Seven years follow-up of ballistocardiogaphy

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Abstract

This work serves as a method description, where ballistocardiography (BCG) and pulse waves were used to study longer term alterations of heart-vasculature system. BCG and pulse signals were recorded from one person in sitting position by using Electromechanical Film (EMFi) sensors during 7 years time interval. ECG, BCG, carotid pulse (CP) signal from the right side of the neck near the carotid artery and the left ankle pulse wave (in five recordings) were recorded from one person. Duration of the signal components according to R wave from the ECG, amplitudes and spectral components of the signals were studied. Pulse wave velocity (PWV) values were calculated in order to compare aortic blood pressure (BP) to values obtained with commercial Omron BP measurement device.

The time domain properties of CP and BCG signals during seven years time remained fairly stable within the same person. Also when the signals were estimated visually in spectral domain from the seat BCG and especially from the CP, no major differences were found. Minor alterations in the frequency of the spectral spikes may be due to heart rate changes between measurements or due to slight changes in the arterial elasticity having an influence to the spectral traces. Obtained PWV values followed closely BP changes measured with Omron BP measurement device.

Keywords: EMFi, BCG, follow-up, blood pressure

Tiivistelmä

Työssä tutkittiin menetelmäkuvauksena sydän-verisuoniston tilan muuttumista seitsemän vuoden aikavälillä käyttäen hyväksi EMFi anturia, jolla mitattiin ballistokardiogrammia (sydämen rekyylivoimien mittaaminen kehon ulkopuolelta ei-tunkeutuvalla menetelmällä) sisältäen pulssiaallon mittauksen. Yhdeltä henkilöltä äänitettiin istuin ballistokardiogrammi, kaulavaltimon pulssiaalto ja nilkasta nilkan pulssiaalto. Signaalien ajalliset kestot ja amplitudit määritettiin käyttäen EKG:n (sydämen sähköinen signaali) R aaltoa viitekohtana ja signaaleille suoritettiin Fourier muunnos ja saatiin signaalien spektrit. Tarkoituksena oli tutkia sydän-verisuoniston pidemmän aikavälin muutoksia ja määrittää menetelmän toistettavuutta. Jotta menetelmä olisi hyödyllinen sydän-verisuoniston tilan diagnosoinnissa, sen täytyy tarjota myös uutta tietoa diagnoosin tueksi ja oltava toistettava ollakseen hyödyllinen tavanomaisessa kliinisessä tutkimuksessa. Jos menetelmän toistettavuus on huono, ei sen diagnostinen herkkyyskään voi olla hyvä. Aikatason ja vastaavien spektrien muutokset olivat melko pieniä seitsemän vuoden aikana tutkitulla henkilöllä. Tässä tutkimuksessa esitetty mittausjärjestelmä, mikä käyttää EMFi anturia ballistisen informaation saamiseksi ihmiskehon sydän-verisuonistosta tunkeutumattomasti on osoittanut olevansa lupaava ehdokas hankittaessa olennaista tietoa diagnoosin tueksi.

Avainsanat: Elektromekaaninen kalvo (EMFi), seuranta, verenpaine

Introduction

Ballistocardiography (BCG) is a non-invasive method for cardiac and respiratory evaluation and it reflects closely the strength of myocardial contraction revealing the condition of the heart [1]. When the heart pumps blood from atrium via ventricles to the pulmonary arteries and ascending aorta, through aortic arch to the peripheral circulation, recoil of opposite direction is applied to the body and its force and direction is changing according to the cardiac cycle. The BCG waveforms have been divided into three groups, labelled with letters; Pre-ejection (FGH), ejection (IJK) and diastolic part of the heart cycle (LMN) [1]. The peak of the H coincides with the end of the tension phase and the onset of the rapid expulsion of the blood from the heart into aorta [2]. The foot ward pointing I wave reflects the rapid acceleration of blood in the ascending aorta and pulmonary arteries around the aortic arch and into the carotid arteries. The J wave describes acceleration of blood in the descending and abdominal aorta and deceleration of blood in the ascending aorta. I-J amplitude reflects the force of contraction of the left ventricle [3] and I-J velocity reflects contractility [1]. It is also defined, that the upper smaller part of the HI segment represents the recoil generated by the contraction of the left atrium and the lower part of the HI and the entire IJ segment correspond to the contraction of the left ventricle. The HI amplitude is formed mainly by the acceleration of flow in the ascending aorta and the IJ amplitude from the accelerating and after aortic arch in the descending part of the aorta from decelerating of blood flow [3]. BCG has been used former to detect myocardial weakness and incoordination, that is to evaluate myocardial contractility [4]. Early typical defects in myocardial contractility were registered with high sensitivity in patients with coronary atherosclerosis and ischemic heart disease [5].

