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Volumetric analysis of day of injury computed tomography is associated with rehabilitation outcomes after traumatic brain injury

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Abstract

Introduction—Day-of-injury (DOI) brain lesion volumes in traumatic brain injury (TBI) patients are rarely used to predict long-term outcomes in the acute setting. The purpose of this study was to investigate the relationship between acute brain injury lesion volume and rehabilitation outcomes in patients with TBI at a Level One Trauma Center.

Methods—Patients with TBI who were admitted to our rehabilitation unit after the acute care trauma service from February 2009-July 2011 were eligible for the study. Demographic data and outcome variables including cognitive and motor FIM scores, length of stay (LOS) in the rehabilitation unit, and ability to return to home were obtained. DOI quantitative injury lesion volumes and degree of midline shift were obtained from day-of-injury (DOI) brain computed tomography (CT) scans. A multiple step-wise regression model including 13 independent variables was created. This model was used to predict post-rehabilitation outcomes, including FIM scores and ability to return to home. $P < 0.05$ was considered significant.

Results—96 patients were enrolled in the study. Mean age was 43 ± 21 years, admission Glasgow Coma Score 8.4 ± 4.8 , Injury Severity Score 24.7 ± 9.9 , and head Abbreviated Injury Scale score 3.73 ± 0.97 . Acute hospital length of stay (LOS) was 12.3 ± 8.9 days and rehabilitation LOS was 15.9 ± 9.3 days. Day-of-injury TBI lesion volumes were inversely associated with cognitive FIM scores at rehabilitation admission ($p = 0.004$) and discharge ($p = 0.004$) and inversely associated with ability to be discharged to home after rehabilitation ($p = 0.006$).

Conclusion—In a cohort of patients with moderate to severe TBI requiring a rehabilitation unit stay after the acute care hospital stay, DOI brain injury lesion volumes are associated with worse cognitive FIM scores at the time of rehabilitation admission and discharge. Smaller injury volumes were associated with eventual discharge to home. Volumetric neuroimaging in the acute injury phase may improve surgeons' ultimate outcome predictions in TBI patients.

Level of Evidence/Study Type—Level V, case series, Prognostic/Epidemiological

Keywords

traumatic brain injury; outcomes; volumetric analysis of computed tomography; rehabilitation outcomes

Background

Unintentional injury is the leading cause of death in the United States for individuals age 45 years and under [1]. Traumatic brain injury (TBI) is a major contributor in about one third of these deaths [2]. The death rate from TBI is only part of the story, however, as 43% of patients who suffer a TBI that requires hospitalization have some sort of disability one year after the injury [3]. This translates to about 5.3 million Americans living with a neurologic or functional impairment attributable to TBI [4], which is often associated with emotional and financial hardship for these patients and their families. The overall socioeconomic burden of TBI in the United States in 2006 was estimated to be about \$76.5 billion per year [5].

Early treatment decisions and prognostication for patients with TBI are made using a combination of physical exam findings, radiographic injury characteristics such as lesion size, location and degree of midline shift, patient age, admission physiology (Glasgow Coma Scale (GCS), vital signs, response to initial resuscitation), associated injuries, medical comorbidities, laboratory parameters, and clinician experience/judgment. Generally, clinicians do not try to prognosticate long-term outcomes from TBI on the day of injury, except to predict mortality in the most extreme circumstances. Secondary brain injury has not yet occurred on the day of injury, which makes it difficult to estimate the total magnitude of the insult, but also, there is no well-validated model that uses data from the day of injury to predict the functional abilities of a patient after recovery. Thus, despite all of the technology available to us to treat the patient in the acute phase, we remain relatively ill-equipped to definitively answer patients' and families' questions about long-term outcomes early in the course of TBI.

Brain computed tomography (CT) is almost universally the first (and often only) imaging study performed on TBI patients who present to the hospital. CT is consistently done on the day of injury (DOI), and then may or may not be repeated during the patient's hospital stay. Scoring systems using CT findings such as the Marshall classification [6], the Rotterdam score [7], and most recently, the Helsinki score [8] have been developed, but these have primarily been found to be useful as predictors of mortality, as opposed to predicting long-term function. A limitation of the studies is that they primarily utilize a categorical CT

abnormality classification system that relies heavily on neuroradiologist report, rather than direct examination of CT scans.

Specific volumetric analysis of the DOI brain CT has not been widely used to describe the severity of TBI, or to predict outcomes after rehabilitation. The purpose of this study was to investigate the relationship between DOI CT abnormalities and eventual rehabilitation outcomes in patients with TBI at a single Level One Trauma Center using semi-quantitative rating scales and quantitative CT analysis. We hypothesized that abnormalities on brain CT (largest lesion volume) would correlate with FIM scores at the time of discharge from the rehabilitation unit.

Methods

Consecutive adult (age ≥ 18 years) patients with a diagnosis of moderate to severe TBI (based on ICD-9 codes 800.0-801.9, 803.0-804.9, 850.0-854.1, and 959.01) who were admitted to Intermountain Medical Center's (IMC) trauma service and were subsequently transferred to the rehabilitation unit at IMC between February 2009 and July 2011 were eligible for this retrospective study. All patients were enrolled in a National Institutes of Health, the Ontario Neurotrauma Foundation, and the National Institute for Disability and Rehabilitation Research funded parent study of acute rehabilitation outcomes and who underwent a DOI CT scan. [10]. This parent study enrolled patients at ten acute rehabilitation facilities in the United States and Canada and focused on outcomes during the rehabilitation stay, but did not collect data from the acute care hospital stay. The Intermountain Health Care Urban Central Region Institutional Review Board approved this study.

