Seminars in Pediatric Surgery 30 (2021) 151085

Contents lists available at ScienceDirect

Seminars in Pediatric Surgery

journal homepage: www.elsevier.com/locate/sempedsurg

Trauma in pediatric urology

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ARTICLE INFO

Children
Renal Injury
Renal Vascular Injury
Ureteral Injury
Bladder Injury
Urethral Injury

ABSTRACT

In pediatric trauma, the kidney is the most commonly injured organ of the urinary tract. Renal trauma occurs in 10% to 20% of all pediatric blunt abdominal trauma cases. The vast majority of renal injuries can be treated conservatively. However, cases associated with hemodynamic instability require operative interventions. Injuries to the ureter, bladder or urethra are almost exclusively encountered in polytraumatized children. The aim of this article is to give an overview on traumatic injuries to the pediatric urinary system.

Renal injury

Epidemiology and mechanisms of injury

In children, the kidney is the most commonly injured organ of the urinary system.[1] Renal trauma occurs in 10% to 20% of all pediatric blunt abdominal trauma cases and the kidney is more frequently injured than the spleen, liver, pancreas or bowel. While in European studies up to 95% of renal injuries are caused by blunt trauma, penetrating trauma is described more often in American reports.[2]

In comparison to adults, children seem to be more susceptible to renal injury following blunt abdominal trauma.[3] In a retrospective data base study including 1,093 children with renal injuries following motor vehicle accidents, children had 48% higher odds of renal injuries compared to adults aged 20-50 years.[4] Underlying reasons include a decreased amount of perirenal fat, incompletely ossified lower ribs, weaker abdominal muscles and the fact that the kidneys are relatively larger compared to the rest of the body.[5]

In a report including 2,213 cases of pediatric renal injuries, more than half of the patients were adolescents aged between 15 and 18 years.[1] Only 6% of the patients were younger than 5 years. Moreover, about two thirds of children sustaining renal injuries are male.[1,4]

Pediatric renal injuries are usually caused by either rapid deceleration forces or direct blows to the flank due to falls, sports injuries, bicycle or motor vehicle accidents.[6,7] The pediatric kidneys are relatively mobile within Gerotaś fascia. Therefore, deceleration causes crushing of the kidney against the ribs or the vertebral column resulting in laceration or contusion. In rare cases, fractured ribs can cause direct injury to the kidneys.

Clinical examination

Renal injuries should be suspected in all cases with an adequate mechanism of injury and appropriate clinical findings including flank bruising and pain, abdominal mass and distension or fractured lower ribs. In case of penetrating trauma (gunshot or stab wounds) the location of entrance and exit wounds can be suggestive of renal injuries.[8]

Due to the underlying high energy mechanisms causing blunt renal injuries, concomitant injuries of the liver, spleen and bowel have to be ruled out.

Urinalysis, hematocrit and baseline creatinine levels have to be performed mandatorily. The hallmark of renal injury is hematuria. *Microscopic* hematuria (defined as four or more red blood cells per high-power field) can be found in most but not all children with blunt renal trauma.[6,9] In a retrospective review of 68 children sustaining renal trauma 20% of the patients with both low- and high-grade injuries did not have microscopic hematuria.[6] Even major injuries such as disruption of the ureteropelvic junction, pedicle injuries and segmental arterial thrombosis can occur without hematuria.[10] Higher grade injuries, however, are associated with increased rates of *gross/visible* hematuria.[6] It is important to acknowledge that studies have reported *visible* hematuria in only 56%-88% of pediatric blunt renal trauma cases.[11–13]

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https://doi.org/10.1016/j.sempedsurg.2021.151085

Significant pediatric kidney injury seems to be unlikely in the absence of gross or significant microscopic hematuria (>50 red blood cells per high-power field).[14] Therefore, it has been recommended that pediatric patients with blunt trauma, microscopic hematuria and no other associated injuries do not require further radiologic evaluation, as significant renal injuries are unlikely.[15] Nevertheless, it has to be kept in mind that in children hematuria may also be the presenting symptom of congenital anomalies and renal neoplasms such as Wilms tumors.[16,17] In fact, undiagnosed pre-existing renal abnormalities are found in up to 19% of children undergoing imaging of the abdomen for trauma.[18] Taken together, it seems to be advisable to perform further radiological examinations in all cases of clinically suspected renal lesions with both microscopic or visible hematuria.[6]

