

External Ventricular Drains versus Intraparenchymal ICP Monitors in Traumatic Brain Injury: An Evaluation of Outcomes Utilizing Trauma Quality Improvement Program (TQIP) Data

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Abstract

Objectives

Measuring and managing intracranial pressure (ICP) is central to the management of severe traumatic brain injuries (TBI). External ventricular drains (EVD) and/or intraparenchymal intracranial pressure (IP-ICP) monitors are often utilized. Studies evaluating the effect of monitor type on outcomes have produced conflicting results. We hypothesized that the type of ICP monitor used would impact ventilator/ICU/hospital length of stay (LOS) and in-hospital mortality.

Methods

National trauma registry (TQIP) data from 2011–2019 for severe TBI patients was obtained. Patients were categorized as those receiving IP-ICP monitor or EVD. Demographic, comorbidity, injury severity scores and glasgow coma scale data were collected. Negative binomial regression models utilizing propensity score weighting assessed differences in ventilator/ICU/hospital LOS by monitor type. Binary logistic regression utilizing propensity score weighting examined the association between monitor type and in-hospital mortality as well as operative rate. Validation of propensity weighting was assessed by analyzing the standardized mean difference of model covariate.

Results

Of the 46,087 patients identified, 32,677 (70.9%) underwent IP-ICP monitor, 13,410 (29.1%) underwent EVD. Ventilator/ICU/hospital LOS and in-hospital mortality were found to be significantly lower in those patients managed with IP-ICP monitors while operative intervention was higher in this group.

Conclusion

In this patient population, patients managed with IP-ICP monitors had a higher rate of operative intervention and a lower ventilator/ICU/hospital LOS as well as an improved in-hospital mortality compared to those managed with EVDs. This remained true when accounting for the type of brain injury. While improvement in LOS and in-hospital mortality is encouraging, future studies evaluating impact on long-term functional outcomes is warranted.

INTRODUCTION

Traumatic brain injuries (TBI) have been called the “silent epidemic”^{1,2} and are the leading cause of death and disability following trauma related injury.^{1,2,3} Most patients with severe traumatic brain injuries require ICU admission and intra-cranial pressure (ICP) monitoring and management.² Elevated ICP can

lead to cerebral compression and secondary brain injury.^{4,5,6} ICP directed therapies is a mainstay of severe TBI management.^{7,8,9,10,19} Previous editions of the brain trauma foundation guidelines recommended the use of invasive ICP monitors for salvageable patients with severe traumatic brain injuries and an abnormal CT scan.¹⁰ A recent South American study has brought into question whether invasive ICP monitoring is warranted for patients with severe TBI.¹¹ Despite this, the current 4th edition brain trauma foundation guidelines recommends the use of ICP monitoring to reduce in-hospital mortality and 2-week post injury mortality.¹⁰ The recommendation for use of ICP monitoring was also echoed by the International Multidisciplinary Consensus Conference on Multimodality Monitoring in Neurocritical Care in 2014 as well as the World Society of Emergency Surgery conference in 2019.¹⁹ Although the language of the brain foundation guideline was weakened, invasive ICP monitoring continues to be recommended and remains the mainstay for management of severe TBI.^{7,8,9,10,19}

Despite clear guidelines regarding ICP monitoring, there is little guidance regarding which type of monitor to use.^{2,10,12,13} The two most common forms of ICP monitoring are intraparenchymal ICP (IP-ICP) monitor and external ventricular drain (EVD). Numerous studies evaluating these two modalities.^{2,12,13,14,17,18} These studies have demonstrated mixed results. One prospective study of 122 patients demonstrated improved mortality rate and glasgow outcome scale (GOS) at six months¹² when EVD's are utilized. Other studies have demonstrated improved in-hospital mortality, ICU length of stay (LOS), GOS at one month, GOS-Extended (GOS-E) at 180 days, and lower device-related complication rates with IP-ICP monitor use.^{13,14,17}

Conversely, other studies have found no difference in mortality, hospital LOS, clinical outcomes, device-related complication rates, or GOS-E at six months.^{2,12,13,15,17,18} One study noted that 25% of patients managed with IP-ICP monitors ultimately required EVD placement due to refractory ICP.¹⁷ A systematic review and meta-analysis including six studies found no difference in mortality or functional outcomes, although EVDs were associated with higher complication rates.¹⁸

Although it is expected that monitor selection is influenced by injury patterns, this has not been consistently demonstrated in the literature. Additionally, prior studies have not adequately accounted for the impact of injury heterogeneity on outcomes. This study utilizes the American College of Surgeons National Trauma Data Bank (NTDB) to evaluate the association between ICP monitor type and in-hospital mortality, ICU LOS, ventilator LOS, and hospital LOS while accounting for differences in injury pattern. Secondary outcomes include rates of craniotomy and craniectomy as well as the impact of hospital teaching status and trauma center designation on monitor utilization.

METHODS

This retrospective cohort study utilized data from the Trauma Quality Improvement Program (TQIP) database from 2011–2019. TQIP contains validated, standardized, de-identified data from trauma

centers across the United States as defined by the NTDS data dictionary.¹⁶ Institutional review board approval was obtained.

Patients aged ≥ 18 years who underwent IP-ICP monitor or EVD placement were included. Patients who received both devices were excluded. Collected variables included demographics, injury severity score (ISS), abbreviated injury scale (AIS), type of intracranial hemorrhage, hospital characteristics, medical comorbidities, ventilator LOS, ICU LOS, hospital LOS, in-hospital mortality, and complications.

