Statewide Trends in Intracranial Pressure Monitor Use in 36,915 Patients with Severe Traumatic Brain Injury in a Mature Trauma System over the Past 18 Years

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■ OBJECTIVE: **Intracranial pressure (ICP)—guided therapy has been the mainstay of treatment of patients with severe traumatic brain injury (TBI), but recent data have questioned its efficacy. The aim of this study was to demonstrate trends in compliance to TBI guidelines and use of ICP-guided care in a mature trauma system.**

■ METHODS: **A retrospective analysis was conducted of 36,915 patients with severe TBI collected by the Pennsylvania Trauma Systems Foundation. The registry includes all patients >18 years old with a diagnosis of TBI with a Glasgow Coma Scale score ≤8 who were admitted from January 2000 to December 2017.**

■ RESULTS: **Of 36,915 patients, 73.6% were men with a median age of 43.0 ± 21.3 years. An ICP monitor was placed in 16.3% of all patients. The rate of ICP monitoring ranged from 17.8% of patients in 2000—2004 to 16.7% in 2005—2009, 16.4% in 2010—2014, and 12.8% in 2015—2017 ($P < 0.001$). The most statistically significant decrease was noted from 2014 (16.4%) to 2015 (14.1%, $P = 0.042$). The percent decrease in ICP monitoring from 2000—2014 to 2015—2017 was equivalent for patients with Glasgow Coma Scale scores of 3—5 (−4.0%) and 6—8 (−4.5%).**

■ CONCLUSIONS: **As studies emerged that demonstrated unclear benefit of ICP monitoring in improving care in patients with severe TBI, there was a significant statewide decline in the use of ICP monitoring after 2014 among all TBI subpopulations despite noteworthy limitations in the aforementioned studies and clear recommendations from the Brain Trauma Foundation guidelines.**

INTRODUCTION

Traumatic brain injury (TBI) affects an estimated 10 million people annually worldwide.[1] In the United States, TBI contributed to 30% of all injury-related deaths in 2002—2006 and was associated with approximately 2.8 million emergency department visits, hospitalizations, or deaths in 2013.[2,3] In patients with TBI, the most frequent cause of death and disability is high intracranial pressure (ICP) defined as an ICP >20 mm Hg.[4] Uncontrolled ICP can lead to brain herniation, impaired cerebral perfusion, and further brain damage.[5] Because of its fundamental place in the care of patients with severe TBI and its relationship to overall outcomes, ICP monitoring has been included in every guideline for severe TBI published by the Brain Trauma Foundation (BTF).[6] However, despite its routine use in this population, the effectiveness of ICP monitoring has not been well established. This is in part due to the lack of clinical equipoise in well-developed countries to perform a trial with a subgroup that does not receive an ICP monitor. Although recent data have questioned efficacy of ICP monitoring in improving patient outcome and medical practice, a wealth of evidence remains that aggressive management of intracranial hypertension leads to better outcomes.[7-11]

Up until the third edition of the BTF guidelines, ICP monitoring was recommended in patients with severe TBI with an abnormal computed tomography scan or in patients with TBI with a normal computed tomography scan but with ≥2 of the following risk

Key words
- Intracranial pressure monitoring
- Neurocritical care
- Trauma
- Traumatic brain injury

Abbreviations and Acronyms
BTF: Brain Trauma Foundation
GCS: Glasgow Coma Scale
ICP: Intracranial pressure
TBI: Traumatic brain injury

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factors: age >40 years, unilateral or bilateral motor posturing, or systolic blood pressure <90 mm Hg.[12] However, the fourth edition of the BTF guidelines recommends the management of patients with severe TBI using ICP monitoring regardless of the aforementioned criteria. These recommendations are based on level IIB evidence consisting primarily of retrospective cohort studies and 1 prospective cohort study showing significantly lower mortality in patients treated with an ICP monitor.[13-15] Despite the latest BTF guidelines, however, several studies have questioned the effectiveness of ICP monitoring.[16-18] Among these is the BEST:TRIP (Benchmark Evidence from South American Trials: Treatment of Intracranial Pressure) trial, a large multicenter randomized controlled study published in December 2012 that suggested that care based on the use of ICP monitoring was not superior to care based on imaging and clinical examination.[19] In addition, ICP monitoring has been associated with worse survival, increased mechanical ventilation, and increased levels of therapy intensity.[20,21]

