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Journal
Journal of Trauma and Acute Care Surgery, 96(5)

ISSN
2163-0755

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Publication Date
2024-05-01

DOI
10.1097/ta.0000000000004198

Management of pediatric renal trauma: Results from the American Association for Surgery and Trauma Multi-Institutional Pediatric Acute Renal Trauma Study

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BACKGROUND: Pediatric renal trauma is rare and lacks sufficient population-specific data to generate evidence-based management guidelines. A nonoperative approach is preferred and has been shown to be safe. However, bleeding risk assessment and management of collecting system injury are not well understood. We introduce the Multi-institutional Pediatric Acute Renal Trauma Study (Mi-PARTS), a retrospective cohort study designed to address these questions. This article describes the demographics and contemporary management of pediatric renal trauma at Level I trauma centers in the United States.

METHODS: Retrospective data were collected at 13 participating Level I trauma centers on pediatric patients presenting with renal trauma between 2010 and 2019. Data were gathered on demographics, injury characteristics, management, and short-term outcomes. Descriptive statistics were used to report on demographics, acute management, and outcomes.

RESULTS: In total, 1,216 cases were included in this study. Of all patients, 67.2% were male, and 93.8% had a blunt injury mechanism. In addition, 29.3% had isolated renal injuries, and 65.6% were high-grade (American Association for the Surgery of Trauma Grades III–V) injuries. The mean Injury Severity Score was 20.5. Most patients were managed nonoperatively (86.4%), and 3.9% had an open surgical intervention, including 2.7% having nephrectomy. Angioembolization was performed in 0.9%. Collecting system intervention was performed in 7.9%. Overall mortality was 3.3% and was only observed in patients with multiple injuries. The rate of avoidable transfer was 28.2%.

CONCLUSION: The management and outcomes of pediatric renal trauma lack data to inform evidence-based guidelines. Nonoperative management of bleeding following renal injury is a well-established practice. Intervention for renal trauma is rare. Our findings reinforce differences from the adult population and highlights opportunities for further investigation. With data made available through Mi-PARTS, we aimed to answer pediatric specific questions, including a pediatric-specific bleeding risk nomogram, and better understanding indications for interventions for collecting system injuries. (*J Trauma Acute Care Surg.* 2024;96: 805–812. Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic and Epidemiological; Level IV.

KEY WORDS: Multi-institutional; pediatric trauma; renal trauma; trauma centers; conservative management.

Submitted: July 13, 2023, Revised: October 3, 2023, Accepted: October 19, 2023, Published online: November 15, 2023.

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DOI: 10.1097/TA.0000000000004198

Traumatic kidney injury is relatively uncommon in the pediatric population, estimated at 10% to 20% of all blunt abdominal injuries.[1] The study of pediatric renal trauma has remained limited by the relative rarity of these injuries. To date, the management of pediatric renal trauma is largely extrapolated from that of adult patients, as described in society guidelines including the American Urologic Association Urotrauma guidelines.[2] The Eastern Association for the Surgery of Trauma recently established pediatric-specific renal trauma guidelines.[3] These were based primarily on small single-institution studies, which together yield insufficient data for strong evidence-based recommendations. This calls for a multi-institutional effort to inform management of pediatric renal trauma.

Acute complications from renal injury can be secondary to bleeding (parenchymal or vascular insult) or collecting system injury, or a combination thereof. Nonoperative management is safe and preferred for all grades of renal injury.[2,4] Observation strategies generally center on serial monitoring for laboratory or hemodynamic changes. Indications for and timing of bleeding intervention are well described as including hemodynamic instability and inadequate response to resuscitation. Recent efforts have focused on establishing risk factors for bleeding intervention. A nomogram for bleeding intervention for adult renal trauma patients was published through data from the Multi-institutional Genitourinary Trauma Study (Mi-GUTS) consortium and gives providers a tool incorporating specific criteria to predict bleeding risk in the acute setting such as hematoma rim distance and shock.[5] At this time, it is not clear to what extent these criteria can be translated and applied to pediatric patients. Intervention for urine leak is less well defined, with management options ranging from observation, ureteral stent placement, percutaneous drainage, open repair, and, more rarely, nephrectomy.[6] These can be performed in response to complications of urine leak, or they can be performed preemptively with the goal of avoiding complication. Observation strategies and timing of intervention are not defined by any existing guidelines, and its management may even vary within institutions.[7]

Multi-institutional studies are paramount in clarifying the management and outcomes of rare disease entities including pediatric renal trauma.[8,9] Mi-PARTS is a retrospective review across 13 Level I trauma centers of this condition. This article introduces the Mi-PARTS cohort and presents the descriptive analysis on population characteristics, management, and outcomes, as well as sets the stage for future work to fill ongoing gaps in knowledge.

