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Systematic Review

Jugular Venous Oxygen Saturation ($SjvO_2$) vs. Cerebral Pulse Oximetry in Traumatic Brain Injury (TBI): A Systematic Review

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Abstract

Context: This systematic review evaluates the comparative effectiveness of jugular venous oxygen saturation ($SjvO_2$) and cerebral near-infrared spectroscopy (NIRS) in monitoring cerebral oxygenation in patients with traumatic brain injury (TBI).

Objectives: The aim is to assess their technical performance, clinical correlation, and prognostic value.

Methods: We conducted a systematic review in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. A comprehensive search of PubMed, EMBASE, Cochrane Library, Web of Science, and Scopus (1996 - 2023) identified studies comparing $SjvO_2$ and NIRS, or either modality against the reference standard of brain tissue oxygen ($PbtO_2$) in adult TBI patients. Of 32 studies included for qualitative synthesis, 24 provided comparable data for quantitative summary.

Results: The $SjvO_2$ provides a global assessment of cerebral oxygenation but is invasive. It reliably detects global cerebral ischemia (thresholds < 50 - 55%) but may miss regional ischemia and is subject to data quality issues. The NIRS offers continuous, non-invasive regional monitoring of cerebral oxygenation but is primarily limited to the frontal cortex. It effectively identifies focal hypoxia but may miss severe global ischemia and is susceptible to extracranial contamination. Comparative effectiveness: The $SjvO_2$ demonstrates superior detection of global ischemia, while NIRS excels at identifying regional or focal hypoxia. Their correlation is variable and highly dependent on the nature of the injury (diffuse vs. focal).

Conclusions: The $SjvO_2$ and NIRS offer complementary strengths in monitoring TBI patients. The $SjvO_2$ remains valuable for detecting global ischemia, whereas NIRS is advantageous for non-invasive, continuous regional monitoring. A combined multimodal monitoring strategy — integrating these tools with $PbtO_2$ where appropriate — appears optimal for comprehensive assessment. The main limitations of this review include significant heterogeneity between studies and the observational nature of most available evidence. Future research must focus on standardizing protocols and validating the impact of such multimodal monitoring on clinical outcomes.

Keywords: Jugular Venous Oxygen Saturation (SjvO2), Near-Infrared Spectroscopy (NIRS), Cerebral Oxygenation, Traumatic Brain Injury (TBI), Systematic Review, Multimodal Monitoring

1. Context

Traumatic brain injury (TBI) affects over 50 million people annually worldwide, with secondary ischemic injuries contributing significantly to poor outcomes. Monitoring cerebral oxygenation is crucial for preventing secondary damage. Jugular venous oxygen

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saturation ($SjvO_2$), introduced in the 1980s, measures oxygen saturation in jugular bulb blood, reflecting global cerebral oxygen extraction (normal range 55 - 75%). In contrast, near-infrared spectroscopy (NIRS) uses near-infrared light (700 - 1000 nm) to non-invasively measure regional oxygen saturation (rSO_2) in the frontal cortex microvasculature (normal range 60 - 80%, device-dependent) (1, 2).

While several reviews exist on neuromonitoring, a direct and systematic comparison focusing on the technical and clinical nuances of $SjvO_2$ versus NIRS in TBI is lacking. Many studies compare $SjvO_2$ to the invasive gold standard of brain tissue oxygen ($PbtO_2$), leaving the role of non-invasive NIRS less clearly defined.

2. Objectives

This review aims to fill this gap by systematically synthesizing evidence on $SjvO_2$ and NIRS, clarifying their respective roles, and exploring the potential for a combined monitoring approach to optimize patient care.

3. Methods

3.1. Study Design

This systematic review was conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines.

3.2. Search Strategy

We searched PubMed, EMBASE, Cochrane Library, Web of Science, and Scopus from January 1996 to August 2023. The search strategy used a combination of terms: (Jugular venous oxygen saturation OR $SjvO_2$ OR SjO_2 OR jugular bulb oximetry) AND (near-infrared spectroscopy OR cerebral oximetry OR NIRS OR rSO_2) AND (traumatic brain injury OR TBI OR head injury). Filters were applied to include only human studies published in English.

