

## Rate and Outcomes of TBI among Patients with ATV-Related Injuries: A Hospital-Based Non-Concurrent Cohort Study

Kyara Berríos-Toledo, MS\*†; Ediel O. Ramos-Meléndez, MPH, DrPH\*†;

Lourdes Guerrios-Rivera, MD, MSc\*†; Pablo Rodríguez-Ortiz, MD, FACS, FCCM, FACP, FCCP\*†

**Objective:** The growing use of all-terrain vehicles (ATVs) has resulted in a rise in traumatic injuries, particularly traumatic brain injury (TBI) cases. This study estimated the TBI rate and its association with hospital outcomes among ATV-related admissions at the Puerto Rico Trauma Hospital (PRTH).

**Methods:** This IRB-approved non-concurrent cohort study of ATV-related admissions at the PRTH from 2000 to 2022 categorized patients based on admission Glasgow Coma Scale (GCS) scores into TBI (GCS 3-12) and non-TBI (GCS 13-15) groups. We evaluated sociodemographic characteristics, injury profiles, and hospital outcomes using Pearson's chi-square test, Wilcoxon rank-sum test, and regression models.

**Results:** Among 581 patients with ATV-related admissions, 80% were men in their mid-twenties. The TBI rate was 33.7%. Although ATV-related hospitalizations declined significantly over time, the TBI rate showed a weak, non-significant upward trend. ATV-related patients with TBI faced significantly higher risk of in-hospital mortality (ARR: 11.71; 95%-CI: 4.41-31.08), post-discharge care facility admissions (AOR: 4.01; 95%-CI: 1.42-11.37), and longer hospitalizations (AIRR: 1.57; 95%-CI: 1.28-1.94). Additionally, adjusted predicted mean hospital costs were significantly higher for TBI patients than non-TBI patients (\$65,925 vs. \$26,793;  $p=0.009$ ).

**Conclusion:** ATV-related admissions frequently involve TBIs, characterized by more severe injuries, significant in-hospital mortality risk, longer hospitalization, elevated hospital costs, and required post-discharge care. These findings highlight the need for targeted clinical care and preventive strategies to mitigate the frequency and severity of TBIs in ATV-related trauma.

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**T**raumatic brain injury (TBI) is a growing global public health concern and one of the leading causes of trauma-related deaths (1,2). In the United States (US), TBI-related emergency department (ED) visits resulted in 214,110 hospitalizations in 2020, with 69,473 fatalities in 2021 (2). Motor vehicle collisions (MVCs) are among the top three causes of TBI fatalities (1), accounting for 17% of all deaths (3). All-terrain vehicle (ATV) collisions, meanwhile, result in a high rate of head injuries (~30%), multiple fractures, and other trauma across all age groups (4,5). ATV-related injuries, regardless of TBI status, have a higher in-hospital mortality rate, ranging from 2% to 20%, than those traumas involving MVCs, motorcycle collisions, and non-traffic accidents (5,6). These injuries also result in extended hospitalizations (up to 9 days), increased admission to intensive care, and high injury severity scores (ISSs) (4-9). Despite this, to the best of our knowledge, few studies have evaluated fatalities and hospital courses among ATV-related injured patients with TBI (10,11).

In the US, legislation governing ATVs falls under state sovereignty, creating inconsistent ATV regulations across states (7). Regulations regarding ATV use include mandatory training courses, liability insurance requirements, speed limits (<35 mph), mandatory helmet use, and eye protection (12,13). Unfortunately, around 15 states lack minimum age requirements, safety training, or helmet mandates (7). Puerto Rico, a US territory, has poorly regulated ATV use, prohibiting drivers on public roads and riders

under 16 years old (14), along with a requirement for some safety gear. These disparate regulations underscore the need for consistent laws governing ATV riders across the US and its territories (15).

Despite extensive research on ATV-related mortality, comprehensive data on admission trends, patient characteristics, and hospital outcomes in ATV patients with TBI remain limited. Therefore, our objective was to determine the proportion of TBI among ATV-related admissions at Puerto Rico Trauma Hospital (PRTH), examine their yearly trends, and their association with hospital outcomes. We hypothesized that patients with ATV-related TBI would have more severe injuries, extended hospitalization, and higher mortality rates. These findings inform clinical management and support injury-prevention interventions tailored to ATV users, ultimately enhancing safety and outcomes for this population.

\*Department of Surgery, School of Medicine, University of Puerto Rico, Medical Sciences Campus, San Juan, Puerto Rico; †Puerto Rico Trauma Hospital, San Juan, Puerto Rico

*The authors have no conflict of interest to disclose.*

Address correspondence to: Kyara Berríos-Toledo, MS, Department of Surgery, School of Medicine, University of Puerto Rico, Medical Sciences Campus, PO Box 365067, San Juan, Puerto Rico 00967-5067. Email: kyara.berrios@upr.edu

## Methods

We conducted a non-concurrent cohort study using data from the PRTH, a state-designated Level I trauma center, from April 2000 to October 2022. PRTH is the only major referral trauma hospital covering Puerto Rico and the rest of the Caribbean, mainly treating patients with moderate-to-severe trauma. Patient data were obtained from the Puerto Rico Trauma Registry, a hospital-based registry that contributes data to the US National Trauma Data Bank. The registry personnel gathered data from the medical records and conducted quality assessments using the standardized protocol established by the American College of Surgeons (16).

### Patient population

We evaluated hospitalizations meeting the following inclusion criteria: a) being admitted due to ATV crashes and b) having a known Glasgow Coma Scale (GCS) score. Patients lacking information on admission and discharge dates, in-hospital mortality, or GCS were excluded. Our study categorized patients into two groups based on the first recorded GCS score at hospital admission (1): a TBI group (GCS 3–12) and a non-TBI group (GCS 13–15). Despite variability in prehospital and ED GCS scores, admission GCS remains a widely accepted measure for assessing TBI severity in trauma research (17,18).

### Variables

This study obtained data from three domains: sociodemographic characteristics, clinical profiles, and hospital course and outcomes. Sociodemographic parameters included sex, age, and health insurance status. The clinical profiles included alcohol consumption, blood alcohol concentration, ISS, and helmet use at the time of the collision. The ISS was analyzed as a discrete numerical variable and dichotomized at  $>15$ , the internationally accepted threshold for identifying major trauma (19–21). We also assessed the injured body regions and recorded vital signs upon admission [i.e., systolic blood pressure (SBP) and heart rate]. The hospital course and outcome domains included trauma intensive care unit (TICU) admission, need for assisted ventilation, days on mechanical ventilation (MV), hospital and TICU length of stay (LOS), in-hospital mortality, hospital costs, and discharge disposition. Discharge disposition was dichotomized into facility-based care and community-based disposition. Patients who died while in hospital were excluded from this variable.