Hospital data were collected from the electronic medical record at IMC and the trauma registry (TraumaBase v.9, Clinical Data Management, Conifer, CO). IMC is relatively unique in that medical data from both acute care hospital stay and the rehabilitation stay are included in the same electronic medical record. Medical data was obtained by trained data extractors, and was checked for quality over the course of the study. Variables included demographic information (age, gender, race/ethnicity, marital status, insurance status), injury data (Injury Severity Score (ISS), Abbreviated Injury Scale (AIS) for head injury, first GCS score in the Emergency Department (ED), vital signs in the ED), acute care hospital data (ICU and hospital length of stay (LOS), need for neurosurgical intervention, need for endotracheal intubation/duration of mechanical ventilation), and rehabilitation unit data (admission, discharge, and nine month post-discharge Functional Independence Measure (FIM) scores, rehabilitation LOS, and discharge disposition).

The FIM is an eighteen-item scale designed to assess the level of a patient's disability and how much assistance he requires to carry out activities of daily living. Each item is scored on a seven level scale ranging from 0 "activity does not occur" to 7 "complete independence". [11] FIM is used in all types of rehabilitation patients, but has been shown to be applicable to the TBI population. [12] [13]

Semi-quantitative ratings of the DOI brain CT were carried out using the Marshall and Rotterdam semi-quantitative rating scales [6] [7]. Rating of brain imaging was conducted by

two raters trained to 0.90 inter-rater reliability by a board-certified neuroradiologist. Both raters independently rated each DOI scan for Marshall and Rotterdam scores. Raters were blind to patient outcomes. In addition to semi-quantitative rating scales cerebral lesion volumes, lesion location, and midline shift in millimeters were obtained using the procedures described by Sherer et al. [14]. Briefly, the lesion areas were calculated by manually tracing the outlines of each lesion on each slice then multiplying the lesion area by slice thickness (see Sherer et al. for full protocol). Cerebral atrophy/edema was quantified using third ventricle width and the ratio of third ventricle width to the width of the inner table of the skull [15] [16]. Third ventricle width was measured at the level of the foramen of Monro at the junction of the middle and posterior third of the ventricle. Disagreement between raters was adjudicated via consensus conference that included the raters and MJL; rater scores were averaged for lesion volume and midline shift.

Statistical analysis

An ordinary least squares (OLS) model was constructed for dependent (outcome) variables including ICU, acute care hospital, and rehabilitation LOS, Rasch-adjusted FIM (motor and cognitive) at rehabilitation admission, discharge, and nine months post discharge, and discharge to home after rehabilitation. Thirteen independent variables were allowed to enter each model: age, ISS, head AIS, ED GCS, intubated in the field or ED, neurosurgical procedure in first twenty-four hours after admission, volume of largest brain lesion, distance of the midline shift, third ventricle to skull ratio, Rotterdam score, pre-injury use of anti-platelet agents (aspirin or clopidogrel), and pre-injury use of oral anti-coagulants such as warfarin.

Not all models included all variables. Stepwise variable selection with entry and exit criteria of $p=0.05$ were used in all cases. Prior to running the regression, multicollinearity was checked among predictors and those with an absolute Spearman correlation coefficient <0.6 were allowed to stay; one of the variables with coefficient >0.6 was chosen using a theoretical rather than empirical framework for selection. Variables with fewer than five occurrences were excluded from the multivariate models. After the aforementioned pre-processing, the remaining variables were allowed to enter the ordinary least squares (OLS) model, but only those with $p<0.05$ remained in the final model. Missing data points, including nine month FIM motor and cognitive, were verified to be missing at random, without evidence of selection bias causing those points to be omitted. If a categorical variable had cell counts fewer than five per category, categories were collapsed where possible.

Descriptive statistics (percentages for dichotomous variables and means/standard deviations or median/IQR for continuous as appropriate) for patient and injury characteristics were carried out. Bivariate outcome/predictor statistics were performed using pooled or Satterthwaite T-test, Spearman rank correlation coefficient, or chi squared as appropriate. Multiple step-wise regression analyses were carried out to assess which variables predicted outcomes in the hospital and after discharge from rehabilitation. Entry and stay criteria for in the statistical models were set at 0.05 (i.e. all variables significant in the final model had p -values <0.05).

Results

During the study period, 96 patients met inclusion criteria and were analyzed. The study population included 71 (74%) males with mean age of 43 ± 21 years, and 78 (81%) (Table 1), which is reflective of the general trauma service population at our trauma center. A majority (67%) of patients were employed, students, or both prior to admission. Seventy-four (77%) patients had some type of health care insurance at the time of admission.

