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Pediatric spinal injury patterns and management in all-terrain vehicle and dirt bike crashes, 2010–2019

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OBJECTIVE Pediatric spinal injuries in all-terrain vehicle (ATV) and dirt bike crashes are relatively uncommon but may be associated with significant morbidity. There are no recent studies examining these injuries, their management, and outcomes. Therefore, a retrospective study was performed to characterize pediatric spinal injuries related to ATV and dirt bike crashes over the last decade.

METHODS Data on all patients involved in ATV or dirt bike crashes evaluated at a regional level 1 pediatric trauma center over a 10-year period (2010–2019) were analyzed. Descriptive statistics were analyzed and chi-square, Fisher exact, and Mann-Whitney U-tests were performed comparing the demographics, injury characteristics, and clinical outcomes in patients with versus those without spinal injuries.

RESULTS Of 680 patients evaluated, 35 (5.1%) were diagnosed with spinal injuries. Over the study period, both spinal injuries and emergency department visits related to ATV or dirt bike crashes increased in frequency. All spinal injuries were initially diagnosed on CT scans, and 57.9% underwent spinal MRI. Injuries were most commonly thoracic (50%), followed by cervical (36.8%). The injuries of most patients were classified as American Spinal Injury Association (ASIA) grade E on presentation (86.8%), while 2 (5.3%) had complete spinal cord injuries (ASIA grade A) and 3 patients (8.6%) were ASIA grade B–D. Operative management was required for 13 patients (28.9%). Nonoperative management was used in 71.1% of injuries, including bracing in 33% of all injuries. Patients with spinal injuries were older than those without (13.4 ± 3.35 vs 11.5 ± 3.79 years, p = 0.003). Spinal injuries occurred via similar crash mechanisms (p = 0.48) and in similar locations (p = 0.29) to nonspinal injuries. Patients with spinal injuries more frequently required admission to the intensive care unit (ICU; 34.2% vs 14.6%, p = 0.011) and had longer hospital stays (mean 4.7 ± 5.5 vs 2.7 ± 4.0 days, p = 0.0025).

CONCLUSIONS Although infrequent among young ATV and dirt bike riders, spinal injuries are associated with longer hospital stays, increased ICU use, and required operative intervention in 29%. Increasing awareness among ATV and dirt bike riders about the severity of riding-related injuries may encourage safer riding behaviors.

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KEYWORDS ATV; dirt bike; pediatric spine injury; bracing; nonoperative management; injury prevention; public health; trauma

All-terrain vehicles (ATVs) are a common form of recreation in the US and are a frequent cause of injury. Rates of injuries from ATV crashes are significantly higher in the pediatric population compared with adults.[1] Both the American Academy of Pediatrics and the American Academy of Orthopaedic Surgeons have position statements that encourage limited use of ATVs by children.[2,3] Despite these statements, there were an estimated 28,300 injuries and 115 deaths in children younger than 16 years of age due to ATV-related incidents in 2017.[4] Injury to the spine occurs in 2%–13% of these patients,[5–13] and multilevel injuries are relatively common.[8] As a result of the severity of these injuries, these patients experience longer hospital stays and increased hospital costs.[8] How-

ABBREVIATIONS ASIA = American Spinal Injury Association; ATV = all-terrain vehicle; ED = emergency department; GCS = Glasgow Coma Scale; ICU = intensive care unit; ISS = Injury Severity Score; SLICS = Subaxial Injury Classification and Severity Scale; TLICS = Thoracolumbar Injury Classification and Severity Scale; TLSO = thoracic lumbar sacral orthosis.

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ever, previous studies in this patient population have not been powered to analyze additional clinical outcomes of interest, such as length of intensive care unit (ICU) stay, disposition to rehabilitation facilities, or recovery status at follow-up.

While previous studies reported rates of spinal injuries among other organ systems,[5–16] few provide detailed reporting of the types of spinal injuries seen in pediatric ATV crashes and their management. More detailed reporting of injury type and classification, operative and nonoperative management including bracing, and outcomes including American Spinal Injury Association (ASIA) impairment scale grade at follow-up would aid in preparation for treating these injuries. Understanding the importance of spinal injuries in ATV crashes may also contribute to better public understanding of the risks of ATV ridership and is useful for informing public health initiatives. Additionally, given that most studies examining pediatric spinal injuries in ATV crashes are now more than a decade old, continued updating of the literature for this relatively rare spectrum of injuries is necessary for both public health interventions and physicians treating these patients.

Recognizing these issues, we performed a retrospective analysis to better characterize the spectrum of spinal injuries related to ATV and dirt bike crashes over a recent 10-year period. The objectives of this study were to 1) describe the occurrence and type of spinal injuries among ATV and dirt bike riders, 2) understand risk factors for spinal injuries, and 3) understand the impact of spinal injuries compared with nonspinal injuries on clinical outcomes and postinjury course among ATV and dirt bike riders.

