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INTRACRANIAL PRESSURE MONITORING IN TRAUMATIC BRAIN INJURY: INDICATIONS AND IMPACT ON OUTCOMES

Leonardo Silva Canales, Rodolfo de Oliveira Medeiros, Cristiano Machado Galhardi, Ana Laura Jorge Manzini, Gabriel Francisco Alves, Ligiane Aparecida Barboza de Araújo Brant, Ana Laura Santos Golinelli, Enzo Carone Carloti, Lara Carmelin Brasil, Gabriela Pinheiro Bravo, Henrique Felipin Da Silva Evangelisa, Diego Durante de Oliveira

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NARRATIVE LITERATURE REVIEW

ABSTRACT

Severe traumatic brain injury remains one of the leading causes of neurological morbidity and mortality, particularly due to secondary injuries associated with intracranial hypertension, cerebral hypoperfusion, hypoxia, edema, and brain herniation. In this context, intracranial pressure monitoring has been incorporated into neurocritical care as a strategy to identify potentially reversible physiological changes early and to guide individualized therapeutic interventions. This narrative review aimed to analyze the main indications for intracranial pressure monitoring in patients with traumatic brain injury and to discuss its impact on clinical and functional outcomes. The search strategy was guided by the PICo framework, considering patients with moderate to severe traumatic brain injury as the population, intracranial pressure monitoring as the phenomenon of interest, and hospital and neurocritical care settings as the context. Publications between 2019 and 2026 were prioritized, including guidelines, consensus statements, reviews, multicenter observational studies, and investigations on multimodal monitoring. The literature indicates that intracranial pressure monitoring is especially recommended in patients with severe traumatic brain injury, significant impairment of consciousness, tomographic findings suggestive of mass lesions, cerebral edema, cisternal compression, or signs of neurological deterioration. Although its isolated impact on mortality and functional recovery remains heterogeneous across studies, monitoring appears to provide greater value when integrated into structured protocols, stepwise algorithms, and multimodal strategies, such as cerebral oxygenation and cerebral perfusion pressure assessment. It is concluded that intracranial pressure monitoring should not be viewed as an isolated therapeutic intervention, but rather as a

decision-support tool within contemporary neurocritical care.

Keywords: Traumatic brain injury; Intracranial pressure; Neurocritical care monitoring; Intracranial hypertension; Clinical outcomes.

Instituição afiliada – Universidade de Marília

Autor correspondente*:* Rodolfo de Oliveira Medeiros
e-mail: rodolfomedeiros@unimar.br

1 INTRODUCTION

Traumatic brain injury is a highly complex clinical condition associated with substantial mortality, functional disability, and social burden. Even when the initial trauma does not immediately result in irreversible injury, the in-hospital course may be marked by secondary events such as hypoxia, hypotension, cerebral edema, metabolic disturbances, seizures, and intracranial hypertension. These mechanisms aggravate the primary injury and may significantly compromise neurological recovery (MAAS *et al*., 2022).

Intracranial pressure refers to the pressure exerted by the components contained within the cranial vault, particularly brain tissue, blood, and cerebrospinal fluid. Under physiological conditions, these compartments remain in balance; however, after traumatic brain injury, hemorrhage, edema, contusions, hydrocephalus, or disturbances in cerebral autoregulation may increase intracranial volume and reduce cerebral perfusion pressure. If not promptly recognized and treated, intracranial hypertension may lead to ischemia, brain herniation, and brain death (ZOERLE *et al*., 2024).

In this setting, intracranial pressure monitoring emerged as a strategy capable of transforming physiological signals into objective clinical data to guide therapeutic decision-making. Its use allows clinicians to identify sustained or recurrent elevations in intracranial pressure, evaluate responses to clinical and surgical interventions, and adjust measures such as sedation, osmotherapy, cerebrospinal fluid drainage, ventilation, temperature control, decompressive craniectomy, and cerebral perfusion pressure targets (HAWRYLUK *et al*., 2019).

Despite being widely adopted in trauma centers and neurointensive care units, intracranial pressure monitoring remains a matter of debate. Observational studies and clinical trials have shown heterogeneous results regarding its impact on mortality, length of stay, therapeutic intensity, and functional recovery. Part of this controversy derives from the fact that monitoring alone does not change outcomes; its benefit depends on proper patient selection, clinical interpretation of the collected data, and the existence of therapeutic protocols capable of responding to the abnormalities detected (ROBBA *et al*., 2021; NATTINO *et al*., 2023).