In adults, radiographic imaging is suggested only in patients who present with gross hematuria or microscopic hematuria and hypotension (systolic blood pressure less than 90 mmHg), high index of suspicion for abdominal injuries and high velocity trauma mechanisms as significant renal injuries are unlikely in patients who do not meet these criteria.[16,19] In children, however, hypotension is a late manifestation of hypovolemia and therefore cannot be considered a reliable indicator to perform further imaging.

Imaging

The main objectives of renal trauma imaging are to adequately stage the injury of the kidney, to reveal preexisting pathologies and to identify concomitant injuries to other organs.

Guidelines by the European Association of Urology on upper urinary tract injuries published in 2014have stated that even though sonography may help to identify patients requiring more detailed investigations and is useful for follow-up examinations of parenchymal lesions, hematomas and urinomas, it has a low sensitivity for detecting renal lacerations.[10] Likewise, the WSES-AAST (World Society of Emergency Surgeons and American Association for the Surgery of Trauma) guidelines recommend ultrasound in pediatric patients as an alternative to CT in the presence of hemodynamic stability during the immediate assessment and in follow-up examinations.[20] Following initial CT for accurate staging of pediatric blunt renal trauma, sonographic monitoring is safe in most pediatric patients excluding those with hemodynamic instability.[21,22]

Contrast enhanced computed tomography (CECT) with a delayed urographic phase is considered the gold standard for grading renal injuries.[23] It allows accurate evaluation of the renal parenchyma, vasculature and the collecting system with a negative predictive value of as high as 99.8%.[15,24–26] Therefore, CT is recommended in pediatric patients with high energy/penetrating/deceleration trauma and/or in cases of drop in hematocrit associated with any degree of hematuria.[20] Furthermore, Dalton and coworkers recommend performing CT as initial imaging modality in pediatric patients with concerns for intra-abdominal injury and visible or microscopic hematuria.[16]

The exposure to ionizing radiation coupled with a higher radiosensitivity of children compared to adults, associated costs and the absent therapeutic consequences (most renal injuries do not require any intervention), however, have challenged the routine use of CT imaging for diagnosing pediatric renal trauma. It is unquestionable that an initial CT scan allows accurate grading of the renal injury and detection of hematomas, urinomas, extravasation and renal fragmentation. Nevertheless, an increasing number of trauma centers no longer guide their management solely by the grade of injury.[27] As a consequence, studies have assessed the necessity of CT examinations of pediatric patients with blunt renal trauma. In a prospective observational study Streck et al. have developed a prediction rule using history and physical examination, chest x-ray, and laboratory evaluation at the time of presentation after blunt abdominal trauma and could successfully identify children at very low risk for intra-abdominal injuries for whom CT could be avoided.[28] Additional future studies should aim to develop well-defined guidelines based on injury mechanism, clinical findings and non-invasive, non-radioactive imaging modalities to limit the number of "unnecessary" negative CT scans without missing significant renal injuries.[29]

In a recent retrospective study a comparison between renal ultrasound and contrast enhanced CT images including 76 patients, 24 of which had a renal injury, was performed. Renal ultrasound images had a sensitivity of 79-100% to detect grade III-V injuries and negative predictive values of 97-100%.[30] Likewise, another prospective study has demonstrated a high accuracy and specificity of ultrasound for detecting pediatric liver, spleen and kidney injuries.[31] Contrast enhanced ultrasound (CEUS) has emerged as a promising tool to assess renal injuries.[32] This method improved sensitivity over gray-scale ultrasound in trauma because it depicts organ perfusion and therefore increases the conspicuity of injury. CEUS is well-suited to solve unclear findings in gray-scale ultrasound, but is not near as good as CT or MRI in screening for multiple pathologies in different organs and regions. It also requires distinct training and experience. While it seems reasonable to consider alternative imaging methods such as CEUS in hemodynamically stable patients, further larger scale prospective studies are necessary to determine to sensitivity and specificity of this method in pediatric renal trauma.