PATIENTS AND METHODS

Pediatric patients who sustained a renal trauma in the years 2010 through 2019 were reviewed from the 13 participating Level I trauma centers. This study was advertised through the American Association for the Surgery of Trauma Multi-Institutional Trials Committee (http://www.aast.org/Research/MultiInstitutionalStudies.aspx). Centers were also recruited through the Mi-GUTS consortium. Children's hospitals and non–children's hospitals were included, and primary investigators from multiple specialties (general surgery, pediatric surgery, pediatric and adult urology) were recruited to represent the different specialties managing pediatric renal trauma at different institutions. The STrengthening the Reporting of OBservational studies in Epidemiology checklist for observational cohort studies was used to ensure proper reporting of methods, results, and discussion and is provided as Supplemental Digital Content (Supplementary Table 1, http://links.lww.com/TA/D412).

Data Collection

Each participating center obtained individual institutional review board approval. Patients were identified through institutional trauma registries where available based on *International Classification of Diseases, Ninth Revision* or *Tenth Revision*, codes 866 or S37, respectively. Inclusion criteria included the following: age 18 years or younger, any mechanism of injury except iatrogenic, any severity of renal injury, and acute management of the injury performed at the participating institution. To focus on the acute management specific to high-volume Level I trauma centers, patients were excluded if they presented with sequelae of, or in outpatient follow-up for, a renal trauma that was managed in the acute setting at another facility.

A centralized deidentified database was created using REDCap electronic data capture tools hosted at the University of Washington.[10,11] For the subset of centers that maintained a local instance of the same REDCap database, care was taken to ensure data anonymization and uniform data structure before data transfer and integration. Data collection was performed through retrospective chart review. Data included demographics, injury characteristics, acute management, surgical and nonsurgical management, complications, readmissions, and outcomes on follow-up (imaging performed, loss of renal function, need for reconstruction). For consistency in data collection, an annotated data dictionary was distributed across centers to describe each variable. All institutions were asked to perform internal verification of American Association for the Surgery of Trauma (AAST) grading, with the goal of uniform use of the updated 2018 grading scale.[12] All dates were converted to time intervals from the time of injury.

Details about each institution were collected from Medicare data, as provided by the American Hospital Directory (ahd.com), and provided by the principal investigator at each site. Details included geographic region assigned based on US Census definitions, the service responsible for primary management of pediatric renal trauma, children's hospital designation, American College of Surgeons trauma center designation, number of trauma surgeons, and urologists managing renal trauma. For those centers with a trauma registry, the number of total trauma patients treated at each institution between 2010 and 2019 was collected.

Definitions

The AAST Organ Injury Scaling 2018 update was used to grade injury severity. High-grade (HG) injury was defined as AAST Grades III to V. Individual AAST grades for each kidney were assessed. In the case of bilateral injuries, a single final grade is reported.[12] Hypotension and tachycardia were adapted to the age of the patient and assessed based on Pediatric Advanced Life Support vital sign guidelines to mirror clinical emergent assessment.[13]

Interventions were categorized as follows:

1. No intervention: Patients underwent no procedural interventions for kidney-related concerns. These patients include those who were observed and may have had frequent laboratory checks, Foley catheterization, and or imaging.

2. Bleeding intervention: Minimally invasive intervention was renal angioembolization; open surgical intervention included nephrectomy, partial nephrectomy, or renorrhaphy in the acute setting because of concerns for ongoing bleeding.
3. Collecting system intervention: These included ureteral stent, percutaneous nephrostomy tube, and perirenal drain for concern of urine leak from the kidney or the ureteropelvic junction. These procedures may have been performed in the subacute setting because of ongoing urinary extravasation. It does not include pyeloplasty performed in a delayed fashion for congenital obstruction.

Avoidable transfer was defined similarly to Fenton et al.[14] as a patient transferred from another facility and subsequently discharged within 2 days without intervention or advanced imaging.