Given these new data, there has been increased skepticism among neurosurgeons regarding the benefits of ICP monitoring. In a 1991 survey of 219 trauma centers, 35% routinely used ICP monitoring,[15] whereas a Canadian survey in 2000 showed only 20% of neurosurgeons stated that they were highly confident that ICP monitoring improved outcomes.[16] We suspect that the recent published literature has negatively impacted the use of ICP-guided critical care among all TBI subpopulations. The purpose of this study was to report the annual trends in use of ICP monitoring in the mature trauma system of Pennsylvania over the past 18 years and determine if there was a decline in usage despite the updated guidelines. It is hoped that this study will help guide future research toward improving guideline-based ICP management.

MATERIALS AND METHODS

Patient Selection and Variables

The study protocol was approved by the University Institutional Review Board. We conducted a retrospective analysis of 36,915 patients with a diagnosis of severe TBI with a Glasgow Coma Scale (GCS) score ≤8 who were admitted to hospitals in Pennsylvania from January 2000 to December 2017. The patient registry was collected and maintained by the Pennsylvania Trauma Systems Foundation. Date of admission, patient age and sex, GCS score on admission, and use of an ICP monitoring device were collected for all the patients. Data on the trauma center level were not available for each patient. Data collection was conducted securely without sharing of identifiable personal health information. Individual patient consent was not obtained given the retrospective, noninterventional design of the study that was based on query of an existing database.

Statistical Analysis

Data are presented as mean and median for continuous variables according to their normal distribution curve and as frequency for categorical variables. Univariable analysis was carried out using unpaired t test, χ^2 test, or Fisher exact test as appropriate. P values of ≤0.05 were considered statistically significant. Statistical analysis was carried out with IBM SPSS Version 24.0 (IBM Corporation, Armonk, New York, USA).

RESULTS

Analysis included 36,915 patients >18 years old with a diagnosis of severe TBI as defined by GCS score ≤8. Median age was 43.0 ± 21.3 years, and 73.6% of patients were men. A GCS score of 3 was recorded in 72.6% of patients, and GCS score of ≥6 was recorded in 21.3% of patients (Table 1). The mean Injury Severity Score was 23.1 ± 14.6. An ICP monitor was placed in 16.3% of all patients. In 5-year periods, the rate of ICP monitor use ranged from 17.8% of patients (n = 1703) in 2000–2004 to 16.7% (n = 1815) in 2005–2009, 16.4% (n = 1787) in 2010–2014, and 12.8% (n = 719) in 2015–2017 (P < 0.001).

The annual rate of ICP monitor placement is displayed in Figure 1. A statistically significant decrease in ICP monitor use was noted from 2014 (16.4%) to 2015 (14.1%) (P = 0.042). A greater percentage of patients <40 years old underwent ICP monitor placement (19%) compared with patients ≥40 years old (14.0%) (P < 0.001). The percentage of patients <40 years old versus ≥40 years old who underwent ICP monitoring is displayed in Figure 2. Use of ICP monitoring was significantly greater in patients <40 years old in every year except for 2000 and 2007. Both groups showed a similar trend throughout this period with a significant decrease after 2014. The percentage of patients who underwent ICP monitoring stratified by GCS score is displayed in Figure 3A and B (GCS scores 3–5 and GCS scores 6–8, respectively). For GCS scores 3–5, a significant difference in use was seen in the years 2001, 2002, 2005, 2007, 2010, 2011, and 2012 (Figure 3A). For GCS scores 6–8, a significant difference in use was seen in the years 2006, 2010, and 2014 (Figure 3B). The percent decrease in ICP monitoring from 2000–2014 to 2015–2017 was similar for patients with GCS scores of 3–5 (−4.0%) and 6–8 (−4.5%).

