IMPACT OF CENTRAL HYPOVOLEMIA ON PHOTOPLETHYSMOGRAPHIC WAVEFORM PARAMETERS IN HEALTHY VOLUNTEERS. PART 2: FREQUENCY DOMAIN ANALYSIS

Aymen A Alian, MD; Nicholas J Galante, BS; Salman Haider; Lars G Grimm, BS; David G Silverman, MD; Kirk H Shelley, MD, PhD

Department of Anesthesiology, Yale University School of Medicine, New Haven, Connecticut

Background: The photoplethysmographic (PPG) waveforms are modulated by respiratory, cardiac and autonomic nervous systems. PPG had two components; the AC component reflects arterial pulse volume variation while the DC component reflects the constant absorption and scattering of light by bone and non-pulsatile venous blood. Lower body negative pressure (LBNP) has been used as an experimental tool to simulate loss of central blood volume (e.g., hemorrhage) in humans. Heart rate variability has been reported to reflect autonomic (sympathetic and vagal) activities. The efferent vagal activity is a major contributor to the HF component (0.15-0.4 Hz), while the LF component (0.04-0.15 Hz), which is considered as a parameter that includes both sympathetic and vagal influences. It has been shown that the standard deviation of the R-R interval (RRISD) can be used as an index of cardiac vagal tone.The aim of our research is to understanding the physiology of progressive central hypovolemia that leads to cardiovascular decompensation and try to develop effective indicators that predict the magnitude and/or rate of progressive hemorrhage before the onset of hemorrhagic shock.

Methodology: With IRB approval, 11 volunteers underwent a LBNP protocol at baseline, 30, 75, and 90 mm Hg (or until the subject became symptomatic). Subjects were monitored with finger and ear pulse oximeter probes, ECG, and finger arterial blood pressure monitor. Amplitude density of low frequency (0.05-0.11 Hz), intermediate frequency (0.12-0.18 Hz), respiratory (0.19-0.3 Hz) and cardiac (0.75-2.5 Hz) components were computed during different phases of lower body negative pressure protocol. Heart rate variability (HRV) was analyzed to the following RMSSD (square root of the mean of the squared differences between adjacent NN intervals), high frequency (0.12-0.18 Hz) to eliminate the influence of respiration and low frequency (0.05-0.11 Hz). Data are presented as median and inter-quartile range. Friedman ANOVA and Wilcoxon test were used to identify changes in hemodynamic and plethysmographic variables, $P < 0.017$ was considered statistically significant.

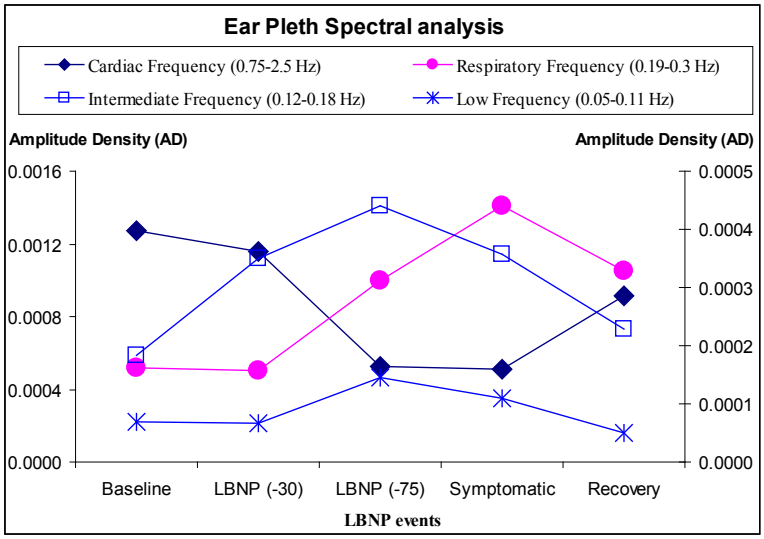

Figure 1: Autonomic, respiratory and cardiac modulation of the ear plethysmographic waveforms during LBNP phases

Results:

- With the progressive increased in LBNP, heart rate increased significantly while systolic, mean and pulse pressure finger arterial blood pressures declined slowly.
- There were significant reduction in RMSSD, high frequency (0.12-0.18 Hz) and low frequency (0.05-0.11 Hz) power of heart rate variability at LBNP 75 mmHg.
- There was significant reduction in the cardiac modulation of finger PPG spectral analysis which is consistent with the reduction in the pulse pressure of the finger arterial blood pressure.
- Ear plethysmographic waveforms spectral analysis had different scenario:
  - shift in the amplitude density from the cardiac component to the respiratory component is evidence of progressive hypovolemia with reduction in pulse pressure and increase in the respiratory induced variations (Figure 1).
  - At LBNP of 75 mmHg, there were a significant increase (>140% increase from the baseline) in intermediate frequency (0.12-0.18 Hz) and significant reduction (>58%) in cardiac modulation amplitude density. At the meantime and during the same LBNP phase, the high frequency amplitude density of HRV which has same frequency, (0.12-0.18 Hz), showed significant reduction (> 80%) from the baseline.

- At the symptomatic phase; there was a shift in ear plethysmographic modulation from the intermediate frequency to respiratory frequency with an increase in the respiratory modulation to ≥ 175% from the baseline.
- The cardiac modulation of ear plethysmographic waveform at the symptomatic phase continued to decrease till it reached > 59% of the baseline value.

Conclusions: The pulse oximeter waveform contains a complex mixture of the influences of arterial, venous, autonomic, and respiratory systems on the central and peripheral circulation. The occurrence of autonomic modulation needs to be taken into account when studying signals that have their origins from central sites (e.g. ear and forehead). The occurrence of autonomic modulation needs to be considered when studying signals that have their origins from central sites (ear). The use of the photoplethysmogram to monitor autonomic balance is intriguing and needs further investigation.