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James Alexander Miller Douglas, III Date

Predictive Modeling of Neurosurgical Intervention and Mortality in Traumatic Brain Injury: Experience from a Level I Trauma Center

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Global Epidemiology

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Abstract

Predictive Modeling of Neurosurgical Intervention and Mortality in Traumatic Brain Injury: Experience from a Level I Trauma Center

By James Alexander Miller Douglas, III

Introduction: Traumatic brain injury (TBI) affects thousands at Grady Memorial Hospital (GMH) annually. Prognostication and management are challenging and lack standardization, especially in grave cases. Given the impact of early decisions, including limitation of life-sustaining treatment, improving prognostication is essential to balance chances of favorable recovery with morbidity, mortality, and public health issues, including resource expenditure.

Methods: Analyses incorporated 6567 TBI patients presenting to GMH from 2016-2021, and 135 were excluded due to arrival without signs of life. Two multivariable logistic regression models were used to evaluate predictors of neurosurgical intervention among all TBI patients (model 1) and those with Glasgow Coma Scale (GCS) of 3-5 (model 2). The corresponding regression analyses assessing predictors of mortality were denoted as models 3 and 4. The models were assessed for collinearity and presented as adjusted odds ratios (OR) with 95% confidence intervals (CI). C-statistics were calculated to evaluate predictive strength of each model.

Results: Presence of major extracranial injury, as evidenced by Injury Severity Score (ISS) ≥ 15 (OR= 13.5, CI 8.3, 23.6) was the only significant predictor in model 1 (C-statistic 0.768). In model 2, sex (male vs. female (OR=3.1, 2.1, 10.4)) and major extracranial injury (OR=19.1, 5.3, 125) were significant predictors (C-statistic 0.827). In model 3, significant prognosticating factors included age (55-64 (OR=1.9, 1.1, 3.2), 65-74 (OR=2.0, 1.1, 3.6), greater than 75 (OR=1.9, 1.0, 3.5), vs. 18-29 years), race (other vs. Black (OR=0.4, 0.1, 0.8)), hypoxia (OR=3.9, 2.2, 7.0), and major extracranial injury (OR=34.1, 16.5, 87.1) (C-statistic=0.812). In model 4, age (65-74 (OR=9.8, 1.5, 84.9), greater than 75 (OR=10.0, 1.4, 95.2) vs. 18-29 years), and mechanism of injury (road traffic collision (RTC) vs. fall (OR=3.53, 1.1, 12.9) were significant predictors (C-statistic=0.740).

Conclusion: The strongest predictors of neurosurgical intervention were male sex, among patients with GCS 3-5, and major extracranial injury in both groups; however, GCS was not significantly associated. With respect to in-hospital mortality, age and presence of major extracranial injury were significantly predictive in both groups along with hypoxia among all TBI patients. Additionally, RTC mechanism of injury was a significant predictor of mortality in the GCS 3-5 group.

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INTRODUCTION AND BACKGROUND

In the United States (US), three million people are affected by traumatic brain injury (TBI) each year.[1] On average, more than 150 people die each day from injuries associated with TBI, representing 2.2% of US deaths annually.[2] With respect to monetary resource expenditure, approximately $2 million is spent per patient case, with a lifetime cost of $93 billion.[3,4] More importantly, effects of TBI on quality of life are innumerable, including changes in a patient's ability to interact with others, to complete activities of daily living, and to provide for themselves and their families. Those with the most severe injuries present particular difficulties within the healthcare system, with respect to prognostication, clinical decision making, resource expenditure and ethics.[5]

Large datasets such as the Corticosteroid Randomisation after Significant Head Injury (CRASH) trial and the International Mission on Prognosis and Analysis of Randomized Controlled Trials in TBI (IMPACT) study were used to develop models using multivariable logistic regression to improve early clinical decision making, describe risk strata and compare outcomes in TBI.[6,7] The CRASH model incorporated age, extent of extracranial injury, and radiographic findings on Computed Tomography (CT).[6] The IMPACT model included additional clinical data, such as vital signs, Glasgow Coma Scale (GCS) motor score, in addition to laboratory and radiographic findings.[8] As the field has progressed, longitudinal cohort studies such as Transforming Research and Clinical Knowledge in TBI (TRACK-TBI) have furthered the connection of early clinical and laboratory data to long-term outcomes and challenged preconceived notions of negativism in the care of the most severe forms TBI[9]. These large pivotal studies and their outgrowths have sought to address the relatively low quality of evidence behind TBI treatment guidelines.[10]

Despite advancements in the study of TBI prognostication, still therein lies uncertainty, especially in the most severe cases. GCS score of 3 and bilaterally, fixed, and dilated pupils are especially poor prognostic indicators, which can lead to early decisions regarding limitation or WLST versus the pursuit of aggressive management. However, study findings in patients with severe TBI have been inconsistent, with a mortality rate ranging from 65% to 100% in patients with a GCS of 3[11,12]. Further studies have

reported 100% in-hospital mortality in patients with bilateral fixed, dilated pupils compared with 67% mortality in those with reactive pupils.[13] These statistics can increase the likelihood of care limitation and avoidance of aggressive therapy in patients with these indicators. However, contemporary studies have shown that patients with a GCS of 3 at presentation had a 50.8% overall survival and 13.2% good functional outcome at 6 months, as defined by Glasgow Outcome Scale, signifying return to baseline or recovery with minor deficits.[14] Greater than 20% survival to discharge has been shown in patients with fixed, dilated pupils; however, just 1.4% had a good functional outcome at 6 months.

