Temporal Trends in Surgical Intervention for Severe Traumatic Brain Injury Caused by Extra-axial Hemorrhage, 1995 to 2012

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Received, August 28, 2014.
Accepted, January 8, 2015.
Published Online, February 12, 2015.

BACKGROUND: Surgical intervention for severe traumatic brain injury (TBI) caused by extra-axial hemorrhage has declined in recent decades. The effect of this change on patient outcomes is unknown.

OBJECTIVE: To determine the change over time in surgical intervention in this population and to assess changes in patient outcomes.

METHODS: In this retrospective cohort study, the Washington State Trauma Registry was queried from 1995 to 2012 for patients with extra-axial hemorrhage and head Abbreviated Injury Scale score of 3 to 5. Data were linked to the state-wide death registry to analyze long-term mortality. The primary outcome was inpatient mortality. Secondary outcomes included 6- and 12-month mortality and modified Functional Independence Measure at discharge. Multivariable analyses were completed for all outcomes.

RESULTS: A total of 22974 patients met inclusion criteria. Over the study period, surgical intervention for severe TBI declined from 36% to 7%. There was a decline in case fatality from 22% to 12%. In 2012, the relative risk of inpatient mortality was 23% lower compared with 1995 (adjusted mortality risk ratio, 0.77; 95% confidence interval, 0.63-0.94). Changes in 6- and 12-month adjusted mortality and modified Functional Independence Measure were not statistically significant.

CONCLUSION: The decline in surgical intervention for severe TBI caused by extra-axial hemorrhage in Washington State was ubiquitous across regional, demographic, and injury characteristic strata. There was concurrently a reduction in inpatient mortality in this population. Functional status and long-term mortality, however, have remained the same. Future studies are needed to better identify modifiable risk factors for improvement in functional status and long-term mortality in this population.

KEY WORDS: Brain injuries, Epidemiology, Mortality, Neurosurgery, Outcome assessment, Wounds and injuries

Neurosurgery 76:451–460, 2015 DOI: 10.1227/NEU.0000000000000693 www.neurosurgery-online.com

Management practices of disease states change over time as they are driven by scientific discovery, new technology, studies of populations and patients, and changes in healthcare infrastructure. Recent examples include paradigm shifts in trauma care related to solid-organ injury, fluid resuscitation, and mechanical ventilation. Changes have also occurred in the management of severe traumatic brain injury (TBI), reflected in new imaging modalities, monitoring techniques, and pharmacologic therapies. Just as the appropriate indications for repeat imaging, intracranial pressure monitoring, brain oxygen monitoring, hyperosmolar therapy, and barbiturate use are debated,[1,2] so is the optimal role for surgery in the management of severe TBI.

ABBREVIATIONS: AIS, Abbreviated Injury Scale; **ED,** emergency department; **FIM,** Functional Independence Measure; **GCS,** Glasgow Coma Scale; **ICD-9,** International Classification of Disease, Ninth Revision, Clinical Modification; **IMPACT I,** International Mission for Prognosis and Clinical Trial; **RescueICP,** Randomised Evaluation of Surgery With Craniectomy for Uncontrollable Elevation of ICP; **SAH,** subarachnoid hemorrhage; **TBI,** traumatic brain injury; **WSTR,** Washington State Trauma Registry

Acknowledging that "the literature regarding surgical management after TBI suffers from extensive limitations, in both quality and scope," the Brain Trauma Foundation published guidelines for surgical management of TBI in 2006.[3] However, it is unclear how surgical management practices for TBI have changed and if changes have affected patient outcomes.

Over the past few decades, surgical intervention for other traumatic injuries, particularly solid-organ injuries, has declined without negatively affecting patient outcomes.[4-7] We sought to determine whether this association was also observed for severe TBI, and we chose to focus on definitive extra-axial hemorrhage diagnoses for which surgical intervention could reasonably be warranted. The objective of this study was to evaluate the change over time in surgical intervention for severe TBI in this population and to assess associated changes in patient outcomes. We hypothesized that surgical intervention for severe TBI resulting from extra-axial hemorrhage declined over the past 2 decades and that inpatient and long-term mortality and functional morbidity at discharge improved for this population.

METHODS

Study Design

We conducted a retrospective cohort study of prospectively collected data from trauma patients presenting with severe TBI caused by extra-axial hemorrhage from 1995 to 2012 in Washington State.

Sample

The study included all patients who had a diagnosis of extra-axial hemorrhage resulting from blunt trauma and met Washington State Trauma Registry (WSTR) inclusion criteria between 1995 and 2012.[8] A diagnosis of extra-axial hemorrhage was determined by *International Classification of Disease, Ninth Revision, Clinical Modification* (*ICD-9*) code designation and included subarachnoid hemorrhage (SAH), subdural hemorrhage, and extradural hemorrhage, with or without skull fracture, based on the American College of Surgeons Committee on Trauma audit filters (800, 801, 803, 804, with fourth digit subclassifications .2 and .7, and 852.20-852.59).[9] Although traumatic SAH is rarely an indication for surgery by itself, it was included because of the limitations in *ICD-9* coding for intracranial injury with skull fracture, which bundles SAH, subdural hemorrhage, and extradural hemorrhage under the same codes. Our diagnostic inclusion criteria intended to capture only patients for whom surgical decompression may have reasonably been indicated.