Intravenous pyelography (IVP) has been historically used. It has been shown that IVP is interpreted as normal in up to 20% of patients with major renal injuries. Moreover, a sensitivity of only 50% has been demonstrated for IVP.[15] Therefore, it is not recommended anymore as diagnostic tool in the initial evaluation of patients with blunt renal trauma and has been replaced by other diagnostic modalities.

Grading

Renal injuries are graded according to the American Association for the Surgery of Trauma (AAST) Organ Injury Scale (OIS) based on CT findings .[33] While grade I describes a subcapsular hematoma and/or parenchymal contusion without lacerations, a grade V injury is defined as a completely shattered kidney (Table 1 and Figure 1). Originally developed and validated for adult patients

Table 1
Kidney Injury Scale according to the 2018 update of the AAST OIS.[33]

AAST Grade	Imaging Criteria
I	- Subcapsular hematoma and/or parenchymal contusion without laceration
II	- Perirenal hematoma confined to Gerota fascia - Renal parenchymal laceration ≤1 cm depth without urinary extravasation
III	- Renal parenchymal laceration >1 cm depth without collecting system rupture or urinary extravasation - Any injury in the presence of a kidney vascular injury or active bleeding contained within Gerota fascia
IV	- Parenchymal laceration extending into urinary collecting system with urinary extravasation - Renal pelvis laceration and/or complete ureteropelvic disruption - Segmental renal vein or artery injury - Active bleeding beyond Gerota fascia into the retroperitoneum or peritoneum - Segmental or complete kidney infarction(s) due to vessel thrombosis without active bleeding
V	- Main renal artery or vein laceration or avulsion of hilum - Devascularized kidney with active bleeding - Shattered kidney with loss of identifiable parenchymal renal anatomy

More than one grade of kidney injury may be present and should be classified by the higher grade of injury; advance one grade for bilateral injuries up to Grade III

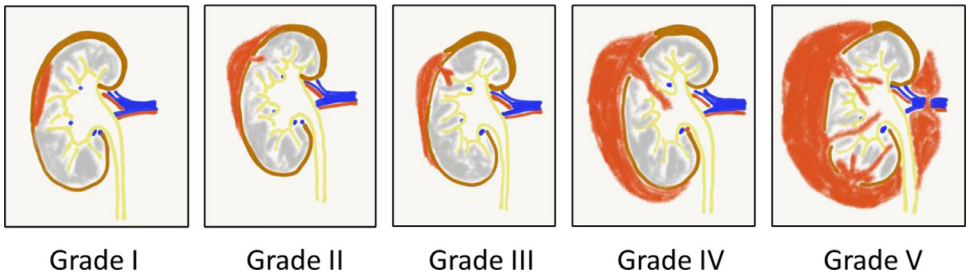

Figure 1. Grading of renal injuries according to the 2018 revision of the AAST OIS.[33]

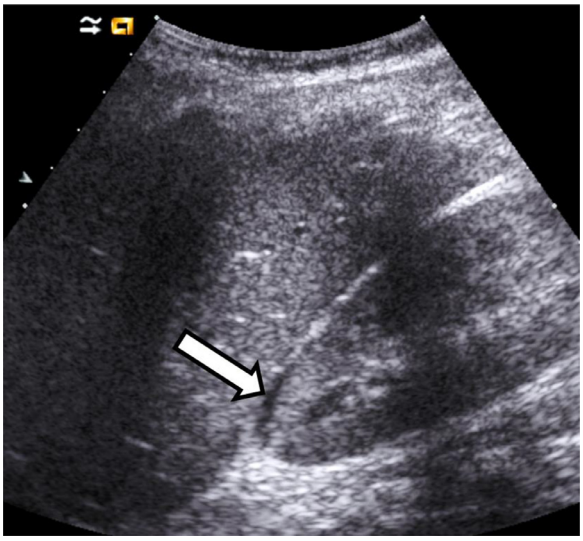

Figure 2. Ultrasound image of the right kidney in a 15-year-old male adolescent following a bicycle accident showing a small posttraumatic subcapsular haematoma (arrow) defined as grade I injury.

the AAST system is also used to grade pediatric injuries. Its advantages include the ability to predict the need for intervention as well as the morbidity and mortality.[10] Examples of different grades of injury are shown in Figures 2-4.

