Analysis of Seismocardiogram Capability for Prediction of Mild to Moderate Haemorrhage; Preliminary Results

Kouhyar Tavakolian[1], Guy A Dumont[1], Andrew P Blaber[2]

[1]Department of Electrical and Computer Engineering, University of British Columbia, Canada
[2]Department of Biomedical Physiology and Kinesiology, Simon Fraser University, BC, Canada

Abstract

Seismocardiogram (SCG) is proposed in this study to be used for earlier detection of hemorrhage and lower body negative pressure (LBNP) was used to create a hemodynamic response similar to hemorrhage. Echocardiogram measurements showed a maximal reduction of 23% in cardiac output. Analysis of left ventricular ejection time (LVET), derived from a seismocardiogram (SCG), demonstrated to be more sensitive in detection of early stage hemorrhage compared to pulse pressure and heart rate. LVET was significantly different between different stages of LBNP for thirty two subjects.

1. Introduction

Hemorrhage is a result of significant blood loss and one of the leading causes of death on battle fields and emergency rooms. Low systolic blood pressure of less than 90 mmHg has been commonly used, clinically, to indicate the hemorrhage [1]. More recently a drop in pulse pressure is suggested for detection of blood loss [2]. However, it is well recognized that when the hypotension is significant it might be too late for a lifesaving intervention. Thus, there is a recent effort towards prediction of hemorrhage using alternative methods [3].

We believe that Seismocardiogram [4] has a potential of providing a low cost, portable solution for triage of hemorrhage while it is still in its mild to moderate stage (10-20% blood loss).

Lower body negative pressure (LBNP) is an accepted experimental surrogate for hemorrhage [5], [6]. Thus, LBNP was implemented in this study and 32 young and healthy adults were placed in a sealed chamber and pressure was gradually lowered to -50 mmHg.

2. Methods

2.1. Subjects and data acquisition

A total of 32 participants took part in this study (age: 27.4±3.6 years, weight: 72.8±12.4 kg and height: 174.3± 7.6 cm). Seven participants were female. The signals were recorded at the Aerospace Physiology Laboratory under an ethics approval from Simon Fraser University research ethics board. The participants followed the informed consent procedure and signed their consent form.

The SCG signal was measured with a high sensitivity piezoelectric accelerometer (Brüel & Kjær model 4381, Nærum, Denmark). The participants were in the supine position and the signals were recorded in back-to-front direction, perpendicular to the body surface (Figure 1). The ECG signal was also acquired and used to segment the cardiac cycles. The SCG annotation originally proposed by Zanetti was used to extract features from SCG as can also be seen in Figure 2 [7].

Figure 1. The LBNP and data acquisition setup. A vacuum was used to reduce the pressure inside the chamber. SCG, ECG and blood pressure were recorded simultaneously. Echocardiogram was also used for 18 participants to measure cardiac output and stroke volume.

2.2. Cardiac output

In 18 participants, out of the total of 32, stroke volume and cardiac output were recorded using an echocardiogram device (Vividi, GE, USA) by an experienced echocardiographer. For every participant a minimum of three consecutive cardiac cycles were chosen and Doppler ultrasound was used to measure the stroke distance. This was then multiplied by their left ventricular output track area (LVOT) to yield the stroke volume. The stroke volume was multiplied by heart rate to yield cardiac output.

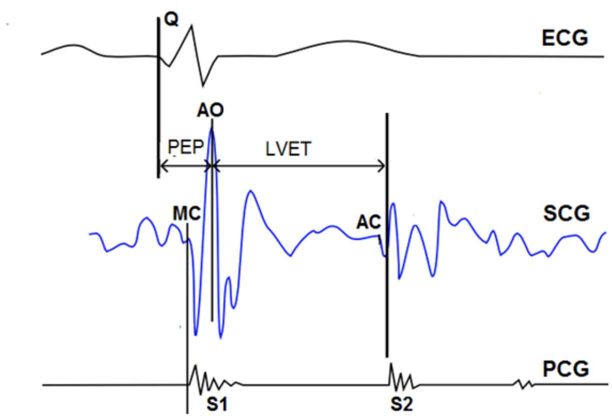

Figure 2. The SCG annotations based on cardiac cycle events shown in the schematic form. Aortic valve closure and opening (AC and AO); Mitral valve closure. Left ventricular ejection time and pre-ejection interval (LVET and PEP). S1 and S2 are first and second sounds of the heart registered through phonocardiography (PCG) and are shown to clarify the correspondences of events on the two signals.

3. Results and discussion

3.1. LBNP effect

As can be seen in Figure 3, the echocardiogram measurements show a gradual drop in the cardiac output through the LBNP stages for the first 18 subjects, corresponding to an overall drop of 23% from the resting pre-LBNP stage to the peak negative pressure of the LBNP. The LBNP setup used in these experiments was capable of inducing a hemodynamic effect similar to mild and moderate as defined in the literature [2].

3.2. SCG and pulse pressure changes

The changes of LVET and pulse pressure with different stages of LBNP are shown in Figure 4. The effect of LBNP on the SCG derived features, heart rate and PP was analyzed using one-way repeated measures ANOVA. If a main effect of LBNP was detected, subsequent post hoc analyses using the Tukey HSD test were performed ($p \leq 0.05$). This analysis showed that LVET was significantly different in all LBNP stages. PP was not significantly different between rest and -20 mm Hg and -30 mm Hg.