DISCUSSION

The use of ICP monitoring in the treatment of TBI can be traced back to the 1960s, when elevated ICP was first identified as playing a key role in the death of patients with TBI.[17] The frequency of ICP monitor device placement has varied significantly over the years, ranging from 10.8% to 67%.[7,10,12-14,18,19] The first guidelines for use of ICP monitoring were published by the BTF in 1996 and delineated the indications for ICP monitoring. Subsequent editions of BTF guidelines published in 2000, 2007, and 2016 reinforced the indications for ICP monitoring.[6,20,21] The most recent recommendations are based on level IIB evidence consisting of retrospective cohort studies and 1 prospective cohort study, all of which reported a decrease in mortality when ICP monitors were used.[7,11,12]

However, recent publications have questioned the benefit of ICP monitoring for the treatment of severe TBI. BEST:TRIP, a randomized clinical trial by Chesnut et al.,[9] demonstrated that ICP monitoring was not superior to management based on imaging and clinical examination in South America given that there was no difference in 6-month mortality. The trial comprised 324 patients with severe TBI admitted to 6 hospitals in Ecuador and Bolivia. It is difficult to extrapolate the findings of this study to the

Table 1. Patient Characteristics

Patient Characteristics	All Patients (*N* = 36,929)	ICP-Guided Treatment (*n* = 6024, 16.3%)	Clinical-Based Treatment (*n* = 30,891, 83.7%)	*P* Value
Age	43.0 ± 21.3	41.2 ± 18.7	46.9 ± 21.6	<0.001
Male sex, %	73.6	76.3	73.1	<0.001
GCS score				
Mean	3.93 ± 1.65	3.90 ± 1.58	3.93 ± 1.66	0.163
Median (IQR)	3.0 (5)	3.0 (5)	3.0 (5)	
3	26,797 (72.6%)	4315 (71.6%)	22,482 (72.8%)	
4	1106 (3.0%)	238 (4.0%)	868 (2.8%)	
5	1182 (3.2%)	246 (4.1%)	936 (3.0%)	
6	2788 (7.6%)	461 (7.7%)	2327 (7.5%)	
7	2790 (7.6%)	501 (8.3%)	2289 (7.4%)	
8	2252 (6.1%)	263 (4.4%)	1989 (6.4%)	
ISS	23.1 ± 14.6	31.6 ± 11.3	21.4 ± 14.7	<0.001

ICP, intracranial pressure; GCS, Glasgow Coma Scale; IQR, interquartile range; ISS, Injury Severity Score.

general population because it had multiple limitations. There was a lack of external validity given that intensive care units in Ecuador and Bolivia may not use the same resources as in the United States or Europe where the guidelines were established. This is especially true for prehospital and posthospital care, which can widely vary between countries, and this may have contributed to long-term outcomes. Additionally, the group with imaging management required a physician at the bedside for 24 hours/day, which may not be able to be extrapolated to the rest of the world given this intense use of resources. Other retrospective studies also suggest that ICP monitoring may increase the risk of mortality, ventilation days, intensive care unit length of stay, complications, and functional outcomes.[10,14]

Despite some negative studies, several studies have reported promising findings supportive of ICP monitoring. Farahvar et al.[7] studied 1202 patients with an ICP monitor and 244 without an ICP monitor who were admitted at a Level I or II hospital in the state of New York in 2000–2009. They demonstrated that 2-week mortality