The carotid pulse (CP) is a pressure signal recorded from the carotid artery when it passes near the surface of the body in the neck. It indicates the variations in arterial blood pressure and volume with each heart beat. As the recording place is located very near the heart, the CP signal resembles the morphology of the pressure signal at the root of aorta [3]. The CP rises abruptly with the ejection of blood from the left ventricle to the ascending aorta reaching a peak called a percussion wave (P). The following secondary wave is called as a tidal wave (T), caused by a reflected pulse returning from the upper body. Dicrotic notch (D) is caused by a closure of aortic valve and this can be followed by dicrotic wave (DW), which is due to reflected pulse from the lower body [6] (Fig. 1). The carotid pulse supplements the BCG data by giving the onset of the ejection phase and can give information about the coordination of the cardiac activity.

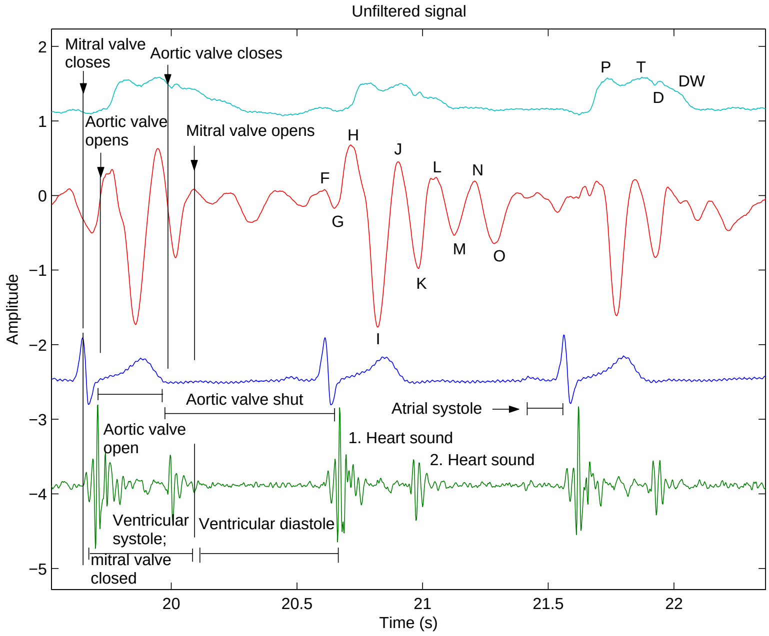

Figure 1. Signals recorded in sitting position; suppressed respiration. Blood pressure 147/93, pulse 67. Signals from the bottom to top: PCG (heart sound), ECG, signal from the EMFi sensor on a chair and from the carotid artery recorded with EMFi sensor strip. The CP pulse wave, shape, amplitude and rhythm of pulsation help in the diagnosis of different cardiovascular diseases.

In order to be useful in cardiovascular diagnostics, a method of a measurement system used has to offer some new information to support diagnosis. Also it has to be repeatable and reproducible in order to be useful in routine clinical studies. If the repeatability and reproducibility of the proposed measurement system is poor, the diagnostic sensitivity cannot be high either.

In this paper a Mobile Physiological Signal Measurement Station has been used as a device, which enables the recording of BCG, carotid and ankle pulse signals with EMFi sensors [7]. The main goal of this study is to analyse reproducibility of the seat BCG, CP and ankle pulse signals by the means of temporal, amplitude, PWV and spectral differences during seven years interval. The mechanical function of the myocardium during the study period was evaluated by defining amplitude ratios from the main systolic complexes of the BCG [3]. We have earlier shown that signal components of BCG are repeatable in consecutive recordings as well as reproducible in longer time recording intervals [8]. Now the reproducibility of the signals was studied between seven years interval. Temporal values of the signal components were also studied in order to define the constancy of the signals.

