 to 4.3	-4.2 to 6.2

Conclusion. Compared to the traditional TT-point and TT-wave methods, the TT-GD approach was more reproducible and more robust to the waveform type and the choice of temporal resolution.

References.

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