EFFECT OF SAUNA BATH TO BCG, CAROTID AND ANKLE PULSE SIGNAL DURING NORMAL BLOOD PRESSURE AND HYPERTENSION

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Abstract: The purpose of this work is to study the effect of sauna bath on BCG, carotid pulse and ankle pulse signal of a person with temporary mild hypertension by using EMFi (Electromechanical Film) sensors. Measurements were done in a sitting position before and after sauna bath. Pulse Transit Times (PTT) and amplitudes from BCG, carotid and ankle pulse signals were studied in order to study the response of the body to the thermal changes induced by the sauna bath.

The time domain properties of CP, ankle pulse signal and BCG changed in some extent as well as PTT between hypertension and normal blood pressure case. PTT times were greater in hypertension case compared to normal BP case after sauna bath, which differs from general situation, where PTT times become longer when blood pressure falls due to decreased tension in the arterial walls.

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 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 and I-J velocity reflects contractility. When systemic vascular resistance or aortic wall stiffness increases, I-K interval decreases and the K wave becomes deeper [1].

The contracting heart forms ballistic recoil via blood flow to the aorta and pulmonary arteries and this pulse wave travels through the vascular system and diminishes gradually. The speed of the pulse wave is 4 – 5 m/s (Pulse Wave Velocity; PWV), which is much higher than the flow velocity of blood and the propagation speed is dependent on the elasticity of the arteries and the level of blood pressure. PWV has been shown to be related to arterial distensibility [2]. Pulse wave transit time (PWTT) is a non-invasive method, which can be measured by using PWV [2] and it describes how quickly a blood pressure wave travels from the aortic valve to the periphery in the human body. Usually it is measured between carotid and femoral artery and it has been shown to correlate inversely with blood pressure [3].

The carotid pulse (CP) is a pressure signal recorded from 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 [4]. The CP rises abruptly with the ejection of blood from left ventricle to ascending aorta reaching a peak called 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 [4] (Fig. 1).

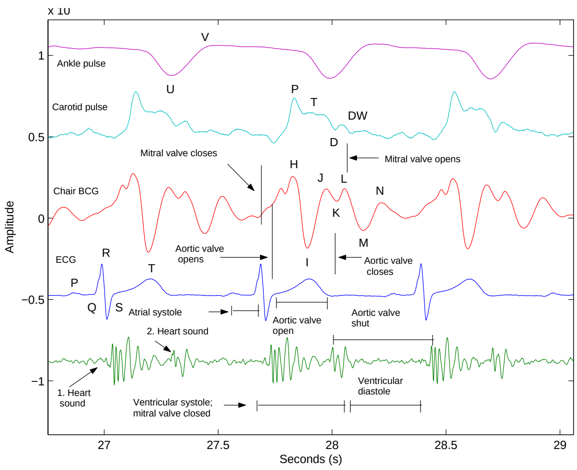

Figure 1: Signals recorded in sitting position. Blood pressure 120/80, pulse 85. The CP pulse wave, shape, amplitude and rhythm of pulsation help in the diagnosis of different cardiovascular diseases.

ISSN: 1727-1983

In this paper a Mobile Physiological Signal Measurement Station [5] has been used as a device, which enables the recording of BCG, carotid and ankle pulse signals [6] with EMFi sensors. The main goal of this study is to present temporal differences between hypertension BP BCG, carotid and ankle pulse signals compared to equivalent signals after sauna bath, when the blood pressure dropped to a normal level.

Methods

The EMFi [7] 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 [5] into a notebook computer with a data acquisition card (Daqp16, recording software Quatech DaqEZ) and the recordings were made into ASCII format. In the 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 person. One EMFi sensor (15 cm x 2 cm) was attached on the neck near carotid artery and the other EMFi sensor (10 cm x 2 cm) was attached on the ankle (near femoral artery).

Measurements

The recordings were made from the BCG, carotid and ankle pulse signals of one person in a sitting position measured with EMFi sensors before and after sauna bath. The measurement consisted of suppressed respiration in the beginning of the measurement and normal respiration after that. Both two measurements lasted about 3 min and the used sampling frequency was 500 Hz. Just before the EMFi measurements the blood pressure and the pulse were measured with Omron M5-I blood Pressure Monitor Device.