In a recent US study analyzing 2,213 pediatric patients between 0 and 18 years derived from the National Trauma Data Bank, almost 80% were grade I, II and III injuries and only 16% and 5% were grade IV and V injuries, respectively.[1]

Therapy

The therapeutical regime of pediatric renal injuries has shifted from an aggressive surgical approach in the past to a non-operative observational approach in the present for most patients.

It is generally accepted that prolonged observation is not necessary in patients with grade I and II injuries and that conservative treatment should also be performed in grade III injuries.[10] The optimal treatment of higher grade renal injuries, however, is still a matter of debate. Even though grade IV and V injuries are associated with higher rates of surgical interventions and complications, initial observation is feasible provided that the patients are hemodynamically stable (Figure 5).[34]

In a study including 419 higher grade renal injuries (grade IV and V) Jacobs and coworkers have demonstrated that initial conservative management decreases the rate of nephrectomies to 11%.[35] Likewise, Umbreit et al reported that non-operative management of children with grade IV injuries is highly successful with a partial renal preservation in 95% of patients.[36] Consequently, a recently published meta-analysis stated that "in pediatric patients with blunt renal trauma of all grades, we strongly recommend non-operative management versus operative management in hemodynamically stable patients."[37]

Conservative treatment consists of bed rest, frequent vital sign evaluation, hemoglobin/hematocrit measurements, pain therapy and intravenous fluid replacement.[38] The length of bed rest has not been clearly defined, but generally it is performed until resolution of visible hematuria. Routine placement of urinary catheters as well as antibiotic prophylaxis do not seem to be necessary.[16] Periodical monitoring of the injury can safely be performed with sonography to rule out complications such as increasing urinary extravasation or ongoing hemorrhage. Recommended time points range from 4-24 hours to 48 to 72 hours following the initial scan.[5,39]

In clinically unstable patients with no or only transient response to resuscitation immediate surgical intervention has to be performed.[23] Other findings described as relative indications for surgical exploration are massive urinary extravasation, extensive (>20%) non-viable tissue and arterial injury.[5] The most commonly performed reconstructive technique is renorrhaphy which is indicated if the injury is not too severe. Partial nephrectomy should be performed to resect non-viable renal tissue. Nephrectomy is performed if the kidney is not salvageable or in case of life-threatening bleeding which cannot be controlled by other measures.[40] Nephrectomy has been shown to be necessary in 3% of grade IV renal injuries and 11% of grade V injuries.[36,41] However, repair should be attempted especially in cases of bilateral injuries or unilateral kidneys.

While a large database study including more than 12,000 pediatric patients with renal trauma, trauma level designation was not found to be predictive for more aggressive management, [42] Grimsby and coworkers have found that the rate of nephrectomies at adult hospitals was 3 times higher than that of pediatric centers suggesting that the rate of organ preservation may be increased in dedicated pediatric hospitals.[1] However, as the authors have stated, the data were not controlled for grade and nature of the lacerations as well as the presence of concomitant injuries.

Angioembolization is successfully used in adult patients to control active renal bleeding.[43] Consequently, several studies have reported successful embolization in children with high-grade injuries, active bleeding with contrast blush on CT even in cases with threatening or persistent hemodynamic instability.[44–46] In adults, repeated embolization has been shown to prevent nephrectomy in more than three quarters of high-grade renal injuries. Patients with failed attempts of embolization usually require nephrectomy in the further course.[47] However, there are currently no valid guidelines when embolization should be performed in a pediatric population.

