Comparison of Impedance Cardiography and Pulse Wave Contour Analysis Measurement of Arterial Compliance in Healthy and Diseased Subjects

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Background

Loss of arterial compliance is a major factor in the age-related development of hypertension and reflects pathologic vascular remodeling and endothelial dysfunction. Noninvasive measurements of arterial compliance are possible using pulse wave contour analysis (PWC) and impedance cardiography (ICG).

ICG provides reliable and reproducible estimates of cardiac output and stroke volume, from which the ratio of stroke volume to pulse pressure (SV/PP) can be calculated. This ratio, termed total arterial compliance (TAC), correlates with more complex models of arterial compliance, including the three-element Windkessel model. PWC analysis provides estimates of arterial elasticity of large arteries (C1) and small arteries (C2).

Objective

The purpose of this study was to compare TAC and additional ICG parameters with C1 and C2 measures by PWC analysis in normal and diseased patients.

Methods

Patients

We evaluated a cohort of 18 healthy volunteers and 87 diseased patients with either hypertension and/or peripheral vascular disease. Hypertension was defined as active treatment with any antihypertensive agent or current systolic BP $\geq$ 140 mm Hg or diastolic BP $\geq$ 90 mm Hg.

Vascular disease was identified through patient history and was defined by clinical diagnosis of peripheral artery disease, or antecedent evidence of a previous stroke, or carotid disease.

Data Collection

ICG hemodynamic measurements were performed using the BioZ® ICG Monitor (CardioDynamics, San Diego, CA) by a technician after five minutes of rest in the supine position. TAC and TAC index (TACI) were calculated as stroke volume divided by pulse pressure and stroke index divided by pulse pressure, respectively. PWC analysis-based large (C1) and small (C2) artery elasticity measurements were performed using the CR-2000 CVProfiler® (HDI, Eagan, MN). Blood pressure was taken with the patient seated using the oscillometric method.

Analysis

Discrete variables, such as gender and race, were summarized as % in both healthy volunteers and patients with hypertensive or peripheral arterial disease. Continuous hemodynamic parameters were summarized as mean ± SD.

Differences were evaluated with the Student's t-test. The relationships between parameters were evaluated using linear regression with Pearson method.

Results

Healthy volunteers were 23 ± 1 years of age, 61% male, 61% white, with a blood pressure of 119 ± 8/72 ± 7 mm Hg. Patients were 55 ± 14 years of age, 47% male, 80% white, with a blood pressure of 153 ± 26/90 ± 13 mm Hg.

Compared to healthy volunteers, diseased patients had a lower C1 (10.8 ± 4.9 vs. 18.9 ± 5.7 mL/mm Hg x 10, $p<0.0001$), C2 (3.9 ± 2.5 vs. 9.7 ± 2.8 mL/mm Hg x 100, $p<0.0001$), TAC (12.4 ± 5.6 vs. 20.2 ± 5.8 mL/mm Hg x 10, $p<0.0001$), and TACI (6.6 ± 3.1 vs. 10.6 ± 2.7, $p<0.001$). (Table 1)

Table 1. Characteristics of Subjects

	Normal Subjects (N=18) (% or Mean ± SD)	Hypertension and/or Peripheral Vascular Disease (N=87) (% or Mean ± SD)
Demographics		
Age (years)	23.4 ± 1.2	54.8 ± 13.6
Height (inches)	70.3 ± 4.0	66.0 ± 3.9
Weight (pounds)	164 ± 33.6	184.3 ± 46.5
BMI (kg/m^2)	23.2 ± 3.0	29.8 ± 6.9
Race (% Caucasian)	61%	80%
Gender (% male)	61%	47%
Vital signs		
Heart rate (bpm)	68.7 ± 12.4	71.1 ± 11.3
Systolic BP (mm Hg)	118.8 ± 8.2	152.6 ± 26.3
Diastolic BP (mm Hg)	71.6 ± 7.3	89.6 ± 13.4
Mean arterial pressure (mm Hg)	85.8 ± 7.0	111.0 ± 18.3
ICG		
Cardiac index ($L/min/m^2$)	3.3 ± 0.5	2.5 ± 0.6
Cardiac output (L/min)	6.2 ± 1.37	4.9 ± 1.5
Stroke index (mL/m^2)	48.5 ± 8.3	36.3 ± 10.9
Stroke volume (mL)	93.3 ± 25.6	68.4 ± 21.8
SVRI (dynes sec cm^{-5} m^2)	1,983 ± 260	3,664 ± 1,604
SVR (dynes sec cm^{-5})	1,054 ± 163	1,973 ± 932
TACI (mL/mm Hg/m^2)	1.06 ± 0.27	0 .66 ± 0.31
TAC (mL/mm Hg x 10)	20.22 ± 5.80	12.37 ± 5.58
PWC		
C1 (mL/mm Hg x 10)	18.89 ± 5.71	10.84 ± 4.90
C2 (mL/mm Hg x 100)	9.66 ± 2.75	3.91 ± 2.51

SVR = systemic vascular resistance;
SVRI = systemic vascular resistance index

For all subjects, young volunteers plus patients, the mean values of C1 and TAC were 12.2 ± 5.9 and 13.7 ± 6.3 mL/mm Hg x 10, respectively.

The mean difference between TAC and C1 was 1.5 ± 5.1 mL/mm Hg x 10. Correlations to C1 and C2 are shown in Table 2. The correlation of TAC by ICG and C1 by PWC is plotted in Figure 1.

Figure 1. Correlation of Large Artery Elasticity (C1) and Total Arterial Compliance (TAC)

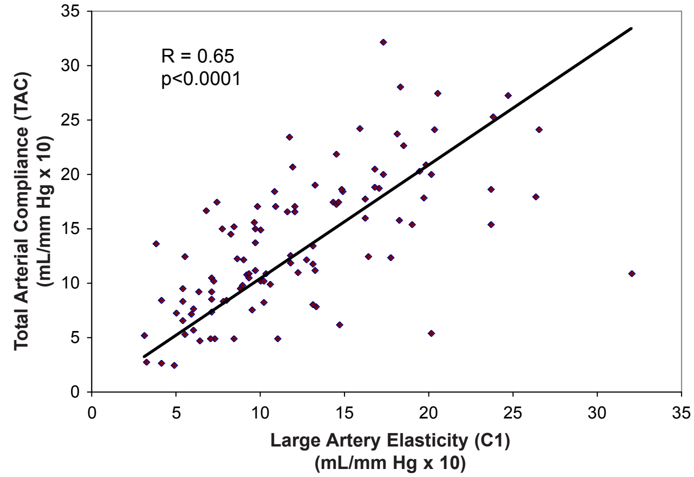

Table 2. Correlations of arterial compliance measures over all subjects (N=105)

	Correlation coefficient (R)
C1 vs.	
TAC	0.65
TACI	0.54
SVRI	- 0.43
SVR	- 0.52
C2	0.67
C2 vs.	
TAC	0.66
TACI	0.53
SVRI	- 0.46
SVR	- 0.54
C1	0.67

C1 = large artery elasticity; TAC = total arterial compliance; TACI = total arterial compliance index; SVRI = systemic vascular resistance index; SVR = systemic vascular resistance; C2 = small artery compliance;
p < 0.0001 for all comparisons

Conclusions

Measures of total arterial compliance by ICG and arterial elasticity by PWC analysis are significantly correlated, indicating that both modalities can be used to assess changes in vascular properties.