Propensity weighting was performed using age, sex, GCS, ISS, head AIS, injury type, hospital teaching status, trauma level, bed size, and comorbidities (dementia, CHF, CVA, advanced directives, bleeding disorder, COPD, MI, cirrhosis). Validation of propensity weighting was assessed by analyzing the standardized mean difference of model covariate. Negative binomial regression models were used to assess the association between monitor type and ventilator, ICU, and hospital LOS. Binary logistic regression models were used to examine the association between monitor type and in-hospital mortality as well as operative decompression. Analyses were performed in SAS 9.4 (SAS Institute, Cary, NC) utilizing the GENMOD procedure for negative binomial regression models and the LOGISTIC procedure for logistic models.

To assess utilization of EVD vs IP-ICP monitors among trauma centers (level 1 vs level 2) and hospital teaching status (teaching or non-teaching), numerous risk factors were analyzed utilizing Wilcoxon rank-sum tests, Fisher's exact tests, and Pearson's chi-squared test. Level of significance was defined as $p \leq 0.05$. Variables identified as significant were utilized in a propensity weighting. After propensity weighting, binary logistical regression was performed.

RESULTS

During the study period, 62,045 patients underwent ICP monitoring. Of these, 38,550 (62.1%) received IP-ICP monitors, 15,234 (24.6%) received EVDs, and 8,261 (13.3%) received both and were excluded. The final cohort included 46,087 patients (70.9% IP-ICP; 29.1% EVD). Demographic data, hospital characteristics, measures of injury severity, type of brain injury, and baseline medical comorbidities were collected. Univariate analysis of these variables identified variables to include in propensity weighting. Level of significance was defined as $p \leq 0.05$. These results can be found in Table 1. Once these variables were identified, propensity weighting was performed. Validation study for the propensity weighting was assessed with results demonstrated in Figure 1. This validation study demonstrated significant variance in age, GCS, AIS, ISS, type of brain injury sustained, and teaching status as defined by standard mean difference >0.1 prior to propensity weighting. Differences in monitor type utilized related to type of brain injury prior to propensity weighting can be found in Table 2. After matching standard mean difference for all variables was <0.1 .

Utilizing this matched sample negative binomial regression models evaluating LOS were performed, Table 3. Ventilator, ICU, and hospital LOS were all found to be longer in those managed with an EVD vs

IP-ICP monitor, 11.5d vs 10.3d, 14.5d vs 12.8d, 21.6d vs 20.0d respectively. Each of these results were found to be statistically significant with a p-value < 0.0001.

Binary logistic regression models were performed to evaluate in-hospital mortality, Table 3. This analysis demonstrated a higher rate of in-hospital mortality in the EVD group compared to the IP-ICP group, 32.3% vs 31.2%, p-value < 0.0001.

When comparing rates of operative intervention (craniotomy and/or craniectomy) between monitor type, IP-ICP monitors were associated with a higher rate of operative intervention, 20.4% vs 18.8%, p < 0.0001. Binary logistic regression models were performed to evaluate effect operative intervention had on ventilatory/ICU/hospital LOS and in-hospital mortality by monitor type, Table 4. This demonstrated a statistically significant increase in each of these outcomes when operative intervention was performed. Of note, in-hospital mortality was the lowest in those managed with IP-ICP monitors who underwent operative intervention.

When assessing hospital teaching status and trauma level designation, most patients were treated at teaching centers compared to non-teaching centers, 90.10% vs 9.80% respectively. Likewise, most patients were treated at level 1 trauma centers compared to level 2 trauma centers, 50.31% vs 20.04% respectively. Demographic data, hospital characteristics, measures of injury severity, type of brain injury, and baseline medical comorbidities were collected. Univariate analysis of these variables identified variables to include in propensity weighting. Level of significance was defined as $p \leq 0.05$. Validation of propensity weighting is demonstrated in Figure 2 and Figure 3. Binary logistic regression demonstrated EVD utilization was higher at teaching hospitals and level 1 centers (Table 5), though IP-ICP monitors remained the predominant modality across all hospital types.

DISCUSSION

TBI is the leading cause of trauma related death and disability.^{1,2,3} High intracranial pressure due to severe TBI can lead to herniation and brain death.^{4,5,6} Due to this risk, most patients with a severe TBI are managed in an ICU setting.² Despite a recent study demonstrating safety in managing these patients without ICP monitoring,¹¹ ICP monitoring remains the mainstay in the management of severe traumatic brain injury.^{7,8,9,10,19}

Although ICP monitoring and ICP directed therapies are recommended in current brain trauma foundation guidelines, no recommendations are made regarding the type of monitor to utilize.¹⁰ The two most utilized monitors are EVD and IP-ICP monitors. Studies have sought to evaluate the impact monitor type utilized has on patient outcomes. Most of these studies were relatively small institutional studies^{2,12,13,14,15}; however, there have been some larger studies including a recent systematic review and meta-analysis.^{17,18} Outcomes assessed in each study were variable. The results are often contradictory with one study demonstrating improved outcomes with EVDs,¹² while other studies demonstrating worse outcomes with EVDs,^{13,14,17,18} while other studies found no difference in outcomes between the two

monitor types.^{2,12,13,15,17,18} As noted above, three studies had mixed results.^{13,17,18} This inconsistency may reflect underlying differences in patient selection and injury severity rather than true performance differences between devices.

It is expected that the type of ICP monitor utilized will be based on the type of brain injury sustained. This has not been consistently demonstrated in the literature. One multicenter study that included 878 patients from 62 centers across Europe found no statistical difference in type of brain bleed between those managed with IP-ICP monitor vs those managed with an EVD.¹⁷ Another study only evaluated the impact presence of IVH had on monitor type utilized.¹³ This study demonstrated increased utilization of EVDs when IVH was present.¹³ Another study only evaluated EDH, SDH, SAH, and DAI.¹⁵ This study only demonstrated a difference in monitor type utilized in the SAH and DAI groups.¹⁵ This study found significant differences in monitor type utilized based on presence of IVH, DAI, IPH, SAH, SDH, and EDH. This brings to light a potential confounder affecting other studies. By including type of brain injury in the propensity weighting, this study is the first study to account for this effect when assessing outcomes related to monitor type utilized. However, the TQIP registry does not include key anatomical details such as hemorrhage volume, degree of midline shift, or number of concurrent injuries, which limits the ability to achieve full adjustment. While this study demonstrated differences in practice pattern based on type of brain injury, future research is needed to assess if one monitor type is superior for a given type of brain bleed.