The most common injury mechanism was motor vehicle collision (58%), followed by falls (25%) (Table 2). Mean GCS in the ED was 8.4 ± 4.8 and 65 (68%) patients required endotracheal intubation in the field or in the ED. The mean ISS was 25 ± 10 and brain AIS score was 3.8 ± 1.0 . The largest lesion volume on the DOI CT was $12.8 \pm 22.2 \text{ cm}^3$, and midline shift was $0.18 \pm 0.24 \text{ cm}$. Overall, patients had 3.2 ± 1.7 brain imaging studies (CT or MRI) during the acute hospitalization. Seventeen (18%) patients underwent urgent or emergent neurosurgical intervention (craniotomy (14), craniectomy (2), or burr hole (1)) in the first 24 hours after admission. Three of these had epidural hematoma evacuations. Only 2 (2.1%) of patients had brainstem lesions on the DOI CT scan. 38 (40%) of patients had at least 1mm of midline shift noted, and 17 (18%) had midline shift $>5 \text{ mm}$. The median ICU LOS, acute care hospital LOS and rehabilitation LOS were 8 days (IQR 5-14), 10 days (IQR 6-16) and 14 days (IQR 9-31), respectively.

Motor and cognitive FIM scores improved from admission to discharge from rehabilitation from 39 to 61 ($p < .001$) and 38 to 64 ($p < .001$), respectively. A majority, 86 (90%) patients were discharged to home after inpatient rehabilitation. Of the 96 patients, 72 (75%) had FIM scores available at nine month follow-up. Both motor and cognitive FIM scores at nine months improved from the FIM scores at rehabilitation discharge (motor FIM score 61 to 89, $p < .001$, cognitive FIM score 64 to 77 $p < .001$).

Bivariate statistical analysis was used to look for independent associations between each of the 11 predictors in the model to each of the 10 outcomes. Results of these analyses are shown in table 3. The overall results of the OLS model are shown in Table 4 with R^2 or c-statistic as for continuous and dichotomous variables, respectively. Independent variables explained 33% of the variability in intensive care unit LOS and cognitive FIM at the time of admission to rehabilitation. The other dependent variables ranged from 3% of variance explained by the model for nine month post-discharge cognitive FIM to 28% explained by acute care hospital LOS.

Multiple stepwise regression analysis was then performed for each dependent variable (Table 3). ISS was negatively associated with motor FIM at the time of discharge from acute care/admission to rehabilitation ($p = 0.001$). A history of pre-injury anti-platelet agent use (aspirin or clopidogrel) ($p = 0.03$), volume of largest lesion on DOI brain CT ($p = 0.004$), ED GCS ($p < 0.001$), and head AIS ($p = 0.03$) all predicted the cognitive FIM score at rehabilitation admission. At the time of rehabilitation discharge, age ($p < 0.001$) and ISS ($p = 0.03$) predicted the motor FIM score. Volume of the largest lesion on DOI brain CT ($p = 0.004$) and Rotterdam score of 5 or 6 ($p = 0.01$) predicted the cognitive FIM at rehabilitation discharge. Age ($p = 0.007$) and mean midline shift ($p = 0.006$) predicted

discharged to home after rehabilitation. For subjects FIM scores nine months post-discharge only intubation in the field or ED was associated with the motor FIM scores.

Discussion

In this study, we examined the utility of DOI brain CT volumetric analysis along with other variables to predict outcomes at the time of discharge from the acute care hospital/admission to rehabilitation, discharge from rehabilitation, and at nine months post discharge in a group of moderate-severe TBI patients. We found that the volume of the largest brain lesion on the DOI predicted the cognitive FIM score at the time of admission and discharge from the rehabilitation unit. In addition, less midline shift was predictive of the ability to be discharged to home after the rehabilitation stay. Neither volumetric analysis nor degree of midline shift on the DOI brain CT predicted cognitive or motor FIM scores at nine months after discharge.

We did not find that any of the variables that we studied, including size of brain injury lesion and degree of midline shift, were predictive of motor FIM at any time point, with the exception of intubation in the field predicting motor FIM at nine months post-discharge. This is likely due to the fact that the population that we studied was a multiply-injured cohort. Motor FIM is far more likely to be affected by fractures, soft tissue, and solid organ injuries as well as brain injury. If we had a larger cohort, and could have selected out a subgroup that had lower non-brain AIS scores, it might have been feasible to assess for relationships between brain lesions and motor FIM at admission and/or discharge from rehabilitation.

In this study, we also did not find that brain injury lesion size or degree of midline shift was predictive of cognitive FIM at nine months post-discharge. This is likely because of the FIM ceiling effect. FIM was originally developed as a measure of inpatient functional status and was not meant to look at long-term TBI outcomes. FIM is not sensitive to cognitive and behavioral impairments, and these are often the major post-TBI morbidities of moderate to severe TBI. Other factors such as employment status or ability to drive a car may be better surrogates for cognitive and executive function at nine months, particularly if age and previous work history are taken into account. Unfortunately, these data were not available for inclusion in our models.

This study is relatively unique in that it combines the medical records/outcomes from the acute care hospital stay with the rehabilitation stay and with quantitative analysis of brain CT scans. Often, the medical literature on traumatic brain injury is divided into the acute phase (where the focus is often mortality) and longer-term studies on outcomes after rehabilitation. There is a body of rehabilitation literature that looks at pre-injury and general injury characteristics to predict outcomes after TBI [17][18][19][20][21][22]. However, much of the time these studies do not utilize specific data or have access to actual radiographic imaging data (beyond printed reports) from the day of injury to prognosticate long-term outcomes. Given the unique integrated data in our health system we are able to access both acute and rehabilitation data via a common medical record.