In order to study contraction of the left ventricle, I-J amplitudes A_{IJ} from the BCG signal, A_{PD} from carotid pulse and A_{UV} from ankle signal were extracted (Fig. 2, 3). Also pulse transit times (PTT) from neck, ankle and buttocks were extracted. The S wave of ECG was used as a reference in detecting the I slope from BCG, P slope from CP and U slope from ankle pulse signal. The reason for using the S wave for reference instead of R of ECG was that the point of S wave corresponds to the beginning of the pre-ejection period of the pulse wave of the aorta in PTT measurements. Also, the end point of pre-ejection was chosen to be the location when the rapid acceleration of blood into ascending aorta and pulmonary arteries around aortic arch and into carotid arteries happens, which can be seen as the I point in buttocks BCG signal and the U point in ankle signal (Fig. 2). The P point in the neck CP signal was chosen for the PTT measurement for the 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).

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 two analysis window lengths. In the hypertension case the length of analysis window was 1.08 s, which moved with 0.54 s steps. In the normal blood pressure case the length of analysis window was 0.76 s, which moved 0.38 s steps. In this way the detections were optimized, as the pulse changed markedly between the two cases. The index of the S point was detected first by differentiating (5 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. The P and the D slopes (max and min detection) from the carotid pulse signal as well as the U and the V slopes (min and max detection) from the ankle signal were detected in the same way.

Results

EMFi sensors were able to produce good quality signals, as seen in (Fig. 1-3). The measured person had mild hypertension values when the first measurement was made before sauna. After the sauna bath (lasted about 30 min) the blood pressure values dropped to normal values. The time domain properties of the hypertension signals (ankle, neck and chair BCG) were to some extent different compared to normal blood pressure signals (Fig. 2, 3). The I-J amplitudes of the chair BCG were higher (Table 1) with the normal blood pressure values (almost doubled) compared to the hypertension BCG values. The same effect was also seen in the A_{PD} carotid pulse signal. The only exception was with the ankle signal, where A_{UV} was larger during the hypertension values than during the normal blood pressure. In the BCG hypertension waveform (Fig, 2) the K wave became deeper compared to the normal BP case (Fig. 3) (where the K wave had almost blended to the L wave) indicating the increased systemic vascular resistance or aortic wall stiffness [1]. One distinctive feature with the PTT times (Table 2) was that in all cases pulse transit times were larger during hypertension.

Figures 4 to 6 present amplitude plots and figures 7 to 9 measured time intervals before and after sauna bath. Figure 10 presents the heart rate measured from the S slope of the ECG.

Table 1: Median values of amplitudes A_{IJ}, A_{PD} and A_{UV} from the part of suppressed respiration and normal respiration in the case of hypertension and normal blood pressure. As the device is not calibrated, the absolute force is not known and the values are in arbitrary units.

	Suppressed respiration	Normal respiration	Whole recording
A_{IJ} Hypert.	5419,0	3320,0	3806,0
A_{PD} Hypert.	760,0	721,0	728,0
A_{UV} Hypert.	2133,0	1737,0	1857,0
A_{IJ} Norm.BP	9597,0	5234,0	6546,0
A_{PD} Norm.BP	1177,0	1233,0	1230,0
A_{UV} Norm.BP	2718,0	1455,0	1533,0
Duration (s)	28,0	136,0	196,0

Table 2: Median of PTT values (T_{SI}, T_{SP}, T_{SU}) from the chair BCG, the neck carotid pulse and the ankle signal.