Methods

The EMFi [9] sensor is basically a thin biaxially oriented plastic film coated with electrically conductive layers which are permanently polarized. Changes in the pressure acting on the film generate a charge on its electrically conductive surfaces and this charge can be measured as a current or a voltage signal. It can convert mechanical energy to electrical and vice versa. Thus the EMFi acts as a sensitive movement sensor suitable for BCG recordings. Signals from EMFi sensors were recorded with the Mobile Physiological Signal Measurement Station [7] into a notebook computer with a data acquisition card (AD card; Daqcard 6036E) and the recordings were made into ASCII format. In the Mobile Physiological Signal Measurement Station an active Butterworth 8. degree low pass filter was used, where the cut-off frequency was 256 Hz. In chair recordings the EMFi sensor (42 cm x 36 cm) was beneath the measured person. One EMFi sensor strip (15 cm x 2 cm) was attached on the neck near carotid artery and to the ankle in some recordings. The same recording device, AD card, chair, BP measuring device (Omron) and EMFi sensors were utilized in recordings during seven years interval.

Measurements

The recordings were made from the BCG and carotid and ankle pulse signals from a single person in a sitting position measured with EMFi sensors. All the measurements lasted about 3 min and the used sampling frequency was 500 Hz. Just before the measurements the blood pressure and the pulse were measured with Omron M5-I BP monitor device.

The R wave of ECG was used as a reference in detecting the slopes from BCG and carotid pulse signals. The P point in the neck CP signal was chosen for the measurement for a reason that the end point of ejection is not seen so clearly as an exact end point in the CP signal, but it is overlapped by two reflected pulses. The CP pulse signal consists of a direct component (peak P), which is followed by a plateau (T; reflected pulse from the upper body) and from the reflected component from the lower body (DW). The direct and reflected pulses overlap, which is seen as traditional CP waveform (Fig. 1). The left ankle pulse signal (dorsalis pedis pulse) in five recordings was used to obtain pulse wave velocity (PWV), as it reflects aortic BP and is a measure of aortic elasticity.

Signals were first band pass filtered (0.5 – 30 Hz FIR, 700 taps, time delay corrected), down sampled into 100 Hz and the analysis was done with 0.5s window length. The index of the R point was detected first by differentiating (2 points), squaring and integrating (5 points) and by taking the maximum from the ECG signal. The I slope from the BCG was detected by local minimum method and then the J slope was detected by local maximum using the index of the I point as a starting point. Other slopes were detected at the same way. Amplitude spectrum was calculated from the raw signal, cumulated (by adding current spectrum value to amplitude scaled value) and normalised.

In order to study the contraction of the left ventricle, amplitudes H-I (AHI), I-J (AIJ), J-K (AJK) and K-L (AKL) from the BCG signal and amplitudes E-P (AEP), E-T (AET) and E-D (AED) from the carotid artery signal were extracted (Fig. 2). Also the median duration of the time intervals of the waveforms with reference to the R wave of the ECG from seat BCG, carotid artery and ankle pulse signals were extracted. Moreover, the median TED of the ejection time from the carotid artery and the THI and THK from the BCG signal along with other temporal parameters were extracted [2]. THI is the time of the rapid ejection phase of the systole. THK is the period of the blood expulsion phase from the ventricles. TRH is the measure of the isometric tension phase of the ventricles. TRK is the duration of the mechanical systole of the heart [2]. The measured time delay seen especially in carotid artery signal between different people is a function of both distance and/or elasticity or compliance of the vessels. The IJ/HI amplitude ratio as an index was defined in order to define the functional state of the myocardium [7].

