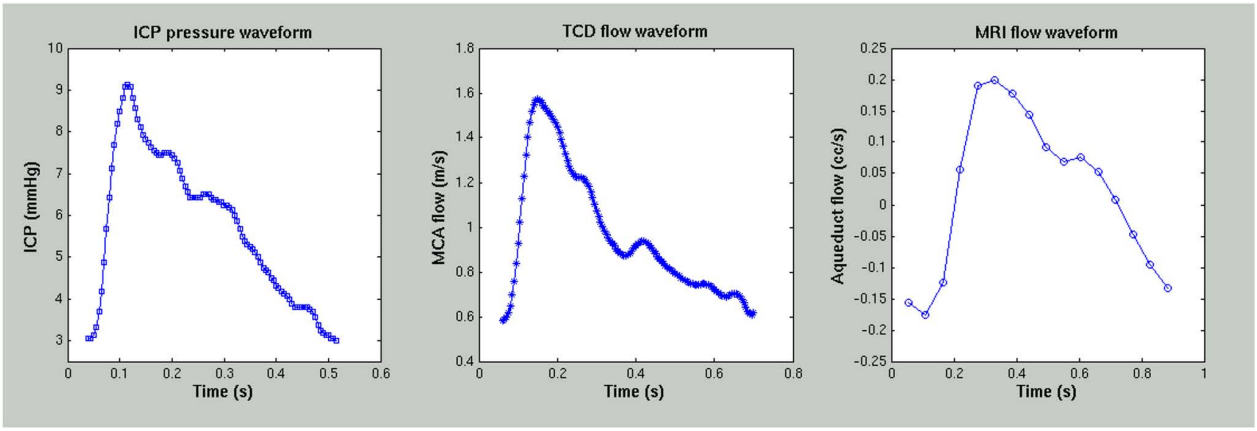

Figure 3 Single pulse waves using the three primary methods reviewed in this paper. Most noteworthy are the morphological differences between these waveforms, with the ICP pulse illustrating significant inter-pulse variations (known as P1, P2 and P3), mostly a result of pressure changes from the opening and closing of the cardiac valves, which are missing or attenuated in the middle cerebral artery blood flow waveform measured with transcranial Doppler ultrasound (middle panel), or in the aqueductal CSF flow waveform measured with phase contrast MRI (right panel). The marked reduction in temporal resolution with MRI as compared to ICP or TCD is also evident, and is due to the fact that MRI information is image-based and therefore much slower than single-point measurement techniques; the flow waveform data are acquired over many minutes and a single pulse wave is generated by averaging over many cardiac cycles.

within a ventricle), or in the spinal compartment. While this technique has been used by many investigators in pre-clinical work, there are only a few centers studying and using pressure pulsatility clinically. To some extent, this is due to the requirement of an invasive, implanted sensor, but it is also likely due to the difficulty of obtaining artifact-free pressure measurement in a clinical setting. As opposed to TCD and MRI, which are taken as one-time measurements with direct patient-operator interaction and good cooperation, ICP monitoring is typically done over a long time period with limited interaction between the patient and the operator. Thus, pressure signals are often corrupted by artifacts such as patient motion and heart rate variability. In addition, standard ICP monitoring software is only equipped to accurately measure mean ICP and is not easily accessed to extract the pressure waveform. Software for automatic identification of cardiac induced ICP waves and for dealing with artifacts has not been readily available (although the Sensometrics software package from dPCom has CE-mark for use in Europe). Thus, clinical examples in the literature using pressure pulsatility are limited.

The primary amplitude measure of pressure pulsatility is the absolute pulse amplitude, that is, the nadir-to-peak variation in pressure. This can be assessed either in the time domain, by measuring the nadir-to-peak (*i.e.*, diastolic to systolic) amplitude of the pressure wave over one cardiac cycle, or in the frequency domain, by measuring the amplitude of the fundamental cardiac component (and possibly the first few harmonic components as well). Investigators have used the pulse pressure amplitude in the time domain as an indicator of intracranial compliance [15-20], and thus as a good indicator of HC severity and prognosis, but this never gained widespread clinical use, most likely due to the technical expertise required (*e.g.*, accurately identifying cardiac-induced ICP waves) and the invasive nature of the procedure. Eide recently introduced a reliable and automated method for reliable identification of pulse pressure waves, incorporating three basic elements: (a) automatic identification of cardiac beat-induced pressure waves (in contrast to artifact-induced pressure waves), (b) characterization of individual pressure waves based on minimum diastolic pressure, maximum systolic pressure, pulse amplitude (*i.e.*, diastolic-to-systolic pressure difference), rise time, and rise time coefficient (*i.e.*, an approximation of dP/dT), (c) and presentation of the static pressure and pulse amplitude as a clinically useful output (see Figure 4). Averaging over a six-second time window, the pulsatility is represented by the mean wave amplitude. By monitoring this amplitude over a long period of time (*e.g.*, many hours), a representative picture of pulsatility is obtained. Such measures have been used to show the importance of pressure pulsatility in diagnosis and shunt prediction for pediatric [21,22] and normal pressure hydrocephalus (NPH) [23-26], as well as for prognosis following TBI [27].

An alternative method for determining pressure pulsatility is in the frequency domain, using the fast Fourier transform, which has been available since the late 1960's. After Fourier transformation, a pressure waveform is broken down into its individual frequency components, and the most prominent component is