Pediatric Trauma

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1. Pediatric Renal Trauma

1.1 Introduction

After sustaining blunt abdominal trauma, 5-20% of children will have a renal injury.[1,2,3] As compared to adults, **children are more susceptible to suffering a kidney injury after blunt trauma due to a lack of perirenal fat, larger size of the pediatric kidney relative to the rest of their body, weaker abdominal musculature, less ossified thoracic rib cage, and lower abdominal location**.[4,5] One retrospective study demonstrated that following blunt abdominal trauma, children had a 48% higher risk of renal injury as compared to adults aged 20-50 years. Controversy[6] exists as to whether congenital anomalies, such as hydronephrosis or ureteropelvic (UPJ) obstruction, make pediatric kidneys more susceptible to injury. However, as compared to adults, renal malformations are more commonly found in pediatric patients following blunt abdominal trauma.[7]

Blunt renal trauma accounts for 90% of pediatric renal injuries.[5,8] The most common causes of severe pediatric trauma are (1) motor vehicle accidents, (2) being struck by a motor vehicle while biking, and (3) being struck by a motor vehicle as a pedestrian. Bicycling is the most common sporting activity resulting in pediatric renal injuries, and renal injuries occurring secondary to a bicycle accident tend to be higher grade. [9,10] While many low- and high-grade pediatric renal injuries, may be managed conservatively without surgery[8,11] the challenge lies in early detection and management of serious, life threatening renal injuries.

1.2 Diagnosis

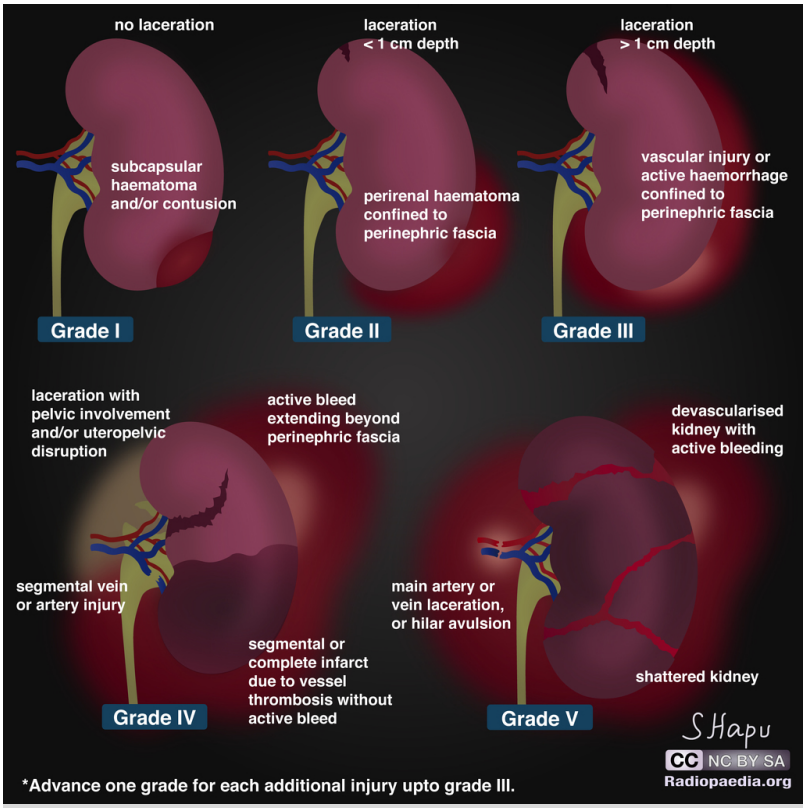

Figure 1: The Renal Trauma Grades

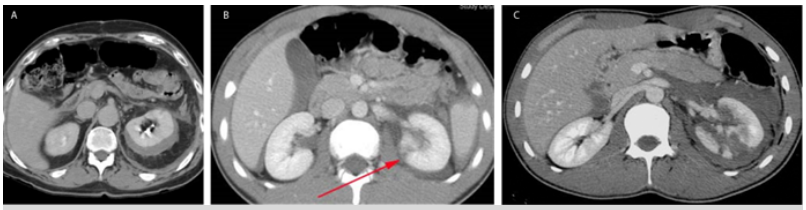

Figure 2: CT Scans of varying grades of left-sided blunt renal trauma (A) Grade 1 renal injury – subcapsular hematoma; (B) Grade 3 renal injury – with deep renal cortical laceration and (C) Grade 5 renal injury – shattered kidney

The initial goal with any pediatric trauma patient is to efficiently assess the patient's hemodynamic stability and to stabilize the patient, if necessary. If possible, the assessment should always begin with performing a complete history and physical examination. If the child is hemodynamically unstable and/or requires immediate surgical intervention because of severe injuries, obtaining a history and physical examination may not be possible.[12] The combination of a focused, detailed history, understanding of the mechanism of injury, and knowledge of other injuries will determine the need to evaluate the patient for genitourinary trauma.

In adults, hematuria and hemodynamic instability dictate the need to evaluate for a renal injury;[13,14] however, upwards of **two-thirds of children may have a normal urinalysis even after sustaining Grade II or higher renal injuries**.[8,12,13,15] In addition, children can maintain sympathetic tone and remain normotensive even in the presence of significant blood loss.[13,16] **Thus, one cannot reliably rule out the presence of a renal injury in a child who is hemodynamically stable with no hematuria. Indications to image a child to evaluate for the presence of a renal injury include: (1) the presence of gross hematuria, (2) microscopic hematuria (>50 RBC/hpf after blunt trauma or > 5 RBC/hpf after penetrating trauma) with shock, (3) a significant deceleration injury (fall or motor vehicle accident), (4) trauma resulting in physical signs concerning for renal injury (including flank ecchymosis and rib injury) and/other mechanism of injury concerning for renal trauma**[12,17] **Microscopic hematuria alone after blunt trauma is not an**

absolute indication for imaging in children. In fact, a meta-analysis evaluating 232 cases of microscopic hematuria alone following blunt trauma, identified that only one patient with a clinically significant renal injury.[18,19]

Blunt renal injuries in children are seldom isolated, and usually multiple organs are affected. A history of rapid deceleration or a direct blow to the flank, should raise the suspicion for renal trauma. Renal vascular injury after blunt injury is rare. For penetrating trauma, location of entrance and exit wounds can help determine the likelihood of a renal injury. [20] In penetrating injuries, most patients with a gunshot wound to the kidney and up to 60% of renal stab injuries will have injury to adjacent organs. Penetrating injuries have a higher incidence (15-33%), as compared to blunt trauma, of renal vascular injury. [21,22]

The 2020 AUA guidelines[23] state that if a renal injury is suspected, IV contrast-enhanced abdominal/pelvic CT with immediate and delayed images (10 minutes) should be performed. The concern for long-term effects of radiation in children has prompted the evaluation of ultrasound to evaluate for a renal injury. Studies though have shown that ultrasonography in the setting of trauma is highly operator dependent and has a low sensitivity for detecting renal lacerations. [24] As such, in the acute setting, in the clinically stable patient, triphasic abdominal and pelvic computed tomography (CT) remains the imaging modality of choice to accurately diagnose children with a suspected renal injury.