In the context of this uncertainty, standardization of early care is necessary in cases with an estimated early poor prognosis according to immediately available clinical data. In a 2015 position statement, the Neurocritical Care Society (NCS) attempted to create a case definition for these cases, termed devastating brain injury (DBI), defined as a neurological disease state upon hospital admission that appears to imminently threaten life or favorable functional recovery, resulting in consideration of early limitation or withdrawal of treatment.[5, 15] The goals of their management framework were to increase accuracy in decision making and circumvent self-fulfilling negativism. By instituting a 72-hour observation period with supportive care, they set to increase the small chances of survival and the likelihood of organ donation.[5]

The NCS definition of DBI does not consider mechanism of injury. Given global and national burden of disease related to TBI, the implications of lost productivity, the lack of prognostic certainty, and potential resource expenditure challenges, additional modeling, and longitudinal outcome studies in devastating TBI are necessary. Given the focus of this study on traumatic mechanism of injury, we will label DBI secondary to trauma, "D-TBI", and define this subgroup as patients with admission GCS of 3-5. Our study aims to incorporate demographic, clinical and imaging data into prognostic models to better understand patient selection for neurosurgical care in TBI and risk factors for in-patient mortality and to build upon past models to better understand the biases affecting care and premature WLST in these groups.

METHODS

Research Design

This is a single center retrospective case-control study epidemiologic and clinical characteristics of all TBI patients and a subgroup of D-TBI patients collected through the Trauma Registry (TR) at Grady Memorial Hospital (GMH) in Atlanta, Georgia. Logistic regression analyses evaluated various predictors of neurosurgical intervention and in-hospital mortality in each group at GMH, a county hospital and level 1 trauma center with a population largely represented by the uninsured, underinsured, and those on Medicare and Medicaid.

Study Population

This analysis included 6567 patients who presented to GMH from 2016 to 2021 who met the following inclusion criteria: 1) had experienced TBI, 2) were over the age of 18 years, and 3) were evaluated and/or treated at GMH. One hundred and thirty-five patients were excluded as they arrived to the hospital with no signs of life. The D-TBI subgroup included 955 patients. The outcome variables of interest included in-hospital mortality and neurosurgical intervention, defined by pertinent ICD-10-PCS codes 0WJ10ZZ, 00940ZZ, 0NB00ZZ, 009630Z, and 4A103RD[16].

Variables of interest

The CRASH and IMPACT models were used in consideration of variable inclusion, along with follow-up studies that included additional demographic and laboratory variables to improve the strength of prediction.[6, 8, 17] Independent variables in the unadjusted analyses included age, sex, race, mechanism of injury, GCS, presence of major extracranial injury as defined by Injury Severity Score (ISS) ≥ 15, Marshall CT score (class I (no observable pathology), class II (open cisterns with midline shift (MLS) ≤ 5 mm and/or acute/subacute lesion ≤ 25 cc), class III (cisternal compression with MLS ≤ 5 mm and/or acute/subacute lesion ≤ 25 cc), class IV (MLS > 5 mm, no acute/subacute lesion > 25 cc), class VI (acute/subacute lesion > 25 cc; class V was not included as this classification is limited to those who have already had neurosurgical intervention), oxygen saturation (Sp02), blood pressure (BP), and coagulation

status (International Normalized Ratio (INR)).[18] For purposes of the analysis, continuous variables such as age, GCS, ISS, Sp02, BP and INR were converted into categorical variables for bivariate and multivariable regression. Age was divided into the following five groups: 18 to 29, 30 to 54, 55 to 64, 65 to 74, and greater than 75 years. Sex was categorized into two groups: male and female. Race was categorized into 3 groups: Black or African American, White, and other (including Asian, American Indian, Native Hawaiian or other Pacific Islander, and Other). Mechanism of injury was divided into 5 categories, including fall (ground level fall, fall from height, and unspecified fall), road traffic collisions (motor vehicle collision, motorcycle collision, pedal cycle accident and pedestrian vs. automobile), gunshot wound, assault (blunt or non-ballistic penetrating injury) and other mechanisms of injury.

In the analysis of all TBI patients, GCS was categorized as follows: mild (GCS 13-15), moderate (GCS 9-12), severe (GCS ≤ 8) and devastating (GCS ≤ 5). In both groups, imaging data was incorporated by converting Abbreviated Injury Scale (AIS) codes into the Marshall CT Classification system.[18] ISS was separated as a binary exposure indicating the presence (ISS ≥ 15) or absence (ISS <15) of major extracranial injury. Oxygen saturation (SpO2) was divided into two categories based on measurements in the ED: hypoxia (Sp02 < 90%), and normal (Sp02 ≥ 90%). BP (in mmHg) was divided into three group based on systolic blood pressure (SBP) measurements in the ED: those less than 90 (hypotension), 90-150 (relative normotension and >150 (hypertension)[7] Coagulation status was defined by the patients INR, with normal (≥ 1.4) and low (< 1.4).[19]

Statistical Analysis

Initial assessment of the data included the calculation of frequencies and proportions for each category, as well as mean values of age, BMI, GCS, GCS Motor, ISS, and Sp02. Unadjusted analysis was conducted to assess crude associations between each independent variable and each outcome of interest. Next, multivariable regression analysis was conducted to assess two outcomes, neurosurgical intervention and in-hospital mortality, in both the all TBI and D-TBI groups. The components of each of the four models are outlined in appendix one and were included based on a priori methods based on prior models. Each model was assessed for multi-collinearity through assessment of the variance inflation factor (VIF).