Intraparenchymal hemorrhage and diffuse injury were excluded because of the lack of granularity in *ICD-9* codes to accurately capture those diagnoses. To prevent bias from inclusion of potentially less severe injuries in later time periods as a result of temporal changes in coding practices, diagnoses of contusion and unspecified injury were excluded. Diagnoses of laceration were also excluded because laceration is bundled with contusion for patients with skull fracture. For study inclusion, patients had to have serious, severe, or critical TBI, determined by a head Abbreviated Injury Scale (AIS) score of 3, 4, or 5, respectively. All head AIS scores were mapped from *ICD-9* codes to maintain consistency in AIS determination.[10] Patients with a head AIS of 6, indicating nonsurvivable injury, were excluded.

Surgical management was defined as craniotomy or craniectomy, identified by *ICD-9* codes 1.24 and 1.25, respectively. Burr-hole and other procedures were excluded because we were unable to distinguish between therapeutic and diagnostic indications. Intracranial pressure monitor placement was not consistently captured by the WSTR and was excluded. All data for transferred patients were deduplicated to ensure that no patient was double counted. The WSTR data were linked to the comprehensive state-wide death registry to assess 6- and 12-month mortality between 2000 and 2012.

Outcomes

The primary outcome of interest was all-cause inpatient mortality. Secondary outcomes included 6- and 12-month mortality and the modified Functional Independence Measure (FIM) score at discharge. The modified FIM, a shortened version of the FIM, is a measure of functional outcome ranging from 3 to 12, where 3 indicates total functional dependence and 12 indicates complete independence.[11] The study was completed as part of a state-based quality improvement project with the Washington State Department of Health and was determined to be exempt from review by the University of Washington Institutional Review Board.

Analysis

Descriptive statistics were completed for the entire study population and separately for each cohort (surgical management and medical management only). Univariable analyses using the Student *t* test or χ^2 test were completed to assess differences between groups and changes over time within groups using the time periods 1995 to 1999, 2000 to 2005, and 2006 to 2012.

For each outcome, multivariable analyses were completed, controlling for potential confounders. A general linear model with Poisson distribution and robust error of variance was used for inpatient mortality (providing adjusted mortality risk ratios) to facilitate relative risk approximation of binary count data related to a relatively common outcome of interest (unadjusted inpatient mortality, 22% in 1995) while maintaining conservative estimates of precision. The reference year was 1995, the first year of the study period.

On the basis of prior literature and the univariable analyses, the regression model for mortality included patient, injury, and hospital characteristics. Covariates related to patient characteristics included age (<15, 15-54, 55-84, ≥85 years), sex, insurance status (Medicaid, Medicare, private, none), and the Charlson comorbidity score (0, ≥1). Injury characteristics included Injury Severity Score (9-15, 16-24, 25-75), head AIS (3, 4, 5), emergency department (ED) motor Glasgow Coma Scale (GCS; 1/chemically paralyzed, 1/not chemically paralyzed, 2, 3, 4, 5, 6), intubation status in the field or ED, hypotension in the ED (systolic blood pressure <90 mm Hg), mechanism of injury (motor vehicle collision, ground-level fall, other fall, other blunt head injury), and transfer status. Hospital characteristics included state-verified trauma center level (1, 2, 3, 4/5) and geographic region (Central, North, North Central, Northwest, South Central, Southwest, East, West), which was included to account for potential clustering. Year of injury was included to account for period cohort effect (eg, general improvements in health care, technology, intensive care unit management) and to evaluate changes in outcomes over time. Six- and 12-month mortality rates for patients who survived to discharge were analyzed with the use of case fatality rate and a Cox proportional hazard model with multivariable regression to provide adjusted hazard ratios. The proportional hazard assumption was tested for each group, and all individuals were censored at 6 and 12 months for their respective analysis. The modified FIM at discharge was analyzed with the use of multivariable linear regression for patients who survived to discharge.

All analyses were completed to assess changes in the outcomes of interest within each group (entire study population, surgical management cohort, medical management cohort) over the duration of the study period. Type of management (surgical vs medical alone) was added to the regression models to assess the effect of management type on patient outcome while controlling for all other covariates, including year of treatment. Multiple imputation using chained equations with 5 imputations for each variable was completed for motor GCS and modified FIM to address missing data. For all analyses, a value of $P < .05$ was considered statistically significant. Stata version 12.0 (Stata Corp, College Station, Texas) was used to complete the analyses.

RESULTS

Patient Characteristics

Of the 22974 study patients, 2436 (11%) had a craniotomy or craniectomy and 20538 (89%) were treated with medical management alone (Table 1). The surgical management cohort was generally younger than the medical management cohort and was more likely to be treated at the state's level I trauma center. Although the maximum head AIS scores were similar, the surgical intervention group had worse ED motor GCS scores, was more likely to be intubated, and had longer intensive care unit lengths of stay. There was no difference in indicators of multisystem injury, including mean Injury Severity Score or prevalence of hypotension in the ED.

