Recent Trends and Advances in Neurocritical Care Monitoring

Neelabh Datta

Department of Biochemistry, Asutosh College (Affiliated to University of Calcutta)

92, Shyamaprasad Mukherjee Road, Kolkata West Bengal, 700026, India

Email: neelabhdatta@gmail.com

Abstract
Neurocritical care is a subspecialty that manages critically ill patients with neurological disorders or injuries. An essential component of it is neuromonitoring, which aims to assess and optimize brain function and outcome. Neuromonitoring encompasses several recent advanced techniques such as clinical assessment, cranial imaging, non-invasive monitoring, and invasive monitoring, along with development of age-appropriate scales, multimodal protocols, quantitative analysis, and machine learning techniques. A common complication of critical illness is post-intensive care syndrome, which affects the physical, cognitive, and psychological well-being of patients and families. Neuromonitoring can thus help to identify and prevent post-intensive care syndrome by providing individualized and continuous feedback.

Keywords: neurocritical care, neuromonitoring, cranial imaging, invasive monitoring, post-intensive care syndrome

“The brain is the organ of destiny. It holds within its humming mechanism secrets that will determine the future of the human race.” - Wilder Penfield

Neurocritical care is a medical subspecialty that focuses on the management of critically ill patients with neurological disorders or insults [1]. These include cerebrovascular diseases (e.g., ischemic or hemorrhagic stroke), traumatic brain injury, subarachnoid hemorrhage, status epilepticus, infectious or inflammatory diseases of the central nervous system (e.g., meningitis, encephalitis), and primary or metastatic brain tumors [1]. The primary objectives of neurocritical care are to prevent or minimize secondary neurological injury, to maintain adequate cerebral blood flow and oxygen delivery, and to enhance neurologic recovery and functional outcome [1]. To accomplish these objectives, neurocritical care employs various modalities of neuromonitoring, both invasive and non-invasive, that allow continuous or intermittent assessment of the neurologic function and cerebral physiology at the bedside or in the laboratory.

Clinical Assessment of Brain Function

One of the most important aspects of neuromonitoring is the clinical assessment of brain function, which includes the evaluation of consciousness, cognition, motor function, cranial nerve function, and brainstem reflexes [2]. However, the clinical assessment can be challenging in critically ill patients due to factors such as sedation, analgesia, paralysis, metabolic disturbances, and systemic organ dysfunction [3]. Therefore, standardized and validated tools are needed to perform accurate and reliable clinical assessment of brain function in different patient populations. One of the recent developments in this field is the use of age-appropriate scales for assessing consciousness and cognition in critically ill children [4]. For example, the Pediatric Glasgow Coma Scale (PGCS) is a modified version of the Glasgow Coma Scale (GCS) that takes into account the developmental stages of children from birth to 18 years [5]. The PGCS consists of three components: eye opening, verbal response, and motor response. Each component is scored from 1 to 6, with higher scores indicating better function [5]. The PGCS has been shown to have good inter-rater reliability and predictive validity for neurological outcome in pediatric patients with traumatic brain injury [5]. Another example is the Pediatric Confusion Assessment Method for the Intensive Care Unit (pCAM-ICU), which is a simplified version of the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) that is used to diagnose delirium in critically ill adults [6]. The pCAM-ICU consists of four features: acute onset or fluctuating course, inattention, altered level of consciousness, and disorganized thinking. The presence of features 1 and 2 plus either feature 3 or 4 indicates delirium [6]. It has been validated in children aged 5 to 17 years and has been shown to have high sensitivity and specificity for detecting delirium in pediatric intensive care unit (PICU) patients [6].

Cranial Imaging

Another important method of neuromonitoring is cranial imaging, which provides structural and functional information about the brain anatomy and pathology. Cranial imaging can be used to diagnose various neurological conditions, monitor disease progression or response to treatment, identify complications or secondary insults, and guide therapeutic interventions [7]. Some of the commonly used cranial imaging modalities in neurocritical care are computed tomography (CT), magnetic resonance imaging (MRI), transcranial Doppler (TCD), and near-infrared spectroscopy (NIRS) [8,9]. One of the recent advances in cranial imaging is the use of multimodal CT or MRI protocols that combine different techniques to obtain comprehensive information about the brain perfusion, metabolism, oxygenation, and function. For example, CT perfusion (CTP) is a technique that measures cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and tissue perfusion pressure (TPP) by injecting a contrast agent into the bloodstream and acquiring serial images of the brain [10]. CTP can be used to identify regions of ischemia or infarction, assess collateral circulation, predict tissue outcome, and guide revascularization therapy in patients with acute ischemic stroke [10,11] Another example is MRI spectroscopy (MRS), which is a technique that measures the concentration of various metabolites in the brain tissue by using radiofrequency pulses to excite specific nuclei and detect their magnetic resonance signals [12]. MRS can be used to evaluate neuronal viability, energy metabolism, oxidative stress, inflammation, and neurotransmission in various neurological conditions such as traumatic brain injury, subarachnoid hemorrhage, seizures, infections, tumors, and metabolic disorders [12].