The adjusted odds ratio (OR) for neurosurgical intervention and in-hospital mortality and 95% confidence intervals (CI) were determined. As a measure of predictive strength, C-statistics were calculated for each model, representing the AUC in an ROC. A C-statistic of 0.5 represents prediction similar to chance, and a C-statistic of 1.0 represents a perfect model[20].

Excel was used for database management, and data were exported into RStudio version 2021.9.2.382 (Rstudio Team, Boston, MA) for statistical analysis[21]. Summary tables for unadjusted and logistic regression models were produced with the gtsummary package in Rstudio[22]. All statistical tests were run with a two-sided significance level of 0.05. The Institutional Review Board (IRB) at Emory University has approved of this study.

RESULTS

Demographic, clinical, and mechanism of injury distributions for all patients are shown in Tables 1 and 2. Mean age of the entire study group was 46.7 years, 31.6% were female, 52.9% were Black or African American, and 6.1% were Hispanic or Latino. Mean BMI greater was about 27 kg/m2, with more than 40% of the overall population being overweight or obese. The leading mechanisms of injury were road traffic collision (RTC) (49.1%), fall (33.8%), and blunt or non-ballistic penetrating assault (9.2%). Patients with mild TBI represented 69.8% of the cases, whereas 14.9% of patients had D-TBI. Among this group, GCS scores of 3 predominated, making up 88.9% of cases. Mean ISS was 18.8 and more than half of patients were categorized with severe or profound extracranial injury on the scale. Among all TBI patients, 564 (8.8%) received neurosurgical intervention and 652 (10.1%) died prior to hospital discharge. In the D-TBI subgroup, 80 (8.4%) received neurosurgical intervention and 110 (11.5%) died prior to hospital discharge.

Tables 3 and 4 summarize the results of unadjusted analyses of the associations between individual predictors of neurosurgical intervention in all TBI patients and the subset with D-TBI. In the entire study group, the odds of neurosurgical intervention in patients with elevated ISS greater than 15 was significantly higher than those with less severe bodily injuries in both groups (OR= 12.7, CI 9.3, 17.7 and OR 12.6, CI 5.91, 32.9). The presence of hypoxia was significantly associated with the need for a neurosurgical procedure amongst all patients (OR=1.8, CI 1.2, 2.7). In the severe subgroup, male sex was related to increased odds of a neurosurgical need (OR=2.19, CI 1.3, 4.0). Summary findings from unadjusted in-hospital mortality analyses are represented in tables 4 and 5. In both the all TBI group and the D-TBI subgroup, major extracranial injury (OR=21.2, CI 15.0, 31.2 and OR=21.2, CI 15.0, 31.2), hypoxia (OR= 5.9, CI 4.3, 8.1 and OR=23.3, CI 10.4, 66.3), and coagulopathy (OR=6.7 , CI 5.1, 8.8 and OR=5.1, CI 2.5, 10.0) were associated with greater odds of death during one's hospital stay.

Table 7 summarizes the results of model 1, a logistic regression model assessing the adjusted associations of various factors with neurosurgical intervention among all TBI cases. Presence of severe or profound extracranial injury (OR= 13.5, CI 8.3, 23.6) was the only significant predictor in the model. The

C-statistic was 0.768. In table 8, regression results of the same predictor and outcome were reported in patients with D-TBI (model 2). Sex (male vs. female (OR=3.1, 2.1, 10.4)) and presence of major extracranial injury (OR=19.1, 5.3, 125) were significant predictors. The C-statistic of the model was 0.827.

Tables 9 and 10 report results of in-hospital mortality outcomes of logistic regression in all TBI (model 3) and D-TBI (model 4), respectively. Significant predictors in model 3 included age (55-64 (OR=1.9, 1.1, 3.2), 65-74 (OR=2.0, 1.1, 3.6), greater than 75 (OR=1.9, 1.0, 3.5), vs. 18-29 years), race (other vs. Black (OR=0.4, 0.1, 0.8)), hypoxia (OR=3.9, 2.2, 7.0), and presence of major extracranial injury (OR=34.1, 16.5, 87.1). The C-statistic of the model was 0.812. In model 4, age (65-74 (OR=9.8, 1.5, 84.9), greater than 75 (OR=10.0, 1.4, 95.2) vs. 18-29 years), and mechanism (RTC vs. fall (OR=3.53, 1.1, 12.9) were significant predictors (C-statistic=0.740). The c-statistic of the model was 0.740. Multicollinearity was not detected in any of the models, with all variance inflation factors < 2.