Methods

Study Design

Data analyzed for this retrospective cohort study were obtained from a prospectively collected pediatric trauma registry containing all patients presenting with traumatic injuries to a large level 1 pediatric trauma center in the southeastern US (Monroe Carell Jr. Children's Hospital at Vanderbilt) between January 1, 2010, and December 31, 2019. The study was approved by the IRB, and data accession and storage were performed in accordance with the Health Insurance Portability and Accountability Act. The requirement for consent was waived due to the minimal risk nature of the study.

Study Population

Included patients were those evaluated by the pediatric trauma surgery service following an ATV or dirt bike crash during the study period. Of note, our institutional standard of practice is for patients older than 16 years involved in an ATV or dirt bike crash to be triaged to the adult hospital, but no strict age-based exclusion criteria were applied for the purpose of this study.

Variables

Patient records were reviewed and extracted data were stored securely using REDCap (Research Electronic Data Capture) data capture.[17] Key injury variables collected from patient records included demographics, mechanism of injury (rollover, crash on jump, ejection, collision with solid structure, collision with other vehicle), location of crash (home/yard, street, farm/field, or racetrack), driver status (passenger or driver), vehicle type (ATV or dirt bike), intubation status prior to hospital arrival, and Glasgow Coma Scale (GCS) score and Injury Severity Score (ISS) on admission.

Spinal injury variables collected included results of spinal imaging performed, comprising the presence, location, and type of fracture or injury. Cervical fractures were classified as atlanto-axial, C1, C2, or subaxial injuries, which were assessed using the Subaxial Injury Classification and Severity Scale (SLICS). Thoracolumbar injuries were classified using the Thoracolumbar Injury Classification and Severity Scale (TLICS) and AO Spine Trauma Classification system. Radiographic variables relied on reports by board-certified radiologists, and imaging was manually reviewed by a senior author (M.J.C.). Operative procedures were categorized based on operative and procedure notes. Decisions on whether to pursue interventions were made at the discretion of the attending surgeon.

Outcomes

Primary outcomes included 1) the presence of a spinal injury, including fracture or spinal cord injury without an associated fracture; 2) length of stay in the hospital and ICU (days); and 3) ASIA grade at the first and final follow-up. Secondary outcomes included demographic information and injury data, such as location and mechanism of injury.

Statistical Analysis

Categorical variables are presented as frequency and proportion. Continuous variables are presented as mean (standard deviation), except in the case of nonnormal distributions, which are presented as median (IQR). Chi-square analysis was used to compare categorical variables, and independent-sample t-tests were used for comparing continuous variables. Statistical analysis was performed using SPSS Statistics (version 27, IBM Corp.). Statistical significance was set a priori as $p < 0.05$.

Results

Demographics, Annual Trends, and General Injury Characteristics

Full demographic, crash, and admission variables are presented in Table 1. A total of 739 patients involved in ATV and dirt bike crashes were included in the analysis. The mean patient age was 11.6 ± 3.7 years (range 1–17 years). The majority of the patients were male (73.4%) and White (93.5%). The mean number of ATV and dirt bike–related emergency department (ED) visits was higher in 2015–2019 (mean 94.2 injuries per year) than in 2010–2014 (mean 53.6 injuries per year, $p = 0.0007$). Similarly, spinal injuries were more frequent in 2015–2019 (mean 5.6 injuries per year) than in 2010–2014 (mean 2.0 injuries per year, $p = 0.0063$). Lines of best fit demonstrated that pediatric ATV and dirt bike–related ED visits ($y = 7.36x$

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+ 33.4, $R^2 = 0.85$) and spinal injuries ($y = 0.64x + 0.27$, $R^2 = 0.66$) increased over the study period (Fig. 1). Spinal injuries occurred in 38 riders (5.1%). Riders with spinal injuries were significantly older than those without spinal injury (mean age 13.4 vs 11.5 years, $p = 0.003$). There were no significant differences between the groups according to race or sex. The crash mechanism was similar among both groups and was most commonly a rollover or ejection event. Crash location was also similar between riders with and without spinal injuries, with most crashes occurring at home in a yard or field. Driver status and vehicle type were also similar among spinal and nonspinal injury groups. Riders had similar rates of field intubation and GCS scores upon arrival to the hospital. No significant relationship between severe traumatic brain injury and spinal injuries was observed. Riders with spinal injuries had higher ISSs on arrival (mean 19.4 vs 9.9, $p < 0.001$) and were more frequently admitted to the ICU (34.2% vs 14.6%, $p = 0.011$; see Table 3).