	Suppressed respiration	Normal respiration	Whole recording
T_{SI} Hypert. (s)	0,16	0,17	0,17
T_{SP} Hypert. (s)	0,11	0,10	0,11
T_{SU} Hypert. (s)	0,24	0,27	0,26
T_{SI} Norm.BP (s)	0,14	0,16	0,16
T_{SP} Norm.BP (s)	0,09	0,10	0,10
T_{SU} Norm.BP (s)	0,23	0,25	0,24
Duration (s)	28,0	136,0	196,0

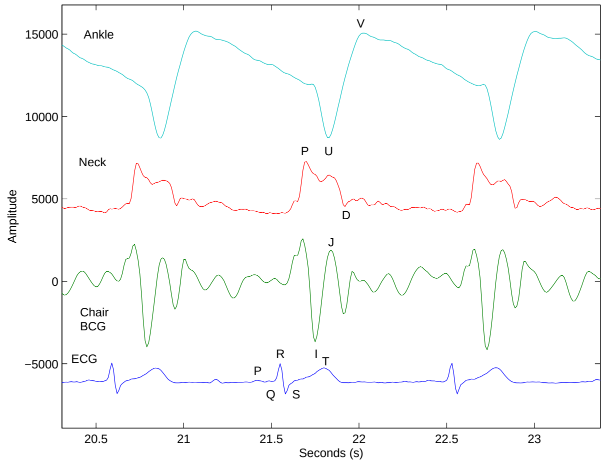

Figure 2: From top to down: ankle signal, carotid pulse, BCG and ECG. Measurement was made with hypertension BP values (162/98, pulse 65) before sauna bath.

Two similar measurements were performed on the same subject and their results were similar to the ones presented here. The blood pressure values before sauna bath were 162/98 (mild hypertension), pulse 65 and after sauna bath 141/80, pulse 80 measured in a sitting position.

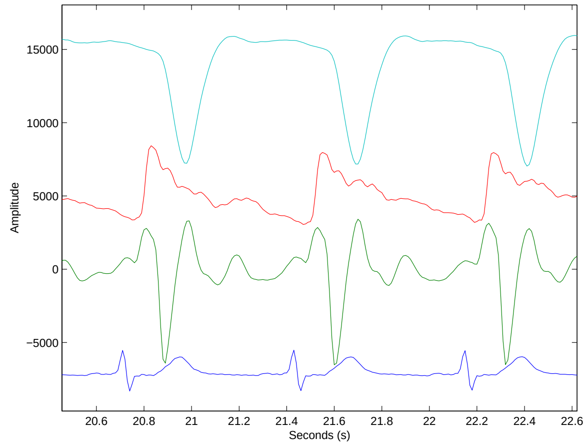

Figure 3: From top to down: ankle pulse, carotid pulse, BCG and ECG. The measurement was made with normal BP values (141/80, pulse 80) after sauna bath.

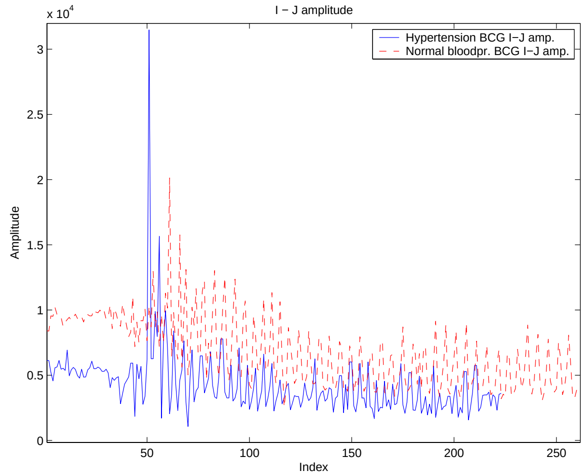

Figure 4: I-J amplitude from chair BCG including suppressed part of respiration (index up to 50) and normal respiration. Hypertension BCG I-J amplitude with a solid line and normal blood pressure with a dashed line. Amplitudes with normal BP are higher than in the hypertension case. More detected amplitudes can be seen in normal BP case.