The therapeutic consequences of the development of urinoma and extravasation of urine remain a matter of vivid debate. Most urinomas are asymptomatic and will resolve in up to 90% of the patients without major intervention.[48] Umbreit and colleagues

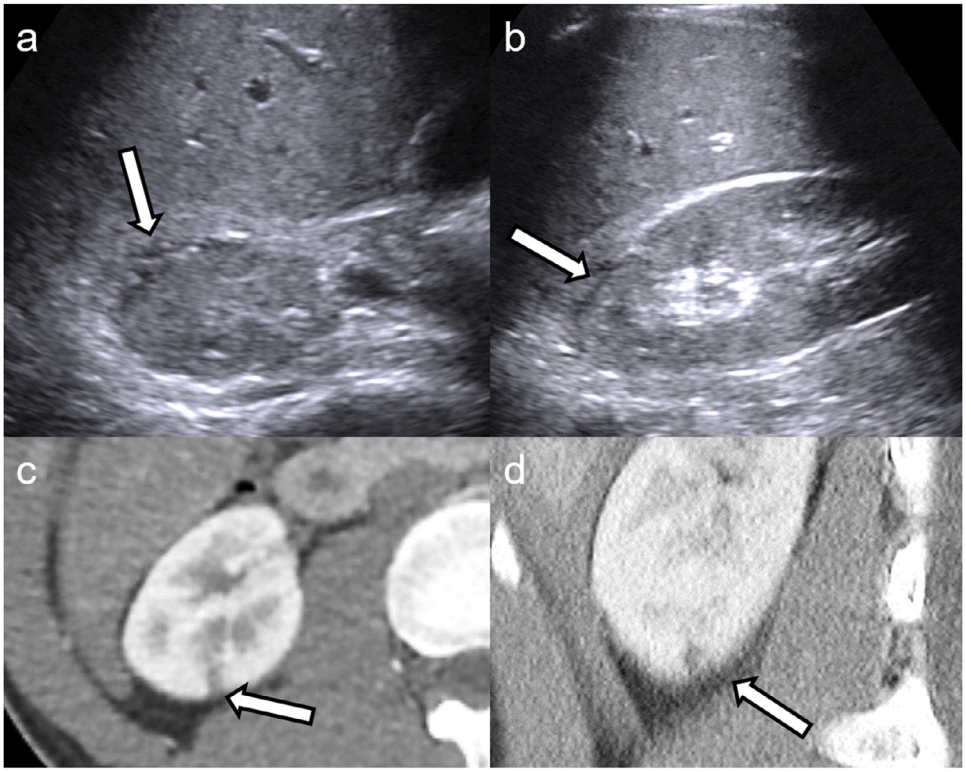

Figure 3. Renal ultrasound of a 17-year-old adolescent in axial (a) and coronal (b) plane on the right side. Slight subcapsular fluid is noted. Contrast-enhanced CT (axial (c), coronal (d)) revealed a grade II injury at the lower kidney pole with a depth below 1 cm diagnosed as grade II injury.

have performed a meta-analysis and systematic review including 95 children with grade IV renal injuries. 17% of the included patients developed symptomatic urinomas defined as concomitant ileus, worsening flank pain, fever, expanding urinoma on repeated imaging and persistent urinary excretion >20 days (Figure 6A-D).[36] Most of these patients could be successfully treated with percutaneous drainage and/or ureteral stent placement. Nevertheless, operative repair is required in the rare cases of complete avulsion of the ureteropelvic junction.[20]

The necessity and duration of observation on intensive care units (ICUs) vary considerably in the literature ranging between 24 hours and one week.[38] While several authors recommend observation on the ICU, others do not admit stable patients to the ICU at all.[16] However, close clinical observation with hemodynamic monitoring in an intensive care environment has been recommended especially for higher grade injuries.[20]