Therefore, this narrative review aims to analyze the main indications for intracranial pressure monitoring in traumatic brain injury, discussing its role in neurocritical care and its impact on patients' clinical and functional outcomes.

2 METHOD

This study consists of a Narrative Literature Review with a descriptive and analytical approach, developed to gather and discuss recent evidence regarding intracranial pressure monitoring in patients with traumatic brain injury. The narrative review design was chosen because it allows a broad and critical discussion of the topic, integrating guidelines, consensus statements, observational studies, clinical trials, reviews, and technical documents relevant to clinical practice.

The guiding research question was structured according to the PICo strategy: P - patients with moderate to severe traumatic brain injury; I - intracranial pressure monitoring; Co - hospital, neurosurgical, and neurocritical care settings. Based on this framework, the following question was formulated: what are the main indications for intracranial pressure monitoring in traumatic brain injury, and what impact does this strategy have on patients' clinical and functional outcomes?

Publications from 2019 to 2026 were prioritized, including studies indexed in databases and scientific sources such as PubMed/MEDLINE, The Lancet Neurology, JAMA Network Open, Intensive Care Medicine, Neurocritical Care, Journal of Neurotrauma, and Trauma Surgery & Acute Care Open, as well as guidelines and recommendations from scientific societies. The descriptors and combined search terms included: "traumatic brain injury", "intracranial pressure monitoring", "severe traumatic brain injury", "intracranial hypertension", "neurocritical care", "outcomes", and "cerebral perfusion pressure".

Studies addressing indications, protocols, therapeutic algorithms, invasive or multimodal monitoring, and outcomes related to mortality, functional recovery, length of stay, and therapeutic intensity were included. Experimental studies, publications unrelated to traumatic brain injury, studies without accessible abstracts, and papers focused primarily on other neurological conditions without direct applicability to trauma care were excluded.

3 RESULTS

Recent literature demonstrates that intracranial pressure monitoring is most commonly indicated in patients with severe traumatic brain injury, particularly when associated with low Glasgow Coma Scale scores, significant tomographic abnormalities, cerebral edema, hematomas, basal cistern compression, midline shift, or neurological deterioration. Contemporary guidelines and consensus statements emphasize that the decision should not rely solely on isolated numerical thresholds, but rather on the integration of neurological examination, neuroimaging findings, age, hemodynamic instability, need for deep sedation, and risk of secondary brain injury (HAWRYLUK *et al*., 2019; ZOERLE *et al*., 2024).

The analyzed studies also indicate that the impact of intracranial pressure monitoring on outcomes remains heterogeneous. The SYNAPSE-ICU study observed that monitoring may be associated with a more intensive therapeutic approach and lower mortality among patients with more severe acute brain injury, although effects on functional recovery appear to be influenced by baseline severity and variability in practices among centers (ROBBA *et al*., 2021). Conversely, a multicenter analysis published in JAMA Network Open found an association between intracranial pressure monitoring and poorer six-month functional recovery, as well as increased use of medical interventions, suggesting that patient selection, therapeutic intensity, and protocol differences directly affect interpretation of these findings (NATTINO *et al*., 2023).

Another relevant finding concerns advances in multimodal monitoring. Recent studies highlight that intracranial pressure, although central, does not fully encompass the physiological assessment of the injured brain. The combination of intracranial pressure monitoring with cerebral perfusion pressure, brain tissue oxygenation, cerebral autoregulation assessment, electroencephalography, and noninvasive methods may enhance individualized care. Trials and consensus recommendations related to combined intracranial pressure and brain oxygen monitoring suggest a trend toward more personalized management strategies, although stronger evidence is still needed (CHESNUT *et al*., 2020; SANTANA *et al*., 2024; ZOERLE *et al*., 2024).