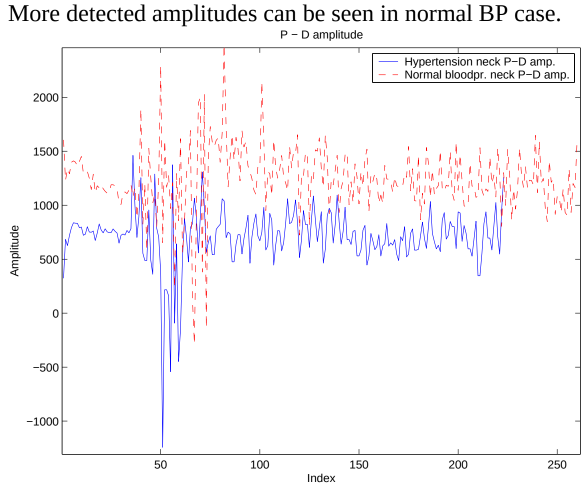

Figure 5: P-D amplitude from the CP signal including suppressed part of respiration (index up to 50) and normal respiration. Hypertension CP P-D amplitude shown with a solid line and normal blood pressure with a dashed line. Amplitudes with normal BP are higher than in the hypertension case. More detected amplitudes can be seen in the normal BP case.

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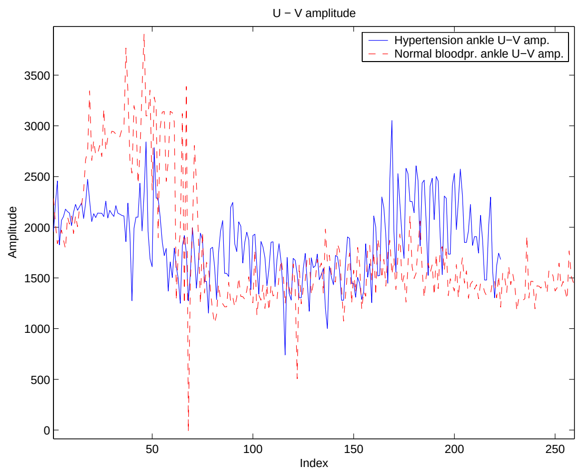

Figure 6: U-V amplitude from the ankle signal including the suppressed part of respiration (index up to 50) and the normal respiration. Hypertension ankle U-V amplitude seen with a solid line and normal blood pressure with a dashed line. Amplitudes with normal BP are slightly lower than in the hypertension case. More detected amplitudes can be seen in normal BP case.

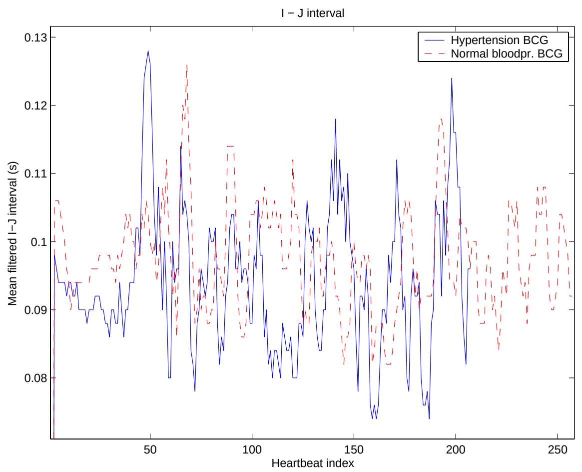

Figure 7: Mean filtered I-J intervals plotted against heartbeat index, sitting position. The I-J intervals are larger in the normal BP case, seen in suppressed respiration part (index up to 50).

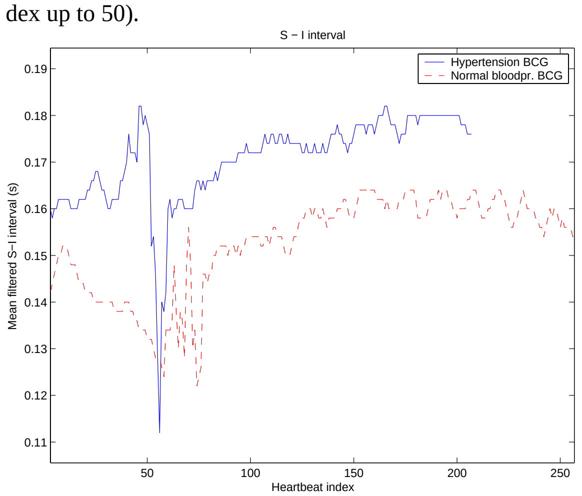

Figure 8: Mean filtered S-I intervals plotted against heartbeat index. The S-I intervals are larger in the hypertension BP case. Suppressed respiration part: index up to 50.

