Chapter 6. Advanced neuromonitoring

I. RECOMMENDATIONS

Strength of Recommendation: Weak.

Quality: Low, from one moderate- and one poor-quality class III study.

A. Level I

There are insufficient data to support a level I recommendation for this topic.

B. Level II

There are insufficient data to support a level II recommendation for this topic.

C. Level III

If brain oxygenation monitoring is used, maintenance of partial pressure of brain tissue oxygen ($PbtO_2$) $\geq$10 mm Hg may be considered.

II. EVIDENCE TABLE (see Table 1)

III. OVERVIEW

Children with severe traumatic brain injury (TBI) frequently have abnormal cerebral hemodynamics, including intracranial hypertension, cerebral hypoxia, delayed and/or altered processing of electrophysiological signals, and impaired cerebral autoregulation. In addition to intracranial pressure (ICP) monitoring, advanced neuromonitoring techniques such as microdialysis, electrophysiological assessments, and examination of cerebral autoregulation may help identify and treat patients with these derangements after TBI. The development of advanced monitoring systems to provide information regarding both cerebrovascular and metabolic function after TBI is critical to providing optimal neurocritical care. If treatment preventing unwanted cerebral pathophysiological processes is shown to improve outcome in children with severe TBI, the use of monitoring systems, beyond ICP monitoring, will mark an important advance in the care of patients with TBI. Advanced neuromonitors may provide useful information about derangements in cerebral oxygenation, blood flow and metabolism, autoregulation, and function after severe pediatric TBI.

DOI: 10.1097/PCC.0b013e31823f659a

IV. PROCESS

For this new topic, MEDLINE was searched from 1950 through 2010 (Appendix B for search strategy), and results were supplemented with literature recommended by peers or identified from reference lists. Of 44 potentially relevant studies, two were included as evidence for this topic.

V. SCIENTIFIC FOUNDATION

Two class III publications met the inclusion criteria for this topic and provide evidence to support the recommendations (1, 2). The recommendations on the use of advanced neuromonitoring in this chapter are for patients with no contraindications for neuromonitoring such as coagulopathy (brain oxygenation) and for patients who do not have a diagnosis of brain death.

In 2009, a study by Figaji et al (1) reported the relationship between $PbtO_2$ and long-term outcome in 52 children with severe TBI. Patients with compromised $PbtO_2$ were treated to a threshold $\geq$20 mm Hg. Overall mortality was nearly 10%. After considering other conventional predictors, authors reported that $PbtO_2$ <5 mm Hg for >1 hr or <10 mm Hg for >2 hrs were associated with a significantly increased risk of unfavorable outcome (Glasgow Outcome Scale and Pediatric Cerebral Performance Category scores) and mortality, independent of other factors that were also significant (e.g., ICP, cerebral perfusion pressure, Glasgow Come Scale, computed tomography classification, and systemic hypoxia). This study provided no comparison group. All patients with compromised $PbtO_2$ were treated to maintain the targeted threshold, and at the same time they may have received various treatments depending on other physiological variables such as ICP, cerebral perfusion pressure, systemic oxygen, and hemoglobin. What can be inferred is that in this sample of patients, those with higher $PbtO_2$ and fewer episodes of $PbtO_2$ <10 mm Hg had better outcomes. We cannot say that this relationship is a direct response to treatment.

In 2006, a study by Narotam et al (2) described changes in $PbtO_2$ in relation to changes in cerebral perfusion pressure, FIO_2, and PaO_2 in 15 children ranging from 1.5 to 18 yrs and Glasgow Coma Scale score $\leq$8. Like with the previous study, patients were managed to maintain a $PbtO_2$ level $\geq$20 mm Hg. In addition, the authors aimed to assess a treatment protocol (Critical Care Guide) for manipulation of physiological factors that influence oxygen delivery to the brain. Survival was associated with normal initial $PbtO_2$ ($\geq$10 mm Hg). There was no difference in the mean initial $PbtO_2$ among the ten survivors and six deaths at 3 months. Final $PbtO_2$ in survivors was higher than that in nonsurvivors (mean $PbtO_2$, 22.7 $\pm$ 9.05 vs. 7.2 $\pm$ 7.85 mm Hg; $p = .0045$). However, only six patients had elevated ICP, making the relationship between ICP and $PbtO_2$ difficult to interpret. Like with the previous study, we cannot infer from this study that response to treatment influenced outcome.

In these two studies, a treatment threshold for $PbtO_2$ of 20 mm Hg was used; however, they both reported an association between unfavorable outcome and $PbtO_2$ <10 mm Hg. Although the study by Figaji et al (1) reported an even stronger association between $PbtO_2$ <5 mm Hg and unfavorable outcome, until proven otherwise, if this advanced monitoring modality is used, it would be prudent to target the more conservative threshold of >10 mm Hg.