DISCUSSION

The study population of TBI patients treated at GMH, made up of greater than 50% Black patients, is considerably more diverse than other TBI cohorts. A study by Missios et al. published in 2016 evaluating 388,580 TBI patients from the National Trauma Database (NTDB) was comprised of 69.2% White and 13.5% Black patients. In Centers for Disease Control and Prevention surveillance data collected in 2017, the majority of TBI-related hospitalizations (30.3%, N= 67,875) and deaths (26.6%, N= 16,284) occurred in individuals greater than 75 years of age.[2] The patients in our cohort were younger, with only 12.8% over the age of 75, representing 9.7% of deaths. With respect to mechanism of injury, our study is similar to national data, led predominantly by falls followed by road traffic collisions and assault.[2, 23]

Identifying candidates for neurosurgical intervention and prognosticating outcomes such as mortality are difficult in TBI, especially the most severe cases. Early studies demonstrated certain mortality rate in the worst cases, resulting in a moribund perspective among clinicians when caring for patients with low GCS scores or fixed, non-reactive pupils. In some cases, fatalistic notions of poor prognosis may have led to early limitation or withdrawal of care, or at the very least, increased the threshold required aggressive management. In our cohort, patients with GCS of 3 on admission had an 88.2% survival to discharge, representing a further increase from a past study describing 50.3% survival to discharge[14].

In model 1, only elevated ISS (>15) was significantly associated with selection for neurosurgical intervention. It follows that a general increase in injury burden may be related to higher impact mechanisms and more severe head trauma. However, neither GCS category nor imaging findings were significantly associated with neurosurgical intervention. In model 2, assessing neurosurgical intervention among the D-TBI cohort, male sex and elevated ISS were associated with the outcome. While both models strongly predict neurosurgical intervention in all TBI and D-TBI, this was heavily dependent on the extracranial injury severity.

In model 3, age, other race, hypoxia, and elevated ISS were significantly associated with in-hospital morality. Severe (16-24) and profound (25-75) ISS signify the presence of major extracranial injury and have been previously identified as predictors of poor prognosis in TBI in the well validated CRASH (n=10,008) and IMPACT models[6, 7]. In the IMPACT study (n=8,509), analysis of race found that Black race was a significant risk factor for poor outcome; however, in the our model, the only significant racial difference existed in the "other" race category including Asians, Native Hawaiian and other Pacific Islanders, Native Americans and other[7]. In model 4, age greater than 65 and RTC were significantly associated with mortality in the D-TBI cohort. Age as a predictor of mortality follows with prior research. However, IMPACT found that RTC had significantly lower odds of poor GOS functional outcome.

As mentioned, severe and devastating TBI have tremendous impacts on society and individual families. With that said, fear of these costs and poor odds should not further a self-fulfilling prophecy leading to premature withdrawal of life sustaining treatment (WLST). Data has demonstrated the value of early, protocol driven care. Results from application the DBI pathway demonstrated delay of withdrawal of life-sustaining treatment (WLST) in DBI patients resulted in an 8% survival to discharge (Rivers). Furthermore, the consent rate in the emergency department (ED) in patients undergoing early WLST had a 21% rate of consent for organ donation, whereas those with delay in WLST had a 76% consent rate.[15] The delay also leads to benefits in communication with family including goals of care planning, expectation setting, and engagement of other team members including palliative care.[15]

LIMITATIONS

The quality and strength of regression analyses were limited by the number of missing values in key variables including GCS. Furthermore, the data is lacking values of two of the most important critical prognostic factors, pupillary size and reactivity. Similarly, the quality of the imaging data used in each of the models relies on conversion of AIS scores into Marshall CT Classifications. Future studies should seek to improve the database with addition pupillary data as well as imaging reports or review of patient scans. Perhaps most importantly, the study is limited by the inclusion criteria used to define the D-TBI

group. With the goal of describing traumatic DBI, use of GCS is a crude measure and does not accurately capture the severity outlined in the NCS definition of DBI, which must depend on integration of GCS, imaging data, and clinician perspective. Finally, the sample size of the D-TBI group, especially certain outcomes affected the outcome of the regression models. Coupled with the number of missing values, this likely explains the presence of widened CI values.

CONCLUSION

The strongest predictors for both neurosurgical intervention and mortality were severe or profound extracranial injury. However, unlike prior foundational TBI models looking at patient outcomes, GCS and GCS Motor scores were not significantly associated with either in this population. Though missing important prognostic indicators, such as pupillary size and reactivity, the models strongly predicted mortality. Despite data points or modeling that predict poor outcome, this study further confirms the limitations of such factors or prognostication techniques when considering early decisions about limitation or withdrawal of care.

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TABLES

TABLE 1. Demographic characteristics and mechanism of injury among TBI cases (n= 6,432), Trauma Registry at Grady Memorial Hospital, 2016-2021