Analysis

Data were summarized as count and percentage for categorical variables and mean and SD for continuous variables. Missingness was assessed and noted to have low rates not requiring adjustment pertinent to this analysis. Monotonic trends over time were calculated using the Kendall-Mann statistic. Univariate analysis was calculated using χ^2 statistics, Fisher's exact test, or Student's *t* test in R (R Foundation for Statistical Computing, Vienna, Austria). All data analysis were performed using the R environment[15] (https://www.R-project.org).

RESULTS

Description of the Centers

Thirteen institutions across all four regions of the continental United States participated in this study. These include five children's hospitals with pediatric Level I trauma designation and eight non–children's hospitals with Level I trauma designation, some of which also had pediatric Level I trauma designation. All have affiliated General Surgery and Urology residency training programs. Primary management of injuries is shared between Urology, General Surgery, Pediatric Urology, and Pediatric Surgery. Excluding those centers without a trauma registry (3 of 13), in 2010 to 2019, pediatric renal trauma amounted to 0.3% (967 of 243,779) of all trauma patients served. Over the 10-year period, pediatric renal trauma represented 1.1% (436 of 40,862) of all traumas presenting to pediatric institutions, with an average median age of 7.5 years. Supplemental Digital Content (Supplementary Table 2, http://links.lww.com/TA/D413) includes further details on each institution's overall trauma patient volume and their distribution of blunt versus penetrating trauma mechanisms; additional descriptors profiling each institution's trauma and number of trauma surgeons are also reported.

Description of the Population

Table 1 summarizes demographics, injury characteristics, initial presentation, initial hospitalization course, and intervention data. Percentages of missingness are reported in Supplemental Digital Content (Supplementary Table 3, http://links.lww.com/TA/D414). Short-term outcomes data were collected but not included in this article. A total of 1,216 pediatric renal trauma patients were included, with a mean (SD) age of 12.3 (4.5) years. Most patients were male (67.2%) and predominantly sustained blunt injury (93.8%). Most patients (65.6%) had an HG renal injury. Renal trauma presentation was isolated in 29.3% of patients. Associated injuries (Table 2) included liver (29.4%), spleen (26.7%), orthopedic (26.4%), rib (18.3%), pelvic fracture (12.5%), spine (10.2%), other neurologic (16.9%), ipsilateral (7.1%) or contralateral adrenal (1.1%), small bowel (5.6%), pancreas (4.8%), spinal cord (4.4%), major vascular (3.8%), colon (2.4%), rectum (0.2%), and bladder (0%).

Blunt trauma etiologies consisted of motor vehicle collisions (36.1%), sports (28.2%), fall from height (14.0%), automobile versus pedestrian (8.7%), environmental/animal (3.8%), assault (1.4%), and other (7.8%). Penetrating trauma etiologies consisted of gunshot wounds (85.5%), stab wounds (9.2%), and other (5.3%).

While 357 (29.4%) of patients were tachycardic on arrival, only 26 (2.1%) presented with both tachycardia and hypotension. The mean (SD) Injury Severity Score (ISS) was 20.5 (13.2). The mean ISS was higher in patients who had an HG renal trauma (21.5 vs. 18.7, $p = 0.001$), although low-grade renal trauma had a higher association with multiple injuries (79.2% vs. 64.5%, $p < 0.001$). High-grade renal injury was more frequently associated with a patient having been transferred from another facility (62.2% vs. 50.1%, $p < 0.001$) and with having a urologist involved in their care (67.9% vs. 30.1%, $p < 0.001$.

Overall mortality was 3.3%, with 0.2% dying in the emergency department. Mortality was not associated with the presence of an HG of renal injury (12.3% vs. 23.4%, $p = 0.77$) but was significantly associated with shock (15.0% vs. 1.7%, $p < 0.001$) and transfusion (95.0% vs. 23.8%, $p < 0.001$). One hundred percent of mortalities had multiple injuries. The mean ISS for mortalities was 47.8 versus 20.5 in those who survived their injuries ($p < 0.001$). The rate of neurologic injury was significantly higher in those with mortality at 65% compared with 24.3% of all patients with multiple injuries (Table 2). Liver and spleen injuries were found in 42.4% versus 42.5%, and 38.% versus 40.0% in those multiple injuries with mortality compared with all multiple injuries.