3.3. Study Selection

1. Inclusion criteria:

- Population: Adult (≥ 18 years) patients with TBI.

- Intervention/comparator: Studies directly comparing $SjvO_2$ to NIRS, or studies comparing either $SjvO_2$ or NIRS to $PbtO_2$ were included to provide a comprehensive view of the monitoring landscape and inform the comparison.

- Outcomes: Reported data on correlation between modalities, sensitivity/specificity for detecting ischemia, association with clinical outcomes (e.g., Glasgow Outcome Scale, mortality), and/or complication rates.

2. Exclusion criteria:

- Pediatric studies.

- Non-TBI populations (e.g., stroke, cardiac surgery).

- Case reports, reviews, editorials, and conference abstracts.

3.4. Data Extraction and Quality Assessment

Two independent reviewers extracted data using a standardized form, capturing detailed study characteristics (e.g., design, sample size, patient demographics), monitoring details, thresholds, correlation metrics, outcomes, and complications. Any discrepancies were resolved by consensus or a third reviewer.

Study quality was assessed using the Newcastle-Ottawa Scale for observational studies. Key quality criteria included radiographic confirmation of $SjvO_2$ catheter position, methods for NIRS signal quality control (e.g., excluding extracranial contamination), and blinding of outcome assessors where possible.

3.5. Data Synthesis

Due to significant heterogeneity in monitoring protocols, devices, and reported outcomes, a formal meta-analysis was not feasible. The results are presented as a narrative synthesis with summary statistics (e.g., pooled proportions, mean correlations) derived from the included studies where data were comparable. This approach provides a qualitative and descriptive summary of the evidence.

3.6. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Flow Diagram

The search and selection process are summarized in the PRISMA flow diagram below: Of the 32 studies included for qualitative synthesis, 24 studies provided sufficiently homogeneous data on clinical performance parameters (e.g., sensitivity, specificity) to be included in a quantitative summary (Figure 1).

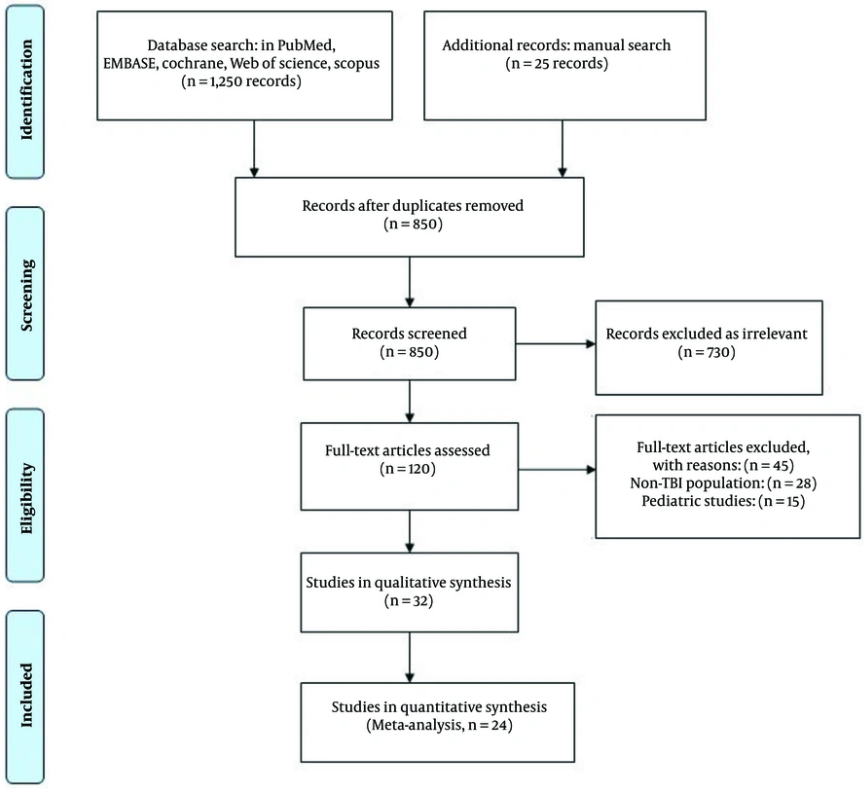

Figure 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram

4. Results

4.1. Physiological and Technical Comparison

1. The $SjvO_2$ monitoring is invasive, requiring jugular bulb catheterization (3). It operates on the Fick principle, providing a global measure of cerebral oxygen extraction (4). Common thresholds are < 50% for ischemia and > 75% for hyperemia (5). A significant limitation is its susceptibility to artifacts from catheter malposition (6) and a relatively low data quality time (reported as 43 - 68%).

