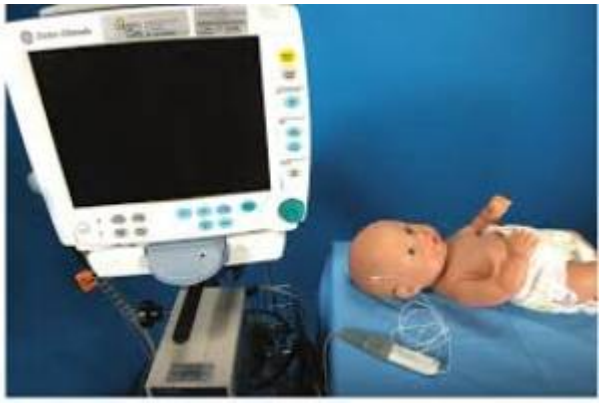
Intracranial pressure monitoring in children



Protocols for treatment of children with severe traumatic brain injury incorporate intracranial pressure monitoring as part of a comprehensive plan to minimize secondary injuries, using either ICP and/or cerebral perfusion pressure (CPP) as the therapeutic target [1].

At least 500 children enrolled in 9 studies have demonstrated at least some association between ICP and outcome [2) 3) 4) 5) 6) 7) 8) 9) 10)].

As a result, most centers adopted ICP monitoring years ago, while some have argued against the need for such an approach [11)].

Data suggest that there is a small, yet statistically significant, survival advantage in patients who have ICP monitors and a GCS score of 3. However, all patients with ICP monitors experienced longer hospital length of stay, longer intensive care unit stay, and more ventilator days compared with those without ICP monitors. A prospective observational study would be helpful to accurately define the population for whom ICP monitoring is advantageous [12)].

EVD and IP measurements of ICP were highly correlated, although intermittent EVD ICP measurements may fail to identify ICP events when continuously draining cerebrospinal fluid. In institutions that use continuous cerebrospinal fluid diversion as a therapy, a two-monitor system may be valuable for accomplishing monitoring and therapeutic goals [13)].

In the search for a reliable, cooperation-independent, noninvasive alternative to invasive intracranial pressure monitoring in children, various approaches have been proposed, but at the present time none are capable of providing fully automated, real-time, calibration-free, continuous and accurate intracranial pressure estimates. Fanelli et al. investigated the feasibility and validity of simultaneously monitored arterial blood pressure (ABP) and middle cerebral artery (MCA) cerebral blood flow velocity (CBFV) waveforms to derive noninvasive ICP (nICP) estimates.

Invasive ICP and ABP recordings were collected from 12 pediatric and young adult patients (aged 2-25 years) undergoing such monitoring as part of routine clinical care. Additionally, simultaneous transcranial Doppler (TCD) ultrasonography-based MCA CBFV waveform measurements were performed at the bedside in dedicated data collection sessions. The ABP and MCA CBFV waveforms were analyzed in the context of a mathematical model, linking them to the cerebral vasculature's biophysical properties and ICP. The authors developed and automated a waveform preprocessing, signal-quality evaluation, and waveform-synchronization “pipeline” in order to test and objectively

validate the algorithm's performance. To generate one nICP estimate, 60 beats of ABP and MCA CBFV waveform data were analyzed. Moving the 60-beat data window forward by one beat at a time (overlapping data windows) resulted in 39,480 ICP-to-nICP comparisons across a total of 44 data-collection sessions (studies). Moving the 60-beat data window forward by 60 beats at a time (nonoverlapping data windows) resulted in 722 paired ICP-to-nICP comparisons.

Greater than 80% of all nICP estimates fell within ± 7 mm Hg of the reference measurement. Overall performance in the nonoverlapping data window approach gave a mean error (bias) of 1.0 mm Hg, standard deviation of the error (precision) of 5.1 mm Hg, and root-mean-square error of 5.2 mm Hg. The associated mean and median absolute errors were 4.2 mm Hg and 3.3 mm Hg, respectively. These results were contingent on ensuring adequate ABP and CBFV signal quality and required accurate hydrostatic pressure correction of the measured ABP waveform in relation to the elevation of the external auditory meatus. Notably, the procedure had no failed attempts at data collection, and all patients had adequate TCD data from at least one hemisphere. Last, an analysis of using study-by-study averaged nICP estimates to detect a measured ICP > 15 mm Hg resulted in an area under the receiver operating characteristic curve of 0.83, with a sensitivity of 71% and specificity of 86% for a detection threshold of nICP = 15 mm Hg.

This nICP estimation algorithm, based on ABP and bedside TCD CBFV waveform measurements, performs in a manner comparable to invasive ICP monitoring. These findings open the possibility for rational, point-of-care treatment decisions in pediatric patients with suspected raised ICP undergoing intensive care [14].