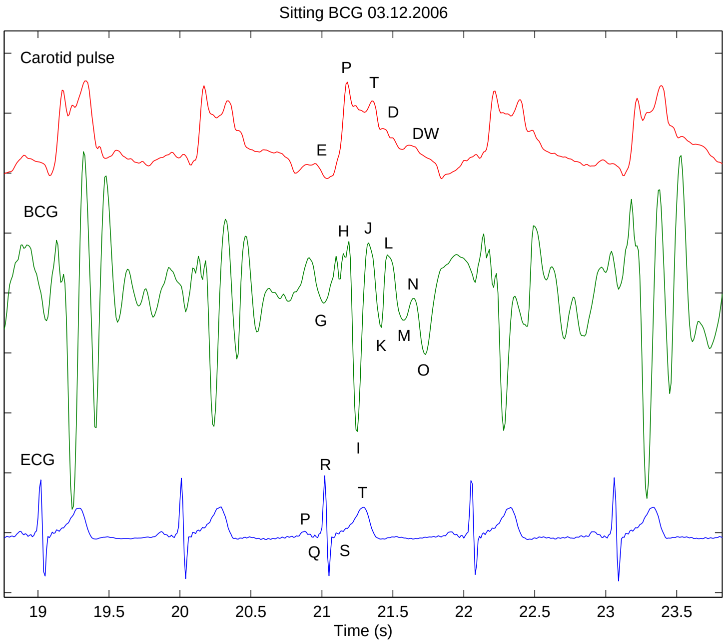

Figure 2. From top to down: CP, BCG and ECG. Respiration modulates BCG signal; when inhaling the amplitudes of the systolic BCG signal increase and when exhaling they decrease. The peaks of the forwarding wave (P) and returning wave (T) as well as other components and dicrotich notch (D) are easily recognizable from the picture.

Results

When obtained recordings were compared between seven years interval from the same person, some minor temporal and in some years amplitude differences were detected (Tables 1-3). All the calculated amplitude ratios (AIJ/AHI, AJK/AIJ) and temporal ratio (TIJ/HI) showed quite large fluctuation (Table 2). Temporal components of the BCG, CP and ankle pulse signal remained fairly stable, being also dependable on the heart rate at the moment of measurement. All EMFi sensors were able to produce good quality signals, as seen in (Figs. 1-4) presenting the ECG, BCG, carotid pulse and ankle pulse (Figs. 3-4) signals measured from the same person with different time intervals.

The constancy of the recordings during seven years is seen in spectral domain pictures from BCG (Fig. 6) and especially from CP signal (Fig. 5). The calculated PWV values reflect the changes measured with Omron BP measurement device (Table 3).

Table 1. Mean time domain values in seconds and amplitudes in arbitrary units in sitting position from seat BCG and recorded with EMFi sensors: T_{HI}, T_{HJ}, T_{IJ}, T_{HK}, T_{RH}, T_{RI}, T_{RJ}, T_{RK}, T_{RL}, A_{HI}, A_{IJ}, A_{JK}, A_{KL}. T_{IJ} is the contraction time, T_{HJ} reflects temporal aortic wall changes, T_{RH} reflect the tension phase of the ventricles. T_{RK} is the duration of the entire mechanical systole. T_{HK} is the time of expulsion from the ventricles; the systolic complex.

Date	T_{HI}	T_{HJ}	T_{IJ}	T_{HK}	T_{RH}	T_{RI}	T_{RJ}	T_{RK}	T_{RL}	A_{HI}	A_{IJ}	A_{JK}	A_{KL}
031206	0,12	0,19	0,08	0,28	0,11	0,22	0,31	0,39	0,46	0,86	0,84	0,48	0,57
141007	0,13	0,21	0,09	0,28	0,11	0,24	0,33	0,40	0,47	0,96	0,96	0,55	0,63

020208	0,13	0,21	0,09	0,29	0,11	0,23	0,32	0,39	0,46	1,20	1,25	0,69	0,63
161208	0,14	0,22	0,08	0,29	0,11	0,24	0,33	0,39	0,47	0,99	0,80	0,54	0,77
060209	0,09	0,18	0,09	0,26	0,11	0,20	0,29	0,37	0,46	1,74	1,65	0,55	0,26
160610	0,11	0,18	0,07	0,27	0,11	0,22	0,29	0,38	0,45	1,14	0,99	0,54	0,78
131110	0,14	0,22	0,08	0,29	0,10	0,23	0,31	0,38	0,46	1,18	1,20	0,66	0,77
130111	0,10	0,18	0,07	0,26	0,10	0,21	0,28	0,36	0,43	1,57	1,79	0,93	0,54
140112	0,13	0,22	0,08	0,29	0,10	0,23	0,32	0,40	0,47	1,15	1,11	0,65	0,79
Mean	0,12	0,20	0,08	0,28	0,11	0,23	0,31	0,38	0,46	1,20	1,18	0,62	0,64
SD	0,02	0,02	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,28	0,35	0,14	0,17

Table 2. Mean time domain values in seconds and amplitudes in arbitrary units recorded with EMFi sensors. T_{RP}, T_{EP}, T_{ED}; ejection time, T_{PT}, T_{PD}, T_{PDW} , amplitudes A_{EP}, A_{ET} and A_{ED}.