Management

Blood product transfusion was given for 318 patients (26.2%) during initial hospitalization, with similar rates seen in low-grade and HG injury. A total of 1,051 children (86.4%) were observed with no bleeding or collecting system intervention. A bleeding intervention was undertaken in 48 patients (3.9%), the most common being an open surgical procedure (83.3%), and was more often performed in HG renal trauma (5.5% vs. 0.3%, $p \leq 0.001$). Thirty-three patients received a nephrectomy, and all had multiple injuries; 48.5% had this performed at the time of initial laparotomy. The mortality rate was 9.1%. The mortality rate in the remaining 1,183 who did not undergo a nephrectomy was 3.1%.

Table 3 describes the breakdown of intervention performed by AAST grade. Bleeding injury was performed with the highest proportion in Grade V renal injuries compared with other grades at 27.4%. There was no statistically significant difference in nephrectomy rate when comparing patients for whom a urologist was or was not involved in the care, at 2.0% versus 3.7% ($p = 0.109$).

A total of 219 (18.0%) had a collecting system injury. A collecting system intervention was performed in 7.9% of all patients or 37.4% of patients with collecting system injury (Table 1). Stent placement was performed in 7.2% of all patients, nephrostomy tube placement in 1.1%, and perirenal drain placement in 1.2% (Table 3). Collecting system interventions were

TABLE 1. Summary of Patient, Injury, and Hospitalization Courses, With Comparison Between Low-Grade and HG Renal Trauma

	Total n = 1,216* (%)	Low-Grade Renal Trauma (I and II) n = 385	HG Renal Trauma (III–V) n = 798	*p*
Age, mean (SD), y	12.3 (4.5)	12.7 (4.6)	12.2 (4.4)	0.016
Male, n (%)	817 (67.2)	244 (63.4)	550 (69.0)	0.062
Laterality				0.008
Left	597 (49.1)	174 (45.2)	404 (50.7)	
Right	573 (47.1)	203 (52.7)	357 (44.7)	
Bilateral	45 (3.7)	8 (2.1)	37 (4.6)	
AAST 2018 injury grade				
1	194 (16.0)			
2	191 (15.7)			
3	389 (32.0)			
4	336 (27.6)			
5	73 (6.0)			
Trauma mechanism				
Blunt	1,140 (93.8)	366 (95.1)	746 (93.5)	0.346
Penetrating	76 (6.2)	19 (4.9)	52 (6.5)	
Concomitant injuries				
Isolated renal trauma	356 (29.3)	80 (20.7)	275 (34.5)	<0.001
Multiple injuries	845 (69.5)	305 (79.2)	515 (64.5)	
ISS, mean (SD)	20.5 (13.2)	18.7 (13.3)	21.5 (13.2)	0.001
Transferred from another facility	705 (58.0)	192 (50.1)	495 (62.2)	<0.001
Involvement of urologist	656 (53.9)	113 (30.1)	540 (67.9)	<0.001
Hypotensive	50 (4.1)	15 (3.9)	32 (4.0)	1.000
Tachycardic	357 (29.4)	122 (30.8)	227 (28.2)	0.310
Tachycardic and hypotensive	26 (2.1)	9 (2.3)	17 (2.2)	0.996
Blood product transfusion	318 (26.2)	87 (22.8)	218 (27.7)	0.086
No intervention	1,051 (86.4)	374 (97.1)	648 (81.2)	<0.001
Any collecting system interventions	96 (7.9)	1 (0.3)	94 (11.9)	<0.001
Any bleeding interventions**	48 (3.9)	1 (0.3)	44 (5.5)	<0.001
Minimally invasive	11 (0.9)	0 (0.0)	11 (1.4)	0.046
Open	40 (3.3)	1 (0.3)	36 (4.5)	<0.001
ED disposition				
Operating room or interventional radiology	172 (14.1)	46 (11.9)	118 (14.8)	0.217
Intensive care unit	573 (47.1)	172 (44.7)	387 (48.5)	0.242
Floor or step-down unit	458 (37.6)	161 (41.8)	286 (35.8)	0.054
Home	11 (0.9)	5 (1.3)	6 (0.8)	0.052
Morgue	2 (0.2)	1 (0.3)	1 (0.1)	
Mortality	40 (3.3)	17 (4.4)	19 (2.4)	0.08
Length of hospitalization, mean (SD)	8.3 (16.5)	8.5 (23.4)	8.2 (12.3)	0.77

*Total numbers in each category may not add up to the total number of patients, 1,216 (100%), if there are any missing values. Missingness is reported in Supplemental Digital Content (Supplementary Table 3, http://links.lww.com/TA/D414).