### Statistical analysis

This study presented descriptive information using means, standard deviations (SDs), medians, interquartile ranges (IQRs), frequencies, and percentages, as appropriate. Comparisons between the groups (TBI and non-TBI) were performed using the Wilcoxon rank-sum test for continuous data and Pearson's chi-square or Fisher's exact tests for categorical variables. Bivariate analyses were also stratified by age category to determine if associations remain consistent across pediatric ( $< 21$  years) and adult ( $\geq 21$  years) populations. The long-term trends in the number and rate of ATV-related admissions, as well as the TBI rate among these patients, were visualized using locally weighted scatterplot smoothing (LOWESS) regression curves and statistically tested using Spearman's rank correlation.

We evaluated the magnitude of the association between TBI and study outcomes via univariable and multivariable regression analyses. Specifically, a binomial logistic regression was used for discharge disposition, while hospital costs were estimated using a generalized linear model with a gamma distribution and log-link function. Because in-hospital mortality was common in the TBI group, we used a Poisson regression with robust variance estimators to obtain accurate relative risk estimates. Finally, a zero-truncated negative binomial regression was employed to analyze hospital LOS. All models were adjusted for age, sex, and ISS. These covariates were selected *a priori* based on theoretical relevance established by the literature (22). No comparative analyses were performed between subjects with complete and incomplete records, as the proportion of missing data in key clinical variables was negligible (age:  $n=1$ , 0.17%; ISS:  $n=2$ , 0.34%). In these cases, listwise deletion was employed for the respective multivariable models, as minimal data loss was unlikely to introduce selection bias.

To validate our TBI classification, we conducted a formal agreement analysis between the primary definition ( $GCS \leq 12$ ) and a stricter sensitivity definition ( $GCS \leq 12$  & head AIS  $\geq 2$ ), which incorporates anatomical criteria, using Cohen's Kappa statistic. Additionally, sensitivity analyses were performed by refitting the four adjusted regression models using the stricter definition to ensure the consistency of the primary results. The threshold for statistical significance was  $p < 0.05$  for all analyses. The researcher used Stata 14 (StataCorp, College Station, Texas, USA) for the statistical analyses. The Institutional Review Board of the Medical Sciences Campus at the University of Puerto Rico approved this study (Protocol: 2502348276).

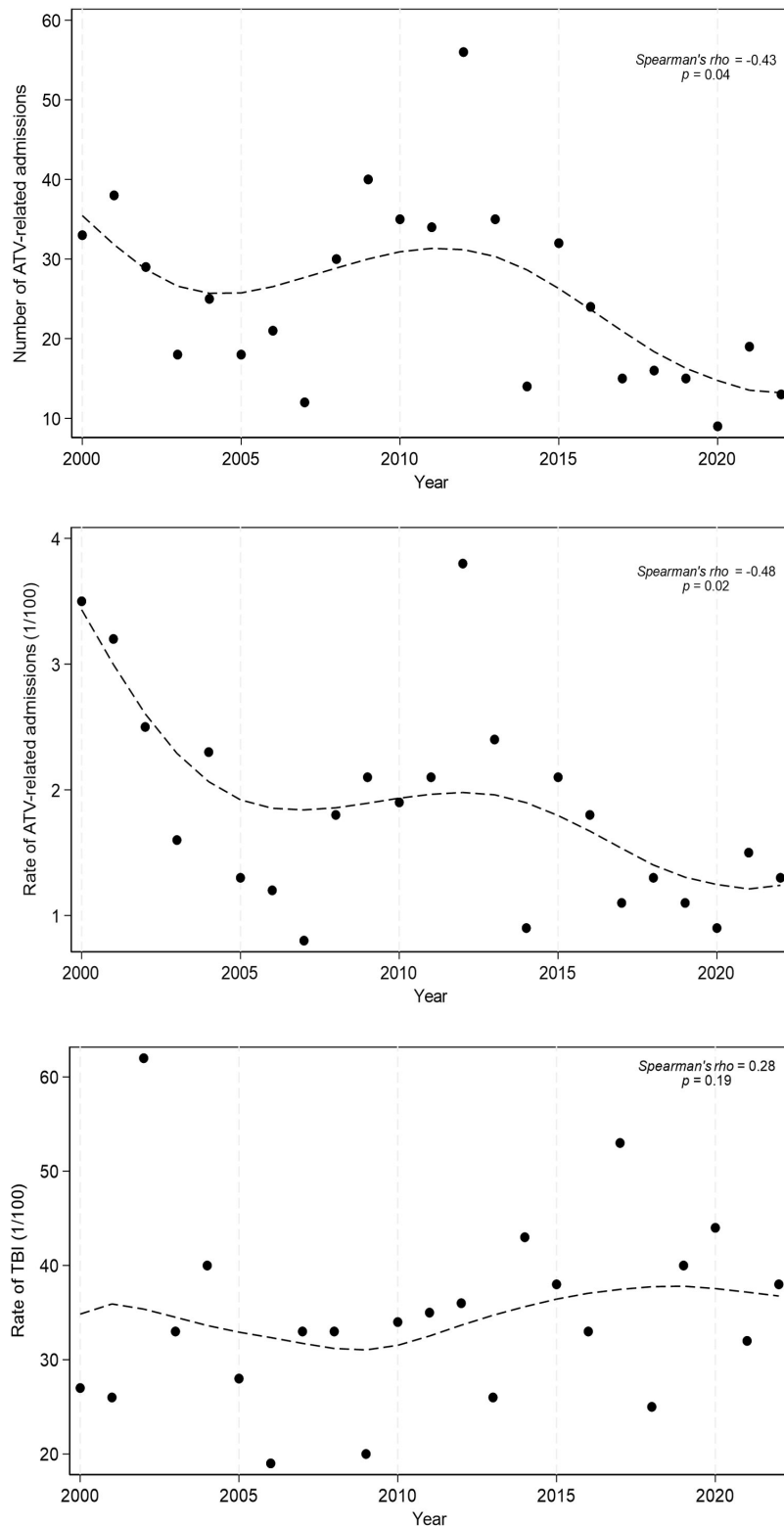
## Results

Among the 581 ATV-related admissions, 33.7% had TBI. The trend analysis found a moderate, significant negative correlation between calendar year and the number of ATV-related hospital admissions (Spearman's rho:  $-0.43$ ;  $p=0.04$ ) and their rate (Spearman's rho:  $-0.48$ ;  $p=0.02$ ), indicating a declining trend over time. Conversely, the TBI rate showed a weak, non-significant positive correlation (Spearman's rho:  $0.28$ ;  $p=0.19$ ) (Figure 1).