As stated above, mechanisms of injury or physical exam findings that are concerning for renal injury include rapid deceleration, a significant blow to the flank, rib fracture, significant flank ecchymosis, and penetrating injury to the abdomen, flank, or lower chest. A triphasic abdominal and pelvic CT not only evaluates the renal parenchyma but also evaluates the renal hilum and collecting system, as well as surrounding organs. A thorough evaluation of the renal vasculature and for a urine leak is important, especially when a trauma involving significant deceleration occurs, as children after such a mechanism of injury are at particular risk for **main renal artery thrombosis, main renal artery avulsion, and ureteropelvic junction disruption**.[14]

1.3 Staging

The majority (85%) of blunt renal trauma occurring in children is low grade (Grade I-III), while the remaining 15% will be Grade IV and V.[9] As previously stated, the most sensitive and specific radiologic test to diagnose both genitourinary and other associated abdominal and pelvic injuries is **a tri-phasic abdominal and pelvic CT**.[17,25] The downside of using a CT scan is its associated radiation exposure and potential sequelae of IV contrast to the child. To avoid these side effects, the use of ultrasound to diagnose clinically significant renal injuries has been evaluated. In evaluating 25 renal injuries after blunt trauma (six grade I-II and 19 grade III-V), one study identified a sensitivity of 79-100% and a negative predictive value of 97-100% when comparing renal ultrasounds to CT imaging. [26,27] Other studies though have shown that ultrasonography in the setting of trauma is highly operator dependent and has a low sensitivity for detecting renal lacerations. [24] Thus while ultrasound utilization may not apply to all trauma settings, it may be considered, with some caution, in the hemodynamically stable pediatric patient. However, triphasic abdominal and pelvic computed tomography (CT) remains the imaging modality of choice to accurately diagnose children with a suspected renal injury.

The grading of renal injuries is shown in **Table 1**, **Figure 1**, and **Figure 2**. In labile patients, a single-phase CT scan, taken immediately after injecting contrast may be performed to visualize renal perfusion and any major renal laceration but may not reliably show urinary extravasation.

In an unstable child taken immediately to the operating room without renal imaging and prior to deciding to repair any kidney injury or proceeding with a retroperitoneal exploration, a single shot intravenous pyelogram (IVP) should be performed in the operating room. The study is performed by intravenous injection of **2 ml/kg of contrast** followed by an **abdominal x-ray taken 10-15 minutes later after injection**. This study is commonly sub-optimal, especially in a hemodynamically unstable patient, but most importantly it serves to document the presence of a contralateral functional renal unit prior to proceeding with retroperitoneal surgery.[28]

Table 1. Grading of Renal Injuries

Grade of Injury	Description
I	Renal Contusion or Subcapsular Non-expanding Hematoma with no Parenchymal Laceration
II	Less than 1 cm Parenchymal Laceration, No Urinary Extravasation, All Renal Segments are Viable
III	Greater than 1 cm Parenchymal Laceration, No Urinary Extravasation, Renal Fragments may be Viable or Devitalized
IV	Laceration extending into the Renal Collecting System with Urinary Extravasation, Renal Segments may be Viable or Devitalized *or* Injury to the Main Renal Vasculature with contained Hemorrhage
V	Completely Shattered Kidney (Multiple Major Lacerations of Greater than 1 cm with Multiple Devitalized Fragments *or* Injury to the Main Renal Vasculature with Uncontrolled Hemorrhage; Renal Hilar Avulsion

1.4 Management

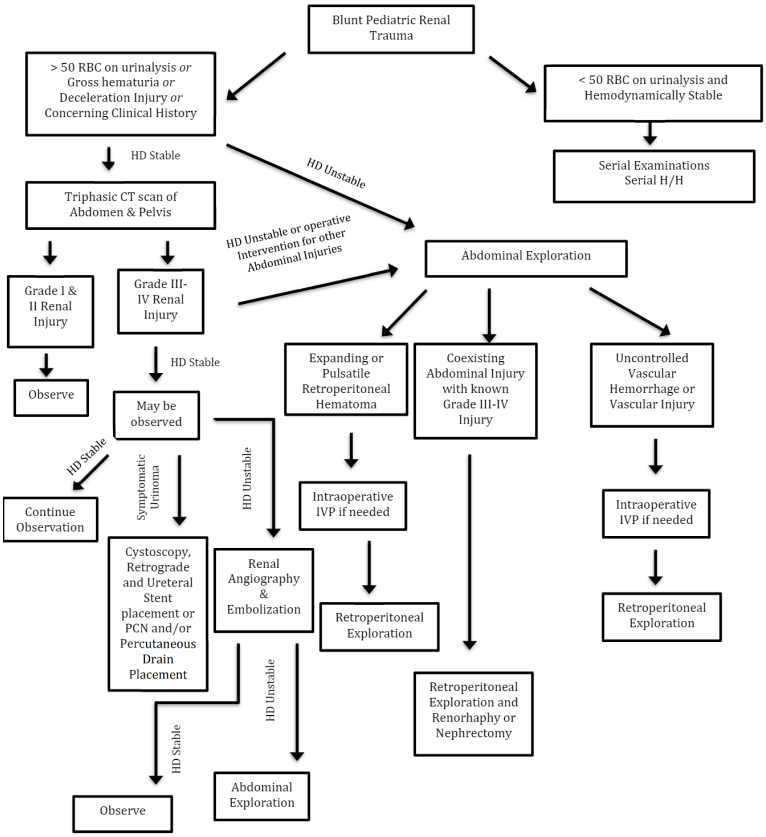

Figure 3. The evaluation, diagnosis and management of blunt pediatric renal trauma. Abbreviations: RBC: Red Blood Cells, CT: Computed Tomography, H/H: Hematocrit and Hemoglobin, HD: Hemodynamically, PCN: Percutaneous Nephrostomy, IVP: Intravenous Pyelogram

