# Beat-to-Beat Variability of Stroke Volume Measured by Whole-Body Impedance Cardiography

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**Abstract: Beat-to-beat stroke volume was recorded by whole-body impedance cardiography together with heart rate, blood pressure and instantaneous lung volume. Beat-to-beat variability was assessed by spectral analysis. The results showed clear respiration-related variability in stroke volume. The study demonstrated the usefulness of the whole-body impedance cardiography to study beat-to-beat changes in stroke volume or cardiac output.**

## INTRODUCTION

Introduction of reliable noninvasive continuous blood pressure (BP) monitoring devices has made it possible to obtain multivariate cardiovascular beat-to-beat data noninvasively. Recently, advances in impedance cardiography have enabled reliable noninvasive continuous monitoring of stroke volume (SV) [1]. This makes it possible to obtain noninvasively the most important actors of the cardiovascular dynamics: heart rate (HR), BP and SV. The basic relationship between these variables - BP = HR * SV * peripheral resistance [1] - makes it possible to obtain a complete picture about the functioning of the cardiovascular system.

Beat-to-beat variability of HR and BP provides information about functioning of the autonomous nervous system. This has been studied extensively during the last three decades [2]. However, the beat-to-beat variability of SV has been studied much less, largely due to a lack of measurement techniques capable to record beat-to-beat SV. Toska and co-workers [3-5] used ultrasound Doppler method to study the variability of SV and cardiac output together with HR and BP. In this study, we used whole-body impedance cardiography to record SV together with HR, noninvasive BP and instantaneous lung volume (ILV) to demonstrate the usefulness of the method to study beat-to-beat variability of SV.

## EXPERIMENTAL METHODS

*Experimental protocol.* A healthy male subject (age 50, height 189 cm, weight 95 kg) was studied in supine position in quiet laboratory conditions, the subject breathing spontaneously. Prior to recordings the subject rested in supine position for 30 minutes. After a baseline recording (7 minutes), a dobutamin infusion (5 μg/kg/min) was started to challenge the cardiovascular control system. The dobutamin infusion was continued for 8 minutes, after which the infusion was terminated. The monitoring was continued until the BP and HR returned to baseline values.

*Measurements.* Continuous noninvasive BP was recorded from the subject's middle finger by Finapress 2300 device (Ohmeda, Englewood, Colorado, USA). ECG, impedance cardiogram, and continuous respiratory flow were recorded by CircMon B202 device (JR Medical Ltd, Tallinn, Estonia) [1]. The respiratory flow was measured by a bi-directional digital turbine (Cosmed Srl., Italy). The BP, ECG, and respiratory flow waveforms were stored on a computer hard disk at 200 Hz sampling frequency for later analysis. Beat-to-beat SV signal was estimated by the CircMon B202 device. The device has been found to provide accurate estimates on SV in various conditions [1], and it hence allows continuous monitoring of SV.

*Signal processing.* Signal processing and analysis was carried out in Matlab® (The Mathworks Inc., South Natic, MA, USA). The HR was derived from R-waves of the ECG. Beat-to-beat systolic BP (SBP) was derived by detecting the maximum of each BP pulse. SV was defined as the stroke volume attached with each BP pulse. The beat-to-beat series obtained were re-sampled at 5 Hz after linear interpolation of consecutive heartbeats, and then low-pass filtered and decimated to 1 Hz sampling frequency. The respiratory flow signal was transformed into ILV signal, low-pass filtered and decimated to 1 Hz.

*Signal analysis.* Stationary periods (run test, $p<0.05$, [6]) of 300 and 210 seconds were selected for further analysis from the basal and dobutamin periods, respectively. Before the analysis the time-series were de-trended. Power spectral densities (PSD) of the signals were estimated by autoregressive (AR) spectral estimation (model order 20). The spectral power was quantified on two frequency bands: the low frequency (LF, 0.05-0.15 Hz), and high frequency (HF, 0.15-0.45 Hz) bands, corresponding to vasomotor and respiratory bands, respectively [2].