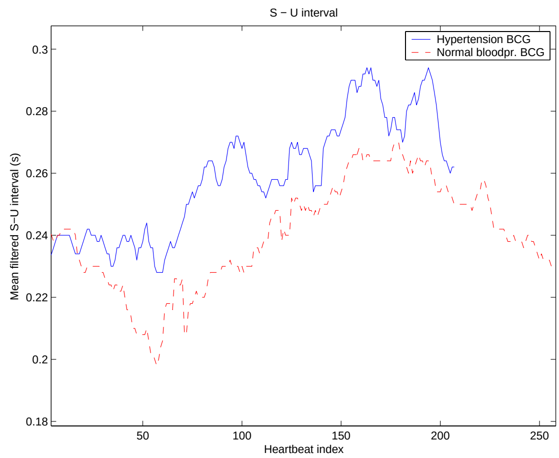

Figure 9: Mean filtered S-U intervals plotted against heartbeat index. S-U intervals are larger in hypertension BP case. Suppressed respiration part: index up to 50.

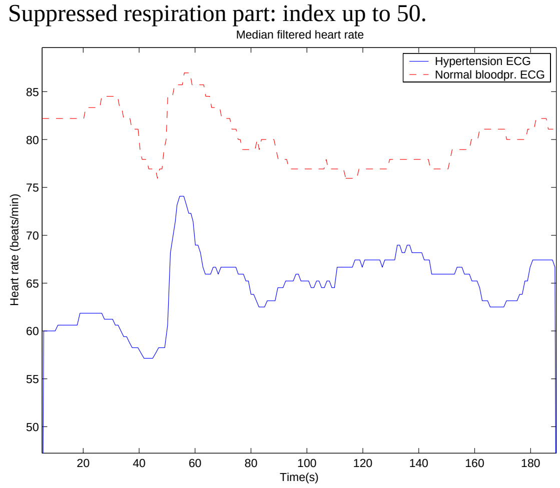

Figure 10: Median filtered heart rate (11 beats filtering). The effect of suppressed respiration can be seen as lower levels of HR (index up to 50) and rising levels in recovery phase. The HR was calculated from the S slopes of the ECG.

Discussion

The temporary influence of sauna bath on mild hypertension seems to be positive, seen as increased amplitudes $A_{IJ,}$ and A_{PD} and decreased blood pressure values. Changes between the hypertension BCG and the normal blood pressure BCG can be seen in the shape of the complexes of the BCG signal in the time domain (Figures 2 and 3). From the literature it is known that the elastic properties of blood vessels change when blood pressure rises and this influence can be seen in the chair BCG, CP and ankle pulse waveforms. Usually, the BCG amplitude decreases while arterial pressure increases [1].

The results of the PTT measurements indicated that in all cases (chair BCG, neck CP and ankle pulse signal) the PTT times were longer during hypertension (Table 2) when compared to the situation after the sauna bath, when the BP dropped to normal values. The reason for that might be the changed distribution of blood in the body veins in order to lower the body temperature caused by external heat caused by the sauna bath. Usually, when the BP falls, the tension in the arterial walls is smaller (vascular tone de-

ISSN: 1727-1983

creases) causing the PTT to increase (the pulse wave travels more slowly). This was the case in a previous measurement setup, where exercise (kickboxing) was used to lower hypertensive BP values [6]. The results obtained raised a question about the difference of the sauna bath compared to regular exercise in the lowering of slightly elevated BP values. Of course, this needs further study. Future studies include also the study of BP changes in relation with the diastolic components of the BCG signal induced by the sauna bath.

The type of measurement in which suppressed respiration was in the beginning of the recording and normal respiration after that, was intended to be as a mild stress test for the body. This could possibly give more information about the condition of the body regulatory system in changing temperature conditions, such as measured after a sauna bath.

Because of the small number of persons measured, these observations about the influence of the sauna bath on blood pressure values require more research in order to make more profound conclusions.

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