An additional potential confounder is the presence of injury to other body systems that may impact outcomes. Previous studies have employed variable measures to assess this effect with three studies utilizing ISS alone^{12,15,17} and one study utilizing ISS as well as head and neck AIS¹³. This study utilized ISS and head AIS in propensity weighting. Although this is in line with previous studies, it does demonstrate one limitation of retrospective studies.

Utilizing a propensity weighted sample, we were able to demonstrate improved ventilator, ICU, and hospital LOS as well as improved in-hospital mortality when IP-ICP monitors were utilized. The use of IP-ICP monitor did result in increased rates of operative intervention. Despite this those managed with IP-ICP monitor who subsequently underwent operative intervention had the lowest in-hospital mortality rate. Additionally, among those who underwent operative intervention, the ventilator, ICU, and hospital LOS were shorter in the IP-ICP group as compared to the EVD group. Given this, the increased operative intervention seen in the IP-ICP monitor group was not found to negatively impact primary outcomes as compared to the EVD group. It is worth noting that one previous study found that 25% of patients managed with IP-ICP monitors required an EVD due to refractory ICPs.¹⁷ This current study identified 13.3% of patients underwent both EVD and IP-ICP monitoring. The reason for both monitors being utilized was not identified and these patients were excluded from this study. Further study would be warranted to assess the impact this patient population may have on overall outcomes.

As discussed, TQIP data does not collect details regarding brain injury patterns such as total blood volume, extent of mass effect and midline shift, etc. Previously published guidelines have recommended

EVD use when CSF diversion is desired.²⁰ An additional meta-analysis and systematic review found that patients who underwent EVD placement tended to have more severe injury characteristics.²¹ It is possible that the differences in outcomes seen by this study could be due to underlying injury characteristics that are not represented by the TQIP data. Future prospective study is warranted to better assess if the results of this study persist when these characteristics are accounted for. Considering this and the results of this study, further prospective research is warranted.

One limitation inherent to TQIP based studies is the lack of long-term functional outcome data. One question raised from this study is whether the improved ventilator, ICU, and hospital LOS as well as in-hospital mortality translates to functional outcomes at long term follow up. This identifies an opportunity for further research. Another limitation of this study is the potential for confounding by indication for one monitor type over another. As mentioned earlier this study did find that monitor type utilized was affected by type of brain bleed. Although type of brain bleed was included in propensity weighting, this weighting was unable to account for the effect size of brain bleed or effect of multiple different brain bleeds in the same patient has on monitor type selected. This data is not included in the TQIP registry. As such, further study is warranted to better understand this relationship.

One study utilizing data from 2013 and 2014 reported that most patients were managed with an EVD rather than an IP-ICP monitor, 53% vs 47% respectively. This differs from the higher utilization of IP-ICP monitors, 70.9%, seen in this study and the 84% seen in the European multicenter study¹⁷. This may represent a national trend toward IP-ICP monitors. Despite this trend there was a relatively higher utilization of EVD monitors at teaching centers and level 1 trauma centers, 29.4% vs 25.2%, $p < 0.0001$ and 32.3% vs 27.5%, $p < 0.0001$ respectively. Propensity weighting for the primary outcomes accounted for hospital teaching status and trauma center designation. Thus, worse outcomes associated with EVD usage were not felt to be due to teaching centers and level 1 trauma centers caring for “sicker patients”. Rather, this may represent differences in preserved benefits or resources between centers.

Several limitations inherent to this observational, registry-based study must be acknowledged. First, causality cannot be inferred, and all results should be interpreted as associations rather than evidence that one monitoring modality improves outcomes. Second, although type of brain injury was included in the propensity model, unmeasured confounding remains substantial, particularly because TQIP lacks detail on hemorrhage size, mass effect, midline shift, and multiplicity of injuries. Third, patients who receive EVDs typically represent a clinically sicker population requiring CSF diversion, which inherently predisposes them to longer ventilator duration and ICU stay and may explain much of the observed outcome differences. Fourth, TQIP does not capture long-term neurological outcomes, limiting understanding of whether short-term improvements translate into functional benefit. Finally, exclusion of patients who received both device types may limit generalizability, as this subgroup likely represents more complex cases. These limitations highlight the need for further research in this area with prospective studies that can focus on answering some of these limitations.

CONCLUSION

Previous studies have evaluated the effect certain types of brain bleed has on monitor type selected. This study is unique in that it included the most complete list of brain bleeds. Previous studies have reported differences in monitor selection based on injury type. This study demonstrated a similar effect. Difference in outcomes remained significant even when type of injury was included in the propensity weighting. This analysis demonstrates an association between IP-ICP monitoring and shorter ventilator, ICU, and hospital lengths of stay and lower in-hospital mortality relative to EVD placement. These associations may be influenced by underlying injury characteristics that are not accounted for in TQIP rather than a true advantage of the monitor. Further prospective study should be conducted to further evaluate the effect injury characteristics has on the observed association.

There was an increased rate of operative intervention in the IP-ICP monitor group, however this did not translate to higher in-hospital mortality. IP-ICP monitors were found to be associated with significantly lower hospital resource utilization as defined by 1 to 1.5 days shorter ventilator, ICU, and hospital LOS, however the higher operative rate certainly adds to resource utilization. Future study is warranted to assess the impact monitor type has on hospital resource utilization as well as on long term functional outcomes. Interestingly, this study found that IP-ICP monitors were the most common monitor type selected regardless of hospital teaching status or designated trauma level. This contrasts with previous studies and likely represents a shift in practice pattern among United States trauma centers.