## RESULTS

The respiratory variation of SV could be clearly detected in SV, especially during dobutamin infusion (Figs. 1-2). The dobutamin markedly increased HR, SV, and BP from the baseline values (Table 1). The overall variability of SBP was decreased, especially on the LF range (Table 1, Fig. 2). The HR power on LF band was decreased as well without any marked effect on the overall HR variability. Spontaneous breathing gave rise to broad respiratory spectrum on baseline conditions, in which 13 % of the spectral power of ILV fell on LF range (Table 1). During dobutamin infusion the respiratory

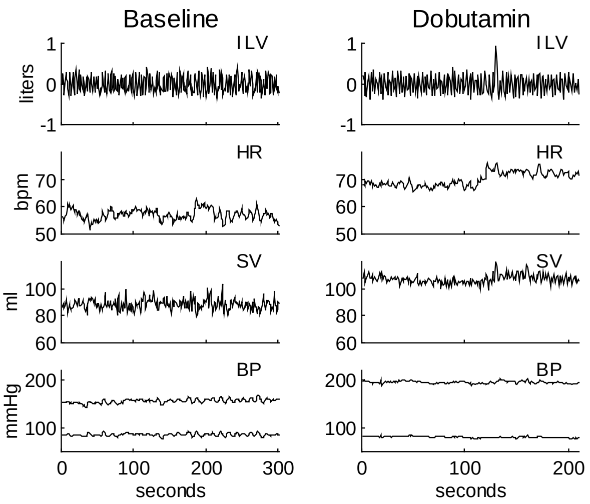


Figure 1. Signals before and after dobutamin infusion.

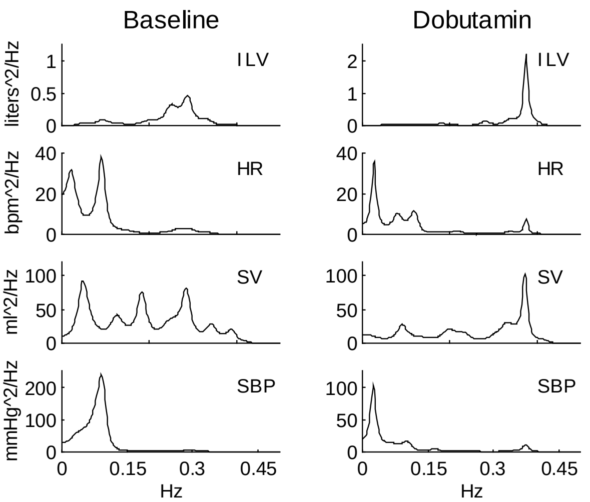


Figure 2. PSDs before and after dobutamin infusion.

Table 1. Effect of dobutamin on hemodymic variables.

| | | Baseline | Dobutamin |
|---|---|---|---|
| Mean (+SD) | | | |
| HR [bpm] | | 57 (1.94) | 70 (2.52) |
| SV [ml] | | 88 (3.86) | 107 (3.22) |
| SBP [mmHg] | | 156 (4.49) | 195 (2.49) |
| ILV [liters] | | 0 (0.20) | 0 (0.23) |
| PSD | | | |
| HR [$bpm^2$] | LF | 1.24 | 0.69 |
| | HF | 0.33 | 0.31 |
| SV [$ml^2$] | LF | 3.70 | 1.38 |
| | HF | 8.62 | 5.43 |
| SBP [$mmHg^2$] | LF | 9.00 | 1.06 |
| | HF | 0.81 | 0.70 |
| ILV [$liters^2$] | LF | 0.0048 | 0.0028 |
| | HF | 0.0335 | 0.0503 |

pattern was regularized, and the respiratory frequency increased (Fig. 2), but the overall power of ILV was not much modified.

## DISCUSSION

In this paper, a novel noninvasive CircMon B202 device was used to measure beat-to-beat SV. The results show that the device provides beat-to-beat estimation of the SV signal in quiet supine conditions. The device is based on whole-body impedance cardiography, which appears to provide good estimation of the mean SV in various conditions [1]. However, the impedance signal appears sensitive to movement and muscle activity artifacts, which may cause some noise in the beat-to-beat measurements. In this study, this may be the partly a reason for the broad SV spectrum (Fig. 2) in baseline conditions (Fig. 2). In addition, the method has potential to disturbance caused by respiratory movements. Our unpublished measurements show that this disturbance is more likely to occur in standing or sitting positions, while during quiet supine position it may be neglected. It may be concluded that the method provides great potential in beat-to-beat monitoring of SV when applied with care.

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