Echocardio-variability - Low and High Frequency Beat-to-beat Variability in Echocardiographic Signals

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Abstract

Measurement signals originating from the cardiovascular system are known to comprise oscillating components and beat-to-beat variability, e.g., heart-rate variability and blood pressure variability. In clinical echocardiographic procedures, typically only a few cardiac cycles are acquired. This pilot study analyses the beat-to-beat variability of echocardiographic variables (echocardio-variability) in minute long acquisitions.

Simultaneous echocardiography, including electrocardiography and respiration, and continuous blood pressure measurement were acquired from seven healthy subjects and two patients with cardiac disease. Variability of echocardiographic variables and their coupling to respiration, heart rate variability and blood pressure was analyzed.

Results showed that healthy subjects had higher variability (30%), compared to patients (10%). The variability in a high frequency band was similar in a low frequency band. Patients had lower coupling to heart rate variability than to blood pressure variations.

Analyzing the echocardio-variability and its coupling strength to additional physiological signals, may serve as the basis for the development of novel diagnostic indices.

1. Introduction

One of the main objectives of echocardiographic examinations is the estimation of intra-cardiac pressures and pressure gradients. In particular, the ratio between early diastolic blood flow velocity and early diastolic myocardial velocity (i.e., E/Em) is often used to assess left ventricular filling pressure (e.g., [1]). Typically, a few cardiac cycles are recorded and the average readings are calculated.

The cardiovascular system comprises several oscillating components with the potential to modulate the E and Em: physiological transients, respiration, load, heart rate variations, blood pressure variations, etc [2, 3]. In particular, the heart rate variability (HRV) has been thoroughly investigated based on the beat-to-beat variation of the R-R interval of the electrocardiogram (ECG).

The aim of this pilot study was to assess the beat-to-beat variability in common clinical echocardiographic variables (echocardiographic variability, ECV) in healthy subjects, and patients.

2. Method

2.1. Subjects

Five young (group Y) and two older (group O) healthy subjects (20-35y and 50-60y), and two patients (group P) with biopsy proven amyloid cardiac disease [4] (50-70y), participated in this pilot study. All subjects were given informed consent and the project conformed to the declaration of Helsinki and was approved by the local ethics committee.

2.2. Echocardiography and blood pressure acquisition

Minute long ultrasound image sequences were acquired using a Vivid E9 ultrasound scanner with a M5S cardiac probe (GE Medical, Horten, Norway). Subjects were examined in the semi-recumbent relaxing position, turned 45 degrees to the left side. Sector depth, width and location was optimized for maximal frame rate, and allowing simultaneous registration of myocardial motion (B-mode) on the septal myocardial wall and blood flow velocity (color Doppler imaging, CDI) across the mitral annulus. Apical two-chamber views with 45 degrees field-of-view in B-mode covering the ventricular septum in an axial orientation was obtained, along with ROI with CDI covering the tip of the mitral valves. Respiration and ECG were recorded simultaneously. The frame rate of the CDI and B images were about 100 Hz and 33 Hz, respectively. Image sequences were exported in the hdf5 format, with B-mode and CDI-modes as separate images at 8-bit resolution, for offline processing.

Simultaneous myocardial tissue velocity (E') and mitral flow velocity (E) were quantified per heart beat by validated in house software [5]. Tissue velocity curves were obtained by a speckle-tracking technique from a ROI within the septum of the corresponding B-mode images, and mitral flow velocity was measured using a spectral velocity representation from a ROI over the tip of the open mitral valves.

In addition to the echocardiography, simultaneous blood pressure signals were recorded from the index finger using the Finometer Pro device (Finapres Medical Systems, Amsterdam, Netherlands).

2.3. Variability analysis

Prior to analysis, the beat-to-beat recordings of echocardiographic variables (E, Em and E/Em), respiration, RR interval and blood pressure (BP) were re-sampled to equidistantly sampled data at 4 Hz.

Three modes of variability were assessed in this work based on the: 1) overall response (up to 0.5 Hz); 2) low frequency (LF) region (0.001 - ~0.15Hz); and 3) high frequency (HF) region (~0.15 – 0.5 Hz). This is similar to procedures used in HRV analysis, were the HF region relates to the response due respiration, and the LF region relates to autonomic activity due to thermal and blood pressure regulation among others [2]. Upper LF and lower HF cut-off frequencies were adjusted manually by visual inspection of the respiration power spectral density plot and finding the low frequency onset of the respiration peak (see Fig 2 for illustration of bands).

Echocardio-variability was quantified using the coefficient of variation (CV)

$$CV = \sigma / \mu ,$$

where σ is the standard deviation and μ is the mean of a signal. The LF and HF subband signals were obtained using 4th order Butterworth bandpass filtering with the LF and HF regions as cut-off frequencies.

