Neurocritical Care Monitoring
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ABSTRACT
Neurocritical care in children is aimed at the prevention and treatment of secondary brain injury. Advanced
neuromonitoring tools have gained popularity over the last decade owing to its ability to gather and
integrate information related to physiological and biochemical variables of brain metabolism, perfusion,
and oxygenation status. Intracranial pressure monitoring complemented with direct brain oxygen (PbtO2)
measurement and cerebral microdialysis might help to target therapy to patient-specific pathophysiology.
Non-invasive modalities like Near infrared spectroscopy (NIRS), Transcranial doppler and advanced
EEG monitoring have also evolved in parallel with the advancement of modern neurocritical care. The
multimodal approach offers promise as it is shown to improve quality of care and neurological outcome
in brain-injured children.
Key words: Multimodal neuromonitoring, ICP monitoring, NIRS, Microdialysis, brain tissue oxygen, children

Traumatic brain injury, acute CNS infections, stroke or status epilepticus are some of the common
neurological illnesses that are treated in PICU's around the world. Though children with such
disorders suffer neurological damage due to primary brain injury, a significant portion of them deteriorate
due to secondary insults like hypoxia, hypotension, hypoglycemia etc. Neurocritical care is aimed at
prevention and management of these secondary brain injuries (SBI). Over the past decade, the
advancement in brain multimodality monitoring has helped intensivists plan and execute a multipronged
approach to minimize the occurrence and progression of SBI. Multimodal monitoring tools both invasive
and non-invasive gather and integrate a variety of data related to physiological and biochemical
derangements thus giving us a composite picture about the brain metabolism, structure, perfusion, and
oxygenation status. In short they enable us to target patient-specific pathophysiology so as to prevent
SBI. With all this intensive monitoring the goal is to ensure a favorable outcome which is not only
survival but a good functional recovery.

Clinical Monitoring
The value of serial bedside neurological examination in the assessment of initial neurological injury and
detection of progression cannot be overemphasized. It helps in monitoring the progress of the illness,
especially in detecting early signs of worsening. It can reveal valuable information when properly
performed in an awake and cooperative child. However the sensitivity of clinical assessment decreases
in patients with altered consciousness, with use of sedatives and/or paralyzing agents. ICU
physician should establish the patient’s baseline status based on initial examination signs and continue
to monitor them for progress.
A formal neurological assessment is not always feasible in critical care, however minimum 5 aspects
of the neurological assessment need to be in place:
• Monitoring of GCS
• Pattern of respiration
• Pupillary response
• Extra ocular movements
• Motor examination

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ICP (Intracranial Pressure) Monitoring

Secondary brain injury may be a direct consequence of intracranial hypertension. Therefore monitoring of ICP and cerebral perfusion pressure (CPP) are immediate priority in patients with any acute neurological insult. Clinical indications for ICP monitoring are a GCS score of 3 to 8 and abnormal head CT. ICP monitoring combined with repeated clinical assessments, radio imaging and timely interventions has been shown to significantly improve outcome. An ideal ICP monitoring device should be (1) easy to use (2) accurate, (3) interpreted within clinical context, (4) reproducible and (5) able to guide clinical interventions. Pediatric intensivists can safely establish ICP monitoring at the bedside. The most commonly used options for ICP monitoring include placement of ventriculostomy and intraparenchymal devices. Ventriculostomy placement is considered the reference standard for ICP monitoring, based on its accurate, and good-quality ICP waveforms and reproducible pressure measurements. Additionally ventriculostomy allows for CSF drainage which can be used when indicated for raised ICP management. On the other hand ICP monitoring by means of fiber optic intraparenchymal catheters provides good-quality ICP waveforms, but does not allow CSF drainage for ICP control. Additional advantage being that placement of intraparenchymal catheters does not require localizing the ventricular system, which may be distorted or compressed consequent to brain edema and/or space-occupying lesions. The ICP treatment threshold is generally 20 mm Hg.

Cerebral perfusion pressure (CPP) is determined by the formula: CPP = Mean arterial pressure (MAP) - ICP. Monitoring CPP is integral for optimal outcomes as has been shown in patients with severe TBI and acute CNS infections. Initial resuscitation and stabilization is directed towards improving the systemic circulation by using crystalloids and vasoactive agents. However it is crucial to maintain MAP within a desirable range (75th - 95th centile) as both hypertension and hypotension can aggravate ICP thus worsening secondary insults. The hyperemia consequent to hypertension can result in surges in CBF, elevating ICP while oligemic CBF state consequent to systemic hypotension can result in brain ischemia.