	ALL TBI	GCS 3-5
N (%)	6432	955 (14.85)
AGE (YEARS) (MEAN, SD)	46.71 (21.12)	46.82 (21.19)
AGE CATEGORY (N, %)		
18-29	1528 (23.76)	225 (23.56)
30-54	2283 (35.49)	355 (37.17)
55-64	887 (13.79)	119 (12.46)
65-74	659 (10.25)	93 (9.74)
75+	821 (12.76)	130 (13.61)
MISSING	254 (3.95)	33 (3.46)
GENDER (N, %)		
FEMALE	2030 (31.56)	326 (34.14)
MALE	4402 (68.44)	629 (65.86)
MISSING	0 (0.00)	0 (0.00)
RACE (N, %)		
BLACK OR AFRICAN AMERICAN	3404 (52.92)	502 (52.57)
WHITE	2387 (37.11)	354 (37.07)
OTHER*	398 (6.19)	61 (6.39)
UNKNOWN	243 (3.78)	38 (3.98)
ETHNICITY (N, %)		
HISPANIC OR LATINO	393 (6.11)	55 (5.76)
NON-HISPANIC OR LATINO	5985 (93.05)	893 (93.51)
MISSING	54 (0.84)	7 (0.73)
BMI (KG/M^2) (MEAN, SD)	26.89 (11.85)	26.96 (13.86)
MISSING (N, %)	1214 (18.87)	193 (3.00)
MECHANISM OF INJURY (N, %)		
FALLS	2175 (33.81)	321 (33.61)
ROAD TRAFFIC COLLISIONS	3160 (49.13)	478 (50.05)
GUNSHOT WOUNDS	338 (5.25)	54 (5.65)
OTHER ASSAULT%	589 (9.16)	79 (8.28)
OTHER	170 (2.64)	23 (2.41)
MISSING	0 (0.00)	0 (0.00)

SD= standard deviation; BMI= body mass index; GCS= Glasgow Coma Scale

*Other race includes the following groups: Asian, American Indian, Native Hawaiian or other Pacific Islander, Other Race

TABLE 2. Clinical characteristics of TBI cases (n= 6,432), Trauma Registry at Grady Memorial Hospital, 2016-2021

	ALL TBI GCS 3-15	DEVASTATING TBI GCS 3-5	
ED GCS (MEAN, SD)	12.17 (4.38)	3.16 (0.47)	
MISSING (N, %)	177 (2.75)	0 (0.00)	
GCS CATEGORY			
MILD GCS 13-15	4490 (69.81)	**GCS**	
MODERATE GCS 9-12	426 (6.62)	3	849 (88.90)
SEVERE GCS ≤8	1399 (20.82)	4	64 (6.70)
DEVASTATING GCS ≤5	955 (14.85)	5	42 (4.40)
ED GCS MOTOR (MEAN, SD)	5.05 (1.79)	1.11 (0.39)	
MISSING (N, %)	179 (2.78)		
ISS (MEAN, SD)	18.74 (12.27)	18.74 (12.50)	
MAJOR EXTRACRANIAL INJURY (N, %)			
PRESENT	3426 (53.26)	506 (52.98)	
ABSENT	3006 (46.74)	449 (47.02)	
MISSING	0 (0.00)	0 (0.00)	
ED BLOOD PRESSURE (N, %)			
HYPOTENSION (SBP <90 MMHG)	327 (5.41)	166 (17.38)	
NORMOTENSION (SBP 90-150 MMHG)	4018 (66.42)	458 (47.96)	
HTN (SBP >150 MMHG)	1704 (28.17)	173 (18.12)	
MISSING	383 (5.95)	158 (16.54)	
ED HYPOXIA (SP02 <90%) (N,%)			
PRESENT	197 (3.06)	35 (3.66)	
ABSENT	5739 (89.23)	845 (88.48)	
MISSING	496 (7.71)	75 (7.85)	
COAGULOPATHY (INR <1.4)			
ELEVATED INR	288 (4.48)	47 (4.92)	
NORMAL INR	4548 (70.71)	668 (69.95)	
MISSING	1596 (24.81)	240 (25.13)	
MARSHALL CT SCORING			
I	83 (1.29)	11 (1.15)	
II	2996 (31.03)	285 (29.84)	
III	243 (3.78)	29 (3.04)	
IV	10 (0.16)	2 (0.21)	
V/VI	758 (11.78)	117 (12.25)	
MISSING	3324 (51.96)	511 (53.51)	
NEUROSURGICAL INTERVENTION (N, %)	564 (8.77)	80 (8.38)	
DISCHARGE STATUS (N, %)			
ALIVE	5780 (89.86)	845 (88.48)	
DEAD	652 (10.14)	110 (11.52)	

ED= emergency department; SBP= systolic blood pressure; HTN= hypertension; INR= International Normalized Ratio; CT= computed tomography

TABLE 3: Unadjusted analysis of the association between potential predictive factors and neurosurgical intervention in traumatic brain injury among all TBI patients (GCS 3-15), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	N	OR[1]	95% CI[1]	p-value
Age_group	6,178			
18-29		—	—	
30-54		1.08	0.86, 1.37	0.5
55-64		0.89	0.65, 1.20	0.4
65-74		1.00	0.72, 1.39	>0.9
75+		1.29	0.97, 1.72	0.082
Sex	6,432			
Female		—	—	
Male		0.99	0.82, 1.20	>0.9
Race_	6,432			
Black or African American		—	—	
Other		0.76	0.49, 1.14	0.2
Unknown		0.88	0.52, 1.40	0.6
White		1.20	1.00, 1.43	0.054
Mechanism_of_Injury	6,432			
Fall		—	—	
Assault		0.89	0.63, 1.22	0.5
GSW		0.89	0.57, 1.33	0.6
Other		1.44	0.87, 2.28	0.14
RTC		0.97	0.80, 1.18	0.8
GCS_cat	6,255			
mild		—	—	
devastating		0.96	0.74, 1.23	0.8
severe		1.02	0.70, 1.45	>0.9
moderate		1.06	0.74, 1.48	0.7
Major_Extracranial_Injury	6,432			
(0,15]		—	—	
(15,75]		12.7	9.34, 17.7	<0.001
Marshall_CT_Classification	3,090			
1		—	—	
2		0.66	0.35, 1.39	0.2
3		0.62	0.28, 1.44	0.2
4		1.82	0.25, 8.66	0.5
5		0.62	0.31, 1.33	0.2
Blood_Pressure	6,049			
Normotension		—	—	
Hypotension		1.06	0.70, 1.54	0.8
Hypertension		1.02	0.83, 1.24	0.9
Hypoxia	5,936			
Absent		—	—	
Present		1.81	1.20, 2.66	0.003
INR	4,836			
low INR		—	—	
high INR		1.25	0.84, 1.80	0.2