Abbreviations

ADLC – Advanced directive limiting care

AIS – Abbreviated Injury Scale

CHF – Congestive heart failure

COPD – Chronic obstructive pulmonary disease

CSF – Cerebrospinal fluid

CVA – Cerebrovascular accident

DAI – Diffuse axonal injury

EDH – Epidural hemorrhage

EVD – External ventricular drain

GCS – Glasgow Coma Scale

GOS – Glasgow Outcome Scale

GOS-E – Glasgow Outcome Scale–Extended

ICP – Intracranial pressure

ICU – Intensive care unit

IP-ICP – Intraparenchymal intracranial pressure

IPH – Intraparenchymal hemorrhage

ISS – Injury Severity Score

IQR – Interquartile range

IVH – Intraventricular hemorrhage

LOS – Length of stay

MI – Myocardial infarction

NTDB – National Trauma Data Bank

NTDS – National Trauma Data Standard

SAH – Subarachnoid hemorrhage

SDH – Subdural hemorrhage

TBI – Traumatic brain injury

TQIP – Trauma Quality Improvement Program

Declarations

Compliance with Instructions to Authors

The authors confirm that this manuscript complies with all instructions to authors provided by the journal, including formatting, structure, word limits, and submission requirements.

Author Contributions

JS – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

MG – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

AB – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

MW – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical

revision of the manuscript.

CC – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

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TL – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

EM – Conceptualization, study design, data collection, data analysis, manuscript drafting, and critical revision of the manuscript.

All authors reviewed and approved the final manuscript.

Authorship Confirmation

All listed authors meet the authorship criteria as defined by the journal. Each author has made significant contributions to the conception, design, execution, or interpretation of the study and has approved the final version of the manuscript.

Originality and Prior Publication

This manuscript has not been previously published and is not currently under consideration for publication elsewhere.

Ethical Approval and Informed Consent

This study was conducted in accordance with ethical standards and institutional guidelines. Given that the database is publicly available and contains deidentified information, this study was exempt from institutional review board approval and informed consent was not required.

Conflicts of Interest

The authors declare that they have no conflicts of interest relevant to this work.

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Reporting Checklist

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References

1. Dewan MC, Rattani A, Gupta S, Baticulon RE, Hung YC, Punchak M, Agrawal A, Adeleye AO, Shrimel MG, Rubiano AM, Rosenfeld JV, Park KB. Estimating the global incidence of traumatic brain injury. J

- Neurosurg. 2018 Apr 27;130(4):1080-1097
2. Dolmans R, Harary M, Nawabi N, Taros T, Kilgallon J, Mekary R, Izz S, Dawood H, Stopa B, Broekman M, Gormley W. External Ventricular Drains Versus Intraparenchymal Pressure Monitors in the Management of Moderate to Severe Traumatic Brain Injury: Experience at Two Academic Centers Over a Decade. *World Neurosurgery*. 2023;178:221-229
 3. Hyder AA, Wunderlich CA, Puvanachandra P, Gururaj G, Kobusingye OC. The impact of traumatic brain injuries: a global perspective. *NeuroRehabilitation*. 2007;22(5):341-53
 4. Monro A. *Observations on the Structure and Functions of the Nervous System*. Creech and Johnson; Edinburgh, UK: 1783
 5. Cushing H. *The Third Circulation in Studies in Intracranial Physiology and Surgery*. Oxford University Press; London, UK: 1926
 6. Harary M, Dolmans RGF, Gormley WB. Intracranial Pressure Monitoring-Review and Avenues for Development. *Sensors (Basel)*. 2018 Feb 5;18(2):465
 7. Perez-Barcena J, Llompарт-Pou JA, O'Phelan KH. Intracranial pressure monitoring and management of intracranial hypertension. *Crit Care Clin*. 2014 Oct;30(4):735-50
 8. Stocchetti N, Maas A. Traumatic Intracranial Hypertension. *N Engl J Med*. 2014;370:2121-2130
 9. Carney N, Totten AM, O'Reilly C, Ullman JS, Hawryluk GW, Bell MJ, Bratton SL, Chesnut R, Harris OA, Kisooson N, Rubiano AM, Shutter L, Tasker RC, Vavilala MS, Wilberger J, Wright DW, Ghajar J. Guidelines for the Management of Severe Traumatic Brain Injury, Fourth Edition. *Neurosurgery*. 2017 Jan 1;80(1):6-15
 10. Brain Trauma Foundation; American Association of Neurological Surgeons; Congress of Neurological Surgeons. Guidelines for the management of severe traumatic brain injury. *J Neurotrauma*. 2007;24 Suppl 1:S1-106
 11. Chesnut RM, Temkin N, Carney N, Dikmen S, Rondina C, Videtta W, Petroni G, Lujan S, Pridgeon J, Barber J, Machamer J, Chaddock K, Celix JM, Cherner M, Hendrix T; Global Neurotrauma Research Group. A trial of intracranial-pressure monitoring in traumatic brain injury. *N Engl J Med*. 2012 Dec 27;367(26):2471-81
 12. Liu H, Wang W, Cheng F, Yuan Q, Yang J, Hu J, Ren G. External Ventricular Drains versus Intraparenchymal Intracranial Pressure Monitors in Traumatic Brain Injury: A Prospective Observational Study. *World Neurosurg*. 2015 May;83(5):794-800
 13. Kasotakis G., Michailidou M., Bramos A., Chang Y., Velmahos G., Alam H., King D., de Moya M.A.: Intraparenchymal vs extracranial ventricular drain intracranial pressure monitors in traumatic brain injury: less is more. *J Am Coll Surg* 2012; 214: pp. 950-957
 14. Bales JW, Bonow RH, Buckley RT, Barber J, Temkin N, Chesnut RM. Primary External Ventricular Drainage Catheter Versus Intraparenchymal ICP Monitoring: Outcome Analysis. *Neurocrit Care*. 2019 Aug;31(1):11-21
 15. Aiolfi A, Khor D, Cho J, Benjamin E, Inaba K, Demetriades D. Intracranial pressure monitoring in severe blunt head trauma: does the type of monitoring device matter? *J Neurosurg*. 2018