Interest in using brain CT findings to prognosticate about long-term outcomes after TBI is not new. Many studies/prediction models have used information from day of injury imaging. Zhu et al. published a review in which they identified forty-nine studies that attempted to predict and/or classify outcomes based solely on CT characteristics [23]. Most of these studies describe anatomical lesions and often assign some score to their presence or absence. The most well-validated is the Marshall classification [6], which assigns patients to diffuse injury I-IV, primarily based on midline shift and presence or absence of visible cistern, and then a V and VI for surgically evacuated/not evacuated mass lesion $>25\text{cm}^3$, respectively. The Marshall classification has been shown to be effective to predict mortality [6], but is less useful for long-term outcomes [24][25]. A 2006 manuscript by Bigler et al. [9] correlated DOI brain CT findings with FIM measures and the Disability Rating Scale (DRS) after a stay in a rehabilitation unit/hospital, using the Marshall classification to rate brain CTs. Their group found that the Marshall score correlated poorly with FIM and DRS at the time of discharge from rehabilitation, which differs from our findings.. A limitation of the Marshall score is the dichotomous nature of the scale and doesn't allow for a difference in score for larger or multiple lesions nor does it does use lesion volumes.

Other outcome prediction models that incorporate DOI CT findings exist. The International Mission on Prognosis and Analysis of Clinical Trials in TBI (IMPACT) is an international, multi-disciplinary group that synthesized data from 11 large clinical trials (total n=8686) and developed models to predict mortality and outcomes at six months after injury [26]. The IMPACT models incorporate multiple data points, ranging from pre-injury demographics to initial laboratory values to brain CT findings, and have been externally validated [27][28] [29]. A limitation of the IMPACT model is that the CT finding variables (presence of shift, presence of mass lesion, presence of sub-arachnoid hemorrhage, and presence of epidural hemorrhage) are dichotomous and not quantitative in nature.

Volumetric neuroimaging analysis has been used for predictive/prognostication of outcomes in many disorders, including autism [30], multiple sclerosis [31], stroke [32] and anoxic brain injury [33]. Quantitative neuroimaging in trauma has mainly focused on long term outcomes after rehabilitation, looking at changes in the brain over time after the acute injury [34] [35] [36]. In these studies, quantitative magnetic resonance imaging (qMRI) was the primary imaging modality, and multiple examinations were performed to document how the morphology of the brain changed over months to years. Clearly, such imaging techniques are not practical in the acute phase of their brain injury. Many TBI patients never undergo MRI at any time during the acute hospitalization. The DOI CT scan is the most consistently performed study for all TBI patients, and as such is the most logical technique on which to base a model incorporating neuroanatomic volumetric data.

To our knowledge, no other researchers have constructed a TBI prediction model using brain volumetric data from the DOI brain CT. The findings from the present study indicate that the largest DOI lesion volume as well as the degree of midline shift may have prognostic value for cognitive functioning at the time of admission and discharge from inpatient rehabilitation, after adjustment for confounding effects of other predictors.

Clearly, this study was limited by its retrospective, small size, and single center nature. Further, the purpose of the study was to evaluate the predictive value of the DOI brain CT. Our model might well have been strengthened by adding volumetric data from the second brain CT. Often, particularly in intraparenchymal contusions or bleeds that are not addressed surgically, a lesion will “blossom”, or grow significantly between the scan done in the ED and the follow up done hours later. Adding either the raw data from this second CT, or perhaps using the difference between lesion size on the first versus the second might have been a valuable variable to add to our model. In the same vein, we might have aggregated the largest two or three lesions, instead of focusing on the single largest in an attempt to make the model more robust. Finally, although we calculated ISS for every patient, we did not note who specifically had an extremity fracture and who did not. Clearly, motor FIM will be influenced by these injuries, and our model could have been improved by controlling for them.

Although we used quantitative methods to perform our analysis, modern CT scanners often possess similar capabilities, making similar volumetric analysis methods more feasible at most major trauma centers, without adding on extra CT examinations, radiation, or even much additional time. These data points, heretofore not widely used or appreciated, may be important in the construction of future prognostication models for long-term outcomes from TBI.

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Table 1
Demographic Information for Study Population

Variable	N	% or Mean (SD)
Gender		
Male	71	74%
Female	25	26%
Age at admission (years)	96	43 (21)
Employment Status		
Employed only	58	60%
Unemployed	16	17%
Retired	15	16%
Student only	6	6%
Employed + Student	1	1%
Primary payer		
No-Fault Auto	40	42%
None	22	23%
Medicare	12	13%
Private/HMO	10	10%
Medicaid	4	4%
Workers Compensation	4	4%
Other/Unknown	4	4%

Table 2
Injury, Hospital, and Rehabilitation Data for Study Population

Variable	N	% or Mean (SD)
Injury		
Mechanism		
Motor Vehicle/Motor Cycle Crash	56	58%
Falls	24	25%
Violence	10	10%
Miscellaneous	4	4%
Sports	2	2%
Intubated in the field or emergency department	65	67.7%
Glasgow Coma Scale in ED	91	8.4 (4.8)
Injury Severity Score (ISS)	96	25 (10)
Head Abbreviated Injury Scale (AIS)	95	3.7 (1.0)
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole)	17	17.7%
Rehabilitation		
Admission FIM Motor	96	39 (12)
Admission FIM Cognitive	96	38 (20)
Discharge FIM Motor	96	61 (10)
Discharge FIM Cognitive	96	64 (18)
Rehab length of stay (days)	96	16 (9.3)
Discharge to home from rehab	86	89.6%
Post discharge		
9-month FIM Motor	72	89 (12)
9-month FIM Cognitive	72	77 (17)