Patient, injury, and hospital characteristics for each cohort over time are presented in Table 2. Column percents within each time period/cohort stratum reflect the temporal changes occurring over time in each cohort. The median age of patients in both cohorts increased over time. Although the proportion of the medical management cohort treated at the state's level I trauma center remained relatively unchanged during the study period, the proportion of the surgical management cohort treated declined. Over time, a larger proportion of the surgical management cohort presented with worse TBI compared with the medical management cohort, evidenced by a relatively greater increase in nonparalyzed motor GCS score of 1 ($\Delta + 8\%$ vs $\Delta - 1\%$) and maximum head AIS of 4/5 ($\Delta + 31\%$ vs $\Delta + 19\%$). Mean Injury Severity Score remained relatively stable in both cohorts over time; however, a smaller proportion in both cohorts had hypotension in the ED.

Surgical Management Trends

Between 1995 and 2012, the proportion of patients with severe TBI resulting from extra-axial hemorrhage who underwent surgical intervention per year (cumulative incidence) declined from 36% to 7%, with a nadir of approximately 5% between 2005 and 2010 (Figure 1). Figure 1 also shows the adjusted proportion of surgical interventions relative to the referent year 1995 (adjusted for all prespecified covariates) and the changing incidence of severe TBI resulting from extra-axial hemorrhage by year, which remained relatively stable from 1995 to 2003 and then began to increase slightly throughout the remainder of the study period. The cumulative incidence of severe TBI is presented per WSTR trauma admission per year to control for temporal increases in trauma registry submission throughout Washington State. As a result of concern for possible selective

TABLE 1. Patient, Injury, and Hospital Characteristics[a]

	Surgical Management (n = 2436), n (%)[b]	Medical Management (n = 20 538), n (%)
Median age (IQR), y	35 (19-56)	55 (27-77)
Male	1796 (77)	12 937 (63)
Insurance		
Commercial	876 (38)	6656 (34)
Medicaid	809 (35)	4235 (22)
Medicare	472 (21)	6998 (36)
None	137 (6)	1718 (9)
Trauma center designation		
Level I	1494 (62)	9601 (47)
Level II	625 (26)	6200 (30)
Level III/IV	302 (12)	3851 (23)
Transferred[c]	871 (36)	8887 (43)
Injury Severity Score		
9-15	685 (28)	5417 (26)
16-24	1344 (55)	11 808 (57)
25-75	407 (17)	3313 (16)
Mean Injury Severity Score (SD)	18.04 (7.52)	18.23 (7.60)
Maximum head AIS		
3	1041 (43)	7436 (36)
4/5	1395 (57)	13102 (64)
Motor GCS		
6	833 (36)	12 442 (65)
4-5	335 (14)	2248 (12)
2-3	80 (3)	436 (2)
None[d]/not paralyzed	150 (6)	1005 (5)
None[d]/paralyzed	937 (40)	3145 (16)
Intubated[e]	1338 (55)	4705 (23)
SBP <90 mm Hg	259 (11)	2225 (11)
Charlson Comorbidity Index ≥1	121 (5)	903 (5)
Mean intensive care unit length of stay (SD), d	5.78 (6.98)	3.87 (6.90)
Mechanism of injury		
Motor vehicle collision	1033 (42)	6606 (32)
Ground-level fall	248 (10)	3689 (18)
Other falls	731 (30)	7690 (37)
Other blunt injury	424 (17)	2553 (12)
Modified FIM		
11-12	886 (48)	9743 (61)
8-10	565 (31)	4216 (26)
3-7	397 (21)	2002 (13)
Mean modified FIM (SD)	9.36 (3.19)	9.98 (2.96)
Died in hospital	429 (18)	2905 (14)
Disposition		
Home without services	780 (32)	9037 (44)
Home with services	43 (2)	730 (4)
Skilled nursing facility	431 (18)	3948 (19)
Rehabilitation	639 (26)	2733 (13)
Other	543 (22)	4082 (20)

[a]AIS, Abbreviated Injury Scale; FIM, Functional Independence Measure; GCS, Glasgow Coma Scale at index emergency department/hospital arrival; IQR, interquartile range; SBP, lowest systolic blood pressure in the emergency department.
[b]*Includes* craniotomy and craniectomy.
[c]Transferred indicates patient was transferred from another facility to the given center of definitive care.
[d]No motor response.
[e]Intubation in the field or emergency department.