16. National Trauma Data Standard Data Dictionary: American College of Surgeons
<https://www.facs.org/quality-programs/trauma/tqp/center-programs/ntdb/ntds>
17. Volovici V, Pisciă D, Gravesteijn BY, Dirven CMF, Steyerberg EW, Ercole A, Stocchetti N, Nelson D, Menon DK, Citerio G, van der Jagt M, Maas AIR, Haitsma IK, Lingsma HF. CENTER-TBI investigators, participants for the ICU stratum. Comparative effectiveness of intracranial hypertension management guided by ventricular versus intraparenchymal pressure monitoring: a CENTER-TBI study. *Acta Neurochir (Wien)*. 2022 Jul;164(7):1693-1705
18. Volovici V, Huijben JA, Ercole A, Stocchetti N, Dirven CMF, van der Jagt M, Steyerberg EW, Lingsma HF, Menon DK, Maas AIR, Haitsma IK. Ventricular Drainage Catheters versus Intracranial Parenchymal Catheters for Intracranial Pressure Monitoring-Based Management of Traumatic Brain Injury: A Systematic Review and Meta-Analysis. *J Neurotrauma*. 2019 Apr 1;36(7):988-995
19. Shim Y, Kim J, Kim HS, Oh J, Lee S, Ha EJ. Intracranial Pressure Monitoring for Acute Brain Injured Patients: When, How, What Should We Monitor. *Korean J Neurotrauma*. 2023 Jun 28;19(2):149-161
20. Carney N, Totten AM, O'Reilly C, et al. Guidelines for the Management of Severe Traumatic Brain Injury, Fourth Edition. *Neurosurgery*. 2017;80(1):6–15.
21. Venturelli S, Rass V, Ianosi B, et al. External Ventricular Drainage Versus Intraparenchymal ICP Monitoring in Severe TBI: A Systematic Review and Meta-analysis. *Crit Care Med*. 2021;49(3):e334–e343.

Tables

Table 1: Univariate Analysis of Demographic, Hospital Characteristics, Injury Severity, and Medical Comorbidity Effect on ICP Monitor Selection

Characteristic	Drain, N = 13,410 ¹	Monitor, N = 32,677 ¹	p-value ²
Demographic			
AGE	49 (30, 64)	39 (26, 56)	<0.0001
GENDER			0.0001
Female	3,322 (25%)	7,546 (23%)	
Male	10,084 (75%)	25,124 (77%)	
RACE			<0.0001
White	8,013 (70%)	20,077 (72%)	
Black	1,556 (14%)	3,751 (13%)	
Asian	304 (2.7%)	693 (2.5%)	
American Indian	144 (1.3%)	226 (0.8%)	
Pacific Islander	23 (0.2%)	129 (0.5%)	
Other	1,345 (12%)	3,040 (11%)	
Hospital Characteristics			
TEACHINGSTATUS			<0.0001
Teaching	12,206 (91.1%)	29,319 (89.8%)	
Nonteaching	1,186 (8.9%)	3,329 (10.2%)	
HOSPITALTYPE			<0.0001
For profit	1,398 (10.4%)	2,228 (7.1%)	
Non-profit	12,007 (89.6%)	29,203 (92.8%)	
Government	2 (<0.1%)	45 (<0.1%)	
BEDSIZE			0.0055
<= 200	2,109 (16%)	4,858 (15%)	
201-400	2,572 (19%)	6,660 (20%)	
401-600	3,559 (27%)	8,755 (27%)	
> 600	5,170 (39%)	12,404 (38%)	
ADULTVERIFICATIONLEVEL			<0.0001
I - Level I Trauma Center	7,502 (75.3%)	15,683 (69.8%)	

II - Level II Trauma Center	2,460 (24.7%)	6,776 (30.2%)	
Injury Severity			
AIS	4.4	4.5	<0.0001
ISS	25 (17, 33)	26 (21, 34)	<0.0001
Medical Comorbidities			
Advanced Directive Limiting Care	377 (2.8%)	555 (1.7%)	<0.0001
Bleeding Disorder	670 (5.0%)	1,151 (3.5%)	<0.0001
Currently Receiving Chemotherapy for Cancer	39 (0.3%)	34 (0.1%)	<0.0001
Cirrhosis	159 (1.2%)	308 (0.9%)	0.0179
Chronic Obstructive Pulmonary Disease (COPD)	583 (4.3%)	1,171 (3.6%)	0.0001
Cerebrovascular Accident (CVA)	350 (2.6%)	505 (1.5%)	<0.0001
Dementia	210 (1.6%)	188 (0.6%)	<0.0001
Diabetes Mellitus	1,548 (12%)	2,715 (8.3%)	<0.0001
Congestive Heart Failure	337 (2.5%)	475 (1.5%)	<0.0001
Hypertension	3,602 (27%)	5,849 (18%)	<0.0001
Myocardial Infarction (MI)	109 (0.8%)	182 (0.6%)	0.0016
Chronic Renal Failure	156 (1.2%)	225 (0.7%)	<0.0001
Current Smoker	2,051 (15%)	5,044 (15%)	0.7025
¹ n (%); Median (IQR)			
² Pearson's Chi-squared test; Wilcoxon rank sum test			