Noninvasive quantitative measures of the peripapillary retinal structure by SD-OCT were correlated with invasively measured intracranial pressure. Optical coherence tomographic parameters showed promise as surrogate, noninvasive measures of intracranial pressure, outperforming other conventional clinical measures. Spectral-domain OCT of the peripapillary region has the potential to advance current treatment paradigms for elevated intracranial pressure in children [15].

References

1)
Adelson PD, Bratton SL, Carney NA, Chesnut RM, du Coudray HE, Goldstein B, Kochanek PM, Miller HC, Partington MP, Selden NR, Warden CR, Wright DW; American Association for Surgery of Trauma; Child Neurology Society; International Society for Pediatric Neurosurgery; International Trauma Anesthesia and Critical Care Society; Society of Critical Care Medicine; World Federation of Pediatric Intensive and Critical Care Societies. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents. Chapter 19. The role of anti-seizure prophylaxis following severe pediatric traumatic brain injury. Pediatr Crit Care Med. 2003 Jul;4(3 Suppl):S72-5. PubMed PMID: 12847355.
2)
Alberico AM, Ward JD, Choi SC, Marmarou A, Young HF. Outcome after severe head injury. Relationship to mass lesions, diffuse injury, and ICP course in pediatric and adult patients. J Neurosurg. 1987;67(5):648–656.
3)
Barzilay Z, Augarten A, Sagy M, Shahar E, Yahav Y, Boichis H. Variables affecting outcome from severe brain injury in children. Intensive Care Med. 1988;14(4):417–421.

4)
Chambers IR, Treadwell L, Mendelow AD. Determination of threshold levels of cerebral perfusion pressure and intracranial pressure in severe head injury by using receiver-operating characteristic curves: an observational study in 291 patients. J Neurosurg. 2001;94(3):412–416.
5)
Downard C, Hulka F, Mullins RJ, Piatt J, Chesnut R, Quint P, Mann NC. Relationship of cerebral perfusion pressure and survival in pediatric brain-injured patients. J Trauma. 2000;49(4):654–658. discussion 658-659.
6)
Eder HG, Legat JA, Gruber W. Traumatic brain stem lesions in children. Childs Nerv Syst. 2000;16(1):21–24.
7)
Esparza J, J MP, Sarabia M, Yuste JA, Roger R, Lamas E. Outcome in children with severe head injuries. Childs Nerv Syst. 1985;1(2):109–114.
8)
Kasoff SS, Lansen TA, Holder D, Filippo JS. Aggressive physiologic monitoring of pediatric head trauma patients with elevated intracranial pressure. Pediatr Neurosci. 1988;14(5):241–249.
9)
Michaud LJ, Rivara FP, Grady MS, Reay DT. Predictors of survival and severity of disability after severe brain injury in children. Neurosurgery. 1992;31(2):254–264.
10)
Shapiro K, Marmarou A. Clinical applications of the pressure-volume index in treatment of pediatric head injuries. J Neurosurg. 1982;56(6):819–825.
11)
Salim A, Hannon M, Brown C, Hadjizacharia P, Backhus L, Teixeira PG, Chan LS, Ford H. Intracranial pressure monitoring in severe isolated pediatric blunt head trauma. Am Surg. 2008 Nov;74(11):1088-93. PubMed PMID: 19062667.
12)
Alkhoury F, Kyriakides TC. Intracranial Pressure Monitoring in Children With Severe Traumatic Brain Injury: National Trauma Data Bank-Based Review of Outcomes. JAMA Surg. 2014 Jun;149(6):544-8. doi: 10.1001/jamasurg.2013.4329. PubMed PMID: 24789426.
13)
Exo J, Kochanek PM, Adelson PD, Greene S, Clark RS, Bayir H, Wisniewski SR, Bell MJ. Intracranial pressure-monitoring systems in children with traumatic brain injury: combining therapeutic and diagnostic tools. Pediatr Crit Care Med. 2011 Sep;12(5):560-5. doi: 10.1097/PCC.0b013e3181e8b3ee. PubMed PMID: 20625341; PubMed Central PMCID: PMC3670608.
14)
Fanelli A, Vonberg FW, LaRovere KL, Walsh BK, Smith ER, Robinson S, Tasker RC, Heldt T. Fully automated, real-time, calibration-free, continuous noninvasive estimation of intracranial pressure in children. J Neurosurg Pediatr. 2019 Aug 23:1-11. doi: 10.3171/2019.5.PEDS19178. [Epub ahead of print] PubMed PMID: 31443086.
15)
Swanson JW, Aleman TS, Xu W, Ying GS, Pan W, Liu GT, Lang SS, Heuer GG, Storm PB, Bartlett SP, Katowitz WR, Taylor JA. Evaluation of Optical Coherence Tomography to Detect Elevated Intracranial Pressure in Children. JAMA Ophthalmol. 2017 Apr 1;135(4):320-328. doi: 10.1001/jamaophthalmol.2017.0025. PubMed PMID: 28241164; PubMed Central PMCID: PMC5470406.