Table 3**Bivariate analyses**

A. Outcome: ICU LOS			
Predictor	N, Correlation or N, Mean (Std Dev)	P-Value	Test
Age	95, −.15	0.157	Spearman
Distance of midline shift	90, 0.37	0.0003	Spearman
Glasgow Coma Scale in ED	91, −.37	0.0003	Spearman
Head Abbreviated Injury Scale (AIS)	95, 0.24	0.0188	Spearman
Injury Severity Score (ISS)	95, 0.51	<.0001	Spearman
NOT intubated in the field or ED	30, 9.1 (13.1)	0.347	Satterthwaite T-test
Intubated in the field or ED	65, 11.6 (6.9)	.	
Volume of largest brain lesion	90, 0.16	0.1304	Spearman
ASA or Plavix NOT administered	80, 9.8 (7.0)	0.1498	Satterthwaite T-test
ASA or Plavix administered	15, 16.3 (16.3)	.	
Coumadin NOT administered	89, 10.0 (7.2)	0.2701	Satterthwaite T-test
Coumadin administered	6, 22.0 (23.6)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	78, 10.8 (9.9)	0.9221	Satterthwaite T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 10.9 (6.2)	.	
Rotterdam Score: 5- 53% mortality	4, 18.0 (3.4)	0.2233	ANOVA + Duncan lines
Rotterdam Score: 2- 7% mortality	23, 12.7 (14.5)	.	
Rotterdam Score: 4- 26% mortality	20, 12.1 (9.8)	.	
Rotterdam Score: 6- 61% mortality	1, 12.0 (NA)	.	
Rotterdam Score: 3- 16% mortality	42, 8.7 (5.1)	.	

B. Outcome: Acute Hospital LOS			
Age	96, −.18	0.0732	Spearman
Distance of midline shift	90, 0.35	0.0007	Spearman
Glasgow Coma Scale in ED	91, −.39	0.0002	Spearman
Head Abbreviated Injury Scale (AIS)	95, 0.24	0.0187	Spearman
Injury Severity Score (ISS)	96, 0.58	<.0001	Spearman
NOT intubated in the field or ED	31, 9.3 (7.9)	0.0197	Pooled T-test
Intubated in the field or ED	65, 13.8 (9.0)	.	
Volume of largest brain lesion	90, 0.13	0.2281	Spearman
ASA or Plavix NOT administered	81, 12.0 (8.8)	0.4094	Pooled T-test
ASA or Plavix administered	15, 14.1 (9.2)	.	
Coumadin NOT administered	90, 12.3 (8.8)	0.96	Pooled T-test
Coumadin administered	6, 12.5 (11.2)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 12.3 (9.1)	0.9401	Pooled T-test

B. Outcome: Acute Hospital LOS			
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 12.5 (7.8)	.	
Rotterdam Score: 5- 53% mortality	4, 22.3 (6.7)	0.1769	ANOVA + Duncan lines
Rotterdam Score: 4- 26% mortality	20, 14.1 (12.2)	.	
Rotterdam Score: 2- 7% mortality	23, 11.6 (9.1)	.	
Rotterdam Score: 3- 16% mortality	42, 11.2 (7.0)	.	
Rotterdam Score: 6- 61% mortality	1, 11.0 (NA)	.	

C. Outcome: Admission FIM Rasch-Adjusted Motor			
Age	96, 0.02	0.8538	Spearman
Distance of midline shift	90, −.22	0.0369	Spearman
Glasgow Coma Scale in ED	91, 0.22	0.0405	Spearman
Head Abbreviated Injury Scale (AIS)	95, −.29	0.0047	Spearman
Injury Severity Score (ISS)	96, −.41	<.0001	Spearman
NOT intubated in the field or ED	31, 42.1 (11.0)	0.0495	Pooled T-test
Intubated in the field or ED	65, 37.0 (12.1)	.	
Volume of largest brain lesion	90, −0.1	0.3451	Spearman
ASA or Plavix NOT administered	81, 39.4 (12.2)	0.1815	Pooled T-test
ASA or Plavix administered	15, 34.9 (10.1)	.	
Coumadin NOT administered	90, 38.5 (12.0)	0.7002	Pooled T-test
Coumadin administered	6, 40.5 (11.7)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 38.5 (12.1)	0.7786	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 39.4 (11.4)	.	
Rotterdam Score: 3- 16% mortality	42, 40.9 (12.1)	0.3016	ANOVA + Duncan lines
Rotterdam Score: 2- 7% mortality	23, 38.3 (11.1)	.	
Rotterdam Score: 5- 53% mortality	4, 37.3 (9.8)	.	
Rotterdam Score: 4- 26% mortality	20, 34.0 (13.0)	.	
Rotterdam Score: 6- 61% mortality	1, 32.0 (NA)	.	