Figure 3: Evaluation, Diagnosis, and Management of Blunt Pediatric Renal Trauma

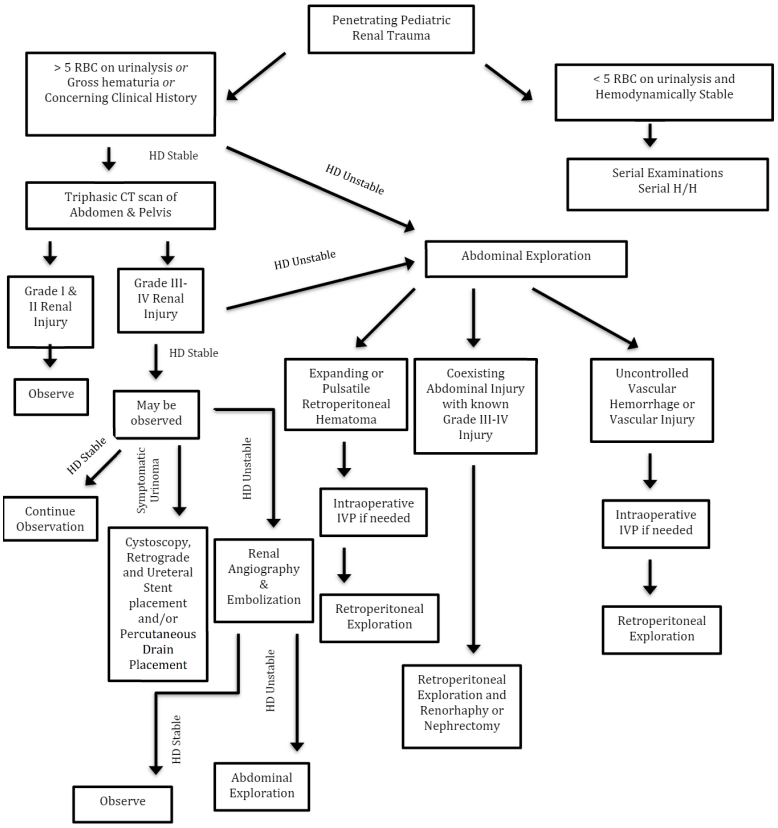

Figure 4. The diagnosis, evaluation and management of penetrating renal trauma. Abbreviations: RBC: Red Blood Cells, CT: Computed Tomography, HD: Hemodynamically, IVP: Intravenous Pyelogram, H/H: Hematocrit and Hemoglobin

Figure 4: Evaluation, Diagnosis, and Management of Penetrating Renal Trauma

Management algorithms for blunt and penetrating pediatric renal trauma are shown in **Figure 3** and **Figure 4**. When managing a child with renal trauma, one must keep in mind the two main goals: saving the patient and saving the kidney (or as much renal function as possible).

Children sustaining blunt or penetrating trauma **lacking indication for imaging may be observed with serial clinical examinations and hematocrit and blood pressure monitoring**.[8,29] Low-grade renal injuries identified with CT (Grade I-II) may be managed similarly, usually without further intervention. In fact, predictive nomograms would indicate that the probability of surgical exploration for grade I and II injuries is 0% and 1% for grade III injuries.[30]

Select higher-grade injuries (IV-V) may also be observed if hemodynamic stability is present. A systemic review evaluating hemodynamically stable pediatric patients with blunt renal trauma of all grades comparing operative to non-operative management identified a higher rate of renal loss in those managed operatively (44.9%) versus those managed non-operatively (1.5%)[31]. Operative management also resulted in a higher rate of blood transfusion (90% versus 23.1%), a higher rate of urinoma development (2.4% versus 1.2%) but a lower rate of additional procedures (2.8% versus 5.7%). Grade IV-V injuries are commonly associated with significant non-urologic injuries requiring surgery.[2,8,15,29] Successful expectant management of high-grade renal injuries range from 40-84%, with up to 67% of grade V injuries managed successfully with observation alone. **In high-grade renal injuries that are initially observed, 25-50% will eventually require intervention** for delayed bleeding and worsening urinary extravasation/urinoma development.[2,3,32] In cases of delayed bleeding, selective segmental renal arterial embolization may be successful and appears to be a good first option. One review evaluating hemodynamically stable pediatric patients with high-grade (III-V) renal injuries from

blunt trauma and ongoing or delayed bleeding comparing embolization and surgical intervention identified a lower late of renal loss in the embolization group (0% versus 66.7%), a lower rate of urine leak/infectious complications for those who were embolized (0% versus 33.3%) as well as a similar rate of blood transfusion [31] between the two cohorts. In cases of worsening urinary extravasation or symptomatic urinoma development, ureteral stents and/or percutaneous nephrostomy tubes with or without drains may be helpful.[33,34,35,36]

In children found to be hemodynamically unstable, either upon initial evaluation or after their staging CT scan, and in those with uncontrolled bleeding not amenable to embolization, surgical management is recommended. If at the time of surgery, an expanding or pulsatile retroperitoneal hematoma is identified or if the child develops hemodynamic instability due to the renal injury, retroperitoneal exploration is recommended. In those undergoing surgery for other abdominal injuries who are known to have a grade III or higher renal injury, controversy exists as to the need to explore the retroperitoneum.[8,12,13,37] In patients who have had inadequate preoperative radiographic imaging, as stated above, a one-shot IVP should be obtained to ensure the presence of a functional contralateral renal unit. With appropriate operative and non-operative management, a **high renal salvage rate of > 98% is achievable**.[8,29]

Renovascular injuries involving the renal artery occur in 1-3% of all blunt renal trauma.[21,38] Rapid deceleration of the kidney results in stretching of the renal artery which may result in intimal tears within the artery, ultimately leading to blood clot formation within the and renal ischemia. In addition, a pseudoaneurysm may also form. Often times, patients who have sustained such renal vascular injuries are significantly unstable and have suffered multiple other traumatic injuries, making the decision to attempt surgical repair to salvage the kidney difficult. In addition, the time since injury is important, as warm ischemia time determines the survivability of the kidney. If the kidney has not been perfused in more than 6 hours, then the kidney will not survive. In fact, the best salvage rates for kidneys with pedicle injuries in ideal circumstances is only 30%.[39,40,41] Direct full-thickness tears to the renal artery and/or vein are rare and require immediate surgery and have a very high associated mortality.

