Evaluation of the Intracranial Pressure (ICP) Wave in the Management of Neurosurgical Patients

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Evaluation of the Intracranial Pressure (ICP) Wave in the Management of Neurosurgical Patients

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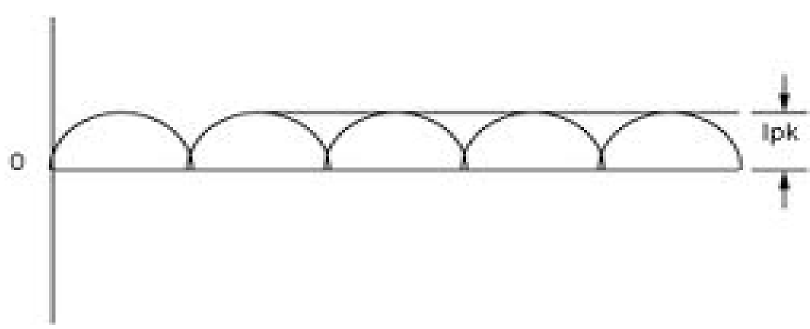
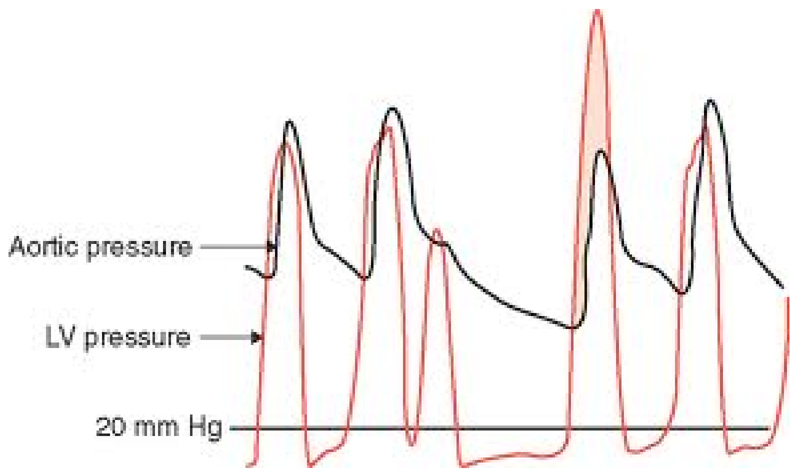
Applicability of the dynamic ICP wave, as obtained by the software developed by Professor Per Kristian Eide, with special emphasis on its value as an indicator of intracranial compliance.

The described ICP wave has great promise on several levels. First, intracranial compliance has long been recognized a challenging variable to assess and treat and the ICP wave appears to be a valuable tool to measure this. If one could reliably estimate intracranial compliance, one could easily imagine that tailoring treatment strategies to optimize compliance would lead to improved outcomes. Using the ICP wave one could tailor treatment strategies to a given patient's pathophysiology. This is important, as there is growing appreciation within neurosurgery and neurocritical care that universal and inflexible treatment algorithms are not the best option for our patients. There is tremendous interest in developing technology that will assess previously unmeasured indices and allow these assessments to determine modifications of management for a specific patient's unique pathophysiology. The ICP wave is a concept in lockstep with such evolution in thought.

Under most circumstances the dynamic ICP wave should be an excellent indicator of compliance. However, there are some areas that require further evaluation. The shape of the waveform needs to be considered, including the time to peak pressure. In these papers a normal waveform with expected peaks is shown. What happens when the waveform is rounded, as illustrated below, as occurs when flow into the brain is slowed in a patient with elevated ICP?



In addition, it is not clear how the measure will perform in a patient with an irregular cardiac rhythm such as atrial fibrillation or frequent premature, ventricular contractions. An example of the arterial wave change shown below would likely affect the ICP wave shape at least in the compliant brain. We wonder if a correlation between the ICP wave and stroke volume variation would be a valuable next step in the validation of the ICP wave as a tool for the neurointensivist.



The electrostatic discharge issue seems less applicable given that the electrical activity of the brain yields very low voltages and currents. The high voltages seen in the study from static electricity discharges would not occur in the brain without it being open to air and still that effect would likely get shifted away from the sensor because of the brain tissue acting as a sink for the energy dissipating it. The semiconductor forming the strain gauge would be expected to be altered in the presence of the static electric discharge because it would unbalance the Wheatstone Bridge substantially and very quickly. That bridge would significantly amplify the electrostatic discharge. If there were a break in the insulation that absorbed an electrostatic discharge there would also likely be a substantial failure noted in the monitor readings before the discharge because of the sensitivity of the bridge to changes in resistance and the leakage of current from the balanced bridge out of the system.

If there are design flaws in the monitors that render them susceptible to electrostatic discharges from health care personnel handling the monitors this is valuable feedback for the companies to address, but is not a rationale to change clinical care.