Date	T_{RP}	T_{EP}	T_{ED}	T_{PT}	T_{PD}	T_{PDW}	$T_{IJ}/_{HI}$	A_{IJ}/A_{HI}	A_{JK}/A_{IJ}	A_{EP}	A_{ET}	A_{ED}
031206	0,16	0,11	0,35	0,17	0,24	0,27	0,68	0,97	0,57	0,12	0,09	0,02
141007	0,18	0,09	0,30	0,14	0,21	0,25	0,66	1,00	0,57	0,11	0,13	0,02
020208	0,17	0,12	0,34	0,15	0,23	0,26	0,69	1,04	0,55	0,07	0,08	0,01
161208	0,16	0,05	0,26	0,12	0,21	0,26	0,59	0,81	0,68	0,04	0,03	0,01
060209	0,13	0,06	0,31	0,14	0,25	0,29	0,95	0,95	0,34	0,09	0,06	0,02
160610	0,15	0,10	0,32	0,17	0,22	0,25	0,62	0,87	0,54	0,09	0,09	0,02
131110	0,16	0,13	0,34	0,32	0,21	0,25	0,59	1,02	0,55	0,08	0,08	0,01
130111	0,14	0,08	0,31	0,16	0,23	0,26	0,72	1,15	0,52	0,11	0,09	0,03
140112	0,16	0,08	0,31	0,16	0,23	0,26	0,64	0,96	0,58	0,07	0,06	0,00
Mean	0,16	0,09	0,31	0,17	0,22	0,26	0,68	0,97	0,54	0,09	0,08	0,02
SD	0,02	0,03	0,03	0,06	0,01	0,01	0,11	0,10	0,09	0,03	0,03	0,01

Table 3. Mean time domain values in seconds and amplitudes in arbitrary units from CP and ankle recorded with EMFi sensors. The pulse value measured from the Omron BP device just before the measurement reflects well a true pulse value calculated from the ECG signal (Pulse $_{RR}$).

Date	T_{RUv}	T_{HK}/T_{RK}	T_{RVv}	A_{UvVv}	$BP_{Sys/diast\ Omron}$	$PWV_{Foot/max}$	Pulse $_{Omron}$	Pulse $_{RR}$
031206	na	0,71	na	na	157/96	na	58	58,7
141007	na	0,71	na	na	145/93	na	59	58,0
020208	na	0,73	na	na	133/87	na	60	63,4
161208	na	0,73	na	na	134/90	na	65	63,9
060209	0,18	0,71	0,28	0,20	158/93	5,8/3,7	75	80,2
160610	0,12	0,72	0,29	0,11	163/103	8,7/3,6	60	60,3
131110	0,18	0,75	0,30	0,03	135/88	5,8/3,5	59	62,4
130111	0,17	0,71	0,26	0,03	156/88	5,8/4,0	76	68,8
140112	0,18	0,74	0,30	0,27	142/87	6,1/3,5	61	62,5
Mean	0,17	0,72	0,29	0,13	147/91,7	6,4/3,7	63,7	64,2
SD	0,02	0,01	0,02	0,10	11,7/5,3	1,3/0,2	7,00	6,78

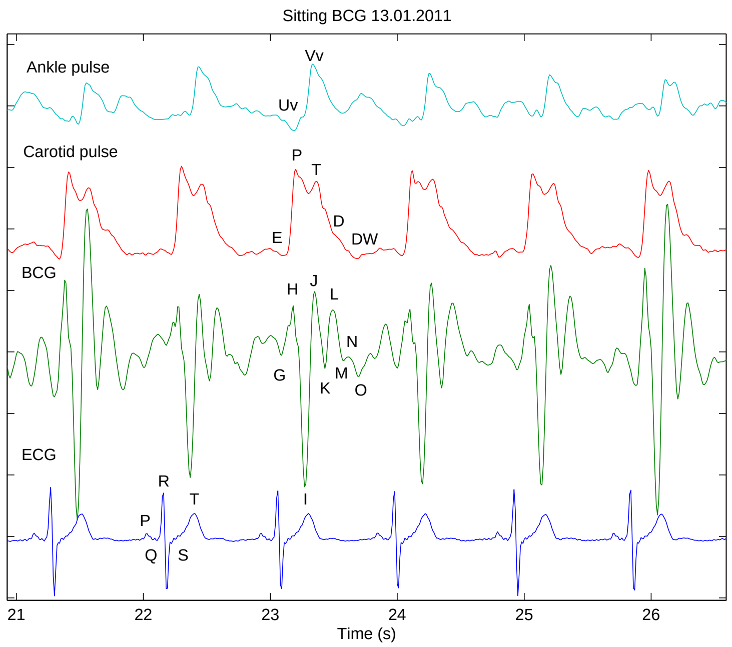

Figure 3. From top to down: Ankle pulse, CP, BCG and ECG. The signal traces seem mostly alike when compared to same traces in figure 2.