Spinal Injuries and Management

Table 2 illustrates characterization of spinal injuries and management. All patients with spinal injuries underwent spinal CT, and most received spinal radiography (71.1%) and spinal MRI (57.9%) as well. Half (50.0%) of the patients had thoracic injuries, followed by cervical (36.8%) and lumbar (31.6%) injuries. Seven patients (18.4%) had injuries to more than one spinal region. Injury region did not vary significantly with age. Spinal fracture occurred in 35 patients (92.1%), accounting for 42 (93.3%) of 45 total injuries. Of the fractures, 45.2% were thoracic, 26.2% were cervical, and 28.6% were in the lumbar region. Figure 2 describes the occurrence and management of these fractures on a per-injury basis. Of the 3 injuries without a fracture, all were ligamentous injuries to the cervical spine with no neurological impairment (ASIA grade E). One of these patients had an atlanto-occipital dissociation injury and was managed operatively with a halo device, whereas the other 2 patients were managed nonoperatively with a cervical collar.

Half (50.0%) of the cervical injuries were subaxial, most of which were graded as SLICS score < 4 (85.7%). There were 2 lateral mass fractures and 1 odontoid fracture to C2. There were 2 anterior arch fractures of C1 and 2 atlanto-occipital dissociation injuries. Only 1 patient with a cervical injury had neurological impairment, graded as ASIA grade B.

Thoracolumbar injuries were most commonly graded as TLICS score < 4 (66.7%). Most thoracolumbar fractures were compression (45.1%) or burst (22.6%) fractures. Translation/rotation (6.5%) and distraction (9.7%) morphologies were less common, and 3 fractures (9.7%) only affected a transverse or spinous process. The majority (85.1%) of patients with thoracolumbar injuries had normal motor and sensory function (ASIA grade E) on presentation, 2 (7.4%) had an incomplete impairment (ASIA grade B–D), and 2 (7.4%) had a complete impairment (ASIA grade A). Using the AO Spine classification system, we found that A1 wedge-compression fractures (41.9%) were most common, followed by A3 incomplete burst fractures (22.6%) and A0 minor fractures of transverse, spinous, or

TABLE 1. Demographics, injury mechanisms, and injury severity

Characteristic	Spine Injury	No Spine Injury	p Value
No. of patients	38	701	
Mean age ± SD, yrs	13.4 ± 3.35	11.5 ± 3.79	**0.003**
Male sex, n (%)	27 (71.1)	516 (73.6)	0.73
Race, n (%)			0.93
White	37 (97.4)	654 (93.3)	
Black	1 (2.6)	34 (4.9)	
Other	0 (0)	7 (1.0)	
Unknown	0 (0)	6 (0.9)	
Injury profile			
Vehicle, n (%)*			0.58
ATV	28 (5.4)	487 (94.6)	
Dirt bike	10 (4.5)	214 (95.5)	
Driver status, n (%)*			0.80
Driver	28 (5.3)	503 (94.7)	
Passenger	10 (4.8)	198 (95.2)	
Mechanism, n (%)			0.48
Rollover	16 (42.1)	246 (35.1)	
Crash during jump	4 (10.5)	56 (8.0)	
Ejected w/o collision	11 (28.9)	170 (24.3)	
Collision w/ vehicle	2 (5.3)	83 (11.8)	
Collision w/ object	5 (13.2)	146 (20.8)	
Location, n (%)			0.29
Home/yard	18 (47.4)	361 (51.5)	
Racetrack	6 (15.8)	81 (11.6)	
Street	4 (10.5)	133 (19.0)	
Farm/field	7 (18.4)	105 (15.0)	
Unspecified	3 (7.9)	21 (3.0)	
Transport			0.43
Ground	20 (52.6)	408 (58.2)	
Helicopter	17 (44.7)	251 (35.8)	
Private	1 (2.6)	42 (6.0)	
Arrival from, n (%)			0.95
Scene	14 (36.8)	253 (36.1)	
Outside hospital	24 (63.2)	442 (63.1)	
Urgent care/clinic	0 (0)	6 (0.9)	
Intubated PTA, n (%)	3 (7.9)	25 (3.6)	0.17
GCS score, n (%)			0.13
3–8	4 (10.5)	28 (4.0)	
9–12	1 (2.6)	10 (1.4)	
13–15	33 (86.8)	663 (94.6)	
Mean ISS ± SD	19.4 ± 11.9	9.9 ± 7.7	**<0.001**
1–8	4 ± 10.5	299 ± 42.7	
9–15	14 ± 36.8	276 ± 39.4	
16–24	9 ± 23.7	87 ± 12.4	
25–49	9 ± 23.7	38 ± 5.4	
50–75	2 ± 5.3	1 ± 0.1	

PTA = prior to emergency department arrival.
Boldface type indicates statistical significance.
* Percentages were calculated for each row (e.g., percentage of spine injuries among all drivers or passengers).