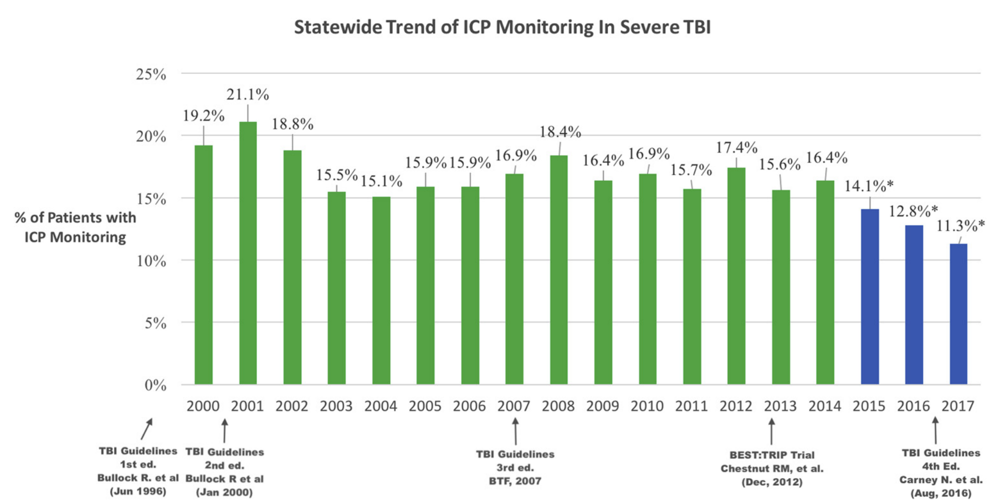

Figure 1. Annual rate of intracranial pressure monitoring device placement in 2000–2017 in the state of Pennsylvania. The annual rate was 15.1%–21.1% in 2000–2014, but significantly declined to 14.1% in 2015, 12.8% in 2016, and 11.3% in 2017. The timing of publication of the Brain Trauma Foundation guidelines and of landmark trial BEST:TRIP is displayed. ICP, intracranial pressure; TBI, traumatic brain injury; BTF, Brain Trauma Foundation.

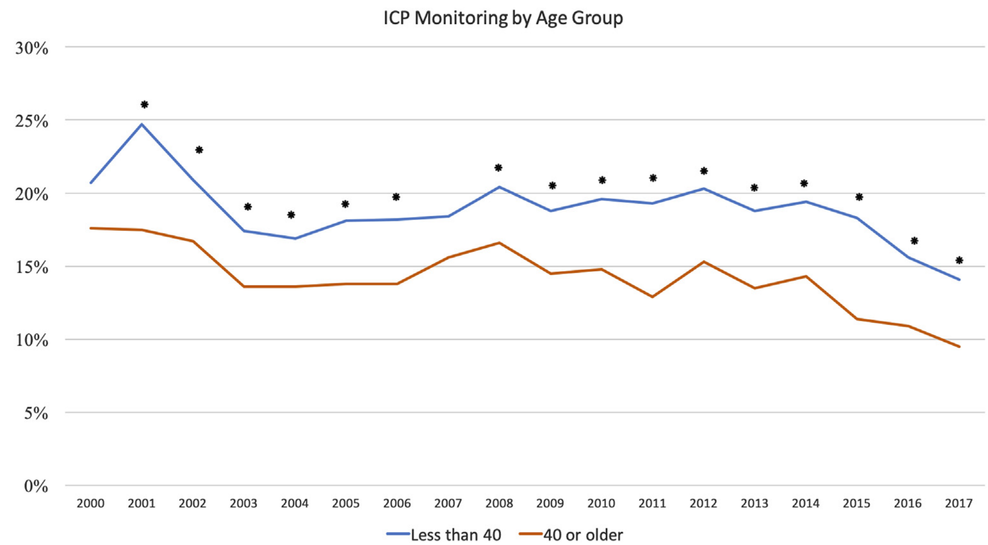

Figure 2. Annual rate of intracranial pressure (ICP) monitoring use in 2000–2017 for patients <40 years old and ≥40 years old. The rate of ICP monitoring is greater in patients <40 years old in every year of study period. *Asterisks* denote the years when the difference in ICP monitoring was statistically significant ($P < 0.05$). ICP, intracranial pressure.

was significantly higher in patients without ICP monitors placed (33.2% vs. 19.6%, $P < 0.0001$). ICP monitoring was also a significant predictor of 2-week mortality in the multivariable logistic regression model after controlling for age, GCS score, hypotension, computed tomography scan findings, and pupillary abnormalities (odds ratio, 0.63; 95% confidence interval, 0.41–0.94; $P = 0.02$). Their findings were corroborated by Gerber et al.,[22] who showed a significant decrease in the case-fatality rate in New York State in 2001–2009 from 22% to 13% ($P < 0.0001$). Interestingly, these authors noted an increase in the adherence to the BTF guidelines during that time frame with an increase in the use of ICP monitoring from 56% to 75% ($P < 0.0001$) as well as the use of cerebral perfusion pressure as a treatment metric from 15% to 48% ($P < 0.0001$). Furthermore, Alali et al.[11] investigated the mortality rate based on ICP monitoring use between hospitals. They compared hospitals with the highest use of ICP monitoring with hospitals with the lowest and showed an odds ratio of 0.52 (95% confidence interval, 0.35–0.78) for mortality when receiving care in the hospitals with highest ICP monitoring use.

