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Reproducibility of Arterial Elasticity Parameters Derived from Radial Artery Diastolic Pulse Contour Analysis: The Multi-Ethnic Study of Atherosclerosis

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Abstract

Objective—The aim of this report was to describe the reproducibility of arterial elasticity parameters derived from radial artery diastolic pulse contour analysis.

Methods—Two measurements were performed on the same day by the same technician with the HDI/Pulsewave CR-2000 (Eagan, MN) on each of a subset of participants selected at random from the Multi-Ethnic Study of Atherosclerosis (MESA). Large and small artery elasticity (C1 and C2), C1 and C2 each multiplied by systemic vascular resistance (C1xR and C2xR, which are functions of the radial artery pulse waveform only), and systolic and diastolic blood pressure (SBP and DBP) were evaluated.

Results—Two measurements were performed on each of 131 participants. The mean difference $\pm$ standard deviation of the difference was -0.13 ± 3.5 mmHg $\times 10$ for C1, -0.03 ± 1.5 mmHg $\times 100$ for C2, 0.10 ± 4.6 seconds $\times 10$ for C1xR, 0.05 ± 1.8 seconds $\times 100$ for C2xR, 2.8 ± 8.2 mmHg for SBP, and 1.5 ± 5.0 mmHg for DBP. The between-measure correlation was 0.74 for C1, 0.84 for C2, 0.58 for C1xR, 0.74 for C2xR, 0.90 for SBP, and 0.86 for DBP.

Conclusion—The reproducibility of arterial elasticity measurements is less than that of systolic and diastolic blood pressure. Multiple measurements of arterial elasticity from a participant are recommended.

Keywords

arterial elasticity; arterial compliance; reproducibility; blood pressure measurement

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Introduction

Large (C1) and small artery elasticity (C2) are functions of the radial artery pulse waveform and other participant characteristics. In the ongoing Multi-Ethnic Study of Atherosclerosis (MESA), higher C1 and C2 have been found to be associated with lower risk of congestive heart failure [1], while C2 only was associated with lower risk for coronary heart disease [2].

Reproducibility of the arterial elasticity measurements is crucial for detecting effects of interest in research studies, and for using these measurements in medical decision making and monitoring vascular therapy. The aim of this report was to describe the reproducibility and components of variability of arterial elasticity and related measurements performed with the HDI/Pulsewave CR-2000 (Eagan,MN) on MESA participants. The following parameters were evaluated: C1, C2; C1 and C2 each multiplied by systemic vascular resistance (C1xR and C2xR); and systolic and diastolic blood pressure (SBP and DBP). There has been limited information about the reproducibility of C1 and C2 from other studies [3-6], however, the reproducibility of C1xR and C2xR, which are functions of the pulse waveform only, have never been reported.

Methods

Participants for this report were the subset of MESA participants who, for quality control purposes, had two measurements of arterial elasticity performed on the same day by the same technician. MESA was initiated to investigate the prevalence, correlates, and progression of subclinical cardiovascular disease [7]. In brief, between July 2000 and September 2002, 6814 men and women who identified themselves as Caucasian, African-American, Hispanic, or Chinese and were 45 to 84 years old and free of clinically apparent CVD were recruited from 6 US communities.

The MESA participants who had two measurements of arterial elasticity obtained on the same day were selected as follows. One of 6 types of procedures (arterial elasticity was one of the procedures) was selected at random each day to be performed a second time on either the first or last participant (also randomly selected) at each site. The technician for the second measurement was selected at random to be the same or different as the technician for the first measurement, but a different technician was available in only 13 cases and the technician was unknown in 1 case. This report was restricted to the 131 participants with two measurements performed by the same technician.

The arterial elasticity measurements were performed by trained technicians with the HDI/Pulsewave CR-2000 and Arterial PulseWave™ Sensor (Hypertension Diagnostics, Inc, Egan, MN, USA). Initial training was centralized and included lectures describing the procedure, the protocol in the manual of operations for MESA, and the HDI system; demonstration of the procedure according to the protocol; and hands-on practice with the system. The system consisted of a wrist stabilizer, a piezoelectric pressure sensor mounted in a holder, an oscillometric blood pressure cuff, and an instrument/software algorithm, including display feedback of the sensor pressure. The stabilizer was used to immobilize the participant's right wrist and the sensor holder was positioned over the area of maximum

radial artery pulsation. Oscillometric systolic and diastolic blood pressure (SBP and DBP) measurements were obtained with the cuff on the participant's left arm, and pressures were sampled from the right radial artery at a rate of 200 per second for a total of 30 seconds. The instrument/software algorithm computed C1, C2, and R. C1 and C2 are each a function of parameters, estimated from a modified Windkessel model [8] of the pulse waveform (sequence of pressures calibrated with SBP and DBP), divided by R, an estimate of systemic vascular resistance. R is a function of the pulse waveform and also height, weight, blood pressure, and age of the participant. Thus, C1 and C2 are functions of the pulse waveform and participant characteristics while C1xR and C2xR are functions of the pulse waveform only.

Reproducibility was summarized by the mean and standard deviation of the difference of the two measurements, Pearson correlation coefficient, and intraclass correlation coefficients (ICC₁ and ICC₂). ICC₂ and ICC₁ were defined as the component of variability due to differences in measurements among participants divided by the sum of it and the variability due to differences within participants, and estimated from a mixed effects model with and without a fixed effect for technician. ICC₂ accounts for potential differences among technicians.