Non-Invasive Monitoring

Non-invasive monitoring refers to methods that measure various aspects of brain physiology without requiring direct contact with the brain tissue or cerebrospinal fluid (CSF). Non-invasive monitoring can be useful for continuous or repeated assessment of brain function or perfusion in critically ill patients who cannot undergo invasive procedures or who need frequent monitoring. Some of the commonly used non-invasive monitoring techniques in neurocritical care are electroencephalography (EEG), evoked potentials (EPs), and brain tissue oxygenation (PbtO2) [13]. One of the recent trends in non-invasive monitoring is the use of quantitative EEG (qEEG) or automated EEG analysis, which involves the application of mathematical or statistical methods to extract meaningful parameters from the raw EEG signals. qEEG can provide information about the brain electrical activity, such as frequency, amplitude, power, coherence, symmetry, and complexity [14]. qEEG can be used to detect seizures, ischemia, hypoxia, brain death, and delirium in critically ill patients [14]. qEEG can also be used to monitor the effects of sedation, analgesia, hypothermia, and neuroprotective agents on the brain function [14]. Another trend in non-invasive monitoring is the use of multimodal NIRS (mNIRS), which is a technique that combines NIRS with other modalities such as TCD, EEG, or EPs to measure multiple parameters of brain physiology simultaneously. mNIRS can provide information about the brain oxygenation, hemodynamics, metabolism, and function [15]. mNIRS can be used to monitor cerebral autoregulation, cerebral vasospasm, cerebral metabolic rate of oxygen (CMRO2), and cerebral functional connectivity in various neurological conditions such as stroke, traumatic brain injury, subarachnoid hemorrhage, and cardiac arrest [15].

Invasive Monitoring

Invasive monitoring refers to methods that require direct contact with the brain tissue or CSF to measure various aspects of brain physiology. Invasive monitoring can provide more accurate and reliable information than non-invasive monitoring, but it also carries more risks and complications such as infection, hemorrhage, or damage to the brain tissue. Therefore, invasive monitoring should be reserved for selected patients who have severe neurological impairment or who do not respond to conventional therapies [16]. Some of the commonly used invasive monitoring techniques in neurocritical care are intracranial pressure (ICP), cerebral microdialysis (CMD), and electrocorticography (ECoG) [16]. One of the recent advances in invasive monitoring is the use of multimodal ICP (mICP) or advanced ICP analysis, which involves the application of mathematical or statistical methods to extract meaningful parameters from the raw ICP signals [17]. mICP can provide information about the brain compliance, pulsatility, autoregulation, and cerebrovascular reactivity. mICP can be used to guide the management of intracranial hypertension, optimize cerebral perfusion pressure (CPP), and predict neurological outcome in patients with severe traumatic brain injury [18]. The use of multimodal CMD (mCMD) or advanced CMD analysis, which involves the application of mathematical or statistical methods to extract meaningful parameters from the raw CMD signals has became popular in recent diagnosis of patients [19]. mCMD can provide information about the brain metabolism, such as glucose, lactate, pyruvate, glutamate, glycerol, and cytokines. mCMD can be used to detect ischemia, hypoxia, inflammation, and excitotoxicity in various neurological conditions such as stroke, traumatic brain injury, subarachnoid hemorrhage, and infections [19]. mCMD can also be used to monitor the effects of hypothermia, neuroprotective agents, and nutritional support on the brain metabolism.

Post-Intensive Care Syndrome

Post-intensive care syndrome (PICS) is a term that describes the long-term physical, cognitive, and psychological impairments that may affect survivors of critical illness and their families [20]. PICS can have a significant impact on the quality of life, functional status, and social participation of patients and caregivers. PICS can also increase the risk of mortality, readmission, and healthcare costs [20]. Therefore, it is important to identify patients at risk of PICS and provide appropriate interventions to prevent or mitigate PICS. One of the recent developments in this field is the use of age-appropriate physiological thresholds and targets for neuromonitoring in children. For example, the optimal range of intracranial pressure (ICP) and cerebral perfusion pressure (CPP) may vary depending on the age and developmental stage of the child, as well as the underlying cause of brain injury [21,22]. Therefore, individualized neuromonitoring protocols based on age-specific criteria and continuous feedback are needed to optimize the management of pediatric neurocritical care patients. The integration of multimodal neuromonitoring data to provide a more comprehensive and dynamic picture of brain function and injury is widely used nowadays. [23] For example, combining EEG with other modalities, such as NIRS, TCD, or microdialysis, can help to detect and prevent cerebral ischemia, seizures, or metabolic disturbance [24]. Furthermore, advanced signal processing and machine learning techniques can be applied to multimodal neuromonitoring data to extract meaningful features, identify patterns, and predict outcomes [25]. These developments can improve the quality and utility of neuromonitoring in pediatric critical care.