TABLE 2. Patient, Injury, and Hospital Characteristics by Cohort Over Time[a]

	Surgical Management Cohort[b]			Medical Management Cohort		
	1995-1999	2000-2005	2006-2012	1995-1999	2000-2005	2006-2012
n	1057	654	725	2242	6092	12204
Median age (IQR), y	33 (19-51)	34 (19-54)	40 (21-62)	43 (21-71)	50 (24-76)	58 (32-79)
Male, %	74	74	73	66	63	62
Insurance, %						
Commercial	38	39	37	34	35	34
Medicaid	41	34	29	29	24	19
Medicare	18	21	24	31	33	37
None	3	7	10	5	8	10
Trauma center designation, %						
Level I	84	54	37	48	52	45
Level II	11	30	44	30	31	30
Level III/IV	6	16	19	23	18	26
Transferred[c]	32	36	42	33	41	46
Injury Severity Score, %						
9-15	35	28	19	33	31	23
16-24	46	58	66	48	52	63
25-75	20	14	15	19	16	16
Mean Injury Severity Score (SD)	18.19 (8.21)	17.44 (6.93)	18.36 (6.94)	17.82 (8.49)	17.78 (7.63)	18.54 (7.40)
Maximum head AIS, %						
3	56	41	25	49	44	30
4/5	44	59	75	51	56	70
Motor GCS, %						
6	28	40	43	51	61	69
4-5	14	14	16	15	12	10
2-3	4	2	3	5	2	2
None[d]/not paralyzed	4	4	12	7	4	6
None[d]/paralyzed	50	39	26	22	20	13
Intubated, %[e]	70	50	37	31	30	18
SBP $<$90 mm|Hg, %	14	9	8	15	11	10
Charlson Comorbidity Index $\geq$1, %	7	7	0	8	10	1
Mean intensive care unit length of stay (SD), d	5.26 (2.98)	5.67 (7.09)	6.61 (8.05)	3.97 (5.87)	4.41 (9.21)	3.59 (5.65)
Mechanism of injury, %						
Motor vehicle collision	54	37	30	43	36	28
Ground-level fall	5	12	17	10	16	21
Other falls	25	33	35	33	35	40
Other blunt injury	17	18	18	15	13	12
Modified FIM, %						
11-12	45	49	51	57	56	64
8-10	33	31	26	25	30	25
3-7	21	20	23	19	14	11
Mean modified FIM (SD)	9.40 (3.04)	9.55 (3.02)	9.11 (3.55)	9.51 (3.33)	9.94 (2.89)	10.07 (2.93)
Death in hospital, %	19	14	18	21	16	12
Disposition, %						
Home without services	29	37	32	40	41	47
Home with services	2	2	2	3	3	4
Skilled nursing facility	21	16	15	18	19	20
Rehabilitation	26	27	27	15	16	12
Other	23	19	25	28	21	18

[a]AIS, Abbreviated Injury Scale; FIM, Functional Independence Measure; GCS, Glasgow Coma Scale at index emergency department/hospital arrival; IQR, interquartile range; SBP, lowest systolic blood pressure in the emergency department.
[b]Includes craniotomy and craniectomy.
[c]Transferred indicates patient was transferred from another facility to the given center of definitive care.
[d]No motor response.
[e]Intubation in the field or emergency department.

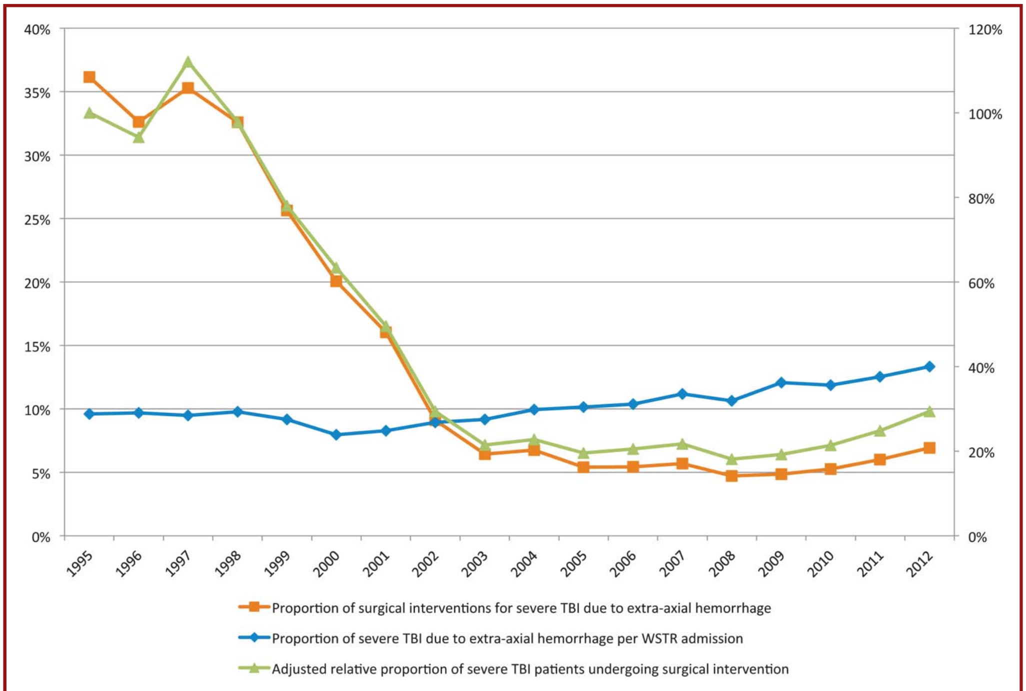

FIGURE 1. *Cumulative incidence of surgical interventions for severe traumatic brain injury (TBI) resulting from extra-axial hemorrhage in Washington State by year of injury, presented as an unadjusted proportion (main axis) and as an adjusted proportion relative to 1995 (secondary axis). The proportion of patients with severe TBI is the number of patients with extra-axial hemorrhage and a maximum head Abbreviated Injury Scale score of 3 to 5 caused by blunt head injury per number of trauma admissions included in the Washington State Trauma Registry (WSTR) during the calendar year.*