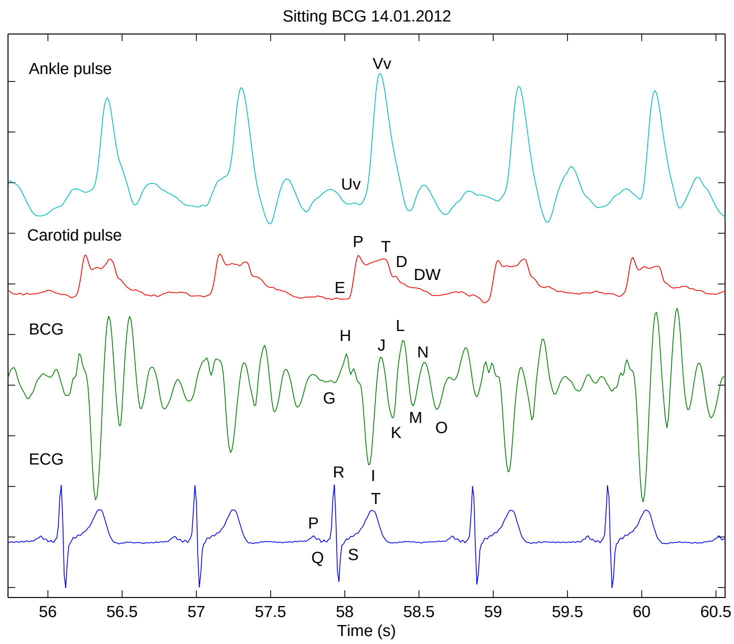

Figure 4. Signal traces labelled as in (Fig. 3). Very well developed ankle pulse signal is seen. This may be due to vigorous physical exercise done in a previous day before the measurement and moderate exercise was made also about three hours before the measurement.

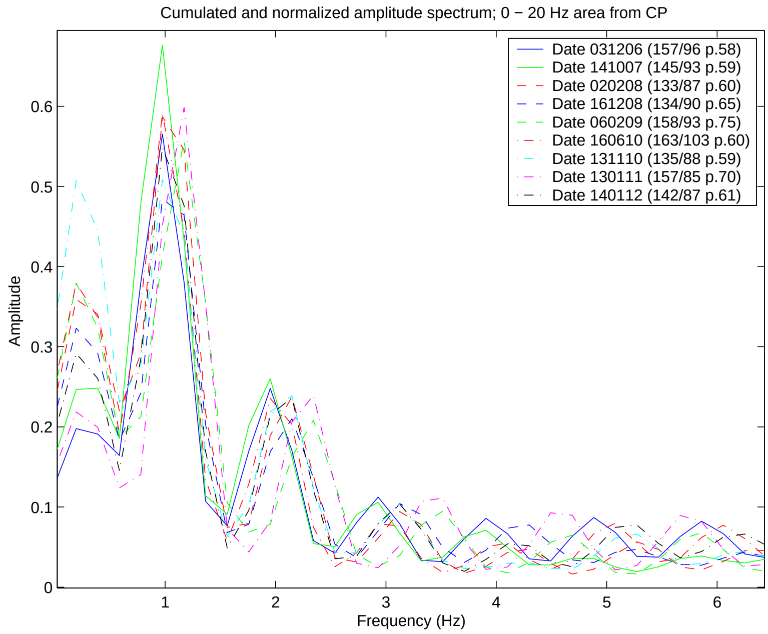

Figure 5. CP spectrum shows a stability of a carotid pulse signals and thus a constancy of systolic ejection pattern of the heart. The constancy of the spectral components in longer time interval is apparent. The shifting of the frequency spikes to the right towards higher frequencies due to increase in heart rate is seen especially with elevated heart rates in 060209 and 130111. The 1 Hz is the heart rate frequency.