[1] OR = Odds Ratio, CI = Confidence Interval

TABLE 4: Unadjusted analysis of the association between potential predictive factors and neurosurgical intervention in traumatic brain injury among devastating TBI patients (GCS 3-5), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	N	OR[1]	95% CI[1]	p-value
Age_group	922			
18-29		—	—	
30-54		0.69	0.39, 1.23	0.2
55-64		0.52	0.20, 1.19	0.15
65-74		1.12	0.51, 2.35	0.8
75+		0.70	0.31, 1.47	0.4
Sex	955			
Female		—	—	
Male		2.19	1.28, 3.99	0.006
Race_	955			
Black or African American		—	—	
Other		1.41	0.52, 3.28	0.5
Unknown		1.52	0.44, 4.09	0.4
White		1.38	0.84, 2.25	0.2
Mechanism_of_Injury	955			
Fall		—	—	
Assault		1.52	0.65, 3.30	0.3
GSW		1.21	0.39, 3.07	0.7
Other		1.78	0.40, 5.65	0.4
RTC		1.02	0.61, 1.75	>0.9
GCS_Total	955			
5		—	—	
3		1.20	0.42, 5.07	0.8
4		1.10	0.26, 5.62	0.9
Major_Extracranial_Injury	955			
(0,15]		—	—	
(15,75]		12.6	5.91, 32.9	<0.001
Marshall_CT_Classification	444			
1		—	—	
2		0.40	0.09, 2.69	0.3
3		0.33	0.04, 3.10	0.3
4		0.00		>0.9
5		0.33	0.07, 2.40	0.2
Blood_Pressure	797			
Normotension		—	—	
Hypotension		1.42	0.76, 2.59	0.3
Hypertension		1.10	0.56, 2.06	0.8
Hypoxia	880			
Absent		—	—	
Present		1.85	0.61, 4.52	0.2
INR	715			
low INR		—	—	
high INR		1.88	0.74, 4.14	0.15

[1] OR = Odds Ratio, CI = Confidence Interval

TABLE 5: Unadjusted analysis of the association between potential risk factors and mortality in all TBI patients (GCS 3-15), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	N	OR[1]	95% CI[1]	p-value
Agegrp	6,178			
18-29		—	—	
30-54		1.15	0.93, 1.43	0.2
55-64		1.05	0.79, 1.39	0.7
65-74		1.06	0.78, 1.44	0.7
75+		1.07	0.80, 1.42	0.6
Gender	6,432			
Female		—	—	
Male		1.09	0.92, 1.30	0.3
Race	6,432			
Black or African American		—	—	
Other		0.84	0.57, 1.19	0.3
Unknown		0.91	0.57, 1.39	0.7
White		0.99	0.83, 1.17	0.9
Mechanism_of_Injury	6,432			
Fall		—	—	
Assault		1.02	0.74, 1.38	>0.9
GSW		0.81	0.52, 1.21	0.3
Other		0.94	0.52, 1.57	0.8
RTC		1.21	1.01, 1.45	0.042
GCS_cat	6,255			
mild		—	—	
devastating		1.22	0.97, 1.52	0.080
severe		1.34	0.96, 1.82	0.073
moderate		1.00	0.70, 1.38	>0.9
Major_Extracranial_Injury	6,432			
(0,15]		—	—	
(15,75]		21.2	15.0, 31.2	<0.001
Marshall_CT_Classification	3,090			
1		—	—	
2		0.89	0.46, 1.92	0.7
3		0.86	0.39, 2.04	0.7
4		0.00	0.00, 0.00	>0.9
5		0.93	0.47, 2.06	0.8
Blood_Pressure	6,049			
Normotension		—	—	
Hypotension		1.04	0.71, 1.47	0.9
Hypertension		0.90	0.74, 1.09	0.3
Hypoxia	5,936			
Absent		—	—	
Present		5.92	4.30, 8.09	<0.001
INR	4,836			
low INR		—	—	
high INR		6.72	5.08, 8.84	<0.001

