Impedance cardiography in uncomplicated pregnancy and pre-eclampsia: A reliability study

DOI: 10.3109/01443615.2012.673036
Handle: http://hdl.handle.net/1942/14248

Impedance cardiography in uncomplicated pregnancy and pre-eclampsia: correlation between diurne- and position-challenged measurements

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Short title: ICG in pregnancy

Keywords: Hemodynamic Monitoring, Non-Invasive Method, Correlation Coefficient, Diurnal Variation, Postural Challenge

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Abstract

Background/Aims: To evaluate intra- and intersession correlation of Impedance Cardiography (ICG) measurements after orthostatic and diurnal challenges in three clinical situations: uncomplicated pregnancy, pre-eclampsia and cardiovascular disease.

Methods: Twice in one day (AM and PM), a standard protocol was used to record ICG measurements before and after three position changes in uncomplicated third trimester pregnancy, pre-eclampsia and cardiovascular disease (n=10 each). A total of 22 cardiovascular parameters was measured, classified in five groups: pressures, time periods, volumes, contractility and resistance. For each parameter, Pearson's correlation coefficient (PCC) was calculated for mean values of 30 measurements per position per subject. Intra-session PCC was used to correlate position-challenged measurements, whereas inter-session PCC was used to correlate AM and PM values.

Results: In all populations, intra- and intersession PCC was consistently ≥ 0.80 for three contractility parameters (acceleration-, velocity- and heather-index). This was also true for thoracic resistance parameters in uncomplicated pregnancy and pre-eclampsia.

Conclusion: Our data illustrate that correlation between diurne- and orthostatic-challenged ICG measurements of cardiac contractility is high under standardised conditions in normal pregnancy, pre-eclampsia and cardiovascular disease. As such, ICG is a useful method to study changes of cardiac (dys)contractility in pregnancy and pre-eclampsia.

Introduction

Human pregnancy is characterised by major cardiovascular adaptations, such as plasma volume expansion, reduced vascular resistance and increased heart rate [1]. Maladaptation of the cardiovascular system plays a significant role in the pathophysiology of pre-eclampsia, a disease associated with significant morbidity and mortality for both mother and child. It has been reported that cardiac contractility is altered in pre-eclampsia compared to normal pregnancy [2-6]. Current methods to evaluate cardiovascular (mal)adaptation during pregnancy have not gained popularity because of their invasive nature [7-9] or the lack of required expertise [10].

Impedance cardiography (ICG) is designed for non-invasive measurement and monitoring of cardiovascular parameters on a beat-to-beat basis. ICG enables a continuous parallel registration of multiple parameters in a single session [11-13]. Good correlation between diurne- and position-challenged ICG measurements was reported in healthy non-pregnant subjects, especially when mean values of multiple measurements were used for each parameter [14].

We evaluated intra- and intersession correlation of ICG measurements for 22 cardiovascular parameters with a third generation device after orthostatic challenge and between morning- and afternoon-sessions in women with uncomplicated third trimester pregnancy, women with pre-eclampsia and cardiovascular diseased patients.

Materials and Methods

Approval of the local ethical committee was obtained before study onset (MEC ZOL reference: 09/050). Three populations of each ten randomly selected subjects were included: pregnant women in normal third trimester gestation (UP) presenting at the antenatal clinic of the department of obstetrics and gynaecology in Ziekenhuis Oost-Limburg, Genk, Belgium, and women with pre-eclampsia (PE) admitted to the Unit for Fetomaternal Medicine in the same hospital. A third group of critically-ill cardiology patients, admitted to the cardiovascular intensive care unit (CV) was also included as a reference and control group. PE was defined according to standard criteria [15]: gestation induced hypertension > 140/90 on at least two occasions 6 hours apart, in combination with > 300 mg proteinuria per 24 hours.