Table 2: Percentage of patients utilizing an IP-ICP monitor based on type of brain injury

Model Adjusted with Propensity Score Weighting Point Estimates with 95% Confidence Interval		
SDH	Not SDH	p-value
67.37% (66.94%, 67.79%)	70.98% (70.57%, 71.39%)	<0.0001
EDH	Not EDH	p-value
64.92% (64.48%, 65.35%)	70.95% (70.53%, 71.36%)	<0.0001
IPH	Not IPH	p-value
73.46% (73.05%, 73.86%)	70.33% (69.91%, 70.75%)	<0.0001
IVH	Not IVH	p-value
63.09% (62.65%, 63.53%)	71.95% (71.54%, 72.36%)	<0.0001
SAH	Not SAH	p-value
69.88% (69.46%, 70.30%)	71.84% (71.43%, 72.25%)	<0.0001
DAI	Not DAI	p-value
73.28% (72.84%, 73.71%)	70.91% (70.50%, 71.32%)	<0.0001
A binary logistic regression model was used to predict the likelihood of monitor use.		
SDH: subdural hemorrhage, EDH: epidural hemorrhage, IPH: intraparenchymal hemorrhage, IVH: intraventricular hemorrhage, SAH: subarachnoid hemorrhage, DAI: diffuse axonal injury		

Tables 3: Model Adjusted Point Estimates for Ventilator/ICU/Hospital Length of Stay and In-hospital Mortality

Model Adjusted Point Estimates with 95% Confidence Interval				
	Model Used	EVD	IP-ICP	p-value
Vent LOS*	Zero-Truncated Negative Binomial Regression	11.52 (11.42,11.62)	10.33 (10.12,10.56)	<0.0001
ICU LOS*	Zero-Truncated Negative Binomial Regression	14.46 (14.35,14.57)	12.83 (12.60,13.07)	<0.0001
Hospital LOS*	Zero-Truncated Negative Binomial Regression	21.63 (21.44,21.81)	20.01 (19.60, 20.43)	<0.0001
Mortality	Binary Logistic Regression	32.29% (31.86%,32.71%)	31.21% (30.79%,31.63%)	<0.0001
Propensity weights were calculated using inverse probability weighting methods with Gender, Age, GCS Total, Type of Brain Bleed, ISS, Advanced Directive Limiting Care, Bleeding Disorder, Cirrhosis, COPD, CVA, Dementia, CHF, MI, and CRF as confounders to treatment type. Poisson regression was considered, but a dispersion parameter was required in modeling ventilator LOS, ICU LOS, Hospital LOS.				
*LOS reported in days				

Table 4: Operative Intervention Effect on Primary Outcomes by Monitor Type

IP-ICP (n=32677)			
	Operation	No Operation	p-value
Vent LOS*	11.39 (11.13, 11.66)	10.40 (10.30, 10.50)	<0.0001
ICU LOS*	14.16 (13.87, 14.46)	12.85 (12.74, 12.96)	<0.0001
Hospital LOS*	21.89 (21.38, 22.41)	20.04 (19.84, 20.24)	<0.0001
Mortality	30.54%	31.44%	0.013
EVD (n=13410)			
	Operation	No Operation	p-value
Vent LOS*	12.08 (11.61, 12.57)	10.86 (10.69, 11.05)	<0.0001
ICU LOS*	15.22 (14.70, 15.76)	13.48 (13.29, 13.68)	<0.0001
Hospital LOS*	23.03 (22.16, 23.94)	20.11 (19.79, 20.44)	<0.0001
Mortality	32.31%	32.65%	0.558
Point estimates and 95% confidence intervals from binary logistic and zero-truncated negative binomial regression with propensity score weighting from patient demographics and medical comorbidities.			
*LOS reported in days			

Table 5: Distribution of Monitor Type Utilized by Hospital Teaching Status and Trauma Center Designation

Model Adjusted with Propensity Score Weighting Point Estimates with 95% Confidence Interval			
Monitor Type	Teaching	Non-Teaching	p-value*
<i>IP-ICP Monitor</i>	70.60% (70.18%, 71.02%)	74.76% (74.36%, 75.15%)	<0.0001
Monitor Type	Level I	Level II	p-value
<i>IP-ICP Monitor</i>	67.66% (67.64%, 68.65%)	72.48% (71.99%, 72.97%)	<0.0001