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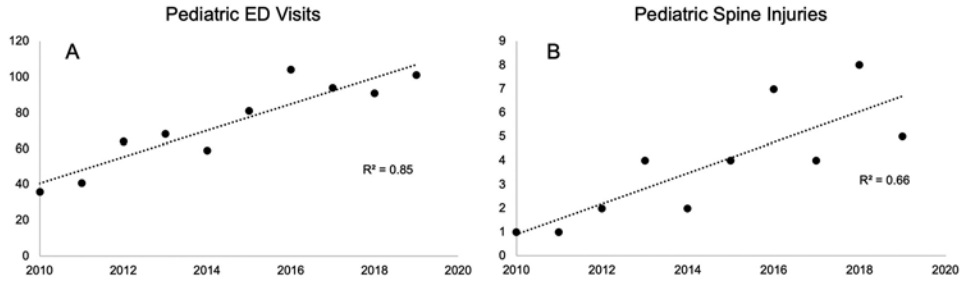

FIG. 1. Annual count of pediatric ED visits (**A**) and spinal injuries (**B**) for ATV- and dirt bike–related injuries from 2010 to 2019.

articulating processes (12.9%). B2 posterior tension band injuries (9.7%) and C translation injuries (9.7%) were less common.

Most injuries were treated with nonoperative management (71.1%), with no brace or operation required in 37.8% of injuries. Bracing included a cervical collar (34.4% of injuries) or thoracic lumbar sacral orthosis (TLSO) brace (12.5%). Of those 13 patients (28.9%) requiring operation, the majority underwent decompression with internal fixation (69.2%), with 2 patients (15.4%) undergoing halo device placement and 2 patients (15.4%) internal fixation only.

Clinical Outcomes

Length of hospitalization was higher among patients with compared to those without spinal injuries (mean 4.7 ± 5.5 vs 2.7 ± 4.0 days, $p = 0.0025$), as was length of ICU stay (mean 2.2 ± 4.6 vs 0.4 ± 2.4 days, $p < 0.001$; Table 3). ASIA grade E spinal injury patients alone also had higher lengths of hospitalization (mean 4.1 ± 5.5 vs 2.7 ± 4.0 days, $p = 0.049$) and ICU stays (mean 1.9 ± 4.9 vs 0.4 ± 2.4 days, $p = 0.0013$) compared with nonspinal injury patients. The median length of hospitalization was 3 days (IQR 1–7 days) for all spinal injury patients, 2 days (IQR 1–5 days) for ASIA grade E spinal injury patients, and 2 days (IQR 1–3 days) among nonspinal injury patients. Hospital disposition also differed between spinal and nonspinal injuries, with spinal patients more frequently requiring in-home rehabilitation services or placement in a rehabilitation facility as compared with patients without spinal injury (13.2% vs 1.7%, $p = 0.0012$). One death (2.6%) occurred among patients with spinal injuries, as compared with 4 deaths among all other riders (0.6%).

The median follow-up duration was 85.5 days (IQR 42–430 days), and all operative patients had follow-up greater than 12 months. The presence of motor and sensory impairments decreased from the initial to the final follow-up. One patient with ASIA grade A impairment improved to ASIA grade C, and 2 patients with ASIA grade D impairment improved to ASIA grade E. Two patients with ASIA grade A impairments remained unchanged at follow-up. No revision procedures were required among operative patients. No patient treated with a brace required an operation in the follow-up period. Patients treated with braces most commonly completed treatment in 30–90 days (47.1%). Complete clinical outcomes are presented in Table 3.

Discussion

In our study, spinal injuries occurred in 38 (5.1%) of 739 pediatric patients presenting to a level 1 trauma center following an ATV or dirt bike crash. Among the 45 injuries observed, 13 (29%) required operative intervention, while 15 (33%) underwent conservative management with external orthosis, and a further 17 (38%) required no further management.

The goal of reducing the occurrence and severity of ATV-related injuries in children has been a multidecade effort. In 1988, a 10-year consent decree between the Consumer Product Safety Commission and the ATV industry was signed and resulted in decreased rates of pediatric injury from ATV accidents.[1,13] However, following the expiration of the decree in 1998, there was a significant increase in the rates of ATV-related injury in the pediatric population.[18] Given this context, updating the public record of ATV-related injuries is essential for continued efforts to reduce these injuries. Literature on pediatric spinal injuries in ATV accidents has seldom been updated in the last 2 decades, and these reports are often lacking in characterization of specific injuries, management patterns, and outcomes. Our analysis adds granularity to the study of spinal injuries among patients injured on recreational vehicles.