Overall, sociodemographic profiles were comparable between TBI and non-TBI patients, as both groups were predominantly male (81.6% vs. 79.2%;  $p=0.49$ ), in their mid-twenties (median age 25 vs. 26;  $p=0.92$ ), and had similar insurance profiles (public insurance: 50.5% vs. 41.5%;  $p=0.08$ ). Helmet use and alcohol consumption had high rates of missing values (71.1% and 79.3%, respectively). Among the available data, helmet use was marginally lower in TBI patients (6.5% vs. 16%;  $p=0.07$ ), whereas alcohol consumption did not differ significantly (88.9% vs. 93.9%;  $p=0.34$ ) (Table 1). However, TBI patients had a higher SBP (133 mmHg vs. 124 mmHg;  $p<0.001$ ) and pulse rate (106 bpm vs. 94 bpm;  $p<0.0001$ ) than non-TBI patients. Also, TBI patients showed a lower proportion of severe abdominal (3.6% vs. 14.3%;  $p<0.001$ ) and extremity injuries (12.8% vs. 24.9%;  $p<0.01$ ). This group had a notably higher proportion of patients with an ISS  $>15$  than non-TBI patients (78.1% vs. 37.6%;  $p<0.001$ ) (Table 1).

Regarding the hospital course, TBI patients more often required TICU admission (46.9% vs. 7.5%;  $p<0.001$ ), and their LOS in it

**Figure 1.** A) Number of ATV-related admissions, B) Rate of ATV-related admissions, C) Rate of TBI among ATV-related injuries. Yearly trends in the number of ATV-related admissions, the rate of ATV-related admissions, and the rate of TBI at the Puerto Rico Trauma Hospital from 2000 to 2022. Circles represent observed annual data. The trend is represented by Locally Weighted Scatterplot Smoothing (LOWESS) regression curves.



was twice as long as that of non-TBI patients (16 vs. 8 days;  $p < 0.01$ ). They also needed MV 10 times more often (67.4% vs. 6.8%,  $p < 0.001$ ) but had a median duration of MV similar to that of their counterparts (9 vs. 10 days;  $p = 0.74$ ). Compared with controls, TBI patients had a longer median LOS, with around six-day difference (13.5 vs. 8 days;  $p < 0.0001$ ). Furthermore, they had an in-hospital mortality rate of 21.9% (vs. 1.3%;  $p < 0.001$ ), and 8.2% were discharged to a care facility (vs. 2.1%;  $p < 0.01$ ) (Table 1). Stratified analyses by age group (<21 and  $\geq 21$  years) yielded consistent results with the overall bivariable findings (Supplementary Table 1).

Sensitivity and primary TBI definitions showed near-perfect agreement (Cohen's  $\kappa$ : 0.992; 95% CI: 0.982-1.000;  $p < 0.001$ ), supporting the robustness of our classification (Supplementary Table 2). In unadjusted analyses, TBI patients had a 75% longer hospital LOS compared to non-TBI patients (IRR: 1.75; 95% CI: 1.44-2.12), and this association remained significant but reduced to 57% after adjusting for sex, age, and ISS (AIRR: 1.57; 95% CI: 1.28-1.94) (Table 2). Regarding in-hospital mortality, patients with TBI had a significantly greater risk of death than non-TBI patients, with an unadjusted risk ratio of 16.89 (95% CI: 6.79-42.00). This association remained strong after adjustment, with TBI patients showing an approximately 12-fold higher risk (ARR: 11.71; 95% CI: 4.41-31.08) (Table 3).

Moreover, TBI patients were over four times more likely to be discharged to a care facility than non-TBI patients (OR: 4.13; 95% CI: 1.65-10.33), an association that remained after controlling for covariates (AOR: 4.01; 95% CI: 1.42-11.37) (Table 4). Regarding hospital costs, TBI patients had significantly higher adjusted predicted mean costs (\$65,925; 95% CI: \$37,853-\$93,997) compared to non-TBI patients (\$26,793; 95% CI: \$18,369-\$35,217), representing a significant mean difference of \$39,132 (95% CI: \$9,771-\$68,493;  $p = 0.009$ ) (Table 5). Sensitivity analyses using a more stringent TBI definition (GCS  $\leq 12$  and Head AIS  $\geq 2$ ) yielded estimates consistent with the primary analyses across all outcomes (Supplementary Table 3).

## Discussion

TBI is common among ATV-related injuries, yet hospital admission patterns and outcomes in trauma settings remain understudied. Therefore, this study examined the TBI rate, yearly trends,

**Table 1.** Sociodemographic and clinical profile of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes according to traumatic brain injury status.

| Characteristic                          | Total (N=581)<br>n (%) | TBI (n=196)<br>n (%) | Non-TBI (n=385)<br>n (%) | p-value |
|-----------------------------------------|------------------------|----------------------|--------------------------|---------|
| <b>Sociodemographic data</b>            |                        |                      |                          |         |
| Sex                                     |                        |                      |                          |         |
| Male                                    | 465 (80.0)             | 160 (81.6)           | 305 (79.2)               | 0.49    |
| Age, years                              | (n=580)                |                      | (n=384)                  |         |
| Mean $\pm$ SD                           | 28.2 $\pm$ 12.5        | 27.9 $\pm$ 11.4      | 28.4 $\pm$ 13.1          | -       |
| Median (IQR)                            | 26 (12)                | 25 (10.5)            | 26 (13)                  | 0.92    |
| Health insurance status                 | (n=552)                | (n=186)              | (n=366)                  | 0.08    |
| Private                                 | 228 (41.3)             | 72 (38.7)            | 156 (42.6)               |         |
| Public                                  | 246 (44.6)             | 94 (50.5)            | 152 (41.5)               |         |
| Uninsured                               | 78 (14.1)              | 20 (10.8)            | 58 (15.9)                |         |
| Helmet use                              | (n=168)                | (n=62)               | (n=106)                  | 0.07    |
| Yes                                     | 21 (12.5)              | 4 (6.5)              | 17 (16.0)                |         |
| Alcohol use                             | (n=120)                | (n=54)               | (n=66)                   | 0.34†   |
| Yes                                     | 110 (91.7)             | 48 (88.9)            | 62 (93.9)                |         |
| Blood alcohol concentration             | (n=110)                | (n=48)               | (n=62)                   |         |
| Median (IQR)                            | 10 (24)                | 13 (53)              | 10 (3)                   | <0.001  |
| $\geq$ 80 mg/dL                         | 16 (14.6)              | 10 (20.8)            | 6 (9.7)                  | 0.10    |
| Systolic blood pressure                 | (n=578)                | (n=195)              | (n=383)                  |         |
| Median (IQR)                            | 127 (28)               | 133 (29)             | 124 (26)                 | <0.001  |
| < 90 mmHg                               | 24 (4.2)               | 10 (5.1)             | 14 (3.7)                 | 0.40    |
| Pulse                                   | (n=577)                | (n=195)              | (n=382)                  |         |
| Median (IQR)                            | 97 (31)                | 106 (43)             | 94 (26)                  | <0.0001 |
| > 120 bpm                               | 93 (16.1)              | 60 (30.8)            | 33 (8.6)                 | <0.001  |
| Body region injured                     |                        |                      |                          |         |
| Major head & neck                       | 235 (40.5)             | 156 (79.6)           | 79 (20.5)                | <0.001  |
| Major chest                             | 228 (39.2)             | 86 (43.9)            | 142 (36.9)               | 0.10    |
| Major abdomen                           | 62 (10.7)              | 7 (3.6)              | 55 (14.3)                | <0.001  |
| Major extremity                         | 121 (20.8)             | 25 (12.8)            | 96 (24.9)                | <0.01   |
| Injury severity score                   | (n=579)                |                      | (n=383)                  |         |
| Mean $\pm$ SD                           | 16.4 $\pm$ 9.7         | 22.1 $\pm$ 9.6       | 13.5 $\pm$ 8.3           | -       |
| Median (IQR)                            | 16 (13)                | 22 (11)              | 12 (9)                   | <0.0001 |
| > 15                                    | 297 (51.3)             | 153 (78.1)           | 144 (37.6)               | <0.001  |
| <b>Hospital course and outcome data</b> |                        |                      |                          |         |
| Admission to TICU                       |                        |                      |                          |         |
| Yes                                     | 121 (20.8)             | 92 (46.9)            | 29 (7.5)                 | <0.001  |
| TICU LOS, days                          | (n=121)                | (n=92)               | (n=29)                   | <0.01   |
| Median (IQR)                            | 13 (18)                | 16 (18.5)            | 8 (9)                    |         |
| MV required                             |                        |                      |                          | <0.001  |
| Yes                                     | 158 (27.2)             | 132 (67.4)           | 26 (6.8)                 |         |
| MV, days                                | (n=158)                | (n=132)              | (n=26)                   | 0.74    |
| Median (IQR)                            | 10 (15)                | 9 (15.5)             | 10 (16)                  |         |
| Hospital LOS, days                      |                        |                      |                          | <0.0001 |
| Median (IQR)                            | 9 (16)                 | 13.5 (28.5)          | 8 (10)                   |         |
| In-hospital mortality                   |                        |                      |                          | <0.001  |
| Dead                                    | 48 (8.3)               | 43 (21.9)            | 5 (1.3)                  |         |
| Hospital costs, USD                     | (n=512)                | (n=173)              | (n=339)                  |         |
| Mean $\pm$ SD                           | 38,821 $\pm$ 109,677   | 62,931 $\pm$ 97,094  | 26,517 $\pm$ 113,750     | -       |
| Median (IQR)                            | 14,899 (32,119)        | 32,861 (76,184)      | 11,651 (21,233)          | <0.0001 |
| Discharge disposition                   | (n=527)                | (n=147)              | (n=380)                  | <0.01   |
| Care facility                           | 20 (3.8)               | 12 (8.2)             | 8 (2.1)                  |         |
| Community                               | 507 (96.2)             | 135 (91.8)           | 372 (97.9)               |         |