D Outcome: Rehab Admission FIM Rasch-Adjusted Cognitive			
Age	96, −.05	0.6318	Spearman
Distance of midline shift	90, −0.4	<.0001	Spearman
Glasgow Coma Scale in ED	91, 0.25	0.0153	Spearman
Head Abbreviated Injury Scale (AIS)	95, −0.4	<.0001	Spearman
Injury Severity Score (ISS)	96, −.11	0.2737	Spearman
NOT intubated in the field or ED	31, 43.2 (20.1)	0.1092	Pooled T-test
Intubated in the field or ED	65, 36.1 (20.1)	.	
Volume of largest brain lesion	90, −.52	<.0001	Spearman
ASA or Plavix NOT administered	81, 39.4 (20.0)	0.2392	Pooled T-test
ASA or Plavix administered	15, 32.7 (21.5)	.	

D Outcome: Rehab Admission FIM Rasch-Adjusted Cognitive			
Coumadin NOT administered	90, 38.1 (20.8)	0.5792	Pooled T-test
Coumadin administered	6, 42.8 (9.6)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 39.8 (18.9)	0.1269	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 31.5 (25.4)	.	
Rotterdam Score: 3- 16% mortality	42, 44.5 (16.5)	0.0005	ANOVA + Duncan lines
Rotterdam Score: 2- 7% mortality	23, 43.5 (22.9)	.	
Rotterdam Score: 4- 26% mortality	20, 27.2 (18.4)	.	
Rotterdam Score: 5- 53% mortality	4, 18.5 (7.4)	.	
Rotterdam Score: 6- 61% mortality	1, 0.0 (NA)	.	

E. Outcome: Rehab Discharge FIM Rasch-Adjusted Motor			
Age	96, -.27	0.009	Spearman
Distance of midline shift	90, 0.06	0.5847	Spearman
Glasgow Coma Scale in ED	91, -.24	0.02	Spearman
Head Abbreviated Injury Scale (AIS)	95, -.02	0.8724	Spearman
Injury Severity Score (ISS)	96, -.08	0.4346	Spearman
NOT intubated in the field or ED	31, 58.3 (11.9)	0.0719	Pooled T-test
Intubated in the field or ED	65, 62.4 (9.5)	.	
Volume of largest brain lesion	90, 0.03	0.7912	Spearman
ASA or Plavix NOT administered	81, 62.0 (10.3)	0.0504	Pooled T-test
ASA or Plavix administered	15, 56.3 (10.3)	.	
Coumadin NOT administered	90, 61.3 (10.4)	0.4805	Pooled T-test
Coumadin administered	6, 58.2 (11.4)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 61.0 (10.8)	0.9107	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 61.4 (8.9)	.	
Rotterdam Score: 3- 16% mortality	42, 61.9 (10.6)	0.7516	ANOVA + Duncan lines
Rotterdam Score: 4- 26% mortality	20, 61.2 (8.1)	.	
Rotterdam Score: 2- 7% mortality	23, 59.4 (10.7)	.	
Rotterdam Score: 5- 53% mortality	4, 58.3 (14.6)	.	
Rotterdam Score: 6- 61% mortality	1, 52.0 (NA)	.	

F. Outcome: Rehab Discharge FIM Rasch-Adjusted Cognitive			
Age	96, -.18	0.0746	Spearman
Distance of midline shift	90, -.23	0.0281	Spearman
Glasgow Coma Scale in ED	91, 0.01	0.9227	Spearman
Head Abbreviated Injury Scale (AIS)	95, -.24	0.0181	Spearman
Injury Severity Score (ISS)	96, 0.16	0.1253	Spearman
NOT intubated in the field or ED	31, 62.5 (18.4)	0.4822	Pooled T-test
Intubated in the field or ED	65, 65.2 (17.5)	.	

F. Outcome: Rehab Discharge FIM Rasch-Adjusted Cognitive			
Volume of largest brain lesion	90, −.44	<.0001	Spearman
ASA or Plavix NOT administered	81, 65.0 (17.6)	0.3777	Pooled T-test
ASA or Plavix administered	15, 60.6 (18.9)	.	
Coumadin NOT administered	90, 64.5 (18.3)	0.7767	Pooled T-test
Coumadin administered	6, 62.3 (7.8)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 65.3 (16.7)	0.2826	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 60.1 (22.3)	.	
Rotterdam Score: 3- 16% mortality	42, 67.5 (15.0)	0.0064	ANOVA + Duncan lines
Rotterdam Score: 2- 7% mortality	23, 66.7 (16.2)	.	
Rotterdam Score: 4- 26% mortality	20, 59.4 (17.5)	.	
Rotterdam Score: 6- 61% mortality	1, 41.0 (NA)	.	
Rotterdam Score: 5- 53% mortality	4, 39.8 (20.6)	.	