[1] OR = Odds Ratio, CI = Confidence Interval

TABLE 6: Unadjusted analysis of the association between potential risk factors and mortality in devastating TBI (GCS 3-5), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	N	OR[1]	95% CI[1]	p-value
Age_group	922			
18-29		—	—	
30-54		1.48	0.87, 2.60	0.2
55-64		1.51	0.75, 3.01	0.2
65-74		1.04	0.44, 2.30	>0.9
75+		1.17	0.56, 2.37	0.7
Sex	955			
Female		—	—	
Male		1.18	0.78, 1.83	0.4
Race_	955			
Black or African American		—	—	
Other		0.63	0.21, 1.50	0.3
Unknown		0.61	0.14, 1.76	0.4
White		0.90	0.59, 1.37	0.6
Mechanism_of_Injury	955			
Fall		—	—	
Assault		1.66	0.81, 3.26	0.2
GSW		0.68	0.20, 1.79	0.5
Other		0.38	0.02, 1.92	0.4
RTC		1.17	0.75, 1.84	0.5
GCS_Total	955			
5		—	—	
3		0.80	0.35, 2.16	0.6
4		0.40	0.10, 1.49	0.2
Major_Extracranial_Injury	955			
(0,15]		—	—	
(15,75]		23.3	10.4, 66.3	<0.001
Marshall_CT_Classification	444			
1		—	—	
2		0.26	0.07, 1.23	0.055
3		0.20	0.02, 1.38	0.10
4		0.00		>0.9
5		0.30	0.08, 1.53	0.11
Blood_Pressure	797			
Normotension		—	—	
Hypotension		1.13	0.65, 1.92	0.7
Hypertension		0.91	0.50, 1.57	0.7
Hypoxia	880			
Absent		—	—	
Present		7.62	3.64, 15.5	<0.001
INR	715			
low INR		—	—	
high INR		5.13	2.52, 10.0	<0.001

[1] OR = Odds Ratio, CI = Confidence Interval

TABLE 7. Model 1. Multiple logistic regression analysis of the association between potential factors and neurosurgical intervention among all TBI cases (GCS 3-15), (n= 6432), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	OR[1]	95% CI[1]	p-value
Age_group			
18-29	—	—	
30-54	1.22	0.81, 1.86	0.3
55-64	1.08	0.63, 1.83	0.8
65-74	0.87	0.47, 1.58	0.7
75+	1.60	0.91, 2.82	0.10
Sex			
Female	—	—	
Male	1.13	0.82, 1.58	0.5
Race_			
Black or African American	—	—	
Other	0.77	0.38, 1.45	0.5
Unknown	0.53	0.13, 1.53	0.3
White	1.23	0.89, 1.71	0.2
Hypoxia			
Absent	—	—	
Present	1.12	0.52, 2.20	0.8
Blood_Pressure			
Normotension	—	—	
Hypotension	0.94	0.46, 1.76	0.8
Hypertension	1.02	0.73, 1.42	0.9
GCS_Category			
mild	—	—	
devastating	1.12	0.70, 1.74	0.6
severe	0.96	0.51, 1.70	0.9
moderate	1.13	0.62, 1.95	0.7
Marshall_CT_Classification			
1	—	—	
2	0.55	0.26, 1.27	0.14
3	0.52	0.21, 1.37	0.2
4	1.92	0.23, 12.1	0.5
5	0.50	0.23, 1.19	0.10
Major_Extracranial_Injury			
(0,15]	—	—	
(15,75]	13.5	8.33, 23.6	<0.001
Mechanism_of_Injury			
Fall	—	—	
Assault	0.63	0.34, 1.13	0.13
GSW	0.87	0.41, 1.73	0.7
Other	1.12	0.43, 2.54	0.8
RTC	0.78	0.53, 1.13	0.2

[1] OR = Odds Ratio, CI = Confidence Interval

C-statistic= 0.768; All VIF < 2

TABLE 8. Model 2. Multiple logistic regression analysis of the association between potential factors and neurosurgical intervention among TBI cases (GCS 3-5), (n= 955), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	OR[1]	95% CI[1]	p-value
Age_group			
18-29	—	—	
30-54	1.03	0.32, 3.52	>0.9
55-64	0.44	0.06, 2.38	0.4
65-74	1.60	0.33, 7.51	0.5
75+	1.37	0.23, 7.82	0.7
Sex			
Female	—	—	
Male	3.13	1.12, 10.4	0.041
Race.			
Black or African American	—	—	
Other	0.74	0.10, 3.61	0.7
White	1.17	0.41, 3.20	0.8
Hypoxia			
Absent	—	—	
Present	0.71	0.03, 5.27	0.8
Blood_Pressure			
Normotension	—	—	
Hypotension	1.68	0.58, 4.65	0.3
Hypertension	0.92	0.25, 2.91	0.9
GCS_Total			
3	—	—	
4	0.59	0.03, 4.02	0.6
5	0.48	0.02, 3.11	0.5
Marshall_CT_Classification			
1	—	—	
2	0.29	0.04, 2.59	0.2
3	0.48	0.03, 6.31	0.6
4	0.00		>0.9
5	0.29	0.04, 2.92	0.3
Major_Extracranial_Injury			
(0,15]	—	—	
(15,75]	19.1	5.25, 125	<0.001
Mechanism_of_Injury			
Fall	—	—	
Assault	1.52	0.27, 7.17	0.6
GSW	0.70	0.09, 3.92	0.7
RTC	1.05	0.32, 3.50	>0.9