**Three patients had an embolization followed by an open procedure (one nephrectomy, one renorrhaphy, and one partial nephrectomy).

about as likely in Grade IV injuries as in Grade V injuries (22.0% and 21.9%, respectively). A urologist was more likely to be involved in the care of patients requiring a collecting system intervention, at 94.8% versus 5.2% ($p \leq 0.001$).

No significant differences were found between low-grade and HG injury with regard to disposition from the emergency department, with almost half (47.1%) of all patients going to an intensive care unit. Few, or 0.9%, of all patients, were discharged home from the emergency department, half of whom had HG injury (Table 1).

Table 3 describes the breakdown of intervention performed by AAST grade. Concerning bleeding interventions, Grade V renal injuries had the highest incidence of bleeding intervention (27.4%). Collecting system interventions were about as likely in Grade IV injuries as in Grade V injuries (22.0% and 21.9%, respectively). Stent placement was performed in 7.2% of children, followed by nephrostomy tube placement (1.1%) and perirenal drain placement (1.2%).

Patient/Interfacility Transfer

More than half (58.0%) of patients were transferred from another facility (Table 1). Of those patients, 37.0% had an isolated renal trauma, 27.2% had a low-grade renal trauma, and 6.8% had

TABLE 2. Concomitant Injuries Found in Patients With Multiple Injuries, Comparing All Multiple Injuries With Those Who Suffered From Multiple Injuries and Died

Concomitant Injury	All Multiple Injuries (%) n = 845	Multiple Injuries With Mortality (%) n = 40
Liver	358 (42.4)	17 (42.5)
Spleen	325 (38.5)	16 (40.0)
Pancreas	59 (7.0)	2 (5.0)
Adrenal, ipsilateral	87 (10.3)	6 (15.0)
Adrenal, contralateral	13 (1.5)	2 (5.0)
Small bowel	68 (8.0)	6 (15.0)
Colon	29 (3.4)	4 (10.0)
Rectum	2 (0.8)	2 (5.0)
Spinal cord	53 (6.3)	4 (10.0)
Other neurologic injury	205 (24.3)	26 (65.0)
Orthopedic	321 (38.0)	21 (52.5)
Pelvic fracture	152 (18.0)	16 (40.0)
Rib	223 (26.4)	7 (17.5)
Spine	124 (14.7)	9 (22.5)
Major vascular injury	46 (5.4)	14 (35.0)
Bladder	0 (0)	0 (0)

an isolated low-grade trauma. Table 4 compares characteristics of transferred patients with those with initial presentation to our centers (nontransferred). No significant difference in demographics was seen. The mean ISS for transferred patients was 18.4, while that of nontransferred patients was 23.4 ($p < 0.001$). Significantly lower proportions of transferred patients had isolated renal trauma, penetrative trauma, and mortality. Transferred patients were not more likely to have no genitourinary intervention, but they were found to be more likely to have a collecting system intervention at 11.1% compared with 3.6% but less likely to have a bleeding intervention at 2.8% compared with 6.9%. The mean days to discharge was shorter in the transferred patients compared with nontransferred, at 7.0 versus 10.13 days ($p = 0.001$). The rate of avoidable transfer for the entire cohort was 28.2%.

TABLE 4. Characteristics of Patients Transferred From Another Facility Compared With Nontransferred