Data collection

The ICG system used in this study is the Non-Invasive Continuous Cardiac Output Monitor (NICCOMO™, Software version 2.0, SonoSite, Medis Medizinische Messtechnik GmbH, Ilmenau, Germany) with a four electrode arrangement eliminating skin resistance. This system allows for simultaneous measurement of 22 parameters in five categories: pressure, time period, volume, contractility and resistance parameters [14;16]. The examination was performed according to the protocol as reported [14]. After informed consent, for each subject, a consecutive series of ICG-examinations in different positions were performed during normal breathing (Figure 1): (1) supine 1, (2) standing, (3) sitting and (4) supine 2. To evaluate possible influences of the circadian rhythm, this series of measurements was performed at morning (AM) and in the afternoon (PM).

During the sessions, ICG values were recorded every two seconds, and blood pressure was taken automatically every two minutes. Per position, blood pressure was measured

twice. Data were collected over a timespan of one minute after the second blood pressure value was depicted on the screen. These values were neither influenced by the blood pressure measurement itself nor the movements during change in position.

Data were exported from the monitor into a database: for every position during each session, one value for pressure parameters and 30 values of other parameters were eligible for analysis.

Statistical analyses

For each parameter, Pearson's correlation coefficient (PCC) was calculated for mean values of 30 measurements per position per session per subject. Intersession correlation was evaluated between supine 1 AM and supine 1 PM, between standing AM and standing PM, between sitting AM and sitting PM and between supine 2 AM and supine 2 PM. Intrasession correlation was evaluated between positions supine 1 and supine 2 per AM or PM session.

Results

Patient characteristics of the three study populations are enlisted in Table 1. Mean age was 32.70±3.30, 30.12±6.05 and 68.64±14.51 years for normal pregnancy, preeclampsia and cardiovascular disease respectively. The time interval between AM and PM sessions was 05:50:36 ± 01:13:08 h.

Table 2 and Table 3 represent inter- and intrasession Pearson's correlation coefficients (PCC). The contractility parameters acceleration index, velocity index and heather index consistently showed PCC ≥ 0.80 in the three groups. This was also true for thoracic fluid content and -index in healthy and pre-eclamptic pregnant women, but not for cardiovascular patients (PCC ≥ 0.60). For time periods heart rate and heart period duration, and all volume parameters, PCC was higher in cardiovascular patients (≥ 0.80) than in both healthy and pre-eclamptic pregnant women (< 0.60). For other parameters, PCC was < 0.6 on at least one occasion.

Discussion

Measurements by ICG are reliable as they correlate highly with standard methods [17-22], however imprecise ICG in severely ill patients was reported [13;23]. In healthy non-pregnant subjects, we observed that position-induced changes of ICG measurements are independent from the time of day for time period, volume, contractility and thoracic impedance [14]. We also found that reproducibility of ICG measurements was much better when mean values of multiple measurements were used for each parameter [14]. Non-invasive assessment of the cardiovascular system and cardiac contractility is relevant to explore maternal gestational adaptation mechanisms, as well as background mechanisms behind cardiovascular diseases. We used the same study protocol as reported [14] to evaluate ICG measurements in uncomplicated pregnancy, during pre-eclampsia and in cardiovascular disease.

As shown in Table 2 and Table 3, inter- and intrasession correlation was high for contractility parameters and thoracic fluid content in normal pregnancy and pre-eclampsia. This was different from patients with cardiovascular disease, where correlation coefficient for these parameters were lower.

Cardiac adaptation is an important feature of maternal cardiovascular changes during pregnancy. The increased preload during normal gestation induces a reversible remodeling of the heart, i.e. left ventricular eccentric hypertrophy, together with a well-preserved left ventricular systolic function [2;24]. The latter probably results from enhanced relaxation of the left ventricle at the start of diastole, probably due to hormonal influences [2]. In pre-eclampsia however, an increased afterload results in left ventricular concentric hypertrophy [2;3;25], a condition often associated with unfavorable outcome and extracardiac target organ damage [4;26]. Pre-eclampsia is not only associated with this type of heart remodeling but also with significant changes in cardiac function: systolic but even more diastolic function are impaired [2-5;27].