1.5 Follow Up

In children sustaining Grade I-III injuries, some data suggests that repeat imaging 3-5 days post-injury is no longer routinely necessary.[42] The recent updated **AUA Trauma Guidelines** amended in 2020 recommends (Evidence strength Grade C) that for renal trauma patients suffering deep lacerations (Grade IV-V), follow-up CT scans should be performed after 48 hours.[23] This repeat imaging is performed as these higher grade injuries are prone to developing troubling complications, such as urinoma formation or hemorrhage. If a child develops hemodynamic instability or develops symptoms of a urine leak and/or urinoma (fever, worsening flank pain, ileus), early repeat imaging is recommended. [42]

Radiographic long-term follow-up is no longer indicated with grade I and II injuries. Renal ultrasound 3 months post-injury is recommended in children with grade III injuries without devitalized renal fragments. Grade III injuries with devitalized tissue and all grade IV and V injuries should be followed by CT or MRI 3 months post-injury.[42,43]

Hypertension 30 days after a renal injury may be caused by arteriovenous fistula, pseudoaneurysm, or perinephric scarring;[13,44] angiographic embolization may be effective for these vascular malformations. Nephrectomy is the best treatment option in patients with post-traumatic hypertension in a poorly functioning kidney (<20% function).

In the past, providers have cautioned against participation in contact sports such as football, lacrosse, and hockey in patients with a solitary functional kidney or in patients who have sustained a renal injury. However, in 2012, Ginsell et al. utilized data from the National Athletic Trainers' Association Injury Surveillance study to demonstrate that the overall risk of renal injury in those participating in contact sports was significantly less than rates of traumatic brain, head, neck, and spine injuries. Of 23,666 physical injuries evaluated for over 4.4 million athlete exposures, a total of 18 minor renal injuries occurred, and none of these resulted in the need for surgical management or in loss of renal function. Therefore, it was concluded that children with solitary kidneys or a history of a renal injury can be allowed to participate in contact sports.[45]

2. Pediatric Ureteral Trauma

2.1 Introduction

Pediatric ureteral injuries are rare, occurring in fewer than 4% of children suffering penetrating injuries and are exceedingly rare (less than 1%) following blunt trauma.[46,47,48] **Injury to the ureter typically occurs in conjunction with other abdominal injuries**. In these multi-organ injury patients who have a concomitant ureteral injury, the mortality rate exceeds 30%.[46,48,49] There is a 10% incidence of concomitant renal or bladder injury and a 90% chance of concomitant abdominal organ injury. Pediatric ureteral injuries may also be iatrogenic and occur during open, laparoscopic, and endoscopic injuries. A high degree of clinical suspicion is typically necessary to identify a ureteral injury, as only 40-88% of ureteral injuries are discovered in the first 24 hours after initial injury. [9]

2.2 Diagnosis of Ureteral Injuries

Hematuria is an unreliable sign of a ureteral injury, as two-thirds of patients will have no associated hematuria.[37,46,48] As stated above, a high index of suspicion is a requisite. In patients suffering an acceleration-deceleration injury, extreme hyperextension of the trunk or when the trajectory of penetrating injury is near the ureter, one should be mindful that such a mechanism of injury may lead to a ureteral injury. In the case of an acceleration/deceleration injury and severe hyperextension one should be especially mindful for a ureteropelvic junction (UPJ) disruption.[13,37,50] In trauma patients undergoing initial evaluation with a CT scan, the finding of extravasation of contrast into the medial perirenal space in combination with the absence of parenchymal lacerations and non-visualization of the ipsilateral ureter may be signs of a UPJ injury.[50] In trauma or postoperative patients found to have a prolonged ileus, high drain output, fever/sepsis, flank and/or abdominal pain, and/or an elevated creatinine or flank mass, a missed ureteral injury should also be suspected.[51] The **diagnosis of a ureteral injury is best evaluated with either a tri-phasic CT scan or retrograde ureteropyelography**.

2.3 Treatment

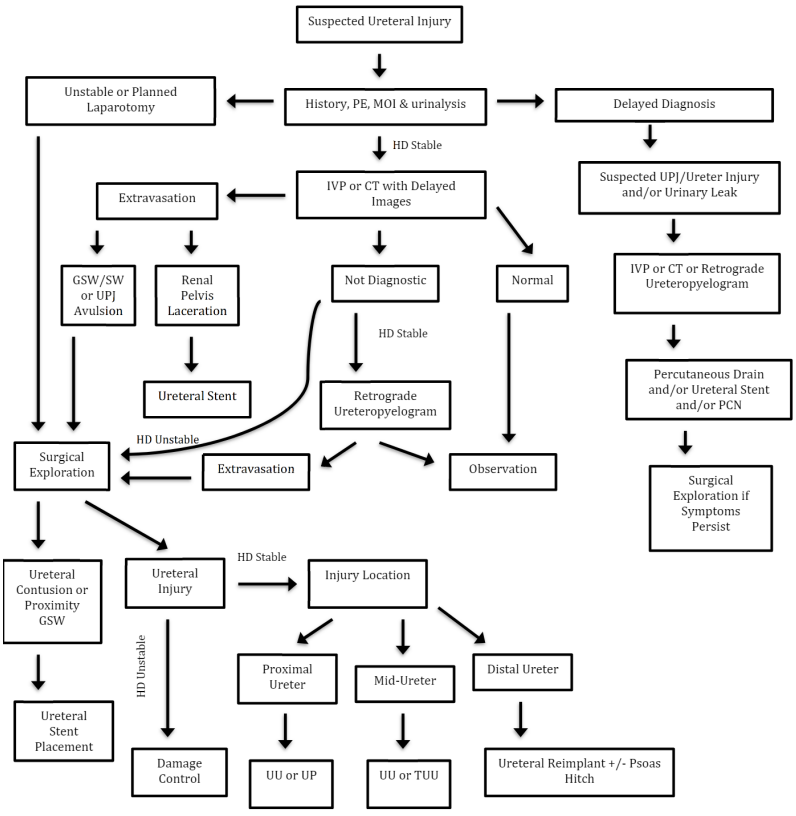

Figure 5. The evaluation, diagnosis and management of the ureteral injury. Abbreviations: GSW: Gun Shot Wound, SW: Stab Wound, IVP: Intravenous Pyelogram, CT: Computed Tomography, UPJ: Ureteropelvic Junction, UU: Ureteroureterostomy, UP: Ureteropyelostomy, TUU: Transureteroureterostomy, PCN: Percutaneous Nephrostomy

Figure 5: Evaluation, Diagnosis and Management of the Ureteral Injury

In a patient with concern for a ureteral injury, if a laparotomy is performed and no preoperative imaging has occurred, then direct ureteral inspection is recommended. As an alternative, retrograde pyelography may be performed when possible. An intraoperative, single-shot IVP cannot reliably exclude a ureteral injury.