Results

Seven technicians performed measurements on between 8 and 32 participants; 2 technicians performed measurements on 2 participants; and 4 technicians performed measurements on only 1 participant. Characteristics of the participants are summarized in Table 1.

Among the 131 participants, the mean difference $\pm$ standard deviation of the difference was -0.13 ± 3.5 mmHg $\times 10$ for C1, -0.03 ± 1.5 mmHg $\times 100$ for C2, 0.10 ± 4.6 seconds $\times 10$ for C1xR, 0.05 ± 1.8 seconds $\times 100$ for C2xR, 2.8 ± 8.2 mmHg for SBP, and 1.5 ± 5.0 mmHg for DBP (Figure 1; Table 2, column 1). The between-measure correlation was 0.74 for C1, 0.84 for C2, 0.58 for C1xR, 0.74 for C2xR, 0.90 for SBP, and 0.86 for DBP (Figure 2; Table 2, column 2). The intraclass correlation coefficient, ICC₁, was 0.74 for C1, 0.84 for C2, 0.58 for C1xR, 0.74 for C2xR, 0.88 for SBP, and 0.85 for DBP (Table 2, column 3). ICC₂ (not tabulated) was similar to ICC₁.

Discussion

In this study, efforts were made to standardize the conditions so that differences between measurements on a participant could be attributed to random error and not, for example, to the technician or changes in a participant's condition over time. The technician needed to place the wrist stabilizer on the participant and locate the area of maximum radial artery pulsation, however, the wrist stabilizer minimized arm movement, a pressure monitor in the display helped the technician regulate the force of the piezoelectric sensor on the participant's skin and the sensor holder helped fix the angle of interrogation. The result from the first measurement was not readily available to the technician at the time of the second measurement. It is reasonable to assume the participant's condition was stable across the two measurements since the measurements were made on the same day.

The mean and standard deviation of differences for C1 and C2 in this report are similar to those described in the literature [3-6]. The reproducibility of C1, C2, C1xR, and C2xR in MESA are less than that of systolic and diastolic blood pressure. While single measurements of C1 and C2 have been shown to be associated with cardiovascular disease in MESA independent of blood pressure and blood pressure medication [1-2], even stronger associations might have been found if within participant variability had been reduced by obtaining multiple measurements of arterial elasticity from a participant and using the mean of the measurements. C1 and C2 can be considered to have clinical utility in identifying early cardiovascular changes, beyond classical blood pressure measurements.

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Figure 1. Bland-Altman plots

Plot symbols denote technician for the pair of measurements. Dashed lines indicate the mean difference and the mean $\pm$ 2 standard deviations of the differences. N=131.

Figure 2. Scatterplots

Plot symbols denote technician for the pair of measurements. Dashed line is the diagonal.

Correlation (r) is provided. N=131.

Table 1

Participant characteristics (N=131).

Age, years	63 ± 11
Gender, % male	59
Race/Ethnicity, %	
Caucasian	25
Chinese	9
African-American	38
Hispanic	28
Height, cm	167 ± 10
Weight, kg	80 ± 15
Body mass index, kg/m²	29 ± 5
Heart rate, beats/minute	64 ± 11
Systolic blood pressure, mmHg	136 ± 19
Diastolic blood pressure, mmHg	77 ± 9
C1, ml/mmHg ×10	13.6 ± 4.8
C2, ml/mm Hg ×100	4.3 ± 2.5
C1×R, seconds × 10	16.0 ± 5.0
C2×R, seconds × 100	5.0 ± 2.4

Mean ± standard deviation or percentage of measurements is tabulated. Body mass index = weight/height². For variables with two measurements, the first measurement is summarized.

Table 2

Estimates of reproducibility and components of variability (N=131)

	Difference	r	ICC ₁	SD _{between}	SD _{within}
C1, ml/mmHg × 10	−0.13±3.5	0.74	0.74	4.2 (3.6, 4.8)	2.5 (2.2, 2.8)
C2, ml/mmHg × 100	−0.03±1.5	0.84	0.84	2.4 (2.1, 2.7)	1.0 (0.9, 1.2)
C1×R, seconds × 10	0.10±4.6	0.58	0.58	3.8 (3.2, 4.5)	3.2 (2.8, 3.6)
C2×R, seconds × 100	0.05±1.8	0.74	0.74	2.1 (1.8, 2.5)	1.3 (1.1, 1.4)
Systolic Blood Pressure, mmHg	2.8±8.2	0.90	0.88	16.8 (14.7, 19.1)	6.1 (5.4, 6.9)
Diastolic Blood Pressure, mmHg	1.5±5.0	0.86	0.85	8.8 (7.7, 10.1)	3.7 (3.3, 4.2)

Difference: mean ± standard deviation of the difference (first measurement – second measurement). **r:** Pearson correlation coefficient. **ICC₁:** intraclass correlation coefficient, computed as the component of variability due to differences in measurements among participants divided by the sum of it and the variability due to differences within participants, estimated from a random effects model; **ICC₁ = SD_{between}²/(SD_{between}² + SD_{within}²)**. Numbers in parentheses are the 95% confidence limits.