Concentric hypertrophy occurs when there is a pressure overload, volume underload and diastolic dysfunction [4], all of which are often present during pre-eclampsia [2-5;25;27]. These features may persist after pre-eclampsia, predisposing to hemodynamic maladaptation to subsequent pregnancy and recurrence of pre-eclampsia [5]. Highly reproducible ICG measurements for contractitily parameters acceleration-, velocity- and heather index indicate that impedance cardiography is an appropriate tool to conduct cardiac contractility studies in pregnancy and preeclampsia.

Thoracic resistance parameters TFC and TFCI also showed high reproducibility in normal and pre-eclamptic pregnancy (Table 2 and Table 3). TFC is a measure of total thoracic fluid content, both intra- and extracellular, which can be measured reliably with ICG [19]. This parameter is for detection of subclinical signs of congestive heart failure in the early stages of pulmonary edema [28;29]. In pre-eclampsia, higher TFC values have been observed in severe than in mild disease [16;30]. At values $\geq$ 65 kohm^{-1}, the relative risk for development of pulmonary edema in peripartum was 18.2 relative to women with lower values [30]. Our results show that ICG may also be a valuable method to assess early stages of pulmonary edema in PE.

Intra- but even more intersession correlation for blood pressure parameters was variable. Diurnal variation for maternal blood pressure has been reported, together with diurnal variation for heart rate [31]. For time periods and volume parameters, intra- and intersession correlation coefficients were lower in pregnancies than in cardiology patients (Table 2 and Table 3) and in healthy subjects [14]. This may relate to the pregnancy-associated inability to regulate heart rate and blood pressure in response to postural alterations [32;33], and increased gestational variability of heart rate and blood pressure [34] which is even higher in pregnancy-induced hypertension [35]. Contrary to observations from others, we found in an heterogenous population of CV patients highly reproducible ICG measurements for contractility, time and volume parameters [13;23;36], which may relate to the specific set-up of our protocol.

From the data presented in Table 2 and Table 3, we conclude that ICG measurements of cardiac contractility and thoracic fluid content using a third generation device in healthy and pre-eclamptic pregnant women correlate well after diurnal- and position-induced challenge. Because normal and pathologic change of cardiac contractility has been reported during pregnancy, our results open perspectives to implement impedance cardiography as a non-invasive method to study (mal)adaptation of cardiac contractility in normal pregnancy and in pre-eclampsia.

Acknowledgements

The authors would like to thank Wilfried Mullens (MD, PhD) of the cardiovascular intensive care unit and Louis Peeters (MD, PhD) of the Maastricht University Medical Centre for their kind help and recommendations in our study.

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Tables

Table 1. Patient characteristics of the three study populations: normal third trimester pregnant women (UP), women with pre-eclampsia (PE) and critically-ill cardiology patients (CV).

NP				PE					CV		
Age	*P*	*Gestational age (weeks)*		*Age*	*P*	*Gestational age (weeks)*		*ProtU (mg)*	*Age*	*Sex*	*Disease*
		Exam	*Delivery*			*Exam*	*Delivery*				
30,5	P1	33,9	36,4	21,1	P0	30,6	31,1	2543	42,2	M	CD4, CD5, non-STEMI
37,0	P4	29,1	40,1	25,9	P0	31,7	32,1	838	82,9	F	HF, V, SD, PD
28,5	P1	35,3	39,4	30,0	P0	34,0	34,1	7823	84,3	F	CD1, CD2, HF
29,1	P0	32,9	40,7	25,5	P0	32,1	32,4	7053	59,5	M	STEMI, CAD
38,0	P2	28,4	39,1	36,9	P1	24,9	26,6	336	73,7	M	CD1, V, CAD
32,2	P1	29,1	38,3	32,2	P1	36,6	36,9	2115	74,3	F	Aortic Dissection
32,3	P2	27,3	35,3	35,4	P0	38,9	40,0	589	84,2	M	CD1, HF, PD
35,2	P1	31,9	38,4	40,5	P0	36,9	39,0	310	62,4	F	CD1, SD, HF, PD
34,2	P1	36,7	40,9	27,2	P0	39,7	40,0	10255	72,0	F	CAD, SD, HF, PD
30,0	P0	33,4	36,9	26,3	P0	36,7	36,9	515	50,9	M	STEMI