If a ureteral injury is identified and the patient is stable, ureteral repair should be performed at the time of initial laparotomy. When the ureter is injured above the iliac vessels, a spatulated, tension-free ureteral repair over a ureteral stent is advisable after all non-viable ureteral tissue has been judiciously debrided. In situations where the anastomosis cannot be completed in a tension-free manner, mobilization of the ureter should be performed in a manner preserving maximal ureteral blood supply. If an anastomosis still cannot be performed in a satisfactory manner, then consideration of a bladder psoas hitch and/or Boari flap should be considered. Interposition with bowel and autotransplant are not considered in the acute setting. If an injury cannot be managed adequately in the acute setting, ureteral ligation with placement of a nephrostomy tube is advised.

When the ureteral injury is located distal to the iliac vessels and the patient is stable, ureteral reimplantation directly into the bladder or primary repair over a ureteral stent should be performed. Again, a psoas hitch and/or a Boari flap may be indicated if the anastomosis cannot be performed in a tension-free manner. Interposition with bowel and autotransplant again are not considered in the acute setting. If a distal injury cannot be managed adequately in the acute setting, ureteral ligation with placement of a nephrostomy tube is advised.

If the patient is unstable, no matter the location of the ureteral injury, temporary urinary drainage should be utilized. In these instances, the ureter may be ligated, and a percutaneous nephrostomy tube may be placed. Definitive repair may then occur when the patient's condition has improved.

When an incomplete ureteral injury is unrecognized or presents in a delayed fashion, retrograde ureteral imaging with ureteral stent placement should be initially attempted. In certain situations, if the injury is identified within one week of injury and the patient requires surgical exploration for other reasons, immediate surgical repair may then be performed. If initial ureteral stent placement is not successful, a percutaneous nephrostomy tube should be placed, and delayed repair of the ureteral injury should then be performed. If a nephrostomy tube alone does not adequately control the urine leak, a periureteral drain may be placed. (**Figure 5**)

2.3.1 Ureteral Contusions

After a gunshot wound or blast injury, ureteral contusions are common. Potential complications from a ureteral contusion include delayed ureteral stricture and/or overt ureteral necrosis and urinary extravasation. Thus, if a ureteral contusion is identified during laparotomy, intact but contused ureters may be primarily managed with ureteral stenting. Resection of the contused area of ureteral injury may also be performed, particularly after a gunshot wound, depending on the severity of contusion and concern for viability of the tissues.

If recognized early, ureteral contusions secondary to surgical ligation/crush injury of the ureter also can be treated by ureteral stent placement after, when necessary, removing the offending clip or ligature.[51] If the injury is recognized late, retrograde stenting is typically unsuccessful, and nephrostomy tube placement followed by staged ureteral reconstruction may be necessary.[51]

2.3.2 Gunshot Injuries

Gunshot wounds from a high velocity missile (>350 m/sec) are associated with high kinetic injury creating an energy wave of 30-40 times the diameter of the missile and will typically yaw and tumble during penetration.[13,52,53] These injuries may damage surrounding tissues that are a significant distance from the path of the missile. The ureter and renal pelvis, which may appear viable at the time of initial exploration, may undergo necrosis 3-5 days after the injury. This may lead to a delayed urine leak classically manifested by an increase in drain output or the signs and symptoms of a urine leak listed above.[13,52,53,54] If concern exists for a high-velocity missile injury in proximity to the ureter, ureteral stenting should

be performed.

2.3.3 Iatrogenic Injuries

Ureteral injuries recognized at the time of the injury, provided that the patient is stable, are treated based upon the location of the injury. In proximal ureteral injuries, the devitalized ureteral tissue is removed and repaired either by ureteropyelostomy or ureteroureterostomy. Mid-ureteral injuries may be treated with a ureteroureterostomy or a transureteroureterostomy. Distal injuries should be treated with a ureteral reimplant, which may require a psoas hitch and/or a Boari flap.

In the unstable patient, ureteral ligation and nephrostomy tube placement may initially be performed with possible repair in the next 48-72 hours. Unfortunately, in 50-60% of patients with these injuries, the diagnosis may be delayed for at least 6 days post-injury.[48,55] Previously, these patients were managed by percutaneous nephrostomy tube drainage and/or ureteral stenting with a planned delayed repair.[52,56] Recent reports state that proceeding at the time of injury recognition with open repair of the ureter based on the location of the injury is feasable.[48,54,55,57]

2.3.4 Ureteropelvic Junction (UPJ) Injuries

In patients with a suspected UPJ injury **a retrograde ureteropyelogram should be performed to evaluate the continuity of the UPJ**. If a UPJ disruption is not identified, these patients may be managed with the placement of a ureteral stent or a percutaneous nephrostomy tube.[58,59,60] If the UPJ injury is identified within 5 days of the injury, surgical repair is recommended; otherwise, percutaneous nephrostomy tube placement is recommended with a delayed repair planned in 6-8 weeks.

2.3.5 Endoscopic Injuries

When a ureteral injury occurs during ureteral endoscopy, a ureteral stent should be placed. If placement of a ureteral stent is not possible, open or laparoscopic repair of the ureteral injury may be performed. If initial stent placement fails to adequately divert the urine, a percutaneous nephrostomy tube should be placed with or without a periureteral drain. Delayed reconstruction is then often necessary.

2.4 Long term Complications

After traumatic repair, **ischemic ureteral strictures may occur secondary to aggressive adventitial dissection, blast injury, or healing by scar tissue**.[52,56,61] If these strictures are identified early and are less than 2 cm in length, endoscopic management may be feasible.[62] In failed endoscopic cases or in those with long strictures, these strictures are **best managed with excision and repair**.[62]

3. Pediatric Bladder Trauma

3.1 Introduction

Since the pediatric bladder is a mobile organ and typically protected by the bony pelvis, significant **pediatric bladder trauma is a rare event**, only accounting for 2% of abdominal injuries requiring surgery.[63] However, when compared to adults and older children, a full bladder in an infant or small child is an **abdominal organ** and may be more susceptible to injury and intraperitoneal rupture. When bladder injuries do occur in children, they are **typically associated with multi-organ trauma with an average of 3 coexisting organ injuries and a mortality rate of 20%**.[63] Blunt trauma is the most common cause of bladder injury in children, with pelvic fracture being the most common associated injury.[64] Up to 57% of pediatric patients with bladder rupture have a concomitant pelvic fracture.[65]

3.2 Diagnosis

Absolute indications for bladder imaging after a blunt abdominal injury are **(i) the presence of gross hematuria coexisting with a pelvic fracture and (ii) inability to void**. Neither gross hematuria alone nor the presence of a pelvic fracture alone is an absolute indication to access for a bladder injury.[66,67,68] Relative indications for bladder imaging after blunt trauma include urinary clot retention, perineal hematoma, and a history of prior bladder augmentation. After

penetrating trauma, bladder imaging should be performed if there is concern that the missile or stab could have injured the bladder and/or if free abdominal fluid is seen on the CT scan. [67]

