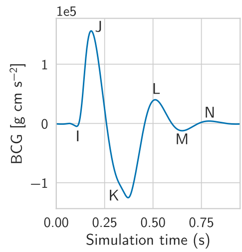
Model-Based Analysis of the Ballistocardiogram Signal During Obstructive and Central Apnea

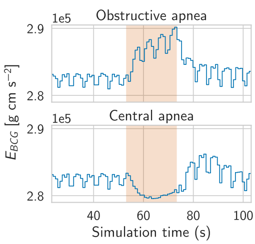
Arthur Ben-Tolila*[1], Virginie Le Rolle[1], Alfredo I Hernández[1]

[1]Univ Rennes, Inserm, LTSI - UMR 1099, F-35000 Rennes, France

Context: The ballistocardiogram (BCG) is the signal generated by body micromovements resulting from the ejection of blood from the heart. Recent research highlights its potential for unobtrusive monitoring of cardiac function and sleep-disordered breathing. In particular, obstructive and central apneas affect BCG, yet the mechanisms behind these variations are under debate. A model-based approach is employed to characterize BCG behavior around both apnea types.



Methods: An integrated model of cardio-respiratory interactions comprising i) systemic and pulmonary circulations, ii) respiration, iii) gas exchange and transport, and iv) neural control, previously validated for the simulation of sleep apnea in adults, was used to simulate 20-second obstructive and central apneas. Blood flows of the ventricular and intrathoracic arterial modeled circulation were differenciated, linearly combined, and low-pass filtered, to obtain a synthetic BCG signal in a post-simulation stage. The envelope of the BCG (E_{BCG}) was calculated as the amplitude difference between the J and K wave for each pulse. The sensitivity of E_{BCG} morphology to model parameters was studied using Morris's method.



Results: The simulated BCG waveform reproduces the main waves usually observed in patient signals, and the variations of E_{BCG} during apnea are in accordance with the literature, increasing during obstructive apnea and decreasing during central apnea: E_{BCG} is $2.83 \pm 0.007 \times 10^5$ g cm s^{-2} before the apnea; $2.87 \pm 0.021 \times 10^5$ g cm s^{-2} during the obstructive apnea and $2.80 \pm 0.010 \times 10^5$ g cm s^{-2} during the central apnea; $2.84 \pm 0.017 \times 10^5$ g cm s^{-2} after the apnea. The mean and standard deviation of E_{BCG} are most sensitive to arterial vascular properties, heart rate control pathways, left ventricular elastance, unstressed lung volume, and CO_2 sensitivity parameters.

Conclusion: A subset of parameters influent on BCG around apneas was identified, illustrating the cardiorespiratory information contained in this signal. These parameters can be used in future work for patient-specific modeling.