Conclusion

Neurocritical care monitoring is a rapidly evolving field that has the potential to improve the diagnosis, treatment, and outcome of patients with acute neurological conditions or injuries. Recent trends and advances in neurocritical care monitoring include the development of new clinical assessment tools, the application of novel imaging techniques, the implementation of non-invasive and invasive monitoring techniques, the integration of multimodal monitoring data, the use of artificial intelligence and machine learning, and the adaptation to specific patient populations and scenarios, such as pediatric, neuro-oncology, and COVID-19 patients. However, there are still many challenges and limitations that need to be addressed, such as the lack of standardized protocols, the variability of physiological thresholds and targets, the ethical issues related to invasive procedures and withdrawal of life-sustaining therapies, and the need for more high-quality evidence and randomized controlled trials to support the clinical utility and cost-effectiveness of neurocritical care monitoring. Therefore, future research and innovation in this field are essential to optimize the care and outcome of patients with acute brain injury.

References

[1] Kuroda Y. (2016). Neurocritical care update. Journal of intensive care, 4, 36. https://doi.org/10.1186/s40560-016-0141-8

[2] Shahrokhi M, Asuncion RMD. Neurologic Exam. [Updated 2023 Jan 16]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK557589/

[3] Karamchandani, K., Dalal, R., Patel, J., Modgil, P., & Quintili, A. (2021). Challenges in Sedation Management in Critically Ill Patients with COVID-19: a Brief Review. Current anesthesiology reports, 11(2), 107–115. https://doi.org/10.1007/s40140-021-00440-x

[4] Silver, G., Kearney, J., Traube, C., & Hertzig, M. (2015). Delirium screening anchored in child development: The Cornell Assessment for Pediatric Delirium. Palliative & supportive care, 13(4), 1005–1011. https://doi.org/10.1017/S1478951514000947

[5] Jain S, Iverson LM. Glasgow Coma Scale. [Updated 2023 Jun 12]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK513298/

[6] Smith, H. A., Gangopadhyay, M., Goben, C. M., Jacobowski, N. L., Chestnut, M. H., Savage, S., Rutherford, M. T., Denton, D., Thompson, J. L., Chandrasekhar, R., Acton, M., Newman, J., Noori, H. P., Terrell, M. K., Williams, S. R., Griffith, K., Cooper, T. J., Ely, E. W., Fuchs, D. C., & Pandharipande, P. P. (2016). The Preschool Confusion Assessment Method for the ICU: Valid and Reliable Delirium Monitoring for Critically Ill Infants and Children. Critical care medicine, 44(3), 592–600. https://doi.org/10.1097/CCM.0000000000001428

[7] Deletis, V., & Fernández-Conejero, I. (2016). Intraoperative Monitoring and Mapping of the Functional Integrity of the Brainstem. Journal of clinical neurology (Seoul, Korea), 12(3), 262–273. https://doi.org/10.3988/jcn.2016.12.3.262

[8] Amyot, F., Arciniegas, D. B., Brazaitis, M. P., Curley, K. C., Diaz-Arrastia, R., Gandjbakhche, A., Herscovitch, P., Hinds, S. R., 2nd, Manley, G. T., Pacifico, A., Razumovsky, A., Riley, J., Salzer, W., Shih, R., Smirniotopoulos, J. G., & Stocker, D. (2015). A Review of the Effectiveness

of Neuroimaging Modalities for the Detection of Traumatic Brain Injury. Journal of neurotrauma, 32(22), 1693–1721. https://doi.org/10.1089/neu.2013.3306

[9] Müller, S. J., Henkes, E., Gounis, M. J., Felber, S., Ganslandt, O., & Henkes, H. (2023). Non-Invasive Intracranial Pressure Monitoring. Journal of clinical medicine, 12(6), 2209. https://doi.org/10.3390/jcm12062209

[10] Konstas, A. A., Goldmakher, G. V., Lee, T. Y., & Lev, M. H. (2009). Theoretic basis and technical implementations of CT perfusion in acute ischemic stroke, part 1: Theoretic basis. AJNR. American journal of neuroradiology, 30(4), 662–668. https://doi.org/10.3174/ajnr.A1487