The diagnosis of a bladder injury should be **evaluated either using a 3-film standard cystogram or a CT cystogram**. Both imaging modalities carry a sensitivity of 90% for the diagnosis of bladder rupture, but CT has the added advantage of diagnosing other injuries. The amount of contrast instilled into a child, should be at least one-half of the estimated bladder capacity calculated for the child's age **[(age + 2) x 30 ml)]**. Contrast instillation may stop once the expected bladder capacity is reached or at 300 ml if the bladder contracts. Just plugging the catheter alone and awaiting antegrade bladder filling followed by CT imaging is inadequate and may miss the diagnosis of traumatic bladder injury.[68,69]

3.3 Classification

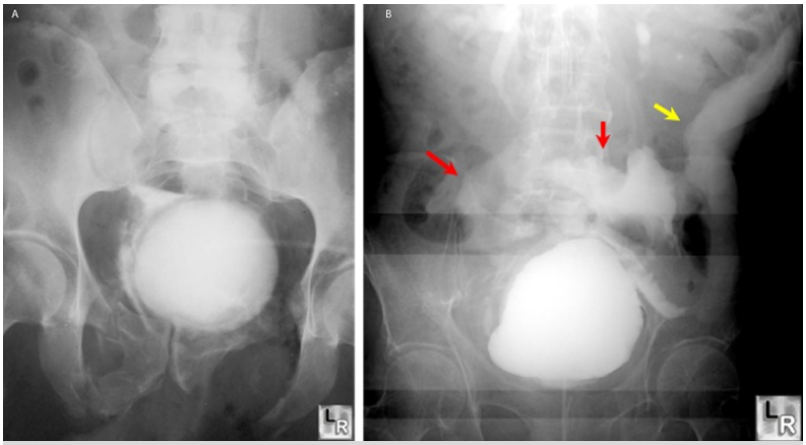

Figure 6: Fluoroscopic cystogram of bladder trauma (A) Extraperitoneal injury (B) Intraperitoneal injury

The **management of bladder injuries is predicated on its classification as either (i) intraperitoneal or (ii) extraperitoneal** . On cystography, intraperitoneal injuries result in extravasation of contrast into the peritoneal cavity with contrast outlining individual loops of bowel. Extraperitoneal injuries elicit a starburst or flame-shaped collection of contrast in the pelvis. (see **Figure 6**)

3.4 Management

3.4.1 Extraperitoneal Injuries

Extraperitoneal bladder injuries are typically managed by placing an indwelling urethral catheter without the need for surgical repair. If the child undergoes surgery for other reasons and bladder repair is feasible, these extraperitoneal injuries could be repaired. In addition, if a bony spicule is found to protrude into the bladder on CT evaluation or if a bladder neck laceration is present, surgical intervention is generally performed. [55,70] If the urethra is small (especially in boys), one may only be able to place a small bore urethral catheter. Such a small catheter may become occluded by clot, therefore, placement of a larger bore suprapubic tube may be considered. Generally, the urethral or suprapubic catheter is left in place for 7-10 days, and a cystogram documenting an intact bladder is obtained prior to catheter removal.

3.4.2 Intraperitoneal Injuries

Open surgical repair is recommended for intraperitoneal injuries. The injured areas should be debrided and the bladder closed in layers. A perivesical drain is typically placed with either a suprapubic tube or urethral catheter at the time of the repair.

3.4.3 Bladder Neck Lacerations

Bladder neck lacerations are twice as likely to occur in children compared to adults.[55,70] Management of these injuries by

urethral catheterization or suprapubic cystostomy tube alone is inadequate as there is typically persistent urinary extravasation with the possibility of developing a urinoma/pelvic abscess. There is also the risk of developing pelvic osteomyelitis and an increased risk of permanent urinary incontinence. [55,70,71] The diagnosis of a bladder neck injury should be suspected if there is extravasation of contrast on the cystogram and an adequate competent bladder neck cannot be documented. In this case, the patient should be evaluated surgically as soon as the child's condition allows. The bladder should be opened at the dome and the bladder neck should be repaired via an intravesical approach. Long-term outcomes of immediate recognition and repair of traumatic bladder neck and proximal urethral injuries in one series revealed high frequency of complications and the need for additional surgery. [72] The surgeon should be aware that anterior bladder neck injuries are frequently associated with urethral injuries and a retrograde urethrogram should be considered. [55,70,71]

4. Pediatric Genital Trauma

4.1 Introduction

Trauma to the pediatric genitalia is rare, representing 0.4-8% of all pediatric trauma.[73,74] While many pediatric genitalia injuries can occur due to accidental trauma, such as straddle injuries and motor vehicle collisions, it should always raise suspicion for sexual abuse, regardless of severity of injury. About 1 in 4 girls and 1 in 13 boys are sexually abused or assaulted during childhood. [75] Over 90% of sexual abuse is committed by a someone known to the child rather than a stranger.[76] All children suspected to have experienced sexual abuse should undergo full assessment including a detailed history and review of systems, with special focus on genitourinary and gastrointestinal symptoms such as dysuria, urinary tract infections, encopresis and enuresis. [77] Complete genitalia examination should include the posterior fourchette in girls and anus for all children. Evaluation and care for these children should take a multidisciplinary approach to address the emotional needs and physical safety of the child after discharge, as well as ensure proper documentation and handling of forensic evidence.

4.2 Penile Trauma

Non-sexual trauma to the penis in the pediatric population is rarely reported and is usually accidental. Underlying causes include animal bites, zipper injuries, motor vehicle accidents and penile strangulation by hair tie or rubber band. Most frequently reported penile injury relates to circumcision, with postoperative complications ranging from 0.2-0.6%. [78] Typical early presentation is either bleeding that fails to stop spontaneously, or wound dehiscence with complete separation of the circumcision edges. Such injuries should be managed initially with wet to dry dressings or topical antibiotic ointment and delayed surgery, if necessary. If all of the penile shaft skin is removed, the discarded skin can be defatted and used as a full thickness skin graft if performed immediately.[79,80,81] Excessive ventral skin removal is frequently encountered in boys with congenital penoscrotal webbing, in which insufficient ventral penile skin is further compromised by circumcision. More severe complications involve partial or complete amputation of the penis, usually at the level of the glans penis. This type of injury is more common in circumcisions performed by an untrained professional with the Mogen clamp, where the glans penis is not protected by a bell device[82] In circumstances of penile amputation by circumcision or tourniquet injury, repair with or without microvascular reanastomosis of the glans or penile shaft along with urethral anastomosis can yield excellent cosmetic outcomes. [83,84]

One of the potential late complications of circumcision is a buried or concealed penis, where a tight phimotic ring creates a cicatrix anterior to the glans. Treatment with topical steroid cream with delayed reconstruction is usually recommended. Urethrocutaneous fistula formation is also possible, thought to be caused by excessive electrocautery use at the level of the frenulum or corona, or inadvertent entrapment of excess ventral skin and urethra into the circumcision clamp device during skin excision[81] Domestic animal attacks may cause severe tissue loss and infection. Management principles include **copious wound irrigation and debridement, suture repair of skin defects or penile reattachment, and broad spectrum antibiotics**. Verification of the patient’s tetanus status and potential presence of rabies in the domestic animal are critically important.