	Transferred	Nontransferred	*p*
n	705	507	
Age, mean (SD), y	14.03 (5.34)	14.08 (3.88)	0.885
Sex, n (%)			
Male	483 (68.5)	330 (65.1)	0.305
Trauma mechanism, n (%)			
Blunt	690 (97.9)	446 (88.0)	<0.001
Penetrating	15 (2.1)	61 (12.0)	
AAST injury grade, n (%)			
1	88 (12.5)	105 (20.7)	<0.001
2	104 (14.8)	86 (17.0)	
3	217 (30.8)	170 (33.5)	
4	229 (32.5)	107 (21.1)	
5	49 (7.0)	24 (4.7)	
Initial trauma center level (transferred population)			
2	155 (22.0)	–	–
3	177 (25.1)	–	
4	106 (15.0)	–	
5	23 (3.3)	–	
Concomitant injury			
Multiple injuries, n (%)	435 (61.7)	408 (80.5)	<0.001
Isolated renal injury, n (%)	261 (37.0)	93 (18.3)	
ISS, mean (SD)	18.38 (11.90)	23.40 (14.36)	<0.001
Involvement of urologist, n (%)	427 (60.6)	227 (44.8)	<0.001
Hypotensive, n (%)	22 (3.1)	28 (5.5)	0.01
Tachycardic, n (%)	174 (24.7)	182 (35.9)	<0.001
Tachycardic and hypotensive, n (%)	14 (2.0)	12 (2.4)	0.172
Blood product transfusion, n (%)	146 (20.7)	170 (33.5)	<0.001
No genitourinary intervention, n (%)	597 (84.7)	450 (88.8)	0.111
Collecting system intervention, n (%)	78 (11.1)	18 (3.6)	<0.001
Bleeding intervention, n (%)	20 (2.8)	35 (6.9)	0.001
Mortality, n (%)	13 (1.8)	27 (5.3)	0.001
Date of discharge, mean (SD), d	6.68 (11.65)	9.71 (16.12)	0.087

DISCUSSION

We herein introduce the first multi-institutional study of pediatric renal trauma. Before this study, the most comprehensive characterizations of pediatric renal injury have been derived from National Trauma Data Bank (NTDB) studies or from systematic reviews of small mostly single-institution studies.[3,16,17] National Trauma Data Bank studies have a host of accepted limitations,

TABLE 3. Interventions Performed by AAST Grade

	Total n = 1,216 (%)	AAST Grade I n = 194(%)	AAST Grade II n = 191 (%)	AAST Grade III n = 389 (%)	AAST Grade IV n = 336 (%)	AAST Grade V n = 73(%)	*p*
No intervention	1,051 (86.4)	187 (96.4)	187 (97.9)	371 (95.4)	241 (71.7)	36 (49.3)	<0.001
Any bleeding intervention	48 (3.9)	1 (0.5)	0 (0.0)	5 (1.3)	19 (5.7)	20 (27.4)	<0.001
Embolization	11 (0.9)	0 (0.0)	0 (0.0)	2 (0.5)	7 (2.1)	2 (2.7)	0.019
Partial Nephrectomy	2 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.6)	0 (0.0)	0.282
Nephrectomy	33 (2.7)	1 (0.5)	0 (0.0)	1 (0.3)	10 (3.0)	19 (26.0)	<0.001
Renorrhaphy	5 (0.4)	0 (0.0)	0 (0.0)	3 (0.8)	1 (0.3)	0 (0.0)	0.443
Any collecting system intervention	96 (7.9)	1 (0.5)	0 (0.0)	4 (1.0)	74 (22.0)	16 (21.9)	<0.001
Ureteral stent	87 (7.2)	0 (0.0)	0 (0.0)	3 (0.8)	67 (19.9)	16 (21.9)	<0.001
Nephrostomy	13 (1.1)	1 (0.5)	0 (0.0)	0 (0.0)	10 (3.0)	2 (2.7)	0.001
Perirenal drain	14 (1.2)	0 (0.0)	0 (0.0)	3 (0.8)	10 (3.0)	1 (1.4)	0.006

There is a 2.7% missingness for AAST grade, and so the sums across each intervention may be less than the total.

including variations in coding, being limited to the first hospital encounter, and poor granularity in variables. Mi-PARTS endeavors to improve upon existing efforts by substantially increasing patient numbers while maintaining robust demographic and clinical detail, all while still providing generalizable data reported from all regions of the continental United States.

The cohort is consisted of patients presenting to 13 Level I trauma centers across the United States over a 10-year period. Pediatric renal trauma was rare, even in pediatric institutions, and was present in 1% or less of all trauma patients seen at the participating institutions. This is similar to that described in a previous NTDB study.[17]

Isolated renal injury represented over a quarter of our patient cohort. This is higher in comparison with published adult studies, which have previously described an incidence of isolated renal trauma around 5% to 20% of all renal traumas.[18] Children are known to be at increased risk for HG renal injury compared with adults because of several anatomic or congenital factors.[1,19] Low-grade renal injury was associated with a significantly lower ISS compared with HG injury but is still substantial at 18.7, suggesting significant associated multiple injuries. This is consistent with the common experience at a trauma center, where isolated injuries are rare. Multiple injuries can therefore not be excluded in the study of renal trauma and indeed represents the typical patient population at a trauma center. Nonetheless, we acknowledge that multiple injuries add complexity to the study of renal trauma, especially questions around avoidable transfer. Isolated renal trauma made up 37% of all transferred patients and were mostly HG injuries. None of the patient with isolated renal trauma died from the injury.