TBI: traumatic brain injury; SD: standard deviation; IQR: interquartile range; TICU: trauma intensive care unit; LOS: length of stay; MV: mechanical ventilation; USD: United States Dollar; †: Fisher's exact test.

and associated hospital outcomes among ATV-related admissions. In our cohort, TBI occurred in about one-third of cases, and while ATV-related hospitalizations declined over time, the TBI rate showed a weak, non-significant upward trend. As expected, TBI patients had higher mortality, longer hospitalizations, greater post-acute care needs, and increased hospital costs.

Our findings align with studies reporting that one-third of ATV-injured patients sustain TBI (5,7,11,23). Although previous studies reported increased TBI-related ED visits (24,25), our analysis found a non-significant rise in ATV-related TBI rate over time. This may reflect our narrower scope, excluding TBIs from MVCs, falls, or other recreational activities (1,8,24-26). Our results support reports of declining ATV-related hospitalizations (13,27), although others found higher ED admission rates between 2000 and 2015 (9,10,28). These discrepancies may arise from our inclusion of moderate-to-severe cases, unlike previous research that included non-severe patients (10,28). A California study reported a significant rise in ATV-related hospitalizations after initial enforcement of restrictive legislation (9). Although our study period spans Puerto Rico's 2007 ATV regulation, which defined ATVs and restricted road use (14,29), we did not evaluate legislative effects. This context is provided for background only, as unmeasured factors, such as enforcement variability, access to safe riding areas, and ATV cost, may also influence these trends.

We corroborated that TBI patients were predominantly male (1), in their mid-20s, and commonly covered by public health insurance (5,9,23). Unlike studies from the US and the United Kingdom identifying more common lower-extremity injuries in TBI patients (10,27,30), we found chest injuries were the most frequent, consistent with a study on MVCs, including ATV crashes (22). Regarding injury severity, our cohort had a median ISS of 16 for ATV-related admissions, regardless of TBI diagnosis, and 22 among TBI patients, both values exceeding those previously reported in studies of MVCs and ATV-related injuries (5-8,11,23). This higher ISS likely reflects our institution's case mix, which predominantly receives moderate-to-severe injuries. Additionally, earlier investigations included factors such as helmet use and

ATV size when comparing ISS between groups (5-8,11,23), variables that were excluded from our analysis due to high missingness (71.1% for helmet use).

Among ATV collisions, we observed a 22% mortality rate in TBI patients, consistent with a prior PRTH study (20%) (5), though that study did not distinguish TBI from non-TBI. Nevertheless, this rate surpasses those reported in California (2.2%) (11) and Qatar (2%) (6) for trauma patients with ATV-related injuries, regardless of TBI status. We also found a 12-fold higher risk of mortality in TBI patients, aligning with studies showing over a 10-fold increased risk of death in pediatric motorcycle riders with TBI (4). The greater need for intensive care among TBI patients likely reflects their higher injury severity, which is associated with an increased mortality rate (6,11). Eight percent of TBI patients were sent to a care facility, representing 4-fold higher odds of transfer than non-TBI patients. This is similar to the 8.9% transfer rate in California ATV crashes, regardless of TBI (9), but double that of other US reports (4,31). Unlike prior studies restricted to pediatric subgroups, such as pediatric motorcycle riders (4) or ATV crash victims (31), using bivariate analyses, our adjusted models included trauma patients across all ages.

Our findings showed that TBI patients had a 57% longer hospital LOS, consistent with studies linking prolonged stays to factors such as lack of helmet use (11), older-aged patients involved in ATV crashes (30), and non-traffic-related TBIs (4). Aligning with previous reports of elevated ATV-related hospitalization costs in both children (4,7,32) and adults (33), TBI patients in our cohort also incurred significantly higher costs, even after adjustment. These increased resource demands likely reflect the greater clinical complexity of TBI cases. Notably, our reported costs (adjusted mean: \$65,925) were similar to those of mainland US studies (up to \$67,370) (32,33), although direct cost comparisons should be interpreted cautiously, given the distinct healthcare financing and delivery structures in Puerto Rico relative to the US mainland (34).