The rate of spinal injury in our study population is similar to that from previous reports, which have noted rates of 2%–13%.[5–13,16] Sawyer et al. used the Kids' Inpatient Database to demonstrate a 476% increase in ATV-related spinal injuries in children between 1996 and 2006, along with a 240% overall increase in ATV-related injuries.[8] That study found a spinal injury rate of 7.4%, which is similar to the 5.1% rate of spinal injuries in the current study. The current study also identified an increase in spinal and overall injuries from the first half of the study period (2010–2014) to the second half (2015–2019). This suggests that efforts to reduce ATV- and dirt bike–related injuries (including devastating spinal injuries) have not made a significant impact or have not kept pace with other trends that contribute to these injuries, at least within the study population.

Demographic data and injury characteristics did not suggest any modifiable risk factors for spinal injury, although these patients were slightly older than patients without spinal injury. Sawyer et al. also reported longer hospital admissions for patients with spine fractures, with a mean length of stay of 5.3 days in those having a spine

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fracture compared with 3.3 days in those without a spine fracture.[8] This result was similar to our findings, with patients with spinal injuries having a longer mean length of stay compared to those without (4.7 vs 2.7 days). Additionally, the current study found evidence of significantly longer ICU stays among spinal injury patients (2.2 vs 0.4 days), a previously unreported complication of this type of injury. We considered that these measures might be increased by patients with significant neurological injuries. However, the lengths of hospitalization and ICU stays for ASIA grade E patients alone were still significantly higher than those for nonspinal injury patients. It is possible that a combination of more significant injury mechanisms (potentially leading to polytrauma), increased time needed for evaluation, or other factors may contribute to increased length of hospitalization among spine-injured patients.

In the current study, the most commonly injured region was the thoracic spine, followed by the cervical and lumbar regions. The vast majority of these injuries were compression and burst fractures. Neurological injury was rare, and most patients were safely managed nonoperatively with or without a brace. Prior literature has found that spinal injuries in motorcycle crashes most often occur in the thoracic region, primarily due to forced flexion or extension of the spine.[19,20] In contrast, spinal injuries in motor vehicle crashes most commonly occur in the cervical and lumbosacral regions, potentially due to the protective effects of abdominothoracic seatbelts.[19–22] These data suggest that spinal injuries in ATV- and dirt bike–related crashes more closely resemble those from motorcycle crashes and should raise suspicion for this pattern of injury.

Few previous studies have characterized the types of fractures seen in ATV accidents in pediatric patients. Jordan et al. identified 36 patients with thoracolumbar spine fractures after ATV accidents from 2004 to 2013,[5] finding that minor fractures of transverse, spinous, or articulating processes (AO Spine classification system A0 fractures) were the most common (49%), followed by wedge-compression fractures (AO Spine classification system A1 fractures) (41%). More significant fractures were rare, with 3.6% being type B2 tension band fractures and 3.6% being type C translational injuries. In our study, the most common fracture type was an A1 wedge-compression fracture (40%). However, our study found a higher proportion of tension band injuries (type B fractures, 9.7%) and translational injuries (type C fractures, 9.7%) compared with the Jordan et al. study.

Additionally, few studies have reported the need for operative intervention in ATV-related pediatric spinal injuries. Mangano et al. evaluated a single-center experience with pediatric spinal injuries due to ATV accidents from 1993 to 2003 and demonstrated a similar rate of spinal fractures (7%).[7] Of the 13 spinal fractures in their cohort, 3 (23.1%) were managed operatively and all injuries were in the cervical spine. Similarly, in our cohort, 12 (28.6%) of 42 fractures required operative intervention, although the majority of these interventions were for thoracic or thoracolumbar injuries (91.7%). Of the operative injuries, 69% underwent decompression and instrumented fusion, while 15% underwent instrumented fusion alone, and 15% required placement of a halo device. These data demonstrate

TABLE 2. Spine injuries and treatments (n = 38 patients)

Event	Value (%)
Spine imaging	38 (100.0)
CT	38 (100.0)
MRI	22 (57.9)
Radiography	27 (71.1)
Injury location & classification	45
Cervical*	14 (36.8)
Atlanto-occipital	2 (14.3)
C1	2 (14.3)
C2	3 (21.4)
Subaxial*	7 (50.0)
SLICS <4	6 (85.7)
SLICS ≥4	1 (14.3)
Thoracic*	19 (50.0)
TLICS <4	14 (73.7)
TLICS ≥4	5 (26.3)
Lumbar*	12 (31.6)
TLICS <4	8 (66.7)
TLICS ≥4	4 (33.3)
Multiple regions	7 (18.4)
Thoracolumbar injuries†	31
A0	4 (12.9)
A1	13 (41.9)
A2	0 (0)
A3	7 (22.6)
A4	0 (0)
B1	1 (3.2)
B2	3 (9.7)
B3	0 (0)
C	3 (9.7)
Initial ASIA grade	
A	2 (5.3)
B	1 (2.6)
C	0 (0.0)
D	2 (5.3)
E	33 (86.8)
Total injuries	45
Fractures	42 (93.3)
Ligamentous or other	3 (6.7)
Operative management*	13 (28.9)
Internal fixation	2 (15.4)
Decompression w/ IF	9 (69.2)
Halo	2 (15.4)
Nonoperative management*	32 (71.1)
Cervical collar	11 (34.4)
TLSO	4 (12.5)
No brace	17 (53.1)

IF = internal fixation.
* Percentages for these sections are calculated for each subcategory (e.g., percentage of cervical injury subtype among all cervical injuries) and reflect per-injury management.
† AO Spine Trauma Classification system.