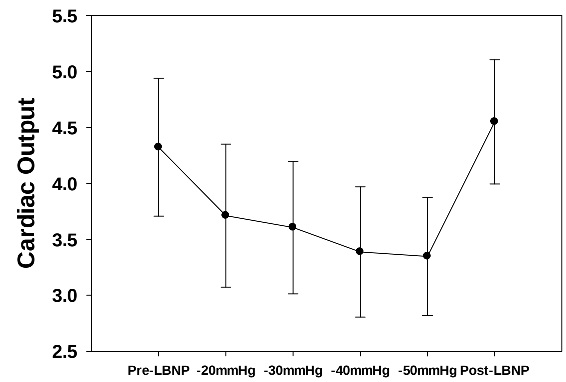

Figure 3. Cardiac output (in Liters/min) changes during LBNP measured by GE Vividi echocardiogram. The standard deviation around the averages values (for 18 participants) is shown by bars.

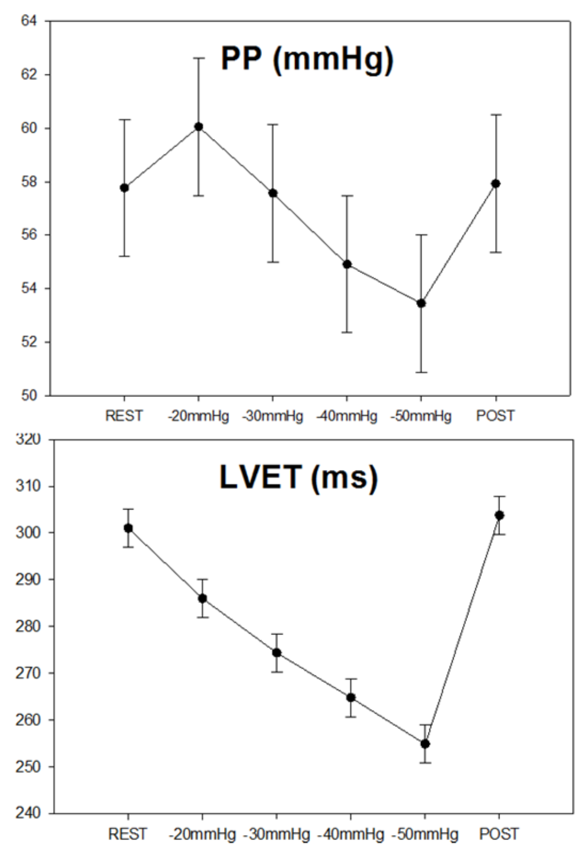

Figure 4. Changes of pulse pressure (PP) and LVET with different stages of LBNP. There was no significant statistical difference between PP for the initial stages.

4. Conclusion

It is important to diagnose hemorrhage as it progresses to mild phase and before it reaches moderate phase. With respect to the LBNP stages this is equivalent to the sensitivity of detecting the change between LBNP levels -20 mm Hg and -30 mm Hg as they are very important precursors to the imminent stages resembling severe hemorrhage. The results of section 3.2 shows that PP is not sensitive enough to detect these stages while SCG extracted LVET is.

Thus, these results suggest the potential for a patient-specific method to monitor progressive hemorrhage using SCG. In this methodology, a baseline recording of an SCG-derived LVET would be obtained upon arrival of a patient at the emergency room, provided the patient is in a reasonably stable condition. However, any significant change in the LVET, relative to the baseline assessment, can be used to trigger re-assessment as a result of potential hemorrhage, which would not be noticed by current measurements using blood pressure, as demonstrated in this paper.

Acknowledgements

This project has been partially funded by Heart Force Medical Inc. We would also like to thank Geoff Houlton and Sara Fleming for their assistance.

References

[1] Convertino VA, Ryan KL, Rickards CA, Salinas, McManus JG, Cooke WH, Holcomb JB. Physiological and medical monitoring for en route care of combat casualties. The Journal of Trauma 2008; 64:342–53.

[2] Convertino VA, Cooke WH, Holcomb JB. Arterial pulse pressure and its association with reduced stroke volume during progressive central hypovolemia. The Journal of Trauma 2006; 61:3:629–34.

[3] Convertino VA, Moulton SL, Grudic GZ, Rickards CA, Hinojosa-Laborde C, Gerhardt RT, Blackbourne LH, Ryan KL. Use of advanced machine-learning techniques for noninvasive monitoring of haemorrhage. The Journal of trauma 2011; 71:1:25–32.

[4] Zanetti JM, Tavakolian K. Seismocardiography : past, present and future. IEEE EMBC 2013: 7004–7007.

[5] Cooke WH, Ryan KL, Convertino VA. Lower body negative pressure as a model to study progression to acute hemorrhagic shock in humans. Journal of Applied Physiology 2004, 96:4:1249–61.

[6] Cote AT, Bredin SSD, Phillips AA, Warburton DER. .Predictors of orthostatic intolerance in healthy young women. Clinical and Investigative Medicine 2012; 35:2:65–74.

[7] Salerno D, Zanetti J. Seismocardiography for monitoring changes in left ventricular function during ischemia. Chest 1991, 100:4:991–993.

Address for correspondence:

Kouhyar Tavakolian, Ph.D
Department of Electrical and Computer Engineering, University of British Columbia, Vancouver, BC Canada
kouhyart@ece.ubc.ca