This study might inform healthcare professionals about the effects of ATV-related TBI on patients' hospital stays and outcomes. We acknowledge the complexity of TBI definitions across studies, with some using diverse diagnostic codes (4), a single indicator (1,18), or multiple indicators (15,35) to define TBI. We used a single indicator, the

**Table 2.** Association between traumatic brain injury and hospital length of stay of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes.

| Predictor   | Unadjusted IRR (95% CI) | p-value | Adjusted IRR (95% CI) | p-value |
|-------------|-------------------------|---------|-----------------------|---------|
|             | (n=581)                 |         | (n=578)               |         |
| TBI status  |                         | <0.001  |                       | <0.001  |
| No          | Reference               |         | Reference             |         |
| Yes         | 1.75 (1.44 – 2.12)      |         | 1.57 (1.28 – 1.94)    |         |
| Sex         | –                       |         |                       | 0.40    |
| Male        |                         |         | Reference             |         |
| Female      |                         |         | 1.01 (0.88 – 1.37)    |         |
| Age (years) | –                       |         | 1.01 (1.01 – 1.02)    | <0.001  |
| ISS         | –                       |         | 1.01 (1.00 – 1.02)    | 0.03    |

IRR: incidence rate ratio; CI: confidence interval; TBI: traumatic brain injury; ISS: injury severity score.

**Table 3.** Association between traumatic brain injury and in-hospital mortality of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes.

| Predictor   | Unadjusted RR (95% CI) | p-value | Adjusted RR (95% CI) | p-value |
|-------------|------------------------|---------|----------------------|---------|
|             | (n=581)                |         | (n=578)              |         |
| TBI status  |                        | <0.001  |                      | <0.001  |
| No          | Reference              |         | Reference            |         |
| Yes         | 16.89 (6.79 – 42.00)   |         | 11.71 (4.41 – 31.08) |         |
| Sex         | –                      |         |                      | 0.76    |
| Male        |                        |         | Reference            |         |
| Female      |                        |         | 0.90 (0.45 – 1.78)   |         |
| Age (years) | –                      |         | 1.02 (0.99 – 1.04)   | 0.16    |
| ISS         | –                      |         | 1.04 (1.02 – 1.06)   | <0.001  |

RR: risk ratio; CI: confidence interval; TBI: traumatic brain injury; ISS: injury severity score.

**Table 4.** Association between traumatic brain injury and discharge disposition (care facility vs. community) of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes.

| Predictor   | Unadjusted OR (95% CI) | p-value | Adjusted OR (95% CI) | p-value |
|-------------|------------------------|---------|----------------------|---------|
|             | (n=527)                |         | (n=524)              |         |
| TBI status  |                        | 0.002   |                      | 0.009   |
| No          | Reference              |         | Reference            |         |
| Yes         | 4.13 (1.65 – 10.33)    |         | 4.01 (1.42 – 11.37)  |         |
| Sex         |                        |         |                      | 0.02    |
| Male        |                        |         | Reference            |         |
| Female      |                        |         | 3.35 (1.27 – 8.82)   |         |
| Age (years) | –                      |         | 1.05 (1.02 – 1.08)   | 0.001   |
| ISS         | –                      |         | 1.02 (0.97 – 1.07)   | 0.43    |

OR: odds ratio; CI: confidence interval; TBI: traumatic brain injury; ISS: injury severity score. Care facility disposition includes patients requiring institutionalized clinical support: Acute Care Facilities, Skilled Nursing Facilities, Inpatient Rehabilitation Facilities, and Long-term Care/Nursing Homes. Community disposition (reference category) includes patients returning to the community: Home/Self-care (with or without home health services), Psychiatric/Mental Health units, and those leaving against medical advice. Patients who died while in hospital were excluded from this analysis.

**Table 5.** Association between traumatic brain injury and hospital costs of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes.

| Predictor               | Coefficient (95% CI) | p-value | Predicted Mean Cost (USD) (95% CI) * |
|-------------------------|----------------------|---------|--------------------------------------|
| (n=509)                 |                      |         |                                      |
| TBI status              |                      |         |                                      |
| No                      | Reference            | 0.001   | \$26,793 (\$18,369 – \$35,217)       |
| Yes                     | 0.90 (0.37 – 1.43)   |         | \$65,925 (\$37,853 – \$93,997)       |
| Sex                     |                      |         |                                      |
| Male                    | Reference            | 0.007   | \$32,487 (\$23,690 – \$41,285)       |
| Female                  | 0.80 (0.22 – 1.38)   |         | \$72,565 (\$32,634 – \$112,496)      |
| Age (years)             |                      |         |                                      |
| At Mean Age (28 years)  | 0.02 (-0.002 – 0.04) | 0.08    | \$39,592 (\$28,542 – \$50,642)       |
| ISS                     |                      |         |                                      |
| At Mean ISS (16 points) | 0.01 (-0.01 – 0.04)  | 0.38    | \$39,172 (\$28,592 – \$49,752)       |

CI: confidence interval; USD: United States Dollar; TBI: traumatic brain injury; ISS: injury severity score. \*Adjusted predicted means represent the marginal effects of each variable while holding all other covariates (sex, age, and ISS) at their mean values.

admission GCS, to determine the comparison groups. Beyond clinical outcomes, our results show a higher likelihood of transfer to a care facility, reflecting the severity of TBI-related functional impairment and the ongoing care needs of these patients, rather than acute care quality. Although annual ATV-related TBI cases are relatively low, our findings suggest that their severity and resource demands place a significant burden on healthcare systems. Even though studies have linked helmet non-use to higher TBI rates (10,11) and intoxication to increased mortality and critical care needs (23), we could not evaluate these associations because this information was largely unavailable.

Despite declining ATV hospitalizations, the persistence of severe TBI cases underscores the need for stricter and standardized legislation. Puerto Rico's 2025 legislative amendments reinforced prohibitions on roadway use and dangerous maneuvers (14,36), yet stopped short of mandating protective gear or designating formal off-road riding areas, leaving important regulatory gaps. In the US, inconsistencies regarding age restrictions, road usage, protective gear, and training courses, coupled with poor enforcement, have been linked to increased injuries and poorer outcomes (7,15). For instance, the predominance of young adult males sustaining severe injuries in our cohort underscores the need for mandatory helmet legislation, minimum age requirements, standardized safety training, and liability insurance requirements, which should be prioritized (12,13,15). These are particularly relevant in jurisdictions like Puerto Rico, where regulations remain incomplete and should be accompanied by community and cultural education efforts to promote sustained behavior change.

Our investigation has several limitations that should be acknowledged. First, our retrospective design and reliance on registry data may introduce information and measurement biases, potentially affecting the results. Second, helmet use and alcohol consumption had substantial missingness, limiting the reliability of interpretation. Third, although we extended the study period to 23 years to improve internal validity, this timeframe could introduce

variability due to changes in clinical care and documentation practices. Fourth, due to small subgroup sizes, we could not analyze outcomes by TBI severity (moderate vs. severe). Fifth, our trend analyses focus only on patients who arrived at the trauma center; therefore, prehospital case-fatality and individuals who were not admitted to PRTH are not captured. Lastly, generalizability may be limited by the characteristics of our institution, which primarily treats moderate-to-severe injuries (high ISS), whereas those with mild injuries (low ISS) may receive treatment at another facility. Notwithstanding these limitations, our study's strengths include multivariable analyses assessing the independent association between TBI and hospital outcomes, as well as the examination of trends in ATV-related admissions in a Caribbean population with distinct regulatory and healthcare contexts.