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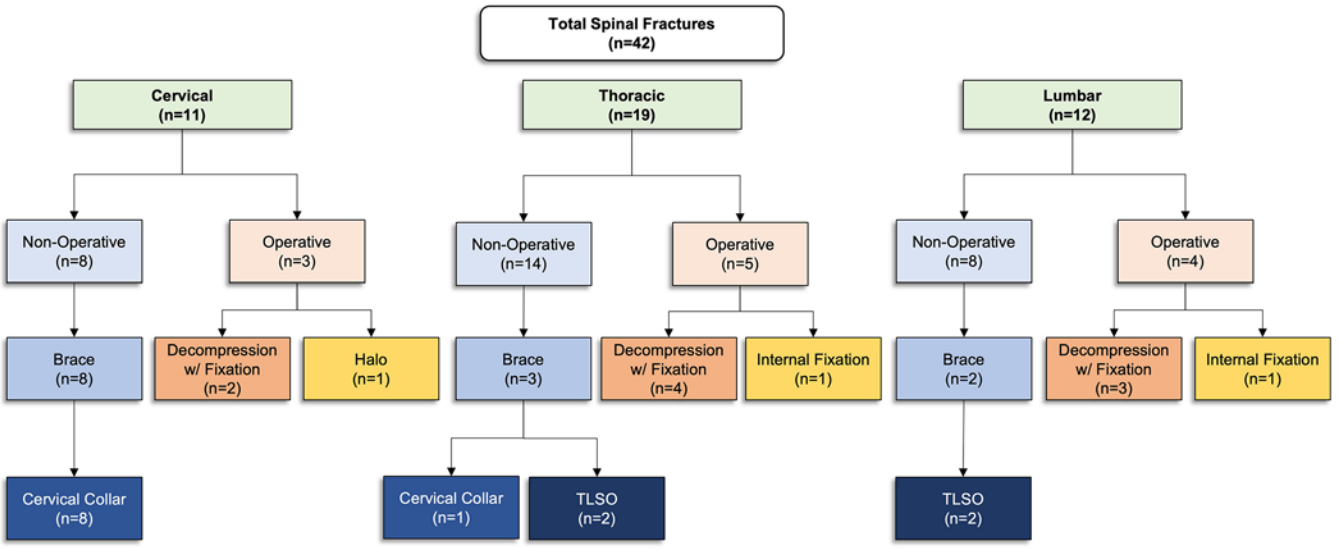

FIG. 2. Chart of fracture locations and management strategies. Figure is available in color online only.

that while many spinal fractures seen in ATV accidents are nondestabilizing, approximately one-quarter require operative management. Among patients who did require operative management in our cohort, none required revision of their operation, and all had stable instrumentation and successful fusion at the 12-month follow-up.

Given their role in treating spinal injuries related to ATV and dirt bike crashes, neurosurgeons should remain updated on current trends in ATV-related injuries as well as management strategies. Additionally, neurosurgeons should continue to support efforts in the public health domain to reduce the frequency and severity of ATV-related injuries, which can often have devastating consequences. Neurosurgeons can aid in these efforts by providing unique, firsthand experiences that add a patient-focused element to educational safety programs. Additionally, advocacy efforts are enhanced by clear messaging based on the current literature. For example, the current study identifies recent increases in ATV- and dirt bike–related spinal injuries that suggest the need for additional urgency in these advocacy efforts. Furthermore, neurosurgeons can aid in targeting educational efforts based on current understanding of the demographics and injury profiles of riders most likely to be injured. Neurosurgical groups and professional societies should use the findings presented in the current study and other recent publications related to neurological injuries from ATV and dirt bike crashes to draft position statements related to the use of these vehicles.