A careful analysis of ICP waveform which includes evaluating individual components of the ICP pulse waveform (P-1, P-2, and P-3) may also yield useful information. P-1 reflects pulsation of the choroid plexus at cardiac systole and has the highest amplitude (under normal conditions). P-2 reflects relative brain volume and is elevated with increasing brain edema and/or rapidly expanding mass lesion. P-3 follows the dicrotic notch on the downslope of the ICP pulse waveform. An elevated P-2 component of ICP pulse waveform may also indicate compromised intracranial compliance and higher predictive value for more significant ICP elevation in response to stimulation.

Brain Tissue Oxygen Monitoring

Since brain tissue ischemia is the commonest form of secondary brain injury, direct measurement of tissue oxygenation is paramount in neuromonitoring. Several techniques have been used to measure brain oxygenation, the most common invasive methods in the ICU being jugular venous bulb oximetry and direct PbtO2 measurement. Near infrared spectroscopy has also been used for this purpose although it measures brain tissue oxygenation non-invasively.

Jugular Venous Bulb Oximetry

Measurement of oxygen saturation in the cerebral venous outflow inversely correlates with global brain oxygen consumption. Thus, placement of a catheter into the jugular bulb and obtaining oxygen saturation (SjVO2) can indirectly estimate cerebral oxygen consumption. The arterio-jugular difference in oxygen content (AJDOL) is proportional to CBF and inversely proportional to oxygen consumption (cerebral metabolic rate for oxygen, CMRO2) and is often used as a global measure of adequate perfusion. Proper positioning of the probe in the jugular bulb is crucial, since blood draining from extra-cerebral structures, such as the neck and face, can contaminate the lower portions of the jugular vein. Under conditions in which arterial hemoglobin saturation is constant, SjVO2 is recorded from intermittent sampling or continuously using fiberoptic probes. Normal values for SjVO2 in patients without brain ischemia.
damage are about 57% (95% confidence interval 52 to 62%)\textsuperscript{10}.

**Direct PbtO\textsubscript{2} Measurement**

Brain tissue oxygen tension (PbtO\textsubscript{2}) monitoring is a more direct technique that can estimate the partial pressure of oxygen in the brain interstitial space. Probe is usually inserted in the white matter and can be confirmed with a CT. The measurements are most reliable when the probe lies in close proximity to intracranial pathology. The readings reflect the balance between regional oxygen supply and cellular oxygen consumption\textsuperscript{11} and though local in nature, may also provide a reasonable estimate of global brain oxygenation. Threshold values vary slightly depending on what type of PbtO2 monitor is used but values <20 mmHg are considered worth treating and values <15 mmHg indicate brain hypoxia or ischemia. However, it should be noted that a low PbtO2 does not always indicate ischemia as it varies not only with cerebral blood flow but also with factors such as changes in arterial oxygen tension (PaO\textsubscript{2}).

Monitoring of PbtO2 can be used in combination with other intra-parenchymal monitors, mainly ICP and cerebral microdialysis. Clinical studies suggest that therapy based on information from both an ICP and a PbtO2 monitor may be associated with better outcomes than that based on ICP monitoring alone\textsuperscript{12}.

**Cerebral Microdialysis**

Continuous monitoring of tissue metabolism is possible using cerebral microdialysis. Cerebral Microdialysis (CMD) involves the insertion of a catheter tipped with a semi-permeable membrane in the brain parenchyma. The CMD catheter is constantly perfused with a lactate-free artificial cerebrospinal fluid, thereby allowing regular sampling of the patient’s brain extracellular fluid. CMD sampling is limited to the interstitial tissue area around the catheter, thus measuring regional brain metabolism. Glucose, lactate, pyruvate, glutamate and glycerol are most frequently measured in clinical practice. A pattern of elevated lactate/pyruvate ratio and low glucose is considered as a warning sign for cerebral ischemia/hypoxia\textsuperscript{13}. High lactate/pyruvate ratios in normoxic conditions have been interpreted as markers of hyper glycolysis. Elevated glutamate is a marker of cellular dysfunction\textsuperscript{14}. Absolute CMD values are important, but trends over time may provide more useful information.