Over the past 23 years, ATV-related hospitalizations have decreased, whereas the rate of TBI among ATV users has remained unchanged. Our findings confirm that, compared to non-TBI patients, those with TBI experience higher in-hospital mortality, longer hospital stays, greater hospital costs, and more frequent discharge to care facilities. These results reinforce the need for targeted prevention and improved clinical management of ATV-related TBI, particularly in Caribbean populations. Further research should examine neurological care, polytrauma effects, financial burdens, and severity-stratified outcomes of ATV-related TBIs, including rehabilitation and long-term care.

## Declarations

### Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the University of Puerto Rico, Medical Sciences Campus (protocol #2502348276). All procedures were conducted in accordance with the ethical standards of the institutional or national research committee. Informed consent was not necessary as the study posed no more than minimal risk to participants and involved no procedures beyond those typically performed under standard hospital protocols.

## Resumen

**Objetivo:** El uso creciente de vehículos todoterreno (ATV) ha incrementado las lesiones traumáticas, en particular las lesiones cerebrales traumáticas (TBI). Este estudio examinó la tasa de TBI y su asociación con desenlaces hospitalarios en pacientes admitidos tras colisiones con ATV en el Hospital de Trauma de Puerto Rico (PRTH). **Métodos:** Estudio de cohorte no concurrente, aprobado por el IRB, de admisiones por ATV en el PRTH (2000-2022). Los pacientes se clasificaron según la Escala de Coma de Glasgow (GCS) de ingreso en grupos TBI (GCS 3-12) y No-TBI (GCS 13-15). Se evaluaron características sociodemográficas, perfiles de lesión y desenlaces hospitalarios mediante pruebas de

chi-cuadrado, Wilcoxon y modelos de regresión. Resultados: De 581 pacientes, el 80% eran hombres, con una mediana de 25 años. La tasa de TBI fue del 33.7%. Aunque las admisiones por ATV disminuyeron significativamente, la proporción de TBI mostró una tendencia débil y no significativa. Los pacientes con TBI admitidos por ATV presentaron mayor riesgo de mortalidad intrahospitalaria (ARR: 11.71; CI-95%: 4.41-31.08), estancias prolongadas (AIRR: 1.57; CI-95%: 1.28-1.94) y más admisiones en centros de cuidado posalta (AOR: 4.01; CI-95%: 1.42-11.37). Además, los costos hospitalarios fueron significativamente mayores en los pacientes con TBI (\$65,925 vs. \$26,793;  $p=0.009$ ). Conclusión: Las admisiones por ATV se asocian con TBI y lesiones severas, mayor riesgo de mortalidad, estancias hospitalarias prolongadas, costos elevados y mayor necesidad de cuidados posalta. Estos hallazgos resaltan la necesidad de estrategias preventivas y de manejo clínico dirigido para mitigar la gravedad del TBI en lesiones por ATV.

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## References

- Brau RH, Acevedo-Salas Y, Giovannetti K. Epidemiological trends of traumatic brain and spinal cord injury in Puerto Rico from November 10th, 2006, through May 24th, 2011. *Puerto Rico health sciences journal*. 2018;37(2):67-77.
- Centers for Disease Control and Prevention NCFIPaC. Traumatic Brain Injury & Concussion: TBI Data. Updated October 29, 2024. Accessed August 11, 2025. <https://www.cdc.gov/TraumaticBrainInjury/data/index.html>
- Peterson AB, Thomas KE, Zhou H. Surveillance Report of Traumatic Brain Injury-Related Deaths by Age Group, Sex, and Mechanism of Injury—United States, 2018 and 2019. Centers for Disease Control and Prevention; 2022. Accessed August 11, 2025. <https://stacks.cdc.gov/view/cdc/122988>
- Weiss H, Agimi Y, Steiner C. Youth motorcycle-related hospitalizations and Traumatic Brain Injuries in the United States in 2006. *Pediatrics*. 2010;126(6):1141-1148.
- Acosta JA, Rodríguez P. Morbidity associated with four-wheel all-terrain vehicles and comparison with that of motorcycles. *Journal of Trauma and Acute Care Surgery*. 2003;55(2):282-284.
- Abdelrahman H, Khan NA, El-Menyar A, et al. All-terrain vehicle (ATV)-related injuries among different age groups: insights from a 9-year observational study. *European Journal of Trauma and Emergency Surgery*. 2022;48(6):4971-4981.
- Stewart MF. More Than a Toy: Pediatric ATV-Related Injury and Prevention. *Pediatric Nursing*. 2022;48(2):86-93.
- Ho CV, Dunne JR, Stroud WR, Fonseca AH, Davis FE, Bromberg WJ. Analysis of all-terrain vehicle trauma data: implications for increased regulation and injury prevention. *The American Surgeon*. 2017;83(4):348-353.
- Bansal V, Fortlage D, Lee J, Kuncir E, Potenza B, Coimbra R. A 21-year history of all-terrain vehicle injuries: has anything changed? *The American Journal of Surgery*. 2008;195(6):789-792.
- Adil M, Konstantinou C, Porter D, Dolan S. All-Terrain Vehicle (ATV) Injuries—An Institutional Review Over 6 Years. *The Ulster Medical Journal*. 2017;86(2):103.
- Benham EC, Ross SW, Mavilia M, Fischer PE, Christmas AB, Sing RF. Injuries from all-terrain vehicles: an opportunity for injury prevention. *The American Journal of Surgery*. 2016;214(2):211-216.
- Associates ES. ATV Laws in the United States. June 23, 2023. Accessed June 23, 2023. <https://www.edgarsnyder.com/atv/atv-laws-by-state/>
- Richards JA, Loder RT. All-terrain vehicle use-related fracture rates, patterns, and associations from 2002 to 2015 in the USA. *Injury*. 2019;50(2):324-331.
- 2020 Laws of Puerto Rico :: Título 9 - Carreteras y Tránsito :: Capítulo 27 - Ley de Vehículos y Tránsito del 2000 :: Subcapítulo X - Reglas y Disposiciones Misceláneas :: § 5296. Uso de vehículos todoterrenos, autociclos o motonetas. Accessed June 27, 2023. <https://law.justia.com/codes/puerto-rico/2020/titulo-9/capitulo-27>
- Rattan R, D'Andrea KJ, Dente CJ, et al. Prevention of all-terrain vehicle injuries: a systematic review from The Eastern Association for the Surgery of Trauma. *The Journal of Trauma and Acute Care Surgery*. 2018;84(6):1017.
- American College of Surgeons. Trauma Quality Programs (TQP) Participant Use File (PUF) User Manual: Admission Year 2024. Version 1.0. 2025:1-48. Accessed 22 April 2026. <https://www.facs.org/media/btgfpkj5/tqp-puf-user-manual-2024.pdf>
- Khormali M, Payandemehr P, Zafarmandi S, Baigi V, Zafarghandi M, Sharif-Alhoseini M. Predictive utility of the Glasgow Coma Scale and the Head Abbreviated Injury Scale in Traumatic Brain Injury: Results from the national trauma registry of Iran. *Archives of Iranian Medicine*. 2022;25(8):496.
- Basak D, Chatterjee S, Attergrim J, et al. Glasgow Coma Scale compared to other trauma scores in discriminating in-hospital mortality of Traumatic Brain Injury patients admitted to urban Indian hospitals: a multicentre prospective cohort study. *Injury*. 2023;54(1):93-99.
- Boyd CR, Tolson MA, Copes WS. Evaluating trauma care: the TRISS method. *Journal of Trauma and Acute Care Surgery*. 1987;27(4):370-378.
- Newgard CD, Fischer PE, Gestrung M, et al. National guideline for the field triage of injured patients: recommendations of the National Expert Panel on Field Triage, 2021. *Journal of Trauma and Acute Care Surgery*. 2022;93(2):e49-e60.
- Sasser SM, Hunt RC, Faul M, et al. Guidelines for field triage of injured patients: recommendations of the National Expert Panel on Field Triage, 2011. *Morbidity and Mortality Weekly Report: Recommendations and Reports*. 2012;61(1):1-20.
- Pascual-Marrero A, Ramos-Meléndez EO, García-Rodríguez O, Morales-Quinones JE, Rodríguez-Ortiz P. Trauma epidemiology in Puerto Rico: in-hospital morbidity and mortality from 2002 to 2011. *International Journal of Injury Control and Safety Promotion*. 2018;25(1):14-22.
- Butts CC, Rostas JW, Lee YL, et al. Larger ATV engine size correlates with an increased rate of traumatic brain injury. *Injury*. 2015;46(4):625-628.
- Hsia RY, Markowitz AJ, Lin F, Guo J, Madhok DY, Manley GT. Ten-year trends in traumatic brain injury: a retrospective cohort study of California emergency department and hospital revisits and readmissions. *BMJ Open*. 2018-12-01 2018;8(12):e022297. doi:10.1136/bmjopen-2018-022297
- Coronado VG, Haileyesus T, Cheng TA, et al. Trends in sports and recreation-related traumatic brain injuries treated in US emergency departments: the National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *The Journal of Head Trauma Rehabilitation*. 2015;30(3):185.