The coupling strength of the E, Em and E/Em signals to the respiration, blood pressure variations and heart rate variability (RR interval), respectively, was quantified by the coherence power index (CPI):

$$CPI = \frac{\int C_{x,y}(f) P_y(f) df}{\int P_y(f) df}$$

where

$$C_{x,y}(f) = \frac{\left| P_x(f) \cdot P_y(f) \right|^2}{P_x(f) \cdot P_y(f)} ,$$

is the coherence function, and *Py(f)* and *Px(f)* is the power spectral density of *y(t)* and *x(t).* Power spectral densities and coherence function were determined using Welch's method (averaged periodograms).

Non-parametric statistical methods were used in all comparisons, with $p<0.05$ was considered significant.

3. Results

Figures 1 and 2 demonstrate typical recordings and corresponding power spectral densities from the different echocardiographic variables and for the respiration, RR interval, and blood pressure signals, respectively.

3.1. Variability

Figure 3 presents the results on the overall, HF band , LF band and difference between HF and LF variability of the E, Em and E/m for the different groups of subjects. For the shole bandwidth and HF band the healthy subjects had the highest CV and the patients the lowest. In specific, for E/Em, the healthy subjects had significantly higher CV compared to patients (20-30 vs 10 %), $p<0.05$ Kruskal-Wallis (Fig. 3 top). E had significantly lower variability than Em. There were no differences in the CV between the HF and LF band (Fig. 3 bottom).

3.2. Coupling

Figure 4 presents the results on the coupling of the E, Em and E/Em variables to respiration, blood pressure, and RR interval signals.

In general the coupling was relatively weak (ranging from 20-40 % in most cases). The difference in coupling between RR and BP was significantly lower in patients and old as compared to young healthy, $p<0.05$, (Fig. 4 bottom).

4. Discussion

This pilot study demonstrated the variability of common clinical echocardiographic variables in low and high frequency subbands, and analyzed their relation with respiration, blood pressure variability and heart rate variability (RR).

In general, the beat-to-beat variability of investigated echocardiographic variables was high (range 10-50 %). The echocardiography guidelines recommend acquiring images at the end-expiration phase, as an attempt to eliminate the influence of respiration. Our results verify

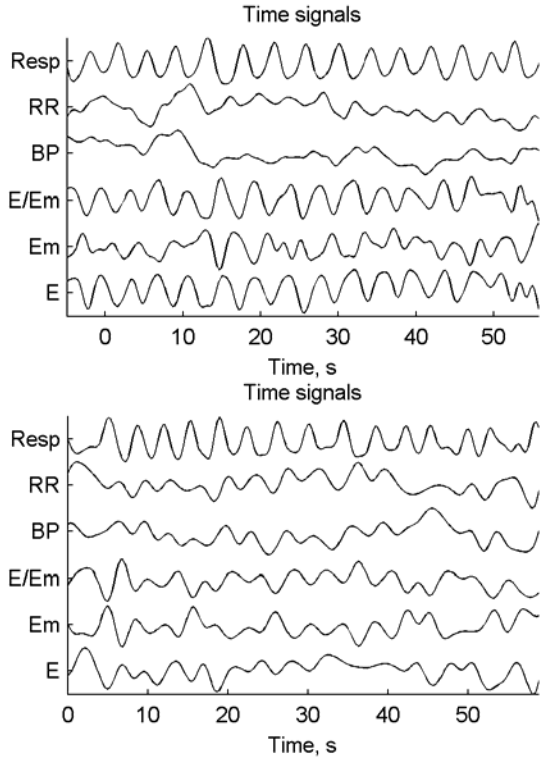

Figure 1: Examples of beat-to-beat variability in some echocardiographic variables, RR, blood pressure (BP), and corresponding respiration, for two subjects A (top) and B (bottom).