P: Parity; ProtU: Proteinuria (mg/24h); Sex: M=Male, F=Female; STEMI: ST Elevated Myocardial Infarction; V: Valve disease; SD: Systolic Dysfunction; HF: left or right-sided decompensated Heart Failure; PD: Pulmonary Disease (pulmonary edema); CAD: Coronary Artery Disease; CD: Cardiac Dysrhythmia (arrhythmia) (types of CD: 1=atrial, 2=junctional, 3=atrio-ventricular, 4=ventricular, 5=heart blocks).

Table 2. Inter-session Pearson's correlation between AM and PM mean values of multiple measurements per position per session per subject (UP: normal third trimester pregnant women, PE: pre-eclamptic women, and CV: critically-ill cardiology patients) (SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, PP: pulse pressure, HR: heart rate, HPD: heart period duration, PEP: pre-ejection period, LVET: left ventricular ejection time , STR: systolic time ratio, ETR: ejection time ratio, SV: stroke volume, SI: stroke index, CO: cardiac output, CI: cardiac index, ACI: acceleration index, VI: velocity index, HI: heather index, O/C-ratio, TFC: thoracic fluid content, TFCI: TFC index, TAC: total arterial compliance, TACI: TAC index).

Mean values		**AM vs PM**											
		UP				***PE***				***CV***			
		A	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
Pressures	*SBP (mmHg)*	0.72	0.41	0.84	0.91	0.67	0.83	0.73	0.60	0.68	0.71	0.48	0.37
	DBP (mmHg)	0.75	0.72	0.69	0.76	0.49	0.37	0.66	0.45	0.63	0.68	0.59	0.81
	MAP (mmHg)	0.85	0.82	0.84	0.83	0.41	0.65	0.69	0.48	0.37	0.65	0.53	0.23
	PP (mmHg)	0.46	0.25	-0.01	0.88	0.60	0.71	0.82	0.60	0.90	0.82	0.76	0.85
Time periods	*HR (1/min)*	0.84	0.38	0.51	0.68	0.77	0.44	0.72	0.61	0.94	0.86	0.86	0.85
	HPD (ms)	0.83	0.46	0.48	0.72	0.74	0.41	0.74	0.51	0.89	0.85	0.84	0.90
	PEP (ms)	0.47	0.25	-0.01	0.88	0.94	0.88	0.57	0.91	0.49	0.71	0.85	0.77
	LVET (ms)	0.18	0.83	0.76	-0.01	0.58	0.00	0.73	0.43	0.46	0.79	0.62	0.74
	STR	0.62	0.79	0.71	-0.22	0.71	0.59	0.55	0.63	0.14	0.69	0.69	0.69
	ETR (%)	0.52	0.69	0.94	-0.27	0.43	0.49	0.74	0.12	0.73	0.88	0.63	0.82
Volumes	*SV (ml)*	0.64	0.79	0.82	0.63	0.85	-0.22	0.74	0.56	0.93	0.89	0.94	0.91
	SI (ml/m²)	0.60	0.84	0.86	0.67	0.82	0.08	0.82	0.60	0.92	0.86	0.90	0.90
	CO (l/min)	0.75	0.70	0.93	0.34	0.82	0.65	0.69	0.43	0.97	0.87	0.90	0.95
	CI (l/min/m²)	0.68	0.67	0.94	0.37	0.75	0.41	0.66	0.39	0.97	0.85	0.90	0.94
Contractility	*ACI (1/100/s²)*	0.90	0.84	0.97	0.93	0.85	0.92	0.89	0.82	0.94	0.94	0.92	0.89
	VI (1/1000/s)	0.94	0.96	0.98	0.95	0.95	0.96	0.95	0.95	0.93	0.95	0.95	0.89
	HI (Ohm/s²)	0.85	0.86	0.92	0.88	0.93	0.90	0.93	0.94	0.93	0.94	0.93	0.93
	O/C (%)	0.26	0.52	0.57	0.60	0.31	0.71	0.54	0.67	0.74	0.24	0.90	0.74
Resistance	*TFC (1/kOhm)*	0.85	0.97	0.97	0.92	0.97	0.95	0.96	0.95	0.63	0.94	0.72	0.70
	TFCI (1/kOhm/m²)	0.90	0.98	0.98	0.94	0.97	0.95	0.96	0.96	0.67	0.95	0.77	0.74
	TAC (ml/mmHg)	0.60	0.76	0.30	0.72	0.85	0.67	0.86	0.42	0.75	0.85	0.85	0.81
	TACI (ml/m²/mmHg)	0.67	0.76	0.49	0.78	0.83	0.69	0.88	0.46	0.71	0.82	0.83	0.81