[1] OR = Odds Ratio, CI = Confidence Interval

C-statistic= 0.827; all VIF < 2

TABLE 9. Model 3. Multiple logistic regression analysis of the association between potential risk factors and mortality among all TBI cases (GCS 3-15), (n= 6432), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	OR[1]	95% CI[1]	p-value
Age_group			
18-29	—	—	
30-54	1.37	0.88, 2.18	0.2
55-64	1.86	1.08, 3.21	0.025
65-74	1.96	1.08, 3.55	0.025
75+	1.88	1.01, 3.50	0.047
Sex			
Female	—	—	
Male	1.03	0.74, 1.45	0.9
Race_			
Black or African American	—	—	
Other	0.38	0.14, 0.84	0.029
Unknown	0.57	0.14, 1.66	0.4
White	0.74	0.52, 1.05	0.093
Hypoxia			
Absent	—	—	
Present	3.92	2.15, 6.99	<0.001
Blood_Pressure			
Normotension	—	—	
Hypotension	0.57	0.23, 1.22	0.2
Hypertension	0.90	0.63, 1.27	0.6
GCS_Motor_score			
6	—	—	
1	0.98	0.57, 1.61	>0.9
2	1.06	0.16, 3.94	>0.9
3	1.05	0.16, 4.03	>0.9
4	1.66	0.81, 3.16	0.14
5	0.98	0.49, 1.79	>0.9
U	1.55	0.60, 3.52	0.3
Marshall_CT_Classification			
1	—	—	
2	0.83	0.35, 2.28	0.7
3	0.67	0.23, 2.08	0.5
4	0.00	0.00, 0.00	>0.9
5	0.77	0.32, 2.17	0.6
Major_Extracranial_Injury			
(0,15]	—	—	
(15,75]	34.1	16.5, 87.1	<0.001
Mechanism_of_Injury			
Fall	—	—	
Assault	0.70	0.37, 1.27	0.3
GSW	0.69	0.28, 1.52	0.4
Other	0.64	0.15, 1.90	0.5
RTC	1.15	0.78, 1.70	0.5

[1] OR = Odds Ratio, CI = Confidence Interval

C-statistic= 0.812; All VIF < 2

TABLE 10. Model 4. Multiple logistic regression analysis of the association between potential risk factors and mortality among TBI cases (GCS 3-5), (n= 955), Trauma Registry at Grady Memorial Hospital, 2016-2021

Characteristic	OR[1]	95% CI[1]	p-value
Age_group			
18-29	—	—	
30-54	3.84	0.92, 26.3	0.10
55-64	3.60	0.50, 31.1	0.2
65-74	9.78	1.53, 84.9	0.020
75+	10.0	1.39, 95.2	0.026
Sex			
Female	—	—	
Male	0.97	0.37, 2.66	>0.9
Race_			
Black or African American	—	—	
Other	0.40	0.02, 2.62	0.4
Unknown	3.45	0.16, 28.8	0.3
White	0.82	0.26, 2.37	0.7
Hypoxia			
Absent	—	—	
Present	3.40	0.43, 18.7	0.2
Blood_Pressure			
Normotension	—	—	
Hypotension	0.93	0.24, 2.96	>0.9
Hypertension	0.85	0.24, 2.55	0.8
GCS_Motor_score			
3	—	—	
1	0.66	0.06, 21.0	0.8
2	1.33	0.08, 53.1	0.9
Marshall_CT_Classification			
1	—	—	
2	0.10	0.01, 0.99	0.032
3	0.08	0.00, 1.40	0.092
4	0.00		>0.9
5	0.14	0.02, 1.54	0.082
Mechanism_of_Injury			
Fall	—	—	
Assault	1.71	0.22, 9.14	0.6
GSW	1.55	0.07, 11.9	0.7
Other	0.00		>0.9
RTC	3.53	1.07, 12.9	0.044

[1] OR = Odds Ratio, CI = Confidence Interval

C-statistic= 0.740; All VIF ≤ 2

APPENDIX 1

Model 1 and Model 2
Assessing neurosurgical intervention among all TBI patients (GCS 3-15) and devastating TBI patients (GCS 3-5)

logit (neurosurgical intervention) = $\beta 0 + \beta 1$(age category) + $\beta 2$(sex) + $\beta 3$ (race) + $\beta 4$(mechanism of injury) + $\beta 5$(oxygen saturation) + $\beta 6$(blood pressure) + $\beta 7$(Marshall CT Classification) + $\beta 8$(Injury Severity Score category) + $\beta 9$(Glasgow Coma Scale category)

Model 3
Assessing in-hospital mortality (as measured by discharge status (alive vs. dead) among all TBI patients (GCS 3-15)

logit (discharge status) = $\beta 0 + \beta 1$(age category) + $\beta 2$(sex) + $\beta 3$ (race)+ $\beta 4$ (mechanism of injury) + $\beta 5$ (oxygen saturation) + $\beta 6$(blood pressure) + $\beta 7$ (Marshall CT Classification) + $\beta 8$(Injury Severity Score category) + $\beta 9$(Glasgow Coma Scale category)

Model 4
Assessing in-hospital mortality among devastating TBI patients (GCS 3-5)

logit (in-hospital mortality) = $\beta 0 + \beta 1$(age category) + $\beta 2$(sex) + $\beta 3$(race) + $\beta 4$(mechanism of injury) + $\beta 5$(oxygen saturation) + $\beta 6$(blood pressure) + $\beta 7$(Marshall CT Classification) + $\beta 8$(Glasgow Coma Scale category)