The recent body of literature that pointed out the limitations of ICP monitoring has influenced decision making in the management of severe TBI. Our study showed a significant statewide decline in the use of ICP monitors after 2014. The incidence of ICP monitoring was 15.1%–21.0% in 2000–2014 and decreased significantly to 11.3%–14.1% in 2015–2017. Our findings demonstrated a clear downward trend in the use of ICP monitors for TBI treatment in Pennsylvania over the last 4 years (Figure 1). Although the compliance rate of ICP monitoring was significantly higher in patients <40 years old in almost all the years studied, a steady decline in use was noted as well after 2014 regardless of age (Figure 2). Regarding GCS score, there did not appear to be a clear relationship between GCS score and use of ICP monitoring, as statistical difference was noted in only a few years, dispersed throughout the study period (Figure 3A and B).

A similar trend in compliance to the BTF guidelines has been noted in Japan in recent years. The rate of ICP-guided therapy initially increased from 34.1% in 1998 to 55% in 2011 and then significantly decreased to 28% in 2017.[23,24] A meta-analysis by Khormi et al.[25] showed extensive variability in the adherence of the various BTF recommendations. The guideline for ICP monitoring in severe TBI was adhered to in 46.4%. Factors such as younger age, more severe neurologic injury, and need for surgical treatment increased adherence, whereas coagulopathy or low systolic blood pressure steered physicians away from ICP monitoring. Similarly, in our study, patients in the ICP-guided therapy group were on average younger and had a higher severity of neurologic injury than patients without an ICP monitor, but variables such as their coagulation profile and blood pressure were not a part of our study.

Although our study demonstrates a clear downtrend in the use of ICP-guided treatment of severe TBI, certain limitations need to be taken into consideration when interpreting our findings. Our data were collected from a large patient registry, and there are a few important clinical variables that were not included in the analysis. These include patient comorbidities, GCS score before and after admission, hospital-acquired complications, trauma center level, need for decompressive hemicraniectomy, code status, and goals of care by the family, all of which affect the treating physician's decision making. Furthermore, despite the universal adoption of the GCS for