Guidelines are also lacking regarding the length of total hospital stay. In a considerable amount of studies the total length of hospital stay is not recorded. Graziano and coworkers prospectively applied an abbreviated protocol in the management of blunt renal injury in children. Mobilization was immediately allowed regardless of injury grade and patients were discharged when tolerating diet and pain regardless of hematuria. Their mean length of stay was 2.9 days; however only four patients had grade V injuries and 7% of the patients had to be readmitted for either pain, hematuria or bladder clot.[45] Most of the other studies report lengths of stays of approximately 10 days increasing with the grade of injury.[38]

There is no robust evidence regarding return to sports activities following renal injuries. Following low-grade injuries two to six weeks seem to be reasonable. Higher-grade injuries may require longer periods.[20] As a potential indicator complete absence of microscopic hematuria has been described.[49]

Complications and outcome

Early complications of renal injuries include persistent bleeding, infection, perinephritic abscess, sepsis, urinary fistula, urinary extravasation and development of urinomas.[10] The risk of developing complications significantly increases with the grade of injury.[50] Grade I, II and II injuries carry a low risk of complication and repeat imaging and close follow-up are likely not necessary.[50] However, it seems to be advisable to routinely perform repeated sonographic scanning in higher grade injuries to facilitate timely diagnosis of complications. However, the usefulness of this measure in otherwise asymptomatic children has not been satisfactorily proven.

Generally, conservative treatment is associated with high success rates with renal salvage rates exceeding 90%.[17] Children with grades II to IV injuries managed conservatively retain near normal function. Those with grade V injuries have a loss of function attributable to scarring and parenchymal volume loss.[51] Decrease in renal function at follow-up directly correlate with renal injury grade.[52] Therefore, long-term follow-up examinations of children with higher grade renal injuries may be warranted.

There is a low risk of developing hypertension after pediatric higher grade renal trauma. Hypertension after renal trauma is usually seen during the initial hospitalization, rather than subsequently during the long-term follow-up.[53] In another study 10% of the patients with grad IV and 50% with grade V injuries developed de novo hypertension, all within 2 months of their injury.[50] Recently, the Eastern Association for the Surgery of Trauma and the Pediatric Trauma Society have published pediatric blunt renal trauma management guidelines.[37] One of the main questions was whether blood pressure examination should be performed in cases of blunt renal trauma. The authors stated that due to the heterogeneity and variability of reporting a meta-analysis could not be performed to answer this question. Therefore, it still seems

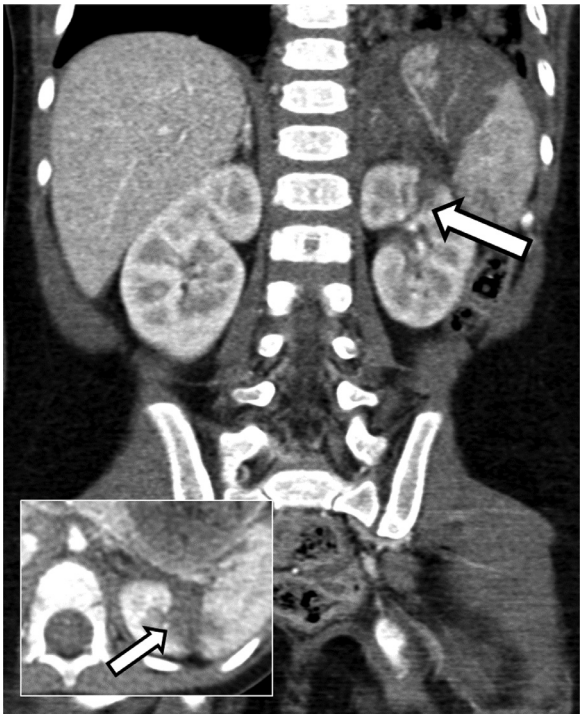

Figure 4. Contrast-enhanced polytrauma CT scan of the abdomen in coronal orientation in a toddler hit by a wooden truss. Apart from lung contusions and splenic lacerations, an upper pole kidney laceration (arrows) was noted. The laceration was deeper than 1 cm, regarded as grade III injury. The inlet shows an axial detail image of the renal laceration.