Table 1. Summary of Main Findings Regarding Intracranial Pressure Monitoring in Traumatic Brain Injury

Author/Year	Study Type	Main Objective	Principal Findings	Clinical Implications
CARNEY *et al.*, 2017	Guideline	To establish evidence-based recommendations for severe traumatic brain injury management	Reinforced the importance of intracranial pressure (ICP) and cerebral perfusion pressure (CPP) monitoring in selected severe TBI patients	Supports protocol-driven neurocritical care and individualized CPP targets
HAWRYLUK *et al.*, 2019	International Consensus	To propose a stepwise management algorithm for ICP-guided treatment	Emphasized escalation-based therapeutic strategies integrating ICP trends and clinical context	Encourages structured and physiologically guided interventions
CHESNUT *et al.*, 2020	Consensus Conference	To discuss combined ICP and brain tissue oxygen monitoring	Suggested that multimodal monitoring may improve individualized treatment approaches	Supports integration of cerebral oxygenation into neurocritical care protocols
ROBBA *et al.*, 2021	Multicenter Observational Cohort Study	To evaluate ICP monitoring practices in acute brain injury patients	ICP monitoring was associated with more intensive therapy and potential mortality reduction in severe cases	Demonstrates variability among centers and importance of institutional expertise
MAAS *et al.*, 2022	Narrative Review	To analyze advances and challenges in traumatic brain injury care	Highlighted secondary brain injury as a major determinant of outcomes	Reinforces the relevance of physiological monitoring in TBI management
BUMBERGER *et al.*, 2022	Retrospective Study	To evaluate indications and complications related to ICP monitoring	Reported complications such as hemorrhage and device-related issues	Emphasizes the need for careful patient selection and technical expertise
JHA *et al.*, 2023	Editorial/Clinical Reflection	To critically discuss the role of ICP monitoring in modern neurocritical care	Argued that ICP monitoring should guide clinical reasoning rather than isolated numerical targets	Supports contextualized interpretation of monitoring data
NATTINO *et al.*, 2023	Multicenter Comparative Study	To assess the effectiveness of ICP monitoring on long-term outcomes	Found heterogeneous associations between monitoring and	Suggests that outcomes depend on protocol quality and therapeutic response

			functional recovery	
TRAN *et al.*, 2023	Evidence-Based Clinical Review	To review current evidence regarding invasive intracranial monitoring	Discussed complications, technical limitations, and staff training requirements	Highlights infrastructure dependency for effective implementation
VITT *et al.*, 2023	Narrative Review	To discuss multimodal and autoregulation monitoring in TBI	Demonstrated the importance of integrating ICP with autoregulation and CPP assessment	Reinforces personalized neurocritical care approaches
ZOERLE *et al.*, 2024	Contemporary Review	To examine current challenges and innovations in ICP monitoring	Highlighted limitations of isolated ICP thresholds and emerging multimodal strategies	Supports precision-based monitoring and individualized care
SANTANA *et al.*, 2024	Clinical Study	To evaluate combined brain oxygen and ICP monitoring	Suggested potential benefits in detecting occult cerebral hypoxia	Supports expansion of multimodal monitoring strategies

Source: Prepared by the authors, 2026.

4. DISCUSSION

Intracranial pressure monitoring in traumatic brain injury should be understood as a physiological surveillance tool designed to support real-time clinical decision-making. Its greatest value lies not merely in obtaining a numerical measurement, but in recognizing patterns of intracranial hypertension, evaluating trends, identifying therapeutic failure, and guiding stepwise interventions. In this way, monitoring contributes to reducing uncertainty in the management of sedated, mechanically ventilated, or neurologically unassessable patients (JHA *et al.*, 2023; STEIN *et al.*, 2023).

Classical indications include patients with severe traumatic brain injury and abnormal computed tomography findings, particularly when hematomas, contusions, diffuse edema, cisternal compression, or midline shift are present. However, monitoring may also be considered in patients with less striking initial imaging findings but significant clinical risk factors, such as advanced age, hypotension, abnormal motor posturing, neurological worsening, or the need for deep sedation. This perspective reinforces the importance of individualized assessment, avoiding both underutilization in high-risk patients and indiscriminate use in situations with limited expected benefit

(ZOERLE *et al*., 2024).

Its impact on clinical outcomes must be interpreted carefully. Intracranial pressure monitoring is not a therapeutic intervention by itself, but rather a diagnostic and decision-support strategy. Therefore, its effectiveness depends on the existence of protocols capable of translating physiological data into timely clinical actions. Centers using structured algorithms, such as those proposed by the Seattle International Severe Traumatic Brain Injury Consensus Conference, tend to organize treatment into progressive levels, beginning with lower-risk measures and escalating to more aggressive interventions only when necessary (HAWRYLUK *et al*., 2019).