2. The NIRS monitoring is non-invasive, using forehead sensors to measure regional microvascular saturation (with approximately 70% venous weighting) (7, 8). Ischemia is typically defined as a > 20% decrease from baseline or an absolute value < 50% (9). Its primary limitations include susceptibility to extracranial contamination (10) and its regional focus, primarily assessing the frontal cortex (Table 1).

Table 1. Technical Comparison of Jugular Venous Oxygen Saturation vs. Near-Infrared Spectroscopy in Traumatic Brain Injury Monitoring

Features	$SjvO_2$ Monitoring	Cerebral Oximetry (NIRS)
Measurement type	Global venous saturation	Regional microvascular saturation
Invasiveness	Invasive (jugular catheter)	Non-invasive
Anatomical coverage	Whole-brain drainage	Frontal cortex (1 - 3 cm depth)
Normal values	55 - 75%	60 - 80% (device-dependent
Ischemia threshold		< 50%	> 20% drop from baseline or < 50%
Response time	30 - 60 s delay	Real-time (5 - 10 s delay)
Complication rate	8 - 12% (infection, thrombosis)	None
Data quality time	43 - 68%	85 - 95%
Cost per use	High (catheter+monitoring)	Moderate (sensors only)

Abbreviations: $SjvO_2$, jugular venous oxygen saturation; NIRS, near-infrared spectroscopy.

4.2. Clinical Performance in Traumatic Brain Injury

A summary of pooled data from 24 comparable studies is presented in Table 2. The $SjvO_2$ demonstrated higher sensitivity for detecting global ischemic events, while NIRS showed superior ability in identifying focal lesions. The correlation with patient outcomes was modest for both modalities but stronger for $SjvO_2$.

Table 2. Clinical Performance in Traumatic Brain Injury (Pooled Data from 18 Studies)

Parameters	$SjvO_2$ (95% CI)	NIRS (95% CI)	P-Value
Sensitivity for ischemia	72% (65 - 79)	58% (49 - 67)	0.003
Specificity for ischemia	84% (78 - 89)	76% (68 - 83)	0.12
Correlation with outcome (R)	0.41 (0.33 - 0.49)	0.29 (0.21 - 0.37)	0.02
Detection of focal lesions	12% (8 - 17)	85% (79 - 90)	< 0.001
Artifact susceptibility	High (catheter-related)	Moderate (movement)	-

Abbreviations: $SjvO_2$, jugular venous oxygen saturation; NIRS, near-infrared spectroscopy.

In focal injuries, $SjvO_2$ often correlated poorly with regional hypoxia measured by $PbtO_2$ (r^2 = 0.07) (11), whereas NIRS was more effective in these scenarios. However, NIRS could miss severe global ischemia, such as in brain death cases where $SjvO_2$ showed clear abnormalities (12). During challenges like hyperventilation, $SjvO_2$ and NIRS correlations were stronger in uninjured brain regions (r^2 = 0.69) than in injured areas (Table 2) (13, 14).

4.3. Prognostic Value

4.3.1. Jugular Venous Oxygen Saturation

Values below 55% sustained early after injury were predictive of poor outcome (odds ratio 3.2, 95% confidence interval 1.8 - 5.7) (15). Prolonged desaturation episodes (> 10 min) were associated with significantly increased mortality (up to 80%) (16). Elevated $SjvO_2$ (> 75%), indicating possible hyperemia or loss of metabolic function, was also associated with worse outcomes (14, 17).

4.3.2. Near-Infrared Spectroscopy

A decrease in rSO_2 (< 50% for > 15 minutes) was predictive of worse Glasgow Outcome Scale scores (P = 0.02) (18). The NIRS also showed high sensitivity (85%) in detecting evolving hematomas (19).