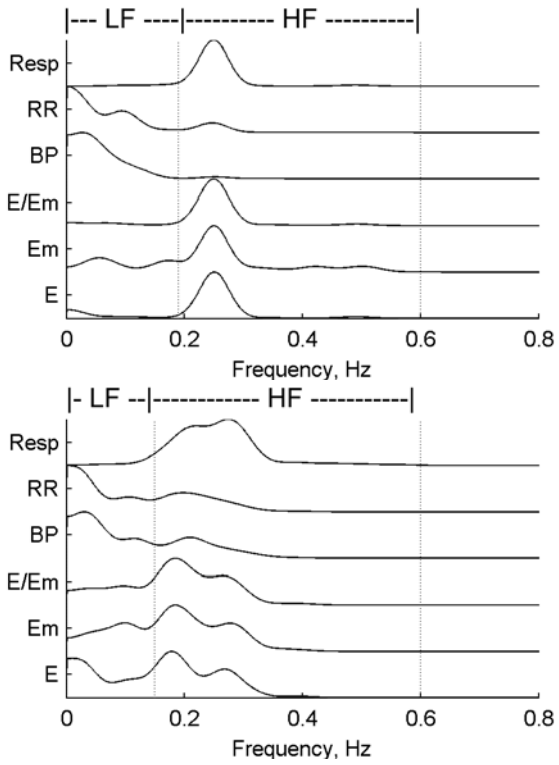

Figure 2: The power spectral densities of the analysed signals for the corresponding signals from the subjects in Fig. 1. Dotted lines indicate cut-off frequencies used for the LF and HF bands, for the variability calculations.

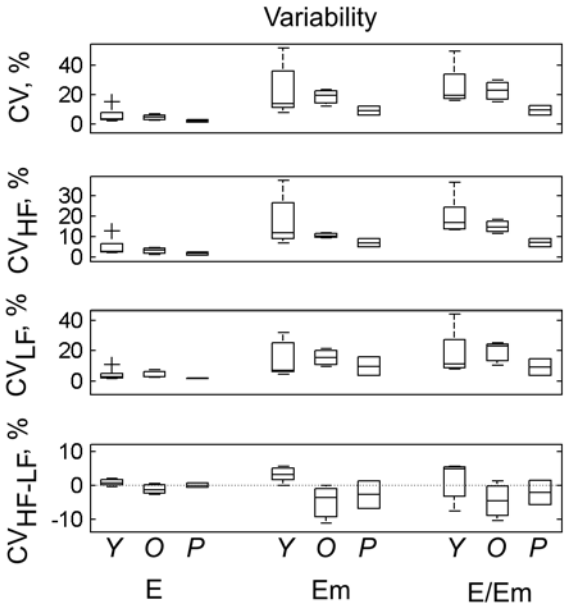

Figure 3: Variability (coefficient of variation, CV) of the variables for the different groups of subjects: Young (Y), Old (O) and patients (P). Top plot is overall variability, second and third plot presents the HF and LF bands, and the bottom is the difference in between the HF and LF bands.

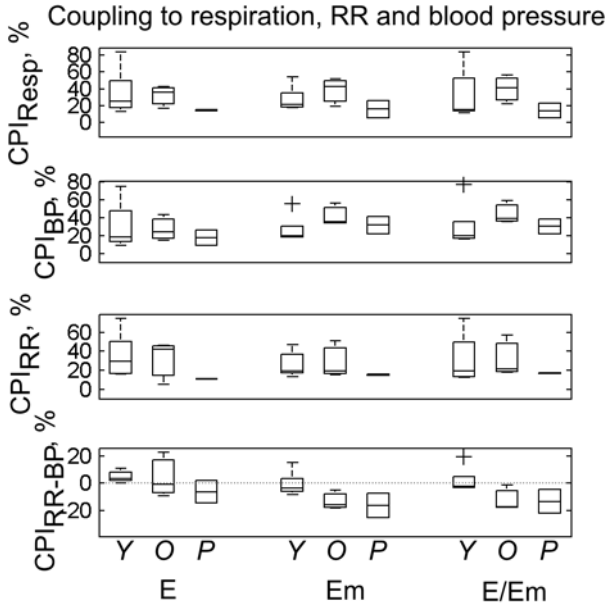

Figure 4: Coupling strength (coherence power index, CPI) between the variables and the respiration (top), blood pressure (BP, second), and RR signals (third). The bottom plot presents the difference between the CPI of the RR and BP signals.

the influence of respiration on the variables (seen in the HF band variation). However, we also found that variability in the LF region had similar magnitude. Thus, even though the guideline procedures are used it seems that similar variability will remain due to LF variations, and may influence the clinical evaluation.

The coupling (CPI) between the variables and the respiration, BP and RR was similar and relatively weak (about 10-60%). In patients and old subjects the coupling to BP was significantly stronger compared to the RR. There was no difference for the young subjects. The weak coupling to respiration may be accounted the free-breathing of the subjects during the recordings (non-stationarity and large bandwidth at the respiration frequency). In addition, the CPI may also have been reduced due to the fact that the beat-to-beat echocardiographic signals had a relatively large bandwidth as compared to the blood pressure and RR signal, and is probably also influenced by several components in the LF region.

5. Conclusions

Analysing echocardio-variability (ECV) demonstrated that variability is similar in echocardiographic variables although guideline procedures are undertaken. Variability was lower in patients compared to healthy subjects.. Taken together, analysing the variability of echo variables and coupling strength to respiration, blood pressure and heart rate variability seems a promising tool for the development of novel diagnostic indices.

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