The heterogeneity of published studies reflects important differences in patient populations, healthcare systems, available resources, indication criteria, and therapeutic targets. In observational studies, monitored patients are often more severely ill, which may generate indication bias and complicate direct comparisons with non-monitored patients. This helps explain why some investigations associate monitoring with greater therapeutic intensity, longer ICU stays, or worse functional outcomes, without necessarily implying a harmful effect of the monitoring itself (NATTINO *et al*., 2023).

On the other hand, there is evidence suggesting that, in selected patients, intracranial pressure monitoring may contribute to lower mortality and better organization of neurocritical care. The SYNAPSE-ICU study indicated that more severely injured patients may benefit from monitoring-based strategies, particularly when collected data are actively used to guide targeted interventions rather than passive observation alone (ROBBA *et al*., 2021). Thus, the central issue is not simply whether to monitor, but rather whom to monitor, when to monitor, and how to respond to the obtained information.

Cerebral perfusion pressure is another essential component of this discussion. Since elevated intracranial pressure may compromise cerebral perfusion, management strategies should seek a balance between reducing intracranial pressure and maintaining adequate systemic arterial pressure. Interventions such as osmotherapy, sedation, ventilatory adjustments, cerebrospinal fluid drainage, and decompressive craniectomy must be evaluated within the patient's physiological context, avoiding automatic approaches that reduce intracranial pressure at the

expense of undesirable systemic effects (CARNEY *et al*., 2017; VITT *et al*., 2023).

Multimodal monitoring represents an important advancement because it recognizes that traumatic brain injury involves complex pathophysiological processes that cannot be fully captured by a single variable. The combination of intracranial pressure and brain tissue oxygenation monitoring, for example, allows clinicians to identify situations in which intracranial pressure is controlled while tissue hypoxia persists. Recent studies on combined monitoring suggest potential benefits regarding mortality and functional recovery, although larger trials and standardized protocols are still necessary before broader implementation can be recommended (CHESNUT *et al*., 2020; SANTANA *et al*., 2024).

It is also necessary to consider the limitations and risks associated with invasive monitoring. Potential complications include hemorrhage, infection, device malfunction, and the need for additional procedures. Furthermore, monitoring requires trained staff, neurosurgical availability, institutional protocols, and the ability to implement therapeutic responses. In settings lacking adequate infrastructure, the simple placement of a monitoring device does not guarantee improved outcomes and may even increase interventions without proportional benefit

Finally, contemporary literature points toward a paradigm shift: intracranial pressure monitoring should be integrated into a personalized neurocritical care model based on continuous assessment, flexible protocols, and contextualized interpretation. The future of the field appears to be moving toward the integration of invasive monitoring, noninvasive technologies, trend analysis, biomarkers, artificial intelligence, and precision medicine strategies applied to traumatic brain injury care.

5 CONCLUSION

Intracranial pressure monitoring remains one of the main tools in the management of severe traumatic brain injury, particularly in patients at high risk of intracranial hypertension and neurological deterioration. Its use enables the identification of relevant physiological alterations and supports interventions aimed at preventing secondary brain injury.

Recent evidence demonstrates, however, that its impact on outcomes should

not be interpreted in a simplistic manner. Monitoring alone does not reduce mortality or improve functional recovery unless it is associated with structured therapeutic protocols, trained multidisciplinary teams, and individualized clinical decision-making. Its benefit depends on appropriate patient selection and on the institution's ability to respond effectively to monitored data.

The literature also highlights that multimodal monitoring is likely to occupy an increasingly important role in neurocritical care by integrating intracranial pressure, cerebral perfusion pressure, tissue oxygenation, and other physiological parameters. This approach may favor greater therapeutic precision and reduce reliance on decisions based exclusively on fixed numerical thresholds.

In conclusion, intracranial pressure monitoring should be viewed as a clinical decision-support instrument in traumatic brain injury rather than a self-sufficient intervention. Its rational, contextualized, and protocol-driven use represents a relevant strategy to improve neurocritical care management and potentially enhance patient outcomes.

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