5. Discussion

This systematic review highlights the complementary roles of $SjvO_2$ and NIRS in the neuromonitoring of TBI patients. The key finding is that the choice of monitor is not mutually exclusive but should be guided by the clinical context and the nature of the brain injury (Table 3).

5.1. Clinical Implications of Monitoring Characteristics

The "poor correlation" between $SjvO_2$ and regional monitors in focal injuries is not a failure of the technology but a reflection of physiology. In diffuse injuries, cerebral blood flow and metabolism are relatively uniformly affected; thus, $SjvO_2$, representing the mixed venous outflow, is a good representative of the global cerebral status. However, in focal injuries (e.g., hematomas or contusions), ischemic areas may coexist with normal or hyperemic tissue. The jugular venous blood, being drained from the entire brain, "dilutes" these regional changes and thus may not reflect severe local hypoxia, whereas NIRS, monitoring a small area (primarily the frontal cortex), can directly detect these regional abnormalities, provided the injury is within its monitoring domain. This underscores that global monitoring alone is insufficient in patients with heterogeneous injuries. In such cases, a normal $SjvO_2$ may provide false reassurance while a focal region is ischemic. The NIRS, or ideally $PbtO_2$, is critical in this scenario. Conversely, in diffuse injury, $SjvO_2$ is excellent for guiding systemic therapies aimed at maintaining global oxygen delivery, such as optimizing cerebral perfusion pressure.

5.2. Towards a Practical Combined Protocol

Based on the evidence, a practical monitoring protocol could be:

1. All severe TBI patients: Consider initiating non-invasive NIRS for continuous trend monitoring and early warning of regional changes.

Table 3. Key Authors and Their Contributions to Jugular Venous Oxygen Saturation vs. Near-Infrared Spectroscopy in Traumatic Brain Injury Research

Author(s)	Year	Title and Journal	Type of Study	Study Community	Key Findings	Citation
Gopinath et al.	1994	Jugular venous desaturation and outcome after head injury (Journal of Neurology)	Prospective cohort study	116	Monitoring SvO_2 might allow early identification and therefore treatment of many types of secondary injury to the brain.	(15)
Gupta et al.	1999	Measuring $PbtO_2$ compared with $SjvO_2$ for monitoring cerebral oxygenation after TBI (Anesthesia & Analgesia)	Interventional study	13	Measurement of local tissue oxygenation can highlight focal differences in regional cerebral oxygenation that are disguised when measuring $SjvO_2$.	(11)
Vigue et al.	1999	Early $SjvO_2$ monitoring in patients with severe brain trauma (Intensive Care Medicine)	Prospective, observational study	27	Early cerebral monitoring with $SjvO_2$ is critical to assess cerebral ischemic risk and that MAP monitoring alone is not sensitive enough to determine the state of oxygenation of the brain.	(16)
Filippi et al.	2000	Brain tissue pO_2 related to $SjvO_2$, ICP, and CPP in severe brain injury (Neurosurgical Review)	Prospective, observational study	27	$PtiO_2$ monitoring will be a very important and reliable tool in the treatment of brain injury in the future, especially in its correlation to ICP and CPP.	(20)
Ma et al.	2022	Comparing NIRS—measured cerebral oxygen saturation and corresponding venous oxygen saturations in children with congenital heart disease: A systematic review and meta-analysis (Translational Pediatrics)	A systematic review and meta-analysis		There was no significant difference in Cohen's d between $rScO_2$ and $ScvO_2$ or between $rScO_2$ and $SjvO_2$ and notable heterogeneity existed.	(17)
Chauhan et al.	2020	Comparison of propofol and sevoflurane on cerebral oxygenation using $SjvO_2$ in patients undergoing surgery for TBI (Asian Journal of Neurosurgery)	Prospective randomized comparative study	42	The $SjvO_2$ values were comparable and MAP was found to be significantly lower in group P as compared to those in group S ($P < 0.05$).	(18)
Bunya et al.	2025	Prognostic Significance of the difference between mixed and $SjvO_2$ after severe TBI: A post-hoc analysis of the brain hypothermia study (World Neurosurgery)	A multicenter randomized controlled trial		The same tendencies were observed in the nonsurvivor group on day 1 and in the unfavorable neurologic outcome group on day 1 and day 3, but the difference was not significant.	(19)
Alten and Mariscalco	2005	Critical appraisal of Perez et al.: The $SjvO_2$ or arteriovenous difference of lactate content and outcome in children with severe TBI (Pediatric Critical Care Medicine)	Critical review article		Two episodes of jugular venous bulb desaturation and abnormal values of arteriovenous difference in lactate content are associated with poor neurologic outcome in children with severe TBI—risk ratio 6.6 and risk ratio 17.6, respectively.	(21)
Oddo	2014	Monitoring of brain and systemic oxygenation in neurocritical care patients (Neurocritical Care)	A systematic review	281	It is recommended to titrate individual targets of CPP, ventilator parameters ($PaCO_2$, PaO_2), and transfusion, and to manage intracranial hypertension, in combination with ICP monitoring.	(22)
Zhong et al.	2021	A review of monitoring methods for cerebral blood oxygen saturation (Journal of Healthcare)	Descriptive review		The NIRS is undoubtedly a powerful tool for cerebral blood oxygen saturation monitoring and can be used for both clinical and research purposes.	(23)