*Model used binary logistic regression

Figures

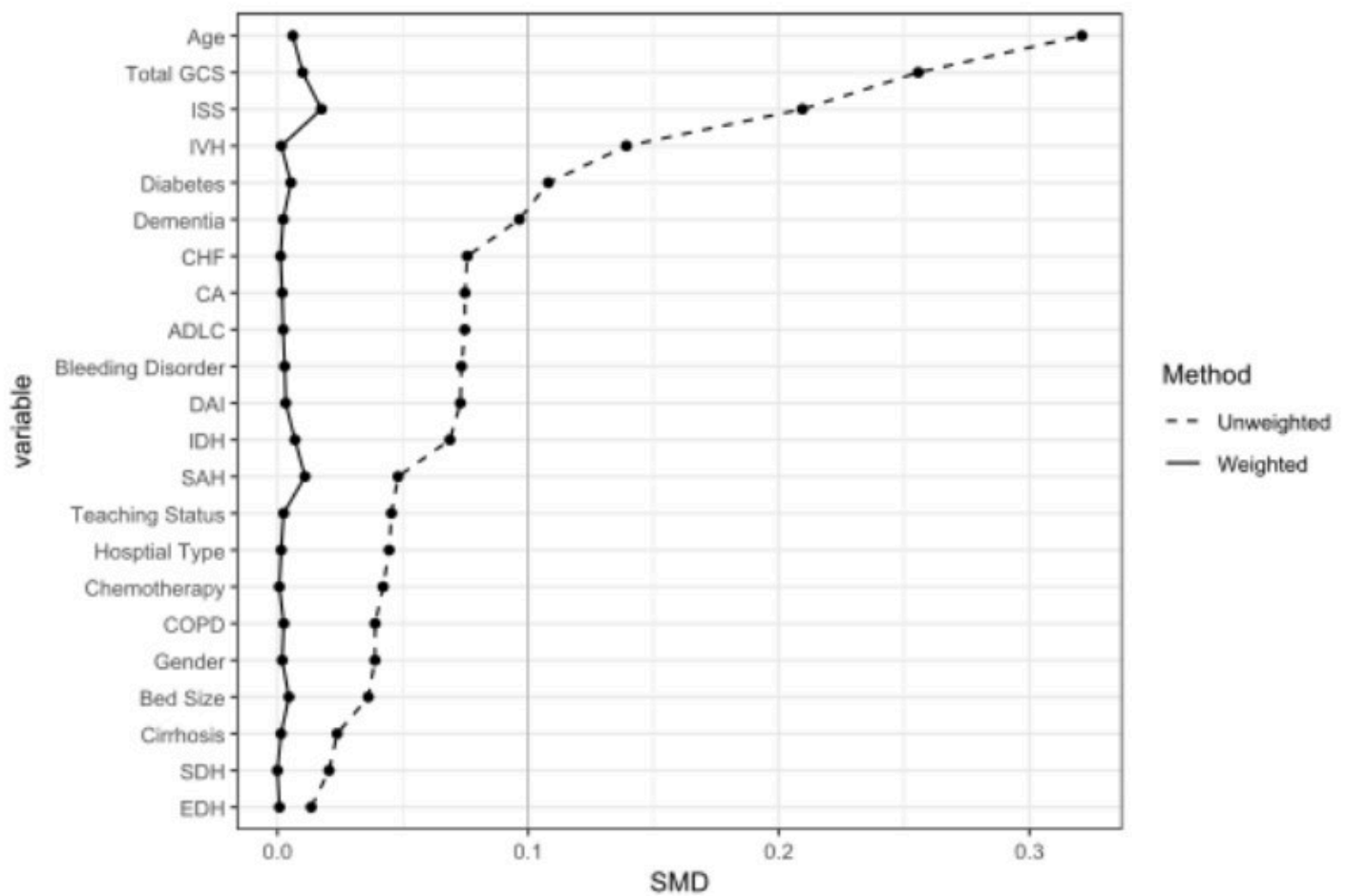


Figure 1

Validation of Propensity Weighting for Primary Outcomes. ISS: injury severity score, IVH: interventricular hemorrhage, CHF: congestive heart failure, CA: cerebrovascular accident, ADLC: advanced directive limiting care, DAI: diffuse axonal injury, IDH: intraparenchymal hemorrhage, SAH: subarachnoid

hemorrhage, COPD: chronic obstructive pulmonary disease, SDH: subdural hemorrhage, EDH: epidural hemorrhage