4.3 Scrotal Trauma and Testicular Trauma

Injuries to the scrotum or testicle may occur from penetrating (usually adolescent or older) or more commonly blunt trauma (sports injuries or motor vehicle accidents in any age group).[85] Physical examination may be difficult to perform if there is significant testicular injury with rupture of tunica albuginea resulting in significant underlying hematoma and pain. In cases where there is high suspicion for testicular injury in blunt trauma, immediate operative intervention is warranted and imaging is not necessary. Superficial skin injuries without violation of tunica vaginalis rarely require surgical intervention beyond debridement and suture closure of skin and subcutaneous tissue. Scrotal ultrasound with doppler flow may be helpful in determining extent of testicular trauma and presence of testicular rupture in cases where clinical history may not correlate with physical exam. **Ultrasonographic findings of testicular rupture requiring immediate surgical exploration include disruption of tunica albuginea with or without extrusion of testicular contents, presence of hematocele, and loss of doppler flow to part or all of the testis.** Management of penetrating testicular trauma is immediate surgical exploration, debridement of devascularized tissue and closure of the tunica albuginea with monofilament absorbable suture.[86,87,88,89] Blunt trauma with testicular contusion can be safely managed without surgery. While immediate surgery with debridement and tunical (closure) are required in many cases, a non-surgical approach has also been advocated in select cases of testicular rupture; testicular atrophy rates in a recent series were reportedly less than 20%.[90]

4.4 Vulvar and Vaginal Trauma

Female accidental genital injuries are generally caused by either straddle accidents or penetrative injuries. In pediatric and adolescent patients, the vagina was more commonly injured than the vulva.[91] Straddle injuries are far more common and account for nearly 80% of all vaginal trauma in the pediatric population.[92] Signs of penetrative injury to the external genitalia in the setting of straddle accidents should raise suspicion for concomitant injury to nearby structures such as urethra, anus, bladder and rectum. Bedside examination may be challenging in this patient group secondary to patient discomfort, body habitus, or presence of significant labial swelling concealing deeper and more extensive injuries. While some have advocated for light conscious sedation in the emergency department for assessment of injuries, examination under anesthesia, cystoscopy and vaginoscopy along with anoscopy with a general surgeon remain the gold standard in these situations.[93,94] Prompt diagnosis of vaginal and associated injuries is important, as delays in diagnosis can result in fistula formation, urinary and fecal incontinence, and even vaginal stenosis.[95]

5. Pediatric Urethral Trauma

5.1 Definition

Traumatic urethral injuries can occur anywhere from the bladder neck/prostatic urethra to the tip of the meatus, but most commonly involve the urethra proximal to the bulbar component, or “posterior urethra”. The key to optimal treatment is to completely define the extent of the injury and to identify other associated injuries.

5.2 Risk Factors, Epidemiology and Pathophysiology

The **vast majority of proximal urethral injuries result from major blunt trauma** (usually a motor vehicle or motor pedestrian accident). Both the immature bones of the pediatric pelvis and the intra-abdominal location of the bladder and bladder neck make pediatric posterior urethral injuries unique and frequently more severe than in adults. In addition, the prostate and puboprostatic ligaments are undeveloped and thus more prone to trauma, specifically complete transection or avulsion type injuries.[96]

There are four main differences that affect the potential type of injury in children compared to adults:[97]

i. Pelvic fractures are more likely to be unstable and can be accompanied by complete separation of the prostatic urethra
ii. Posterior urethral complete disruption is much more common in young boys due to displacement/separation of the bladder neck and prostatic urethra from the pelvic floor

iii. Bladder and proximal injuries are far more likely to involve the bladder neck and sphincter mechanism
iv. Prepubertal girls with pelvic fractures, especially those with associated vaginal laceration, multiple pelvic fractures, or sacral spine injury have a much greater risk of urethral and bladder neck injury[98]

Anterior urethral injuries most often involve the bulbar urethra, and are usually due to a direct straddle injury (fall or kick). Compression of the bulbar urethra and spongiosum against the pubic rami can result in acute urinary extravasation and/or vascular injury with the greatest risk of delayed urethral stricture. Iatrogenic injuries can occur due to traumatic urethral instrumentation or inflation of a catheter balloon inside the smaller lumen pediatric urethra.

Anterior penile urethral injuries are relatively uncommon, but can occur during routine neonatal circumcision, ranging from meatal laceration to urethral fistula to glans/urethral amputation.[80]

Consumer products and household items are common causes of urethral injuries in this age group. One study demonstrated that bicycle-related straddle injuries can account for up to 10% of all urethral injuries. Gross hematuria and urethral tears have also been reported from straddling playground equipment and furniture, although most injuries were mild and treated conservatively in the emergency department. [99]

5.3 Diagnosis and Evaluation

As in adults, the triad of (1) perineal and/or genital hematoma, (2) blood at the meatus or vaginal introitus with or without gross hematuria, and (3) either the inability to void or severe pain with voiding is highly suggestive of a urethral injury and requires complete evaluation. **Because of the nature of the immature pelvis in children, any blunt trauma with a fracture of the pubic rami, especially when associated with diastasis of the pubic symphysis, requires complete radiographic evaluation**.[87] The orthopedic injury associated with the highest risk of severe urethral, and often bladder neck injury occurs in children with coexisting pelvic fracture with disruption of the pubic rami and separation of the sacroiliac joint.[100]

Initial evaluation should include an understanding of the mechanism of injury, thorough examination of the genital and perineal area, digital rectal exam, and retrograde urethrogram (in boys). Many children will have associated severe injuries and will undergo CT evaluation of the abdomen and pelvis which can be helpful in confirming or ruling out other concomitant organ injuries or pelvic fractures. Early and delayed images may be useful in identifying evidence of injury to the bladder, bladder neck, or rectum.

While digital rectal examination provides important information regarding elevation of the bladder neck or prostate, it is less accurate than radiographic imaging and endoscopy for excluding rectal injury, which occurs in roughly 15% of children with severe pelvic fractures and urethral injury.[101] **Unrecognized rectal injury markedly increases the risk of pelvic abscess, osteomyelitis, and severe wound infection, and will usually require diverting colostomy to avoid these complications**.