26. Fernández-Abinader JA, González-Colón K, Feliciano CE, Mosquera-Soler AM. Traumatic brain injury profile of an elderly population in Puerto Rico. *Puerto Rico Health Sciences Journal*. 2017;36(4): 237-239.
27. Kleiner JE, Johnson J, Cruz Jr AI. Trends in all-terrain vehicle injuries from 2000 to 2015 and the effect of targeted public safety campaigns. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*. 2018;26(18):663-668.
28. Padegimas EM, Stepan JG, Stoker GE, Polites GM, Brophy RH. Epidemiology and severity of sports and recreation injuries presenting to a tertiary adult emergency department. *The Physician and Sports-medicine*. 2016;44(3):263-268.
29. Puerto Rico. Ley Núm. 107-2007. Para enmendar los Artículos 1.09, 1.52, 1.63, 3.01, 10.16, 14.02, 14.03, 14.05, 22.05, 23.02 y añadir el Artículo 3.06A a la Ley Núm. 22-2000: Ley de Vehículos y Tránsito de Puerto Rico. *LexJuris*; 2007. Accessed June 27, 2023. <https://www.lexjuris.com/LEXLEX/Leyes2007/lexl2007107.htm>
30. Foote CW, Doan XL, Vanier C, Palacio CH. Adult and pediatric all-terrain vehicle (ATV) injury patterns and outcomes in a community trauma center. *Research Square*. Preprint posted online January 18, 2022. <https://doi.org/10.21203/rs.3.rs-1229350/v1>
31. Levy BE, Quattrone M, Castle JT, Doud AN, Draus JM, Worhunsky DJ. Injury pattern and outcomes following all-terrain vehicle accidents in Kentucky children: a retrospective study. *The American Surgeon™*. 2023;89(12):5874-5880.
32. Cairo SB, Burk JK, Rothstein DH. Pediatric hospitalizations and inpatient mortality from all-terrain vehicle crashes, 2006–2016. *Trauma*. 2020;22(1):56-63.
33. Miller A, Gallegly JD, Orsak G, et al. Potential predictors of hospital length of stay and hospital charges among patients with all-terrain vehicle injuries in rural Northeast Texas. *Journal of Injury and Violence Research*. 2020;12(1):55.
34. Roberts T, Song Z. Medicare Advantage financing and quality in Puerto Rico vs the 50 US states and Washington, DC. *American Medical Association*; 2022:e223073-e223073.
35. Manley GT, Dams-O'Connor K, Alosco ML, et al. A new characterization of acute traumatic brain injury: the NIH-NINDS TBI Classification and Nomenclature Initiative. *The Lancet Neurology*. 2025;24(6):512-523.
36. Gobierno de Puerto Rico. Ley 110-2025. 2025. Accessed May 5, 2026. <https://aldia.microjuris.com/wp-content/uploads/2025/08/Ley-110-2025.pdf>

**Supplementary Table 1.** Sociodemographic and clinical profile of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes according to traumatic brain injury status and stratified by age group

