A Multiscale Intracranial Pressure Signal Simulator

Federico Wadehn[1], David J. Mack[2], Emanuela Keller[2], Thomas Heldt[3]

[1]ETH Zurich, Zurich, Switzerland
[2]University Hospital Zurich, Zurich, Switzerland
[3]Massachusetts Institute of Technology, Massachusetts, USA

Intracranial pressure (ICP) is a key physiological parameter and is monitored in patients with severe neurological disorders, such as subarachnoid haemorrhage or traumatic brain injury. While analyses of the ICP waveform is increasingly being used to assess brain compliance or for predicting episodes of intracranial hypertension, ICP waveform recordings are not as readily available as waveforms of cardiac signals. Additionally, for well-studied signals such as electrocardiograms, there exist a large variety of simulators to simulate realistic waveforms. Such simulators are currently lacking for intracranial pressure. This makes an objective evaluation of different waveform analysis and signal quality assessment algorithms difficult. In addition to providing a ground truth for benchmarking algorithms, ICP signal simulators have the potential to be employed for objectively testing and calibrating patient monitors in (neuro-) intensive care units. As a first step towards this end, we have developed a physiologically-based ICP simulator that represents ICP waveform features across multiple time scales. The simulator's slow temporal dynamics (mean ICP) are based on an established mechanistic model that describes the relationship between cerebral blood and cerebrospinal fluid. To this, we added respiration-induced periodic changes in ICP, modeled by a sinusoid whose amplitude is monotonically increasing with mean ICP. Single ICP pulses are modelled with a three component Gaussian mixture model (GMM), whose parameters (means and variances) are functions of mean ICP. The ICP pulse amplitude increases monotonically with mean ICP, in particular the second peak of the GMM (P2), reflecting a reduction in brain compliance. A database of invasive ICP recordings from 10 patients recorded for about one day each at the University Hospital Zurich formed the basis for the extraction of ICP waveform parameters.
Finally, models for common types of arrhythmias, catheter flushing and signal drop-outs have also been included to increase the realism of the simulated waveforms.

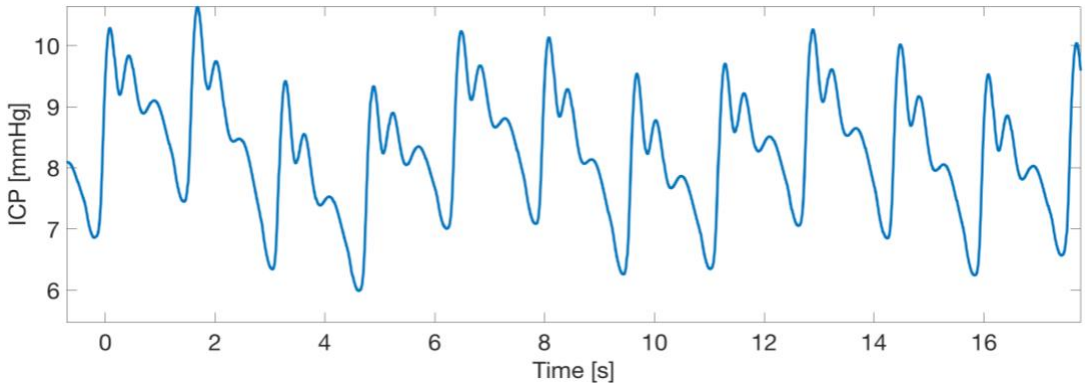

Figure 1 Simulated intracranial pressure signal showing the characteristic three peaks modelled with a three component Gaussian mixture model and respiration induced variations of the ICP baseline.