Analysis of the Contribution of Cardiovascular Components to the Ballistocardiogram Signal Using a Mathematical Model

Mohamed Zaid, Raul Invernizzi, Lorenzo Sala, Laurel Despins, Mihail Popescu, James Keller, Marjorie Skubic, Riccardo Sacco, Marcela Szopos, Virginia H. Huxley, Giovanna Guidoboni

Graduate School of Biomedical Sciences and Engineering
University of Maine, Orono, USA

The ballistocardiogram (BCG) offers a more comprehensive assessment of cardiovascular performance than conventional monitoring techniques by capturing the mechanical and fluid-dynamical characteristics of the cardiovascular system as a whole. While having the great advantage to be acquired non-invasively, the use of BCG as a clinical monitoring and diagnostic tool is limited due to the lack of understanding the cardiovascular mechanisms responsible for changes in the signal. Computer-aided approaches can help provide a mechanistic and quantitative interpretation of BCG signals. To this purpose, Guidoboni et al. (IEEE TBME; 2019) proposed a closed-loop mathematical model based on the physical principles governing vascular physiology to provide a theoretical estimation and interpretation of BCG signals. Using the above-mentioned cardiovascular model as a reference, in this study we assess and analyze the contribution of different circulatory components, including ventricles, aorta, systemic circulation, cerebral circulation, and iliac arteries, to the BCG waveform. Starting from the model by Avanzolini et al (Int. J. Bio-Med. Comput.; 1988), we consider 5 sub-models with step-by-step increased levels of detail in the main arteries and the cerebral arteries (Table 1). In addition to the BCG, we will also analyze pressure and volume (PV) loops in the left ventricle simulated by each model, which is particularly relevant in determining cardiovascular performance and functions. Results show a considerable improvement in the BCG theoretical reconstruction with the addition of the aorta. The addition of the cerebral circulation component shows the smoothing of the pressure waveforms in all the aortic segments and yields the ventricular pressure closer to physiological values.

Table 1: Cardiovascular sub-models considered and compared in this study.

Model type	Heart LV+RV	Pulmonary circulation	Systemic circulation						Cerebral circulation
			Asc	Arc	Thor	Abd	Iliac	Body	
Model 0 (Avanzolini, et al.)	✓	✓						✓	✗
Model 1	✓	✓	Group 1		Group 2			✓	✗
Model 2	✓	✓	✓	✓	✓	Group 3		✓	✗
Model 3	✓	✓	Group 1		Group 2			✓	✓
Model 4	✓	✓	✓	✓	✓	Group 3		✓	✓
Model 5 (Guidoboni, et al.)	✓	✓	✓	✓	✓	✓	✓	✓	✓