| Characteristic                   | < 21 years          |                          | p-value | ≥ 21 years           |                          | p-value |
|----------------------------------|---------------------|--------------------------|---------|----------------------|--------------------------|---------|
|                                  | TBI (n=38)<br>n (%) | Non-TBI (n=103)<br>n (%) |         | TBI (n=158)<br>n (%) | Non-TBI (n=282)<br>n (%) |         |
| Sociodemographic data            |                     |                          |         |                      |                          |         |
| Sex                              |                     |                          | 0.90    |                      |                          | 0.48    |
| Male                             | 28 (73.7)           | 77 (74.8)                |         | 132 (83.5)           | 228 (80.9)               |         |
| Health insurance status          | (n=35)              | (n=95)                   | 0.78    | (n=151)              | (n=271)                  | 0.04    |
| Private                          | 14 (40.0)           | 34 (35.8)                |         | 58 (38.4)            | 122 (45.0)               |         |
| Public                           | 18 (51.4)           | 49 (51.6)                |         | 76 (50.3)            | 103 (38.0)               |         |
| Uninsured                        | 3 (8.6)             | 12 (12.6)                |         | 17 (11.3)            | 46 (17.0)                |         |
| Helmet use                       | (n=13)              | (n=30)                   | 0.65†   | (n=49)               | (n=76)                   | 0.10    |
| Yes                              | 1 (7.7)             | 5 (16.7)                 |         | 3 (6.1)              | 12 (15.8)                |         |
| Systolic blood pressure          | (n=37)              | (n=102)                  |         |                      | (n=281)                  |         |
| Median (IQR)                     | 133 (34)            | 120.5 (23)               | 0.005   | 133 (29)             | 125 (26)                 | <0.001  |
| < 90 mmHg                        | 0 (0)               | 5 (4.9)                  | 0.33†   | 10 (6.3)             | 9 (3.2)                  | 0.12    |
| Pulse                            | (n=37)              | (n=102)                  |         |                      | (n=280)                  |         |
| Median (IQR)                     | 118 (41)            | 98.5 (28)                | <0.001  | 104 (45)             | 93 (26)                  | <0.001  |
| > 120 bpm                        | 17 (46.0)           | 10 (9.8)                 | <0.001  | 43 (27.2)            | 23 (8.2)                 | <0.001  |
| Body region injured              |                     |                          |         |                      |                          |         |
| Major head & neck                | 33 (86.8)           | 28 (27.2)                | <0.001  | 123 (77.9)           | 51 (18.1)                | <0.001  |
| Major chest                      | 13 (34.2)           | 34 (33.0)                | 0.89    | 73 (46.2)            | 108 (38.3)               | 0.11    |
| Major abdomen                    | 2 (5.3)             | 21 (20.4)                | 0.03    | 5 (3.2)              | 34 (12.1)                | 0.002   |
| Major extremity                  | 5 (13.2)            | 32 (31.1)                | 0.03    | 20 (12.7)            | 64 (22.7)                | 0.01    |
|                                  |                     |                          | 0.01    |                      |                          |         |
| Injury severity score            |                     | (n=102)                  |         |                      | (n=281)                  |         |
| Median (IQR)                     | 25 (6)              | 13 (13)                  | <0.001  | 22 (11)              | 10 (8)                   | <0.001  |
| > 15                             | 34 (89.5)           | 47 (46.1)                | <0.001  | 119 (75.3)           | 97 (34.5)                | <0.001  |
| Hospital course and Outcome data |                     |                          |         |                      |                          |         |
| Admission to TICU                |                     |                          | <0.001  |                      |                          |         |
| Yes                              | 14 (36.8)           | 8 (7.8)                  |         | 78 (49.4)            | 21 (7.5)                 | <0.001  |
| TICU LOS, days                   | (n=14)              | (n=8)                    | 0.08    | (n=78)               | (n=21)                   | 0.06    |
| Median (IQR)                     | 10 (18)             | 7 (7)                    |         | 16.5 (19)            | 9 (21)                   |         |
| MV required                      |                     |                          | <0.001  |                      |                          |         |
| Yes                              | 23 (60.5)           | 8 (7.8)                  |         | 109 (69.0)           | 18 (6.4)                 | <0.001  |
| MV, days                         | (n=23)              | (n=8)                    | 0.75    | (n=109)              | (n=18)                   | 0.31    |
| Median (IQR)                     | 7 (15)              | 7 (8)                    |         | 10 (15)              | 13 (22)                  |         |
| Hospital LOS, days               |                     |                          | 0.41    |                      |                          | <0.001  |
| Median (IQR)                     | 9.5 (26)            | 6 (9)                    |         | 16.5 (29)            | 8 (10)                   |         |
| In-hospital mortality            |                     |                          | <0.001  |                      |                          | <0.001  |
| Dead                             | 8 (21.1)            | 1 (1.0)                  |         | 35 (22.2)            | 4 (1.4)                  |         |
| Hospital costs, USD              | (n=32)              | (n=88)                   | 0.009   | (n=141)              | (n=251)                  | <0.001  |
| Median (IQR)                     | 21,192<br>(65,792)  | 10,074<br>(18,976)       |         | 35,088<br>(73,800)   | 12,010<br>(21,683)       |         |
| Discharge disposition            | (n=25)              | (n=102)                  | 0.49†   | (n=122)              | (n=278)                  | 0.002   |
| Care facility                    | 1 (4.0)             | 2 (2.0)                  |         | 11 (9.0)             | 6 (2.2)                  |         |
| Community                        | 24 (96.0)           | 100 (98.0)               |         | 111 (91.0)           | 272 (97.8)               |         |

TBI: traumatic brain injury; IQR: interquartile range; TICU: trauma intensive care unit; LOS: length of stay; MV: mechanical ventilation; USD: United States Dollar; †: Fisher's exact test.

**Supplementary Table 2.** Concordance analysis between primary and sensitivity traumatic brain injury definitions. (N=581)

|                                          | Sensitivity TBI definition<br>(GCS ≤ 12 & Head AIS ≥ 2) | Sensitivity Non-TBI definition<br>(GCS > 12 & Head AIS < 2) | Total n (%) |
|------------------------------------------|---------------------------------------------------------|-------------------------------------------------------------|-------------|
| Primary TBI definition<br>(GCS ≤ 12)     | 194                                                     | 2                                                           | 196 (33.7)  |
| Primary Non-TBI definition<br>(GCS > 12) | 0                                                       | 385                                                         | 385 (66.3)  |
| Total n (%)                              | 194 (33.4)                                              | 387 (66.6)                                                  | 581 (100)   |

TBI: traumatic brain injury; GCS: Glasgow coma scale; AIS: abbreviated injury scale. Cohen's kappa coefficient ( $\kappa$ ) = 0.992 (95% CI: 0.982 – 1.000);  $p < 0.001$ .

**Supplementary Table 3.** Sensitivity analysis of traumatic brain injury definition on outcomes of patients admitted to the Puerto Rico Trauma Hospital following all-terrain vehicle crashes.

| Outcome                | Statistical model            | Estimate type             | Primary definition<br>(GCS ≤ 12) | p-value | Sensitivity analysis<br>(GCS ≤ 12 & Head AIS ≥ 2) | p-value |
|------------------------|------------------------------|---------------------------|----------------------------------|---------|---------------------------------------------------|---------|
| Hospital LOS           | Negative binomial regression | Adjusted IRR (95% CI)     | (n=578)<br>1.57 (1.28 – 1.94)    | <0.001  | (n=578)<br>1.60 (1.30 – 1.97)                     | <0.001  |
| In-hospital mortality  | Poisson regression           | Adjusted RR (95% CI)      | (n=578)<br>11.71 (4.41 – 31.08)  | <0.001  | (n=578)<br>11.89 (4.47 – 31.66)                   | <0.001  |
| Discharge disposition† | Logistic regression          | Adjusted OR (95% CI)      | (n=524)<br>4.01 (1.42 – 11.37)   | 0.009   | (n=524)<br>4.19 (1.46 – 12.01)                    | 0.008   |
| Hospital costs         | GLM (Gamma/Log)              | Adjusted $\beta$ (95% CI) | (n=509)<br>0.90 (0.37 – 1.43)    | 0.001   | (n=509)<br>0.92 (0.39 – 1.45)                     | 0.001   |

GCS: Glasgow coma scale; AIS: abbreviated injury scale; LOS: length of stay; GLM: generalized linear model; IRR: incidence rate ratio; RR: risk ratio; OR: odds ratio; CI: confidence interval. Non-traumatic brain injury was used as the reference category for all models. All models were adjusted for age, sex, and injury severity score. †Compares care facility discharge vs. community disposition.