surgical management based on futility secondary to age or severity of injury, we stratified the yearly cumulative incidence of surgical interventions by age and maximum head AIS and found that surgical intervention for severe TBI resulting from extra-axial hemorrhage declined in a parallel manner across all age and head AIS strata (Figure 2A and 2B). Surgical intervention proportions declined in a similar fashion when stratified by type of injury, mechanism of injury, and region of trauma center (Figure 2C-2E).

Inpatient Mortality

Inpatient mortality declined over the study period. The case fatality for the entire study population declined from 22% in 1995 to 12% in 2012 (Figure 3). Compared with 1995, the unadjusted relative risk of inpatient mortality in 2012 was 0.54 (95% confidence interval [CI], 0.44-0.64). The adjusted relative risk of inpatient mortality was 0.77 (95% CI, 0.63-0.94) in 2012 compared with 1995 (Figure 4A). Adjusted inpatient mortality declined steadily over the study period; the decline reached statistical significance in 2011 and 2012.

Case fatality in the surgical cohort declined from 18% to 15% (adjusted mortality risk ratio, 0.75; 95% CI, 0.45-1.24; Figure 4B) and in the medical cohort from 24% to 11% (adjusted mortality risk ratio, 0.70; 95% CI, 0.55-0.88; Figure 4C). Inpatient mortality was not statistically different between groups over the course of the study. In a comparison of surgical management and medical management alone, the adjusted relative risk of mortality was 0.96 (95% CI, 0.87-1.06).

Long-term Mortality

Long-term mortality at 6 and 12 months was analyzed for all patients who survived to discharge starting in 2000 (Figure 4). Adjusted hazard ratios, however, in comparisons of each year with the referent year 2000, showed no statistically significant change at 6 or 12 months for the entire study population or either cohort alone (Table 3). There was also no statistically significant difference when surgical management was compared with medical management (6-month adjusted hazard ratio, 0.76; 95% CI, 0.55-1.04; 12-month adjusted hazard ratio, 0.86; 95% CI, 0.66-1.11) during the entire study period.

Modified FIM at Discharge

In adjusted analyses, modified FIM scores at discharge did not change significantly over time for the entire study cohort or for each cohort when analyzed individually. In a comparison of the surgical management and medical management cohorts, the modified FIM scores at discharge were lower (worse) for the surgically managed patients (adjusted β coefficient, −0.23; 95% CI, −0.91 to −0.38).