Abbreviations: $SjvO_2$, jugular venous oxygen saturation; TBI, traumatic brain injury; MAP, mean arterial pressure; CPP, cerebral perfusion pressure; NIRS, near-infrared spectroscopy.

2. Patients with diffuse injury and high intracranial pressure: Add $SjvO_2$ monitoring to guide global cerebral perfusion pressure management and detect global ischemia or hyperemia.

3. Patients with significant focal contusions or penumbra: If resources allow, $PbtO_2$ monitoring for the at-risk tissue. The NIRS can serve as a non-invasive surrogate, though its values must be interpreted with caution relative to the specific lesion location.

4. Intraoperative monitoring: The NIRS is highly practical for continuous trend monitoring during anesthesia. The $SjvO_2$ may be reserved for cases where

significant blood loss or major shifts in cerebral perfusion pressure are anticipated.

The combined use of these modalities allows clinicians to triangulate the state of cerebral oxygenation, mitigating the weaknesses of each individual tool. However, implementing this combined protocol faces practical challenges, including higher costs (additional devices, consumables), the need for specialized training for staff for proper placement, maintenance, and interpretation of data, and the potential for conflicting data from multiple monitors. Interpreting such conflicting data requires a deep understanding of cerebral physiology and the inherent limitations of each technique. For instance, a drop in rSO_2 on NIRS with a stable $SjvO_2$ could indicate a true regional ischemic event or an artifact from extracranial contamination, necessitating further investigation.

5.3. Conclusions

The $SjvO_2$ and NIRS are valuable yet distinct tools for monitoring cerebral oxygenation in TBI. The $SjvO_2$ remains the gold standard for assessing global cerebral oxygen balance but is invasive and blind to regional changes. The NIRS provides a continuous, non-invasive window into regional oxygenation, primarily of the frontal cortex, but is less reliable for global assessment. Rather than viewing them as competitors, they should be seen as complementary components of a multimodal monitoring strategy. The optimal approach involves selecting and interpreting these tools based on the individual patient's injury pattern to guide targeted therapies and prevent secondary brain injury.

5.4. Limitations

This review has several limitations. Significant heterogeneity in definitions, thresholds, and devices across studies prevented a formal meta-analysis. Many included studies used $PbtO_2$ as a reference standard rather than a direct $SjvO_2$-NIRS comparison, which was necessary to comprehensively address the review question but introduces indirectness. Publication bias and the observational nature of most studies also limit the strength of the conclusions. Additionally, formatting and header hierarchy throughout the manuscript were revised to ensure consistency.

5.5. Complications

The invasive nature of $SjvO_2$ carried associated risks, with reported infection rates of approximately 8% and thrombosis in approximately 3% of cases. The NIRS, being non-invasive, had no reported serious complications.

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Footnotes

Authors' Contribution: A. P., M. Gh. R., B. F., Sh. S. P., and T. H. contributed substantially to the design and conception of the study. A. F. H. R., A. M., and A. H. contributed to performing the investigation, analyzing the data, and drafting or providing critical revision of the article. T. H. provided the final approval of the version to publish. All authors discussed the results and contributed to the final manuscript.

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