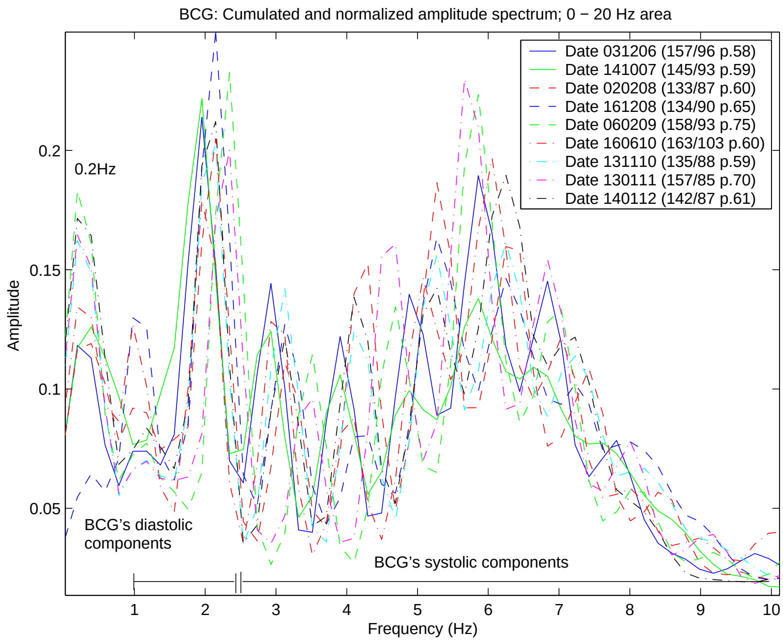

Figure 6. Seat BCG spectrum during seven years interval shows the highest frequency spikes in 2 and 6 Hz. The 0.2 Hz denotes the breathing frequency 12 beats/min. The highest spikes in seat BCG differ from CP both in amplitude and in frequency (Fig. 4). As aortic pulse propagates along with aorta and thru body structures to the seat EMFi sensor, it carries information about elasticity of the aorta and intermediate tissues seen as spectral presentation in the picture.

Discussion

In this study a measurement system, which uses Electromechanical Film (EMFi) sensors in obtaining ballistic information from the heart and connected circulatory system, has proven to be a promising candidate in obtaining vital information to support diagnosis. Being reproducible the proposed measurement system and method could be useful also in clinical studies.

The time domain and spectral properties of the seat BCG, carotid artery and ankle signals remained relatively stable between the same people measured between seven year intervals. The BCG trace from healthy people has been characterized by a 'considerable distinctness of the waves and a constancy of all the time intervals' [2]. This seemed to be the case also in this study. Human blood pressure is characterized by a wide physiological variability, which is influenced by heart rate, breathing, emotional state and the condition of the person in question. Fluctuation happened also in the state of physical condition during study time having its own effect to the measured signals. Pulsation changes constantly and its dynamics reflects the function of the heart-vasculature system. In this study the resting pulse seemed to remain quite stable indicating possibly constancy in general physics.

The IJ/HI amplitude ratio reflects the functional state of the myocardium and showed the largest fluctuation during this study (along with the left ankle pulse amplitude). As the magnitude of the IJ amplitude is determined by the aortic acceleration flow, it mainly correlates with the left ventricle contraction force. The level of physical exercise during past years has its own influence to the contraction force of the heart. The level of physical exercise was not measured during this study, but obtained IJ/HI values also indicate, that there were also changes in the factors affecting to this ratio. These changes may be related to BP and therefore to arterial elasticity changes, as the highest BP values (160610) produced the second smallest amplitude (AIJ/AHI) ratio and fairly low temporal (TIJ/HI) ratio possibly reflecting increased aortic resistance. By using the IJ/HI amplitude ratio many difficulties due to effects of height, weight and body shape on IJ amplitude is avoided [3]. By using amplitude ratio, the problem with calibration disappears, as in this study the amplitudes of the signals are in arbitrary units. The IJ amplitude is known to decrease relatively more than the HI amplitude decreases in subjects with confirmed ischemic heart disease seen as changes in IJ/HI amplitude ratio when compared to normal healthy subjects [3]. In this study the measured person had no confirmed heart disease and as the HI and IJ amplitudes are almost equal as seen in time domain figures, the small differences in amplitudes may be due to fluctuation in the level of physical condition reflected to the BP level seen as in the mechanical function of the myocardium. The level of physical fitness and the age of a person have their own influence into the measured signals.