VI. INFORMATION FROM OTHER SOURCES

Several articles on advanced neuromonitoring in the pediatric TBI literature were identified in the search but excluded from the evidentiary table because they simply described use of a given advanced neuromonitoring device rather than targeting a treatment value for that monitor (i.e., a threshold parameter on

Table 1. Evidence table

Reference	Study Description	Data Class, Quality, and Reasons	Results and Conclusion
New studies			
Figaji et al, 2009 (1)	Design: prospective cohort N = 52 Age: 6.5 ± 3.4 yrs (9 months to 14 yrs) Protocol: treatment protocol was used in patients with compromised $PbtO_2$ to manage to a threshold ≥20 mm Hg Purpose: to examine the relationship between factors, including $PbtO_2$, and outcome Outcome: mortality; 6 months Glasgow Outcome Scale score and Pediatric Cerebral Performance Category	Class III Moderate quality: unclear if outcome assessment was unbiased	$PbtO_2$ <5 mm Hg for >1 hr or $PbtO_2$ <10 mm Hg for >2 hrs were independently associated with higher risk of unfavorable outcome defined as severe disability or death (adjusted odds ratio, 27.4; 95% confidence interval, 1.9–391), independent of other significant factors such as intracranial pressure, computed tomography, low Pao_2, and cerebral perfusion pressure $PbtO_2$ <5 mm Hg for >1 hr or $PbtO_2$ <10 mm Hg for >2 hrs were independently associated with mortality (adjusted odds ratio 26.8; 95% confidence interval, 2.7–265)
Narotam et al, 2006 (2)	Design: prospective case series N = 16 Age: 14 yrs (range, 1.5–18 yrs) Glasgow Coma Scale: 3–12; 15 children had Glasgow Coma Scale ≤ 8 Protocol: patients with low $PbtO_2$ were managed to a threshold ≥20 mm Hg Purpose: to direct treatment based on initial $PbtO_2$ and to examine the effect of a critical care guide to treat low oxygen delivery Outcome: 3-month mortality	Class III Poor quality: unclear if sample selection was unbiased; unclear if outcome assessment was unbiased; no control for confounders for mortality outcome	None of the patients with normal initial $PbtO_2$ (≥10 mm Hg) died There was no difference in the mean initial $PbtO_2$ among the 10 survivors and 6 deaths (measured at 3 months) (16.07 ± 18.7 vs. 6.76 ± 6.69 mm Hg, $p = .247$) Final $PbtO_2$ in survivors was higher than that in nonsurvivors (mean $PbtO_2$, 25.0 ± 11.57 vs. 8.53 ± 11.0 mm Hg; $p = .01$)

$PbtO_2$, partial pressure of brain tissue oxygen.

the advanced monitoring device was not specifically manipulated). Given that this guidelines document is focused on treatment, for these reports, a treatment recommendation regarding the monitoring device could not be given. The devices in those studies included brain microdialysis (3), cerebral blood flow and autoregulation monitors (4–7), signal processing of hemodynamic and hydrostatic signals (8), and jugular venous oxygen saturation monitoring (9).

A. Indications From the Adult Guidelines

Evidence from the adult guidelines (10) supported a level III recommendation for use of jugular venous saturation and $PbtO_2$ monitoring, in addition to standard ICP monitors, in the management of adults with severe TBI. Evidence suggests that episodes of jugular venous desaturation (saturation <50%) are associated with poor outcome and that this value represents a treatment threshold when using this monitoring technique. Similarly, low values of $PbtO_2$ (<15 mm Hg) and the extent of their duration (>30 mins) are associated with high rates of mortality and that 15 mm Hg represents a treatment threshold value for $PbtO_2$. However, the accuracy of jugular venous saturation and $PbtO_2$ monitoring was not evaluated. Although many technologies including cerebral microdialysis, thermal diffusion probes, transcranial Doppler, and near-infrared spectroscopy were recognized to hold promise in advancing the care of adults with severe TBI, there was insufficient evidence to comment on the use of these advanced neuromonitors in this population.

VII. SUMMARY

Overall, advanced neuromonitors have been subjected to very limited clinical investigation in pediatric TBI, particularly study of their use specifically to guide therapy. Most of the medical literature on these agents is composed of observational studies on relatively small numbers and case series receiving some form of local standard TBI care. The lack of sufficient high-quality pediatric studies limits the conclusions that can be made and differences between study centers in the treatment of TBI and inpatient populations limit the generalizability of findings.

VIII. KEY ISSUES FOR FUTURE INVESTIGATION

- Examine critical thresholds for each neuromonitoring modality and determine the risk-benefit ratio, cost-effectiveness, comparative effectiveness, and impact of neuromonitors on patient long-term functional outcomes.
- Address issues of single vs. multimodal neuromonitoring, reliability of technology, optimal combination of monitors, location of neuromonitor vs. site of injury (hemispheric, pericontusional), relationship between neuromonitor data and imaging data, neuromonitor use for optimization of treatment and patient

prognosis as well as optimal duration of advanced monitoring.
- Evaluate the role of advanced neuromonitoring on clinical decision-making and patient outcomes.
- Develop additional bedside and noninvasive advanced neuromonitors.

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