Figure 5. Contrast-enhanced polytrauma CT scan of the abdomen in coronal orientation in a polytraumatized 12-year-old male following a motorcycle accident. Grade V injury of the left kidney with no contrast enhancement of the lower part of the kidney and perirenal hematoma. The remaining parts of the kidney are shattered.

advisable to repeatedly examine patients with high-grade injuries in order to rule out the development of hypertension.

Renal vascular injuries

Injuries of the renal vasculature rarely occur as an isolated event and are frequently associated with other major abdominal injuries.[54,55] Vascular stretch lesions following blunt abdominal trauma can cause intramural hematomas or intimal tears leading to partial or complete obstruction of the renal artery. Renal artery occlusion is a rare complication of blunt abdominal

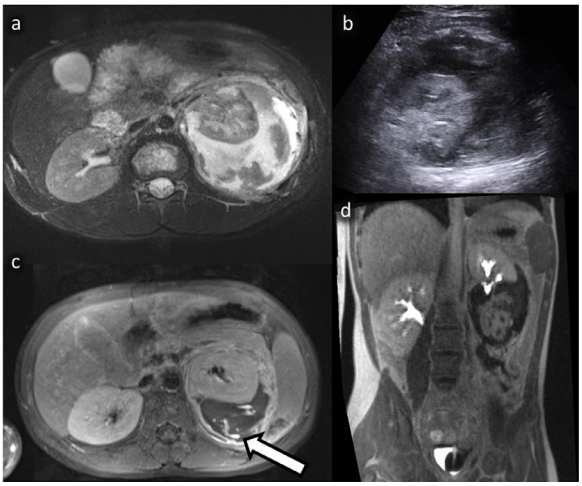

Figure 6. A-D: Urinoma after grade V injury of the left kidney (patient seen in Figure 5). The left lower moiety is devascularized. T2-weighted MRI (A) and ultrasound (B) in axial orientation demonstrate heterogeneous perirenal fluid collections. After administration of intervenous contrast, MRI shows contrast leakages (C) in terms of an urinoma. Note the devascularized caudal renal portion on the left (D). Due to expanding urinoma the patient was treated with ureteral stent placement and percutaneous drainage. In the further course the devascularized part of the left kidney was resected.

Table 2
AAST ureteric injury severity scale.[66]

Grade	Ureteral Injury
I	Hematoma
II	Laceration <50% of circumference
III	Lacerartion >50% of circumference
IV	Complete tear <2cm of devascularization
V	Complete tear >2cm of devascularization

trauma with a reported incidence rate of 0.1%.[54,56] Management algorithms for these patients advise a non-operative approach in hemodynamically stable patients with a normal perfusion of the contralateral kidney, as normal, long-term kidney function is rarely achieved.[54,55] Patients after complete renal artery occlusion need close follow-up for the risk of hypertension. However, the available information is based on small case numbers and large meta-analyses are still lacking.[54]

Ureteral injuries

Due to its small size, mobility and protected location, ureteral lesions are the least common type of genitourinary injuries occurring in less than 1% of pediatric abdominal trauma.[57] Injuries of the ureter are frequently associated with other organ injuries.[58] According to the AAST ureteral lesions are classified into 5 grades (Table 2). The majority of the ureteral injuries is caused by penetrating wounds, but significant injury of the ureter can also occur in blunt trauma, due to the overextension of the pediatric spine, especially in high energy deceleration trauma.[10] Mild perirenal stranding or hematoma and low-density retroperitoneal fluid around the genitourinary tract on initial CT scans must be highly suspicious for ureteral injuries.[59] The diagnostic accuracy of the CT scan can be improved by performing an intravenous contrast-enhanced CT with delayed excretory phase. However, a retrograde pyelogram is seen as the diagnostic procedure of choice in children.[60]

Low-grade ureteral lesions, such as partial lacerations under 50% of the circumference (AAST grade II) may be managed with ureteric stenting alone.[20] If stenting is unsuccessful, minimally invasive procedures such as percutaneous nephrostomy tube

drainage are recommended .[57] For more severe grades, the treatment depends on the location of the injury. During emergency laparotomy direct visualization of the ureter is advisable and ureteral lesions above the iliac vessels should be repaired by either primary uretero-ureterostomy or ureteral re-implantation procedures in case of distal injuries.[20,57] The routine use of ureteral stents is highly recommended following surgical repairs.