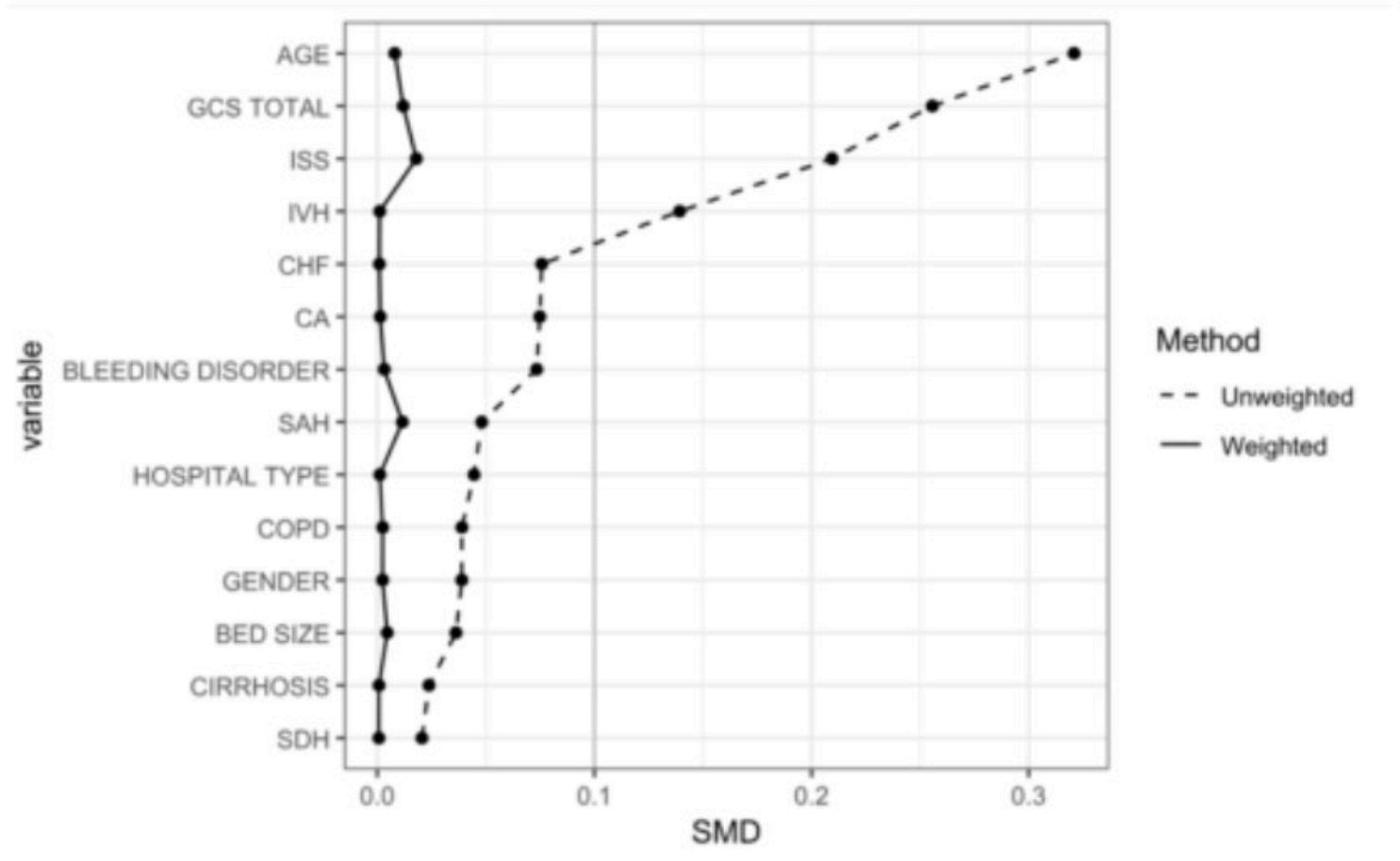


Figure 2

Validation of Propensity Weighting for Monitor Selection by Hospital Teaching Status. ISS: injury severity score, IVH: intraventricular hemorrhage, CHF: congestive heart failure, CA: cerebrovascular accident, SAH: subarachnoid hemorrhage, COPD: chronic obstructive pulmonary disease, SDH: subdural hemorrhage

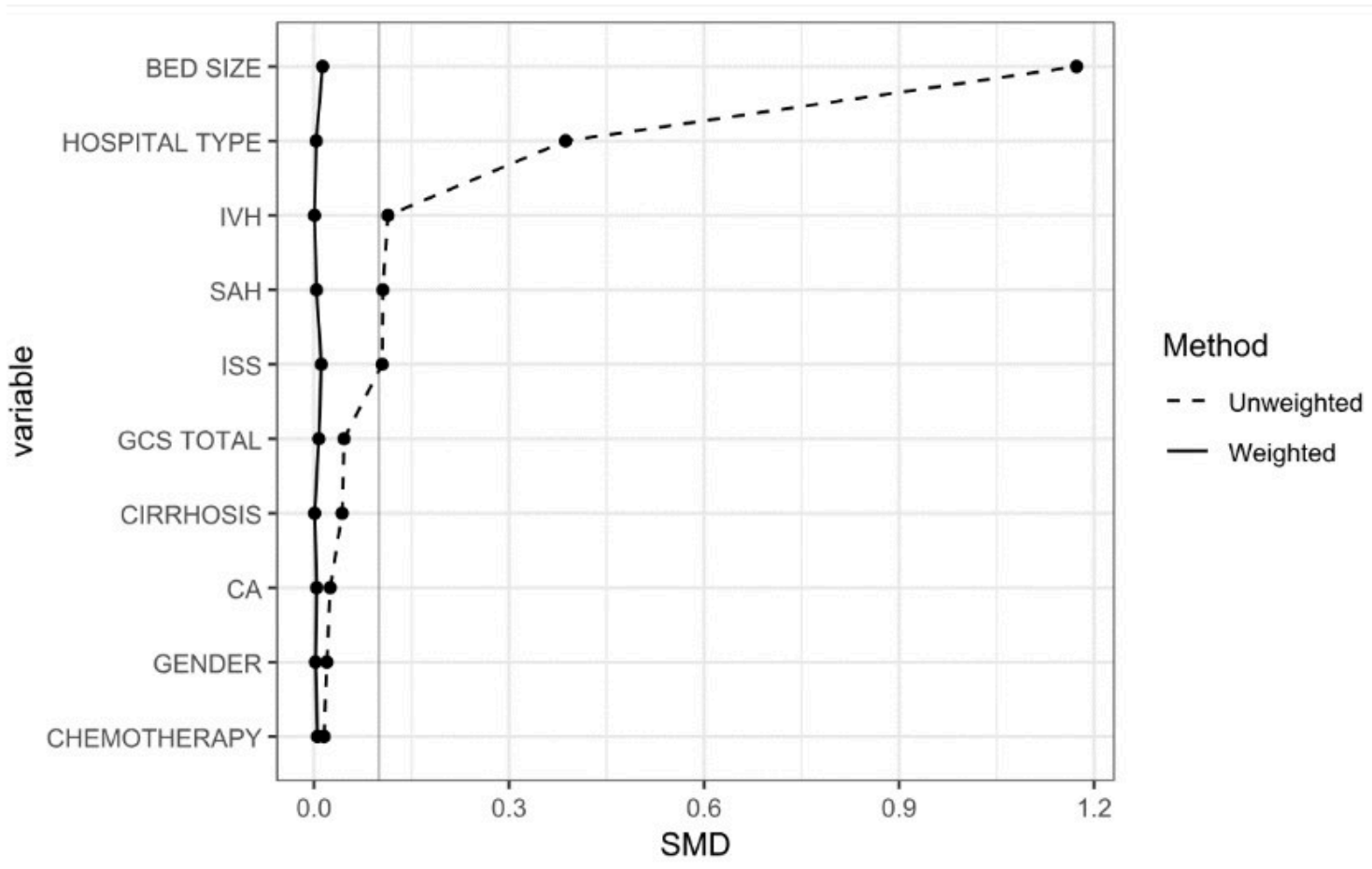


Figure 3

Validation of Propensity Weighting for Monitor Selection by Trauma Center Designation. IVH: intraventricular hemorrhage, SAH: subarachnoid hemorrhage, ISS: injury severity score, CA: cerebrovascular accident

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [STROBEchecklistv4combined.docx](#)