G. Outcome: Rehab LOS			
Age	96, 0.08	0.4591	Spearman
Distance of midline shift	90, 0.24	0.0225	Spearman
Glasgow Coma Scale in ED	91, −.25	0.0175	Spearman
Head Abbreviated Injury Scale (AIS)	95, 0.28	0.0057	Spearman
Injury Severity Score (ISS)	96, 0.36	0.0003	Spearman
NOT intubated in the field or ED	31, 13.0 (6.9)	0.0154	Satterthwaite T-test
Intubated in the field or ED	65, 17.3 (9.9)	.	
Volume of largest brain lesion	90, 0.19	0.0726	Spearman
ASA or Plavix NOT administered	81, 15.4 (9.6)	0.256	Pooled T-test
ASA or Plavix administered	15, 18.4 (6.4)	.	
Coumadin NOT administered	90, 16.0 (9.3)	0.7388	Pooled T-test
Coumadin administered	6, 14.7 (8.4)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	79, 15.1 (8.8)	0.0842	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	17, 19.4 (10.6)	.	
Rotterdam Score: 6- 61% mortality	1, 40.0 (NA)	0.0042	ANOVA + Duncan lines
Rotterdam Score: 4- 26% mortality	20, 20.6 (10.0)	.	
Rotterdam Score: 5- 53% mortality	4, 16.5 (12.9)	.	
Rotterdam Score: 2- 7% mortality	23, 14.8 (9.2)	.	
Rotterdam Score: 3- 16% mortality	42, 13.5 (7.6)	.	

H. Outcome: 9 month post-discharge FIM Rasch-adjusted Motor			
Age	72, −0.2	0.0912	Spearman
Distance of midline shift	72, −.03	0.7901	Spearman
Glasgow Coma Scale in ED	72, −.14	0.2329	Spearman
Head Abbreviated Injury Scale (AIS)	72, −.01	0.9267	Spearman

H. Outcome: 9 month post-discharge FIM Rasch-adjusted Motor			
Injury Severity Score (ISS)	72, -.06	0.59	Spearman
NOT intubated in the field or ED	18, 81.9 (10.3)	0.0015	Pooled T-test
Intubated in the field or ED	54, 91.9 (11.4)	.	
Volume of largest brain lesion	72, -.18	0.14	Spearman
ASA or Plavix NOT administered	61, 89.5 (12.0)	0.9439	Pooled T-test
ASA or Plavix administered	11, 89.2 (11.7)	.	
Coumadin NOT administered	69, 89.9 (11.9)	0.1103	Pooled T-test
Coumadin administered	3, 78.7 (4.5)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	58, 89.0 (12.0)	0.5324	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	14, 91.2 (11.5)	.	
Rotterdam Score: 6- 61% mortality	1, 100.0 (NA)	0.8762	ANOVA + Duncan lines
Rotterdam Score: 4- 26% mortality	14, 90.9 (12.1)	.	
Rotterdam Score: 5- 53% mortality	4, 90.5 (11.1)	.	
Rotterdam Score: 2- 7% mortality	17, 89.1 (12.5)	.	
Rotterdam Score: 3- 16% mortality	31, 88.3 (12.8)	.	

I. Outcome: 9 month post-discharge FIM Rasch-adjusted Cognitive			
Age	72, 0.13	0.2687	Spearman
Distance of midline shift	72, -.03	0.8107	Spearman
Glasgow Coma Scale in ED	72, -.17	0.1695	Spearman
Head Abbreviated Injury Scale (AIS)	72, -.05	0.6689	Spearman
Injury Severity Score (ISS)	72, 0.09	0.4574	Spearman
NOT intubated in the field or ED	18, 76.9 (13.7)	0.9001	Pooled T-test
Intubated in the field or ED	54, 77.5 (17.6)	.	
Volume of largest brain lesion	72, -.16	0.1821	Spearman
ASA or Plavix NOT administered	61, 77.5 (17.2)	0.905	Pooled T-test
ASA or Plavix administered	11, 76.8 (13.6)	.	
Coumadin NOT administered	69, 77.2 (16.9)	0.6767	Pooled T-test
Coumadin administered	3, 81.3 (7.5)	.	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	58, 76.0 (16.2)	0.1599	Pooled T-test
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	14, 83.0 (17.9)	.	
Rotterdam Score: 3- 16% mortality	31, 80.4 (18.0)	0.6834	ANOVA + Duncan lines
Rotterdam Score: 2- 7% mortality	17, 76.6 (12.9)	.	
Rotterdam Score: 5- 53% mortality	4, 74.8 (25.2)	.	
Rotterdam Score: 4- 26% mortality	14, 74.6 (18.3)	.	
Rotterdam Score: 6- 61% mortality	1, 61.0 (NA)	.	

J. Outcome: Discharge to home			
Predictor	DC'd home	Not DC'd home	PValue
Age	86, 39.6 (18.6)	10, 70.2 (19.7)	<.001
Distance of midline shift	80, 0.2 (0.2)	10, 0.3 (0.3)	0.19
Glasgow Coma Scale in ED	83, 8.3 (4.7)	8, 9.4 (5.9)	0.538
Head Abbreviated Injury Scale (AIS)	86, 3.7 (0.9)	9, 4.1 (1.2)	0.214
Injury Severity Score (ISS)	86, 25.1 (10.1)	10, 21.2 (7.6)	0.242
NOT intubated in the field or ED	24, 27.9%	7, 70.0%	0.012
Intubated in the field or ED	62, 72.1%	3, 30.0%	
Volume of largest brain lesion	80, 10.2 (17.5)	10, 33.6 (40.3)	0.102
ASA or Plavix NOT administered	75, 87.2%	6, 60.0%	0.047
ASA or Plavix administered	11, 12.8%	4, 40.0%	
Coumadin NOT administered	80, 93.0%	10, 100.0%	1
Coumadin administered	6, 7.0%	0, 0.0%	
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) NOT done	71, 82.6%	8, 80.0%	1
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole) done	15, 17.4%	2, 20.0%	
Rotterdam Score: 2- 7% mortality	19, 23.8%	4, 40.0%	0.025
Rotterdam Score: 3- 16% mortality	39, 48.8%	3, 30.0%	
Rotterdam Score: 4- 26% mortality	19, 23.8%	1, 10.0%	
Rotterdam Score: 5- 53% mortality	3, 3.8%	1, 10.0%	
Rotterdam Score: 6- 61% mortality	0, 0.0%	1, 10.0%	