Bladder injuries

The bladder represents the second most commonly affected organ in pediatric urinary trauma. In contrast to adults, the bladder is significantly less protected due a more exposed position above the pelvic ring, the scarcely developed abdominal adipose tissue and the poorly developed rectus muscles.[60] High energy trauma mechanisms are necessary to cause bladder injuries. Therefore, up to 57% of pediatric patients with bladder rupture suffer from concomitant pelvic fractures.[61] On the other hand, the incidence of bladder injuries in children with pelvic fractures ranges between 0.5% and 18.6%.[62] Clinical symptoms of bladder rupture include abdominal distension, urinary retention, suprapubic tenderness and visible hematuria, the cardinal symptom of bladder injury.[61] In patients with the combination of pelvic fracture and macrohematuria, bladder rupture must be suspected. For diagnostic evaluation, the bladder should be retrogradely filled and imaged fully distended as well as performing a static or cystic cystography after drainage.[60] In children with a normal genitourinary examination, normal voiding and absent gross hematuria lower urinary tract imaging is not required.[62]

Bladder injuries are classified into contusions, intra- and extraperitoneal ruptures or combined lesions. Contusions can be managed conservatively but may require transurethral drainage in case of larger pelvic hematoma or bladder neck distortion.[63] Intraperitoneal bladder ruptures mainly affect the bladder dome, the weakest and most mobile part of the bladder, and require surgical repair.[61] The majority of bladder injuries, however, are extraperitoneal ruptures due to blunt trauma mechanisms.[64] Uncomplicated, isolated extraperitoneal ruptures can be managed with transurethral catheter drainage and prophylactic antibiotics.[63] Indications for surgical repair are persistent extravasation, concomitant vaginal or rectal injuries, bladder neck lesions and patients undergoing laparotomy for other injuries or internal fixation of a pelvic fracture.[63] A repeat cystogram is usually performed after 7-10 days to exclude persistent leakage.[60]

Urethral injuries

Urethral injuries are rare and mainly affect male patients following blunt trauma.[20] The hallmark signs of urethral are blood at the meatus combined with perineal and penile hematoma or inability to void.[57] Rectal examination is obligatory in male patients to determine the position and fixation of the prostate which may be displaced out of the pelvis.[60] Urethral lesions can be classified into anterior (bulbar and penile) and posterior injuries (prostatic or membranous).[20] The recommended diagnostic method for evaluation of pediatric urethral trauma is a retrograde urethrogram.[57]

The majority of children with urethral trauma is hemodynamically unstable due to combined injuries requiring urinary drainage with a suprapubic catheter as first step.[57,60] A transurethral catheter should only be used if there is a history of voiding after the trauma and in absence of clinical signs for urethral rupture.[20,57] In anterior urethral injuries the initial management is conservatively with a transurethral catheter preventing urethral bleeding or painful voiding.[60] The management of posterior urethral injuries is still discussed controversially with either immediate primary re-anastomosis or suprapubic drainage with delayed repair.[57,60] The aim of a delayed urethral repair is to restore an adequate urethral caliber and to reduce long-term complications, such as stricture formation, urinary incontinence or erectile dysfunction.[65] A recently published review suggests deferred restoration of urethral continuity in children with posterior urethral distraction defect due to a pelvic fracture by anastomotic bulboprostatic repair performing a tension-free spatulated anastomosis.[65]

Conclusion

The kidneys are the most frequently injured of the pediatric urinary system with the majority of these lesion caused by blunt trauma. Provided hemodynamic stability of the patients, the injuries can be managed conservatively yielding good outcome. A small subset of these injuries, however, can be potentially life threatening requiring urgent operative intervention. Injuries to the ureter, bladder and urethra are rarely seen lesions most often encountered in polytraumatized children.

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