The results presented here are useful for informing specific injury prevention programs, such as Injury Free Coalition for Kids, Safe Kids Worldwide, and ThinkFirst by the National Injury Prevention Foundation, and for tailoring messaging efforts toward the prevention of spinal injuries and their significant morbidity relative to other ATV-related injuries.[23] An emphasis on community-based, multipronged prevention programs based on local data can effectively increase knowledge and inspire safe riding behaviors. Analyses such as the current study are key for injury prevention and for public health professionals to develop successful campaigns, tailor inventions, and coordinate new and existing local partnerships.[24]

Limitations

As a retrospective study, there was limited ability to control for the effects of confounding medical conditions and treatment decisions. We recognize the complex nature of patient care and that patients in this study received individualized care based on the judgment of treating physicians with the information available at the time. It is possible that these care decisions may have affected some outcome variables, especially where evidence-based guidelines such as TLICS leave room for individualized decision-making. Additionally, due to the nature of this study, we were unable to control for variability in reporting of crash details, such as mechanism, location, or driver status. Similarly, we were unable to control for the degree of other injuries or polytrauma experienced by patients. We expect that this may have had a confounding effect on outcome measures such as length of stay in the hospital, which could be increased by any range of injuries. Lastly, this study is limited because it was conducted at a single institution in the southeastern US. At this institution, patients older than 16 years are typically triaged to the adult hospital, although no age-based inclusion criteria were used for the study. This triage procedure could limit the number of pediatric patients older than 16 years who were included in the current study and may reduce the generalizability of the findings to this extreme of the pediatric population. Additionally, the use of recreational vehicles, specific crash mechanisms, and ultimate outcomes of these accidents may vary by study population, geographic region, and proximity to a health system. These results are most applicable in informing public health reporting in the study region; however, these results should motivate further regional and national studies and continued updating of the public record related to recreational vehicle injuries.

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TABLE 3. Clinical outcomes

Event	Spine Injury	No Spine Injury	p Value
No. of patients	38	701	
ED disposition			**0.011**
Home	1 (2.6)	62 (8.8)	
Observation	0 (0.0)	44 (6.3)	
Floor	22 (57.9)	403 (57.5)	
ICU	13 (34.2)	102 (14.6)	
OR	2 (5.3)	90 (12.8)	
Hospital disposition			**0.0012**
Home	32 (84.2)	683 (97.4)	
Home services/rehabilitation	5 (13.2)	12 (1.7)	
DCPS	0 (0.0)	2 (0.3)	
Death (all-cause)	1 (2.6)	4 (0.6)	
Length of hospitalization			
Median HD (IQR)	3 (1–7)	2 (1–3)	
Mean HD ± SD	4.7 ± 5.5	2.7 ± 4.0	**0.0025**
Median ICU days (IQR)	3 (2–8)	1 (1–3)	
Mean ICU days ± SD	2.2 ± 4.6	0.4 ± 2.4	**<0.001**
ASIA grade, first follow-up			
A	3 (7.9)		
B	0 (0)		
C	0 (0)		
D	2 (5.3)		
E	24 (63.2)		
Unknown	9 (23.7)		
ASIA grade, final follow-up			
A	2 (5.3)		
B	0 (0)		
C	1 (2.6)		
D	0 (0)		
E	28 (73.7)		
Unknown	7 (18.4)		
Days in brace			
<30	4 (23.5)		
30–90	8 (47.1)		
>90	1 (5.9)		
Unknown	4 (23.5)		

DCPS = Department of Child Protective Services; HD = hospital days; OR = operating room.
Boldface type indicates statistical significance. Values are given as number of patients (%) unless otherwise indicated.

Conclusions

Recreational vehicle injuries continue to affect children in the US, and continued reporting of specific injuries is necessary for public health interventions and the preparedness of neurosurgeons to manage these patients. Over a decade of recreational vehicle crashes, approximately 1 in 20 children evaluated after an ATV or dirt bike crash experienced a spinal injury, with the vast majority of patients (> 90%) experiencing vertebral fractures. Most patients did not require operative management of these injuries and avoided significant neurological injury. Yet, this study provides evidence that children continue to experience significant spinal injuries when riding recreational vehicles and are likely to require longer hospital and ICU stays and careful operative or nonoperative management relative to other pediatric patients without spinal injury.