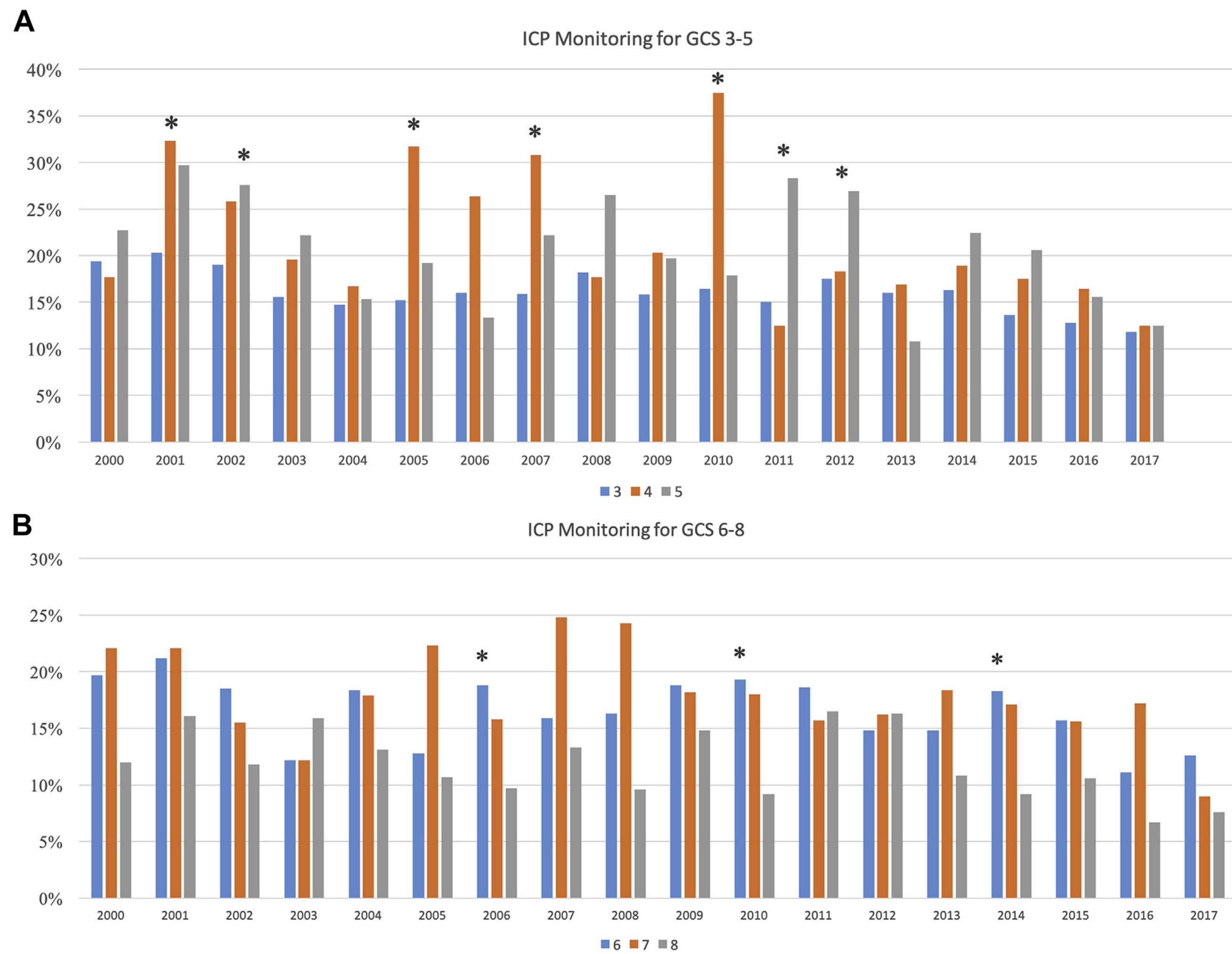

Figure 3. (**A** and **B**) Annual rate of intracranial pressure monitoring use in 2000–2017 stratified by Glasgow Coma Scale (GCS) scores 3–5 (**A**) and 6–8 (**B**). Whereas there is a downward trend in intracranial pressure monitoring after 2014, no clear pattern is seen when stratified by GCS score. *Asterisks* denote the years when a significant difference between GCS groups was seen. ICP, intracranial pressure; GCS, Glasgow Coma Scale.

evaluation of this patient population, there is a lack of reliability in the GCS scoring by first responders. Evaluating the trends in ICP monitoring in a large patient population over 18 years limits this bias. Additionally, our data come from a single state over a long period, and caution is needed when generalizing our findings, as they may not reflect every trauma system. The trauma center level was not available in this registry; however, the American College of Surgeons requires all Level I, II, and III centers with neurosurgical coverage to have adequate ICP-monitoring capabilities. Given these limitations, the goal of our work was to depict the current status of use of ICP monitoring in a mature trauma system and demonstrate the impact recent landmark papers had on its use, whereas identifying the reasons for decreased compliance and refining the indications for ICP monitoring remains outside our scope.

The pressing need to better understand the indications for ICP monitor insertion is unveiled by the seemingly increasing skepticism among neurocritical care and neurosurgery practitioners regarding the benefit of ICP-guided therapy in patients with severe TBI. More studies and stronger evidence are needed to guide management of severe TBI. In the meantime, guideline-based treatment is clear regarding ICP monitoring and should remain the mainstay of good clinical care.

CONCLUSIONS

As studies emerged that demonstrated unclear benefit of ICP monitoring in improving care in patients with severe TBI, there was a significant statewide decline in use of ICP monitoring after 2014 among all TBI subpopulations despite noteworthy limitations in the aforementioned studies and clear recommendations from the BTF guidelines. Most of these studies were based on small patient populations; more randomized controlled trials are needed to further elucidate the benefits of ICP monitoring and guide its use.

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