[11] Lui, Y. W., Tang, E. R., Allmendinger, A. M., & Spektor, V. (2010). Evaluation of CT perfusion in the setting of cerebral ischemia: patterns and pitfalls. AJNR. American journal of neuroradiology, 31(9), 1552–1563. https://doi.org/10.3174/ajnr.A2026

[12] Zhu, H., & Barker, P. B. (2011). MR spectroscopy and spectroscopic imaging of the brain. Methods in molecular biology (Clifton, N.J.), 711, 203–226. https://doi.org/10.1007/978-1-61737-992-5_9

[13] Pandin, Pierre & Renard, Marie & Bianchini, Alessia & Desjardin, Philippe & Van Obbergh, Luc. (2014). Monitoring Brain and Spinal Cord Metabolism and Function. Open Journal of Anesthesiology. 04. 131-152. 10.4236/ojanes.2014.46020.

[14] Hwang, J., Cho, S. M., & Ritzl, E. K. (2022). Recent applications of quantitative electroencephalography in adult intensive care units: a comprehensive review. Journal of neurology, 269(12), 6290–6309. https://doi.org/10.1007/s00415-022-11337-y

[15] Acharya, D., Mukherjea, A., Cao, J., Ruesch, A., Schmitt, S., Yang, J., Smith, M. A., & Kainerstorfer, J. M. (2022). Non-Invasive Spectroscopy for Measuring Cerebral Tissue Oxygenation and Metabolism as a Function of Cerebral Perfusion Pressure. Metabolites, 12(7), 667. https://doi.org/10.3390/metabo12070667

[16] Tas, J., Czosnyka, M., van der Horst, I. C. C., Park, S., van Heugten, C., Sekhon, M., Robba, C., Menon, D. K., Zeiler, F. A., & Aries, M. J. H. (2022). Cerebral multimodality monitoring in adult neurocritical care patients with acute brain injury: A narrative review. Frontiers in physiology, 13, 1071161. https://doi.org/10.3389/fphys.2022.1071161

[17] Casault, C., Couillard, P., Kromm, J., Rosenthal, E., Kramer, A., & Brindley, P. (2022). Multimodal brain monitoring following traumatic brain injury: A primer for intensive care

practitioners. Journal of the Intensive Care Society, 23(2), 191–202. https://doi.org/10.1177/1751143720980273

[18] Schizodimos, T., Soulountsi, V., Iasonidou, C., & Kapravelos, N. (2020). An overview of management of intracranial hypertension in the intensive care unit. Journal of anesthesia, 34(5), 741–757. https://doi.org/10.1007/s00540-020-02795-7

[19] Lindblad, C., Raj, R., Zeiler, F. A., & Thelin, E. P. (2022). Current state of high-fidelity multimodal monitoring in traumatic brain injury. Acta neurochirurgica, 164(12), 3091–3100. https://doi.org/10.1007/s00701-022-05383-8

[20] Smith S, Rahman O. Postintensive Care Syndrome. [Updated 2023 Jun 12]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK558964/

[21] Kukreti, V., Mohseni-Bod, H., & Drake, J. (2014). Management of raised intracranial pressure in children with traumatic brain injury. Journal of pediatric neurosciences, 9(3), 207–215. https://doi.org/10.4103/1817-1745.147572

[22] Woods, K. S., Horvat, C. M., Kantawala, S., Simon, D. W., Rakkar, J., Kochanek, P. M., Clark, R. S. B., & Au, A. K. (2021). Intracranial and Cerebral Perfusion Pressure Thresholds Associated With Inhospital Mortality Across Pediatric Neurocritical Care. Pediatric critical care medicine : a journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies, 22(2), 135–146. https://doi.org/10.1097/PCC.0000000000002618

[23] Vitt, J. R., Loper, N. E., & Mainali, S. (2023). Multimodal and autoregulation monitoring in the neurointensive care unit. Frontiers in neurology, 14, 1155986. https://doi.org/10.3389/fneur.2023.1155986

[24] Ko, T. S., Catennacio, E., Shin, S. S., Stern, J., Massey, S. L., Kilbaugh, T. J., & Hwang, M. (2023). Advanced Neuromonitoring Modalities on the Horizon: Detection and Management of Acute Brain Injury in Children. Neurocritical care, 38(3), 791–811. https://doi.org/10.1007/s12028-023-01690-9

[25] Variane, G. F. T., Camargo, J. P. V., Rodrigues, D. P., Magalhães, M., & Mimica, M. J. (2022). Current Status and Future Directions of Neuromonitoring With Emerging Technologies in Neonatal Care. Frontiers in pediatrics, 9, 755144. https://doi.org/10.3389/fped.2021.755144