In this study the obtained heart rate values remained very stable underlining more the temporal comparability of the signals (Tables 1-3). The increasing heart rate is generally seen as reduced duration of the systolic signal components, as seen in recordings 060209 and 130111 (TIJ/HI). The shifting of the frequency spikes to the right towards higher frequencies due to increase in heart rate was seen also in CP signal (Fig. 5). By computing Fourier transform of the waveforms (signals were derived to their respective sinusoidal components) the frequency dependence of the arterial impedance was obtained describing comprehensively and completely an arterial system [10,11]. The comparatively constant level of impedance modulus at high frequencies equals to characteristic impedance of the proximal aorta [11]. The characteristic impedance of the vessel describes fully the wave propagation characteristics of the vessel segment [12]. In (Fig. 6) the spectral area from about 2.5 to 10 Hz describes BCG's systolic components being related to the blood's recoil due to the ejection of the heart to the ascending aorta. The examination of the BCG's spectrum gives information about the amount of wave reflections in the arterial system. Flatter spectra may imply smaller or more diffuse reflections and an impedance spectral pattern with higher spectral wave amplitudes may reveal more reflections in the arterial system. The differences in impedance spectral traces correlate to the differences in ascending aortic pressure waveforms and are related to the magnitude of the reflections [13]. According to presented time domain and spectral figures the aortic reflection pattern seemed to remain quite stable during the studied interval.

As the PWV was calculated from two different locations of the ankle pulse, allowing the comparison of the PWV results (Table 3) from the foot point and from the top of the ankle pulse signal. Despite the visual confirmation of the right detection point of the foot point in ankle pulse signal, the PWV value in the last recording from the foot shows higher value than expected. In this study, the foot of the pulse wave was detected by local minimum method. Minimum method in foot point detection may fail, as some fluctuation in the signal may happen before the main ejection of the heart placing the detected point before the actual start of ejection. This may explain the increased foot PWV value compared to the PWV value from the top of the wave in last recording. Due to decreased BP, the PWV value should decrease also.

The time interrelationships of the BCG waves have been studied also earlier [2, 14], but the comparison of the temporal values of the BCG waves between different studies was difficult due to the instruments which were designed differently and utilized techniques available at that time. Along with the technical development electronic components used in BCG signal acquisition, filters and signal processing methods developed. An agreement was found between obtained temporal values of the BCG; In [1] a reference picture the temporal ultra low frequency BCG traces correspond in TRH (Ref. 0.16s; obtained mean 0.11s), TRI (Ref. 0.21s; obtained mean 0,23s), TRJ (Ref. 0.30s; obtained mean 0.31s), TRL (Ref. 0.46s, obtained mean 0.46s). Temporal agreement of the BCG components was found also in [15] giving reference values for TRH (0.11s), TRI (0.21s), TRJ (0.31s) and TRK (0.48s; obtained mean 0.38s). Normal time for maximum ejection is 0.12s (from the aortic valve opening to peak left ventricular pressure) following reduced ejection at 0.14s (from peak left ventricular pressure to the end of left ventricular ejection; that is, to the point of dicrotic notch (D; Fig. 1)) [4]. According to this, the THI (max. ejection time) added to TIK (reduced ejection time) would give 0.26s value for THK matching closely to obtained mean value 0.28s from seven years recordings. Moreover, the mean mechanical systole (THK) of the ventricle is 0.30s (form aortic electrokymogram) or 0.34s (from pulmonary artery electrokymogram) matching to obtained value 0.28s (Table 1) [16]. The characteristic change with age due to the altered wave reflections effects to the form of the carotid pulse waveform and in this study a carotid temporal value TPT shows a trend towards decreased TPT temporal values indicating increased large artery stiffness and increased PWV of pressure waves in the aorta and large arteries [17].

According to obtained results BCG from a single person does not change much during seven years time. This suggests, that BCG could be used to accurately study relative changes in the function of the heart-vasculature system from a single person and to predict clinical outcomes. As a conclusion the time domain and spectral properties of CP and BCG signals during seven years time remained comparatively stable within the same person. Minor alterations of the frequency of the spectral spikes may be due to heart rate changes between measurements or due to slight changes in arterial elasticity having an influence to the spectral traces. The minor increase in heart rate was even seen in CP spectral picture. Temporal values of the obtained signals matched closely to those found in the literature emphasizing the utilization of EMFi sensors in accurate waveform detection noninvasively by using a relatively simple and inexpensive biosignal amplification device. Obtained PWV values with a presented method followed closely BP changes measured with commercial Omron BP measurement device. As the amount of measured persons was small, this study serves merely as a method description, how EMFi sensor can be utilized when heart-vasculature system is studied with ballistocardiographic means.

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