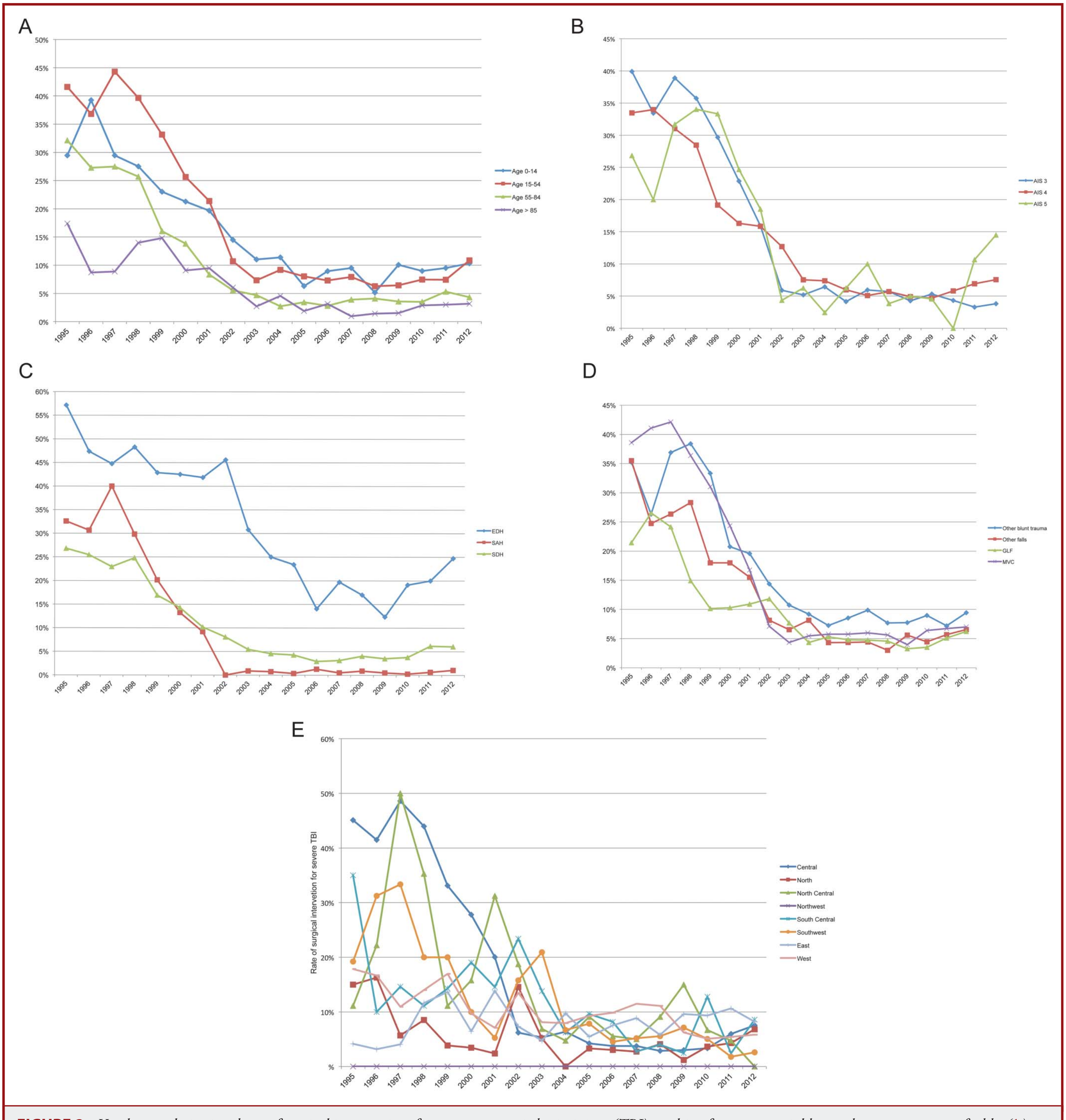

FIGURE 2. *Yearly cumulative incidence of surgical interventions for severe traumatic brain injury (TBI) resulting from extra-axial hemorrhage per year stratified by (***A***) age categories, (***B***) maximum head Abbreviated Injury Scale (AIS), (***C***) type of intracranial hemorrhage, (***D***) mechanism of injury, and (***E***) region of trauma center. EDH, extradural hemorrhage; GLF, ground-level fall; MVC, motor vehicle collision; SAH, subarachnoid hemorrhage; SDH, subdural hemorrhage.*

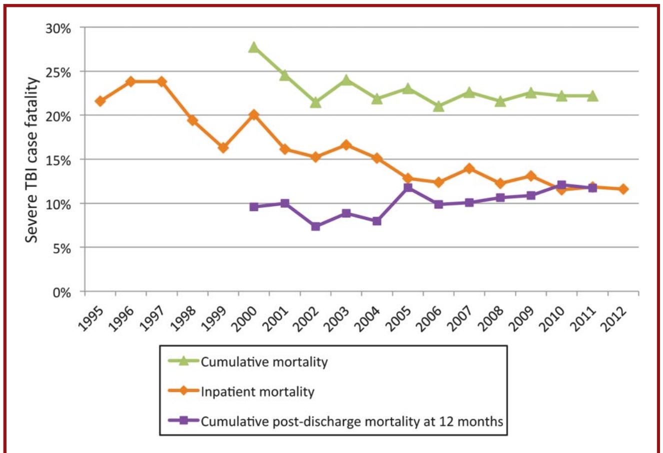

FIGURE 3. *Case fatality for severe traumatic brain injury (TBI) at hospital discharge and 12 months and total.*