For iatrogenic urethral injuries, urethral violations are usually recognized immediately in cases of traumatic catheterization or neonatal circumcision, which do not require radiographic evaluation. In contrast, the urethra can be inadvertently lacerated or partially resected during an anorectal pull-through procedure for imperforate anus. This will present with inability to void or urine leakage through the perineal incision. This can be avoided by careful endoscopic placement of the bladder catheter prior to the pull-through procedure![102]

5.4 Treatment

Regardless of the surgical approach for management, **broad-spectrum antibiotics and long term catheter drainage (1-4 weeks) until the injury or repair has healed are important factors for success of any treatment**. If a catheter can be passed easily and can be confirmed to be in good position in the bladder then management with catheter drainage is all that is necessary. However, ***if there is a suggestion of significant posterior urethral injury then endoscopic placement of the bladder catheter is more appropriate to avoid potentially converting a partial transection into complete urethral disruption***. In the stable patient, endoscopy will also help delineate the extent of injury – this is especially important in the female patient where the bladder neck/urethra and vagina are difficult to image

radiographically.[103,104]

5.5 Female Urethral Injuries

Female urethral injuries are extremely rare. Minor straddle injuries involving the urethra/vagina will sometimes present with significant perineal bleeding. These patients are best managed with external and endoscopic exam under anesthesia, suture repair of the lacerations and catheter drainage as needed.

More significant injuries are usually associated with severe trauma with pelvic fracture. Up to 40% of bladder/urethral injuries are missed in females during initial examination, and on average, these injuries can remain undetected and missed until 3 days later.[105] Pelvic fractures can result in either longitudinal injury through the bladder neck and urethra, or complete transection of the urethra by bone fragments.[103,106,107] 75% of these injuries will involve laceration of the vagina and significant vaginal bleeding and labial hematoma. If a catheter cannot be placed easily, patients should undergo prompt cystoscopy, vaginoscopy and evaluation of the rectum. Some advocate for immediate urethroplasty with realignment of the urethra, repair of any bladder neck injury and vaginal laceration, as well as a diverting colostomy if a rectal injury is identified. However, others recommend immediate suprapubic drainage with delayed repair at least six weeks after initial injury to allow for time for resolution of any pelvic hematomas, particularly in unstable patients. Postoperatively, suprapubic tube and urethral catheter drainage should be maintained for 3-4 weeks.

Outcomes

The more minor urethral injuries will typically heal without incident when treated with catheter drainage alone. Continence outcomes are favorable if bladder neck is not involved; however, up to 30% of females with severe bladder neck/urethral injuries will require some type of proximal urinary diversion or catheterizeable channel due to the inability to achieve continence after repair[72,106,108,109,110]

5.6 Male Urethral Injury

Circumcision injuries usually involve only the distal glans/meatus. These are recognized immediately and should be repaired in the operating room with fine absorbable sutures to prevent meatal stenosis or contraction. Postoperative urinary drainage is often not necessary, and the wound can be managed with topical antibiotic ointment. More significant **glans amputations should be repaired immediately with fine suture repair of the urethra and approximation of the severed glans**. A small urethral catheter is left in place for 7-10 days and broad-spectrum antibiotics continued until the catheter is removed. Potential late problems include meatal stenosis and superficial skin sloughing.[79,80]

Bulbar urethral injuries can usually be managed with catheter drainage alone, or if minor injury, with observation. The bulb-membranous junction is reportedly the most common location for site of injury in primary cases,[111] followed by the bulbar urethra and the prostate-membranous junction. In one series, 2/3 of pediatric posterior urethral injuries were confined to the membranous urethra, and 1/3 involved the proximal prostatic urethra.[112] Retrograde urethrogram and/or endoscopy are not necessary unless there is significant bleeding per urethra or a history of failed attempts at instrumentation with blood at the meatus. **Late urethral strictures can occur despite early management, believed to occur from the crush injury of the bulbar urethra against the pubic bone**. These strictures can be managed by endoscopic incision if very short, but excision of the devascularized portion of the urethra and primary repair yields a 95% success rate.[113]

Male posterior urethral injuries are somewhat controversial regarding optimal timing and technique for management due to a lack of large series in children. Regardless of the surgical approach, broad-spectrum antibiotics and maximum urinary drainage are imperative. Three approaches are described: 1) immediate repair with endoscopic alignment or (less often) primary open surgical repair, 2) delayed repair at 2-14 days post injury with similar surgical techniques, or 3) late repair at > 3 months post injury.[97] Most experts have recommend avoidance of immediate open surgical repair in the absence of an associated bladder neck injury due to the risks of significant bleeding and/or having an unstable patient undergo a lengthy reconstruction. Immediate repair yields a 40-75% risk of incontinence and similar rates of impotence.[112,114,115] In this setting percutaneous suprapubic tube or endoscopic catheter realignment is a reasonable alternative.

For the late approach to traumatic urethral stricture, the defect should be completely defined with retrograde urethrogram and cystogram through the existing suprapubic tube to determine length and location of urethral defect, urodynamics if there is a concern for neurologic impairment of the bladder, and antegrade endoscopic evaluation of the posterior urethra when the radiographic imaging is incomplete. Through a modified lithotomy approach, injuries up to 2 cm can usually be managed with a combination of perineal, transpubic, or trans-symphyseal exposure, excision of the scarred urethra, and primary spatulated end-to-end anastomosis over an age appropriate catheter.[116,116] Longer defects (2-3 cm) may entail a more aggressive approach involving pubectomy or symphysiotomy and potentially splitting the penile crura to allow a tension-free anastomosis.[108,113] Alternatively, exposure can be obtained using the anterior sagittal trans-anorectal (ASTRA) approach in cases with pelvic fracture and severe urethral dislocation.[117]

Defects of > 3 cm will usually require a more complex flap or grafting technique, and in many cases will require a planned 2-stage approach. Regardless of the technique used, postoperative catheter drainage for several weeks with perioperative culture specific antibiotics is essential for a good outcome. Long term follow up is vital, and most surgeons will periodically obtain uroflow and post void bladder ultrasound rather than instrument the urethra to evaluate for late stricture.

If the bladder outlet is not reconstructable in either a male or female, or if it is completely incompetent following initial injury, one option is to forego further surgical attempts at bladder neck/urethral continuity and create an abdominal wall catheterizeable channel using the Mitrofanoff technique.[72]

Long term follow-up and outcomes have been limited to small series, but both urinary and sexual outcomes have been shown to be durable.[118] Continence rates for