In summary, although a number of questions remain, we believe there is enough data to justify incorporating the dynamic ICP wave data, along with other data, in the management of neurosurgical patients.

Value of the dynamic ICP wave in neurointensive care, with emphasis on the management of patients with aneurysmal SAH or traumatic brain injury.

This could be an extremely valuable tool. As mentioned above, great heterogeneity exists among patients treated in a Neuroscience ICU (even with similar primary injuries). The ideal management strategy for CNS injury has not been agreed upon. Traditionally, ICP-directed therapy has been the most widely adopted (although limitations exist as most recently shown by Chesnut et al). Some other treatment strategies investigated are CPP-directed therapy (Rosner), Volume-directed therapy (Lund), institution of multi-modality monitoring (ICP, oxygenation, CBF, micro dialysis, etc.), and autoregulation-directed therapy. While all of these management strategies show promise for some patients, there are ineffective in others. There has always been an appreciation for the diverse and heterogeneous nature of various CNS-injuries (particularly TBI). Conceding that point, it makes sense that a given patient would need their treatment specifically tailored to the pathophysiology of their injury. Adding an important parameter such as intracranial compliance to our armamentarium could be invaluable. While it may not be the one parameter that will prove to be the ideal management strategy for all patients, that single all-purpose parameter likely does not exist. Using the ICP wave in conjunction with other neurophysiologic indices born out of the multi-modality era could prove to be very powerful.

Using this technology to continuously estimate autoregulation (via IAAC), as shown in the paper published in 2012 in the *Journal of Neurosurgery*, shows great promise. It would be fascinating to see if MWA-guided therapy with IAAC could be shown to benefit patients with TBI (acknowledging that PRx has been shown to do so in TBI but not in SAH).

The concept of drift in ICP monitors is not new and it has certainly been seen by all neurosurgeons and neurointensivists. The authors present compelling data that traditional measurements of mean ICP can show significant variations with baseline pressure errors. These errors can cause errant clinical decision making and may be limited the success of some interventions dependent on these values (e.g., PRx). The baseline pressure errors can be frustrating and complicates care. The papers demonstrating ICP sensor's can be altered by ESD's is a compelling observation and potential explains a phenomena most practitioners have seen without a universally agreed upon mechanism. If this technology remains accurate and without drift then it already has an inherent advantage over current technology. The claim that ICP wave amplitude analysis will not be prone to similar baseline errors may prove to be its biggest attraction and benefit to neurophysiologic monitoring (and the key to its value in neurocritical care).

While it would be useful to have a better quantifiable metric for compliance, work remains as to how to optimally manage it. As mentioned by Dr. Czosnyka, the pulse amplitude of the ICP wave is influenced by arterial inflow, venous outflow, compliance of the arterial bed, compliance of the venous system, and compliance of the CSF system. Compliance is also influenced by many things, not the least of which is likely cytotoxic edema. It was interesting that hypertonic saline did lower static ICP but did not ICP wave amplitude. Most of the works cited suggest that CSF drainage was most effective at lowering the ICP wave. This speaks to the complexity and multifactorial nature of cerebral "compliance". That said, it seems a vital physiologic parameter to be able to define and eventually manage effectively.

The paper by Edie et al published in *Neurosurgery* (2011) that demonstrated MWA-guided therapy led to better outcomes was quite compelling. It would be very interesting to replicate such a study in TBI.

Value of the ICP wave as a diagnostic tool in the treatment of hydrocephalus, including the assessment of patients with normal pressure hydrocephalus (NPH).

We believe that this software integrated into a wireless device could provide valuable information in hydrocephalus patients. Further experience with this measurement will help determine its value in selecting patients for surgical treatment and evaluating postoperative clinical deterioration after initial improvement. It could allow to select more appropriate valve resistance settings.

Significance of the ICP wave, in comparison to mean ICP, in enhancing the reliability ICP monitoring.

In regard to using the dynamic ICP reading alone, unless the mean ICP is completely unrelated to the disease process, it would seem prudent to use both mean and dynamic ICP data when both are available. The data presented suggest that both measures may have value. It does not seem likely that one variable or one treatment strategy will prove ideal for all patients. Instead, measuring multiple variables and developing a treatment strategy to optimize them seems to be the developing strategy. It will be helpful to determine which variable is most deranged and most damaging to a particular patient. In some patients mean ICP may be the best measure. Furthermore, it may be difficult to determine which parameter should be addressed first. We suspect that in most cases actively managing ICP wave amplitude (approximating compliance) will also address abnormalities in mean ICP. Further experience with the dynamic ICP wave and mean ICP measurement can show the relative value of each in letting us classify the patient's state. It should also become possible to assess other aspects of the ICP signal.