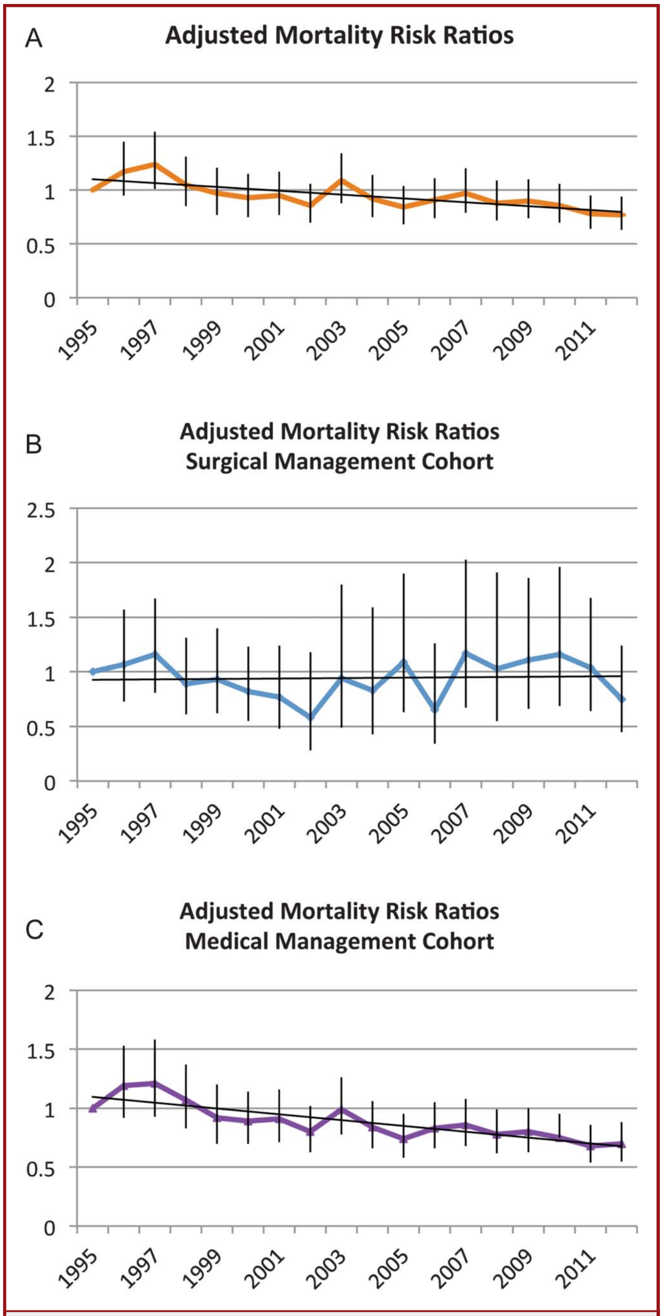

FIGURE 4. *Adjusted mortality risk ratios over time for (**A**) entire study population, (**B**) surgical management cohort, and (**C**) medical management cohort.*

DISCUSSION

Between 1995 and 2012, there was a decline in surgical intervention for severe TBI caused by extra-axial hemorrhage from blunt trauma in Washington State. This decline was consistent across all ages, maximum head AIS, type and mechanism of injury, and region of care. Simultaneously, there was a decline in adjusted inpatient morality. Although the decline appears to be driven by the medical management cohort, the steep decline in surgical intervention was not associated with an increase in inpatient mortality. The gains in survival to discharge, however, were lost by 6 and 12 months after discharge, and there was no apparent improvement in functional status at the time of discharge. This study highlights a practice pattern change over time in the management of extra-axial hemorrhage and suggests multifactorial reasons for the observed changes in patient outcomes.

Our data are consistent with the general TBI literature related to mortality. Mortality for patients with severe TBI resulting from blunt trauma has been improving since the 1980s.[12-15] For example, the International Mission for Prognosis and Clinical Trial (IMPACT I) database combined 8 randomized trials and 3 observational studies in TBI from 1984 to 1997 and examined 9205 patients with moderate to severe TBI, noting a general decline in mortality from 39% to 20%.[16]

Improved mortality in TBI, however, cannot be assessed in isolation. In addition to the decline in surgical intervention, many other changes in TBI care have occurred. There have been advances in imaging so that detailed images can be obtained quickly, improving a provider's ability to evaluate and manage head injury, to guide therapy, and to estimate prognosis.[17-20] Additionally, there have been advances in prehospital resuscitation and triage of severe TBI[21,22] and in the use of diagnostic and therapeutic monitoring techniques, with the literature evaluating the utility and optimal role for pressure and oxygen monitoring, therapeutic ventricular draining, and more.[2,23-30] Finally, TBI care has developed into a team-based approach, with dedicated neurointensivists, neurological surgeons with TBI expertise, and respiratory, physical, and occupational therapists working together to optimize patient outcomes. Overall, the improvements in the care of TBI patients over the study period have been progressive and significant. Many of these improvements likely contributed to a decline in the proportion of patients needing surgery and to the decline in mortality.

TABLE 3. Adjusted Hazard Ratios for Cumulative 6- and 12-Month Mortality, Comparing 2011[a] With the Referent Year, 2000

	6-Month Adjusted Hazard Ratio (95% Confidence Interval)	12-Month Adjusted Hazard Ratio (95% Confidence Interval)
Entire study population	0.84 (0.59-1.18)	0.79 (0.58-1.07)
Surgical management cohort	1.01 (0.20-5.05)	0.66 (0.16-2.66)
Medical management cohort	0.81 (0.57-1.16)	0.76 (0.56-1.05)

[a]Adjusted hazard ratios presented through 2011 as the year of injury to provide a complete 12 months for follow-up to adequately assess 12-month postdischarge mortality.

The popularity of surgical decompression for severe TBI has fluctuated over time.[31] Recently, there has been a reported resurgence of surgical decompression, describing decompressive craniectomy, with attention being paid to the role of early and wide decompression, and bone flap removal.[32-35] However, these data come primarily from conflict zones with limited resources and long transport times. Late decompressive craniectomy for intractable intracranial hypertension has also been reported to be of benefit[36] and is currently being addressed by the Randomised Evaluation of Surgery With Craniectomy for Uncontrollable Elevation of ICP (RescueICP) trial.[37] Acknowledging that decompressive craniectomy is a unique subset of all surgical interventions for severe TBI, the available literature shows mixed short-term results and has failed to show a consistent improvement in long-term mortality, morbidity, or quality of life.[38-41]

The observed decline in surgical interventions for TBI resulting from extra-axial hemorrhage parallels the trend in surgical management for abdominal solid-organ injury, which has also declined over the past 3 decades.[4] It has been well documented that this change in management of solid-organ injury has not negatively affected patient outcomes,[4,42] although concern remains that failed nonoperative management is an unrecognized problem. The decline in surgical interventions observed in our study may also create the risk of failed nonoperative management. There surely exists a specific subset of patients for whom surgical intervention is necessary and optimal. In fact, perhaps the increase in surgical interventions in the most recent years for the extradural hemorrhage and AIS 5 strata represents this population.