Table 4

Stepwise Selection Model Results

A. ICU and Acute Hospital Length of Stay (LOS) (n=96 read, n=84 used)									
Variable	ICU LOS (model R ² 0.3348)				Acute hospital LOS (model R ² 0.2762)				
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Standard Error	P-value	
0 Intercept	7.53165	0	3.28083	0.024	1.17123	0	2.27427	0.608	
Administered ASA or Plavix prior to injury	7.08539	0.27374	2.61018	0.008	.	.	.	.	.
Administered Coumadin prior to injury	14.35014	0.35198	4.14676	<.001	.	.	.	.	.
Glasgow Coma Scale in 1st 24 hours total score	-0.54055	-0.26835	0.21104	0.012	.	.	.	.	.
Injury Severity Score (ISS)	0.24824	0.26189	0.09169	0.008	0.46926	0.52559	0.08388	<.001	

B. Admission to Rehabilitation FIM (n=96 read, n=84 used)									
Variable	FIM Rasch-Adj Motor (model R ² 0.1237)				FIM Rasch-Adj Cognitive (model R ² 0.3336)				
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Standard Error	P-value	
0 Intercept	48.41901	0	3.32314	<.001	48.87002	0	8.65267	<.001	
Administered ASA or Plavix prior to injury	.	.	.	.	11.67755	-0.21265	5.34113	0.032	
Age at admission to rehab	.	.	.	.	.	.	.	.	.
CT: Largest mass (cubic cm)	.	.	.	.	-0.2754	-0.30445	0.09188	0.004	
Glasgow Coma Scale in 1st 24 hours total score	.	.	.	.	1.52314	0.35639	0.41366	<.001	
Head Abbreviated Injury Scale (AIS)	.	.	.	.	-4.88017	-0.22851	2.14159	0.025	
Injury Severity Score (ISS)	-0.41696	-0.35168	0.12256	0.001	.	.	.	.	
Rotterdam score of 5 or 6 (53% or 61% mortality)	.	.	.	.	.	.	.	.	

C. Discharge from Rehabilitation FIM (n=96 read, n=84 used)									
Variable	FIM Rasch-Adj Motor (model R ² 0.1591)				FIM Rasch-Adj Cognitive (model R ² 0.2098)				
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Standard Error	P-value	
0 Intercept	75.40275	0	4.06976	<.001	67.92973	0	1.95062	<.001	

C. Discharge from Rehabilitation FIM (n=96 read, n=84 used)									
Variable	FIM Rasch-Adj Motor (model R ² 0.1591)				FIM Rasch-Adj Cognitive (model R ² 0.2098)				P-value
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Standard Error	P-value	
Administered ASA or Plavix prior to injury	.	.	.	.	.	.	.	.	.
Age at admission to rehab	-0.20147	-0.39094	0.05464	<.001	.	.	.	.	.
CT: Largest mass (cubic cm)	.	.	.	.	-0.22622	-0.303	0.07662	0.004	.
Glasgow Coma Scale in 1st 24 hours total score	.	.	.	.	.	.	.	.	.
Head Abbreviated Injury Scale (AIS)	.	.	.	.	.	.	.	.	.
Injury Severity Score (ISS)	-0.24374	-0.24204	0.10677	0.025	.	.	.	.	.
Rotterdam score of 5 or 6 (53% or 61% mortality)	.	.	.	.	19.34593	-0.27098	7.32625	0.01	.

D. Rehabilitation Length of Stay (LOS), Discharge to home after Rehabilitation (n=96 read, n=84 used)									
Variable	Rehab LOS (model R ² 0.1447)				Discharge to home (c-statistic 0.921)				
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Odds ratio	95% lower bound	95% upper bound
0 Intercept	7.18573	0	2.59157	0.007	8.778	—	.	.	<.001
Age at admission to rehab	.	.	.	.	-0.0892	-0.9838	0.915	0.858	0.976
CT: Mean shift distance	.	.	.	.	-6.2068	-0.6533	0.002	0.001	0.169
Injury Severity Score (ISS)	0.35594	0.38033	0.09558	<.001	.	.	.	.	.

E. Nine month post discharge FIM (n=96 read, n = 64 used)									
Variable	FIM Rasch-Adj Motor (model R ² 0.1014)				FIM Rasch-Adj Cognitive (model R ² 0.0346)				
	Estimate	Standardized Estimate	Standard Error	P-value	Estimate	Standardized Estimate	Standard Error	P-value	P-value
0 Intercept	82.66667	0	2.99378	<.001	75.58824	0	2.38032	<.001	.
Intubated in the field or emergency department in 1st 24 hours	9.04762	0.31836	3.42146	0.01	.	.	.	.	.
Neurosurgical procedure in 1st 24 hours (craniotomy, craniectomy, or burr hole)	.	.	.	.	7.8733	0.18602	5.28145	0.141	.