We report an overall low rate of mortality of about 3%. All deaths were attributed to the severity of the overall multiple injuries; a significant association of mortality was found with the mean ISS and the presence of concomitant injury, and not with the renal injury itself. Concomitant injuries in those with and without mortality are presented in Table 2; the rate of neurologic injury was significantly higher in those with mortality, while other solid organ injuries were not significantly different. Mortality in our cohort is roughly half that found in the pediatric NTDB study by Grimsby et al.[16] One possible explanation for this lower rate is that this study includes only Level I trauma centers, whereas the NTDB studies include all trauma levels (I–V). Van Ditshuizen et al.[20] demonstrated that mortality is lower for major trauma populations at Level I trauma centers that have designated pediatric critical care capabilities that lower-level centers do not have. In addition, our cohort includes a large number of patients transferred from other facilities. We see among our own cohort that nontransferred patients have higher mortality, suggesting potential sampling bias to include those who had survivable injuries and those who were overtriaged.

A large majority of patients were managed nonoperatively, consistent with the 85% rate reported by Grimsby et al.[16] in their pediatric NTDB study. We identified a low rate (2.7%) of nephrectomy, about half the rate reported in the NTDB study (5.5%).[16] As mentioned previously, it is possible that nephrectomies are performed more frequently outside of participating Level I trauma centers in an emergent fashion and possibly in more patients with nonsurvivable injury. The mortality rate in the children who underwent nephrectomy in our study is similar to that reported in the adult literature.[21,22]

We report the rate of bleeding intervention to be around 5%, even in HG renal trauma. This is lower in the adult population, in which rates may reach 14%.[5] This may be driven by the different compensatory mechanisms in pediatric shock compared with adults, reflected in the relatively few patients who exhibited both tachycardia and hypotension in our cohort—3% compared with 23% in the adult population reported in Mi-GUTS.[5] This could secondarily dampen the trigger for intervention. There may also be stronger provider preferences to avoid intervention in this population. While our study is consistent with previous reports that HG injuries are more likely to proceed to bleeding intervention, the current AAST grading system remains an imperfect predictor of bleeding risk and complications.[23,24] The Mi-GUTS nomogram recently demonstrated superiority of using both clinical and radiographic findings in predicting need for bleeding intervention.[5] However, the aforementioned differences in these populations, together with considerations such as smaller patient size, call into question translatability of this nomogram to the pediatric population. In a second phase of our study, we are undergoing imaging review with the goal of assessing radiologic parameters that are predictive of the need for a bleeding intervention.

Although society guidelines give clear preference for minimally invasive surgical interventions including renal angioembolization for bleeding intervention over open surgical intervention, we found that nephrectomy was the main bleeding intervention performed at 68.7% compared with angioembolization, which was only performed in 22% of bleeding interventions. A similar trend was reported for adult HG renal injuries by Mi-GUTS.[25] Interestingly, the Eastern Association for the Surgery of Trauma meta-analysis found that, among a total of 62 children who presented with HG blunt renal trauma, 18 (29%) underwent angioembolization and 9 (14.5%) underwent open surgical intervention.[3] This difference likely reflects small sample sizes, reporting biases, and institutional preference. It is less likely to reflect unavailability of interventional radiology services, given availability at all participating centers, but moreso the acuity of patients as previously described in a survey of practice patterns of practitioners managing HG renal trauma at Level I trauma centers.[26] Primary reasons for nephrectomy were hemodynamic instability with inadequate response to resuscitation or performed at the time of laparotomy for concomitant injuries. However, it bears mentioning that all nephrectomies were performed in patients with multiple injuries, and half were performed at the time of initial laparotomy. We assume that all nephrectomies were performed based on guideline-directed clinical decision making and that the retroperitoneum was not routinely opened during trauma laparotomy.