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References

1. Cvijanovich NZ, Cook LJ, Mann NC, Dean JM. A population-based assessment of pediatric all-terrain vehicle injuries. *Pediatrics*. 2001;108(3):631-635.
2. All-terrain vehicle injury prevention: two-, three-, and four-wheeled unlicensed motor vehicles. *Pediatrics*. 2000;105(6):1352-1354.
3. American Academy of Orthopaedic Surgeons Position Statement. Published online 2015. Accessed July 14, 2022. https://www.aaos.org/contentassets/1cd7f41417ec4dd4b5c4c48532183b96/1101---all-terrain-vehicles.pdf
4. Topping J. 2020 Report of deaths and injuries involving off highway vehicles with more than two wheels. Consumer Product Safety Commission. Accessed July 14, 2022. https://www.cpsc.gov/s3fs-public/2020_Report_of_Deaths_and_Injuries_Invovling_Off_HighwayVehicles.pdf
5. Jordan RW Jr, Beckmann NM, Johnston JH, Johnston SK, Zhang X, Chinapuvvula NR. Characterization of all-terrain vehicle-related thoracolumbar spine injury patterns in children using the AOSpine classification system. *Emerg Radiol*. 2020;27(4):383-391.
6. Yanchar NL, Kennedy R, Russell C. ATVs: motorized toys or vehicles for children? *Inj Prev*. 2006;12(1):30-34.
7. Mangano FT, Menendez JA, Smyth MD, Leonard JR, Narayan P, Park TS. Pediatric neurosurgical injuries associated with all-terrain vehicle accidents: a 10-year experience at St. Louis Children's Hospital. *J Neurosurg*. 2006;105(1 suppl):2-5.
8. Sawyer JR, Bernard MS, Schroeder RJ, Kelly DM, Warner-surname WC Jr. Trends in all-terrain vehicle-related spinal injuries in children and adolescents. *J Pediatr Orthop*. 2011;31(6):623-627.
9. Stiles PJ, Helmer SD, Drake RM, Haan JM. All-terrain vehicle accidents in children. *Am Surg*. 2015;81(1):103-105.
10. Humphries RL, Stone CK, Stapczynski JS, Florea S. An assessment of pediatric all-terrain vehicle injuries. *Pediatr Emerg Care*. 2006;22(7):491-494.
11. Sandler G, Soundappan SSV, Manglick MP, et al. Pediatric "off-road vehicle" trauma: determinants of injury severity and type. *Pediatr Emerg Care*. 2012;28(12):1328-1333.
12. Lister DG, Carl J III, Morgan JH III, et al. Pediatric all-terrain vehicle trauma: a 5-year statewide experience. *J Pediatr Surg*. 1998;33(7):1081-1083.
13. Lynch JM, Gardner MJ, Worsey J. The continuing problem of all-terrain vehicle injuries in children. *J Pediatr Surg*. 1998;33(2):329-332.
14. Kute B, Nyland JA, Roberts CS, Hartwick-Barnes V. Recreational all-terrain vehicle injuries among children: an 11-year review of a Central Kentucky level I pediatric trauma center database. *J Pediatr Orthop*. 2007;27(8):851-855.
15. Garay M, Hess J, Armstrong D, Hennrikus W. Pediatric ATV injuries in a statewide sample: 2004 to 2014. *Pediatrics*. 2017;140(2):e20170945.
16. Sawyer JR, Beebe M, Creek AT, Yantis M, Kelly DM, War-

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ner WC Jr. Age-related patterns of spine injury in children involved in all-terrain vehicle accidents. *J Pediatr Orthop*. 2012;32(5):435-439.
17. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381.
18. Li D, Jatana KR, Kistamgari S, Smith GA. Nonfatal all-terrain vehicle-related head and neck injuries to children treated in US emergency departments. *Clin Pediatr (Phila)*. 2020;59(13):1141-1149.
19. Robertson A, Branfoot T, Barlow IF, Giannoudis PV. Spinal injury patterns resulting from car and motorcycle accidents. *Spine (Phila Pa 1976)*. 2002;27(24):2825-2830.
20. Medina O, Singla V, Liu C, Fukunaga D, Rolfe K. Patterns of spinal cord injury in automobiles versus motorcycles and bicycles. *Spinal Cord Ser Cases*. 2020;6(1):75.
21. Fakharian E, Mohammadzadeh M, Saberi HR, et al. Spinal injury resulting from car accident: focus to prevention. *Asian J Neurosurg*. 2017;12(2):180-184.
22. Pintar FA, Yoganandan N, Maiman DJ, Scarboro M, Rudd RW. Thoracolumbar spine fractures in frontal impact crashes. *Ann Adv Automot Med*. 2012;56:277-283.
23. Aitken ME, Graham CJ, Killingsworth JB, Mullins SH, Parnell DN, Dick RM. All-terrain vehicle injury in children: strategies for prevention. *Inj Prev*. 2004;10(5):303-307.
24. Towner E, Dowswell T. Community-based childhood injury prevention interventions: what works? *Health Promot Int*. 2002;17(3):273-284.

Disclosures

Dr. Yengo-Kahn serves on the scientific advisory board for BlinkTBI, which had no relevant involvement in the design or execution of this work.

Author Contributions

Conception and design: all authors. Acquisition of data: Cools, Allen. Analysis and interpretation of data: Cools, Allen, Yengo-Kahn, Bonfield. Drafting the article: Cools, Allen, Yengo-Kahn, Unni. Critically revising the article: Cools, Allen, Yengo-Kahn, Unni, Martus, Lovvorn, Bonfield. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Cools. Statistical analysis: Allen. Study supervision: Cools, Yengo-Kahn, Martus, Lovvorn, Bonfield.

Supplemental Information

Previous Presentations

This work was presented in abstract form at the Vanderbilt University Graduate Medical Education Research Forum in April 2022.

Abstract Presentations

This work will be presented in abstract form at the AANS/CNS Pediatrics Section Meeting in Salt Lake City, Utah, in December 2022.

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