Our findings reflect a lack of improvement in long-term mortality despite progress in inpatient mortality, which is consistent with the general trauma literature.[43] In TBI, however, morbidity is a major outcome of interest. The burden of disease as a result of disability, in addition to the impact on quality of life, is high in this patient population. Our study observed no change in modified FIM scores at discharge, although this is not a sensitive indicator of long-term recovery or quality of life. Lack of long-term outcome data for TBI patients is a serious limitation to the utility of trauma databases in assessing acute care management strategies.

Limitations

This study has several limitations. It is retrospective, limiting our ability to make causal inferences. The study analyzed a large database in which missing data are likely not missing at random. For long-term analyses, although robust and comprehensive for in-state deaths, the state-wide death registry does not capture deaths for individuals who left the state. There is, however, no reason to believe that number would be meaningfully large or that it would differ between the 2 cohorts. As with many registries, the WSTR is limited in nonmortality outcome data. Additionally, because of the narrow inclusion criteria, this study is limited in its generalizability to patients with TBI other than extra-axial hemorrhage.

From a practice standpoint, the study is limited by its lack of data pertaining to surgical technique, intracranial pressure monitors, detailed imaging results (such as midline shift or compression of the basal cisterns), and laboratory values. The WSTR does not have data often used in prognostic algorithms, including pupillary response, hypoxia, and coagulopathy.[16,17] In addition, the modified FIM has limited sensitivity for functional recovery in the long term, and we are unable to compare it with the Glasgow Outcome Scale—Extended, which is more frequently used in this population.

Perhaps most important are the limitations imposed by *ICD-9* codes. *ICD-9* codes are limited in severe TBI because they are not refined enough to categorize specific injury types and subtypes. For example, *ICD-9* codes collapse types of extra-axial hemorrhage together under the same code if skull fracture is present, limiting the ability to stratify by type of bleed. This also makes it impossible to extricate isolated traumatic SAH from the analyses without removing all injuries with skull fracture. Not only is isolated SAH rarely a surgical indication, as mentioned previously, but over time it has been increasingly recognized and coded. There may also have been temporal changes in coding patterns. In particular, as a result of more frequent and detailed imaging, more highly trained medical coding staff, and even increasing pressure to "upcode" in later time periods, the denominator of interest may have become falsely elevated over time. This, however, is unlikely to have had a significant effect on the findings of this study. Figure 1 demonstrates how the proportion of surgical interventions in the population of interest declined while the denominator remained relatively stable (1995-2003). When the denominator began to increase (2003-2012), the surgical intervention proportion actually plateaued. The denominator, severe TBI resulting from extra-axial hemorrhage, is presented as a proportion (of WSTR admissions) to control for increasing number of trauma centers submitting data to the WSTR over time.

CONCLUSION

This study found that, despite a rise in the yearly cumulative incidence of blunt TBI in Washington State and despite worsening TBI severity over time, there has been a decline in the proportion of patients undergoing surgical intervention in the management of extra-axial hemorrhage, consistent across all age groups, levels of TBI severity, type of bleed, and region of care. In addition, there has been a reduction over time in inpatient mortality in this population. Long-term mortality and functional status at discharge, however, have remained the same. Future studies are needed to better define trauma patients with extra-axial hemorrhage who would benefit from surgical intervention and to identify modifiable risk factors for improvement in functional status and long-term mortality.

Disclosures

Dr Flynn-O'Brien received fellowship support from the National Institute of Child Health and Human Development (T32-HD057822) during the preparation of this paper. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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Acknowledgment

We acknowledge and thank Mark Taylor, BSN, RN, and Joyce McQuaid, BSN, for their assistance and support.

CME QUESTIONS:

1. Improved management of severe traumatic brain injury over the last two decades has led to improvement in what clinical outcome parameter?
   A. Inpatient mortality
   B. Inpatient morbidity
   C. Long-term mortality
   D. Surgical utilization
   E. Long term morbidity
2. According to recent cohort studies, despite an overall decrease in surgeries for traumatic brain injury (TBI), for which TBI indication has there been an overall increase in surgical utilization over the last two decades?
   A. Epidural hematoma
   B. Subdural hematoma
   C. Intraventricular hematoma
   D. Cortical contusion
   E. Hydrocephalus
3. What factor has contributed to the overall improved inpatient survival of trauma patients over the past two decades?
   A. Intracranial pressure monitoring
   B. High quality imaging
   C. High-dose steroid therapy
   D. Surgical intervention
   E. Early tracheostomy