A third of patients with a collecting system injury had a collecting system intervention performed. Comparison in incidence between previous studies is made difficult because of variable practices in the diagnosis of such injury and management. Indeed, this is an aspect of renal trauma for which extrapolation from adult guidelines is particularly difficult. For example, preferences to minimize radiation exposure in children challenges guideline-directed reimaging practices that are perhaps more routine in adults. Proposals around the timing of and indications for collecting system intervention have been the subject of single-institution studies.[7,27–29] Protocols for ultrasonography or limited use of follow-up cross-sectional imaging have also been described but have not yet gained traction.[28,29] In an internal survey among the principal investigators of this study, we found significant differences in practice management of collecting system management, as well as antibiotic prophylaxis and bedrest.[30] The trend of decreased use of bedrest reported here reflects changes in attitudes toward this practice, which has no proven benefit that we are aware of. Future work aims to harness this practice heterogeneity inherent to this multi-institutional study to better provide guidance for these aspects of management.

Pediatric patients have been shown to have higher rates of secondary overtriage, with subsequent greater rates of transfer to a higher level of care compared with adult patients.[31,32] Half of the patients included in this study were transferred from another facility. Few underwent an intervention, and 5% had an isolated low-grade renal trauma. The rate of avoidable transfer in our study was consistent with the 27% avoidable transfer rate reported by Fenton et al.,[14] who included all types of pediatric trauma in their study. The mean ISS of transferred patients was 18.4, which, although significantly lower than that of nontransferred patients, still represents considerable multiple injuries. Even so, Iyer et al.[33] previously reported that 70.4% of avoidable transfer had an isolated renal injury. An NTDB study identified a 22.4% avoidable transfer rate for all pediatric trauma using additional criteria of ISS of <9.[34] Together, these continue to emphasize that the decision making around transfer is multifactorial and difficult to assess in a retrospective manner. Urologists are instrumental in guiding collecting system interventions but are less likely to be involved in decision making around bleeding interventions. Urologists are not always readily available outside of Level I trauma centers, and so may play a role when considering transfer of a patient.

The Mi-PARTS study presents some inherent limitations. All data were retrospectively collected through chart review across institutions. We are therefore unable to ascertain to what extent transfer to a higher level of care, transfusion, surgical interventions, and death were related to the renal trauma in of itself. Only Level I trauma centers participated in this study, which may limit generalizability in interpretation of the data outside of such settings. These data are also subject to transcription errors and data availability. We attempted to homogenize data definitions; however, data collection error and differences in variable interpretation are inherent in multicenter collection. Four individuals reported as AAST Grade III injuries ultimately underwent a collecting system intervention despite this injury severity not involving a collecting system. This may point to the use of presumptive intervention but more likely points to grading subjectivity that may be resultant of variability in radiological evaluation. It is also possible that the collecting system injuries were not identified initially and that the collecting system injury indicates a misgrading of these injuries. Even so, this remains a comprehensive data set with a relatively low level of missingness that reflects the effort of all institutions for rigorous and homogeneous data collection.

CONCLUSION

This is the largest study of pediatric renal trauma to date. It confirms demographic trends previously demonstrated in smaller studies and the safety of nonoperative management. It introduces the opportunity to identify characteristics that may optimize our management of this condition. With data made available through Mi-PARTS, we aim to answer pediatric specific questions that include assessment of imaging practices, bleeding risk, need for collecting system interventions, and others.

AUTHORSHIP

C.K.H., R.M., A.J.S., and J.C.H. designed and conceived of this study. C.K.H., R.M., J.W., A.K.B., K.T.K., A.S., G.S., S.S., A.B.H., K.A.Z., G.C.K., B.E.L., M.S., X.L.-O., J.R.S., M.S., M.E.R., N.V.H., H.M.L., B.N., I.S., K.F., T.P., and J.C.H. extracted data. C.K.H., J.S., and P.N. analyzed the data. C.K.H. and J.C.H. prepared the article. All authors reviewed a draft of this article. C.K.H., R.M., A.J.S., S.A.Z., K.T.F.-O'.B., N.F., K.A.Z., J.M.D., C.C., F.B., R.A.M., V.M.V., H.C., B.B., I.S., P.N., and J.C.H. performed critical revision of the article.

DISCLOSURE

Conflict of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/D415).

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