Table 3. Intra-session Pearson's correlation between mean values of multiple measurements per subject in supine 1 and supine 2 positions within AM or PM sessions (UP: normal third trimester pregnant women, PE: pre-eclamptic women, and CV: critically-ill cardiology patients) (SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, PP: pulse pressure, HR: heart rate, HPD: heart period duration, PEP: pre-ejection period, LVET: left ventricular ejection time , STR: systolic time ratio, ETR: ejection time ratio, SV: stroke volume, SI: stroke index, CO: cardiac output, CI: cardiac index, ACI: acceleration index, VI: velocity index, HI: heather index, O/C-ratio, TFC: thoracic fluid content, TFCI: TFC index, TAC: total arterial compliance, TACI: TAC index).

Mean values		**Supine 1 vs supine 2**					
		UP		***PE***		***CV***	
		AM	*PM*	*AM*	*PM*	*AM*	*PM*
Pressures	*SBP (mmHg)*	0.94	0.89	0.60	0.83	0.77	0.94
	DBP (mmHg)	0.86	0.86	0.92	0.40	0.79	0.72
	MAP (mmHg)	0.88	0.93	0.93	0.63	0.57	0.17
	PP (mmHg)	0.85	0.83	0.29	0.47	0.85	0.94
Time periods	*HR (1/min)*	0.81	0.88	0.92	0.92	0.97	0.93
	HPD (ms)	0.83	0.87	0.94	0.89	0.95	0.94
	PEP (ms)	0.96	0.23	0.91	0.94	0.87	0.73
	LVET (ms)	0.41	0.80	0.70	0.72	0.58	0.92
	STR	0.78	0.38	0.69	0.87	0.65	0.67
	ETR (%)	0.45	0.63	0.57	0.57	0.77	0.78
Volumes	*SV (ml)*	0.47	0.96	0.78	0.89	0.96	0.98
	SI (ml/m²)	0.47	0.97	0.84	0.89	0.96	0.98
	CO (l/min)	0.42	0.92	0.75	0.82	0.96	0.98
	CI (l/min/m²)	0.39	0.92	0.79	0.80	0.95	0.97
Contractility	*ACI (1/100/s²)*	0.96	0.93	0.96	0.98	0.95	0.94
	VI (1/1000/s)	0.97	0.95	0.98	0.99	0.99	0.97
	HI (Ohm/s²)	0.96	0.95	0.95	0.96	0.97	0.96
	O/C (%)	0.51	0.86	0.83	0.67	0.72	0.71
Resistance	*TFC (1/kOhm)*	0.96	0.98	0.99	0.98	0.95	0.99
	TFCI (1/kOhm/m²)	0.98	0.99	0.99	0.98	0.96	0.99
	TAC (ml/mmHg)	0.75	0.86	0.66	0.65	0.79	0.82
	TACI (ml/m²/mmHg)	0.79	0.90	0.65	0.66	0.79	0.80

Figures

Figure 1. Measurement protocol in which blood pressure is taken every two minutes. A calibration period (c) is present before the new blood pressure value is depicted on the screen. The time period during position change is highlighted in black. Data is collected over a timespan of one minute. BP: Blood Pressure.