**Near infra red spectroscopy**

NIRS is based on the principle of ability of light waves of near-infrared wavelength (i.e., 700–1,000 nm) to penetrate scalp, skull and brain to a depth of a few centimeters. These light waves are differentially absorbed by oxygenated hemoglobin (HbO\textsubscript{2}), deoxygenated hemoglobin (Hb) and cytochrome aa\textsubscript{3} (CytOx). Quantification of this optical attenuation is achieved by using reflectance spectroscopy based upon the modified Beer–Lambert law. The relative proportions of oxyhemoglobin and deoxyhemoglobin (HbO\textsubscript{2}/Hb) and oxidized cytochrome oxidase in the tissue are used to calculate an estimate of tissue oxygenation non-invasively and continuously. Measurements are obtained by optodes placed 4–6 cm apart on the forehead, thereby estimating oxygen content of all vascular compartments (arterial, capillary and venous) within a “banana”-shaped region of the brain. Continuous NIRS monitoring provides an early warning of developing or deteriorating injury even when the ischemia is occurring at the regional level\textsuperscript{15}. Normal rSO\textsubscript{2} values ranges from 55% to 75%. Clinical data in children have demonstrated that a cerebral rSO\textsubscript{2} values less than 40 to 50% or change in baseline greater than 20% are associated with hypoxic ischemic neural injury\textsuperscript{16}.

**Cerebral Blood Flow**

**Trans Cranial Doppler**

Transcranial doppler (TCD) combines ultrasound and the Doppler principle to measure the flow velocity (rather than flow itself) in the basal cerebral arteries. The main advantage of TCD is that it is a simple, noninvasive technique which can be carried out in the early management of brain injury even in the absence of ICP monitoring. TCD has also been used together with multimodality monitoring to assess cerebrovascular autoregulation in children with TBI. Changes in middle cerebral artery flow velocity measurements can help to assess the progression of the injury and understand the patterns of perfusion, oxygenation and autoregulation.
TCD derived pulsatility index (PI) is found to be a reliable indicator of intracranial pressure (ICP) in adult patients but a strong correlation is lacking in children\(^2\). An important limitation in using TCD is that the quality of signal is dependent on anatomical barriers and operator skills and correct interpretation requires training.

**Electrophysiological Monitoring**

**Electroencephalogram (EEG)**

The classical indication for EEG is to detect and manage seizures, including status epilepticus. In critically ill patients, seizures are often non-convulsive and may aggravate brain injury. Intermittent EEG is less sensitive than continuous EEG for detecting nonconvulsive status epilepticus. Selected characteristics of raw EEG, such as the background rhythm, spontaneous variability and responsiveness stimulation, have been used to assist in estimating prognosis\(^8\). EEG patterns of burst suppression, monorhythmic alpha like activity, electrocerebral silence or very low amplitude have been associated with poor outcome\(^9\). A more advanced form of EEG, quantitative EEG (qEEG), has been in practice recently, in which the raw EEG signal is converted into a digital form using fast Fourier transformation (compressed spectral array). qEEG is more objective because it uses derived measures, and a larger amount of data that have been trended over time. The percent alpha trend variability (PAV) in qEEG is found to correlate with cerebral blood flow and can be used to detect cerebral ischemia\(^9\).

**Evoked Potentials**

Somatosensory evoked potentials (SSEPs) are measured on the scalp as evoked EEG responses to an electrical stimulus applied typically to the median or tibial nerves. SSEPs are less affected by pharmacological agents or hypothermia than is the EEG. The main variable used for prognosis is the cortical response, which usually occurs at 20 msec after the stimulus, and hence is called the N20 peak. After cardiac arrest, bilateral absence of the N20 SSEP is associated with persistent vegetative state or death in all patients\(^1\).

To conclude, monitoring of brain function in critically ill patients is vital to prevent secondary insults. A baseline clinical status evaluation followed by serial assessments help in monitoring the progress of the disease. Given the limitations of clinical examination in a critical care set up several invasive and non-invasive monitoring devices have evolved. These monitoring systems when taken individually measure single variables like ICP, tissue oxygenation etc. However for optimal bedside management, it is necessary to integrate and synthesize data from all the different monitoring devices so as to arrive at a pathophysiology targeted timely intervention. Most important to remember is that neuromonitoring is a dynamic process and not a one point assessment; the ability to follow changes over time is vital to assess response to therapy and predict prognosis. The final goal of such a comprehensive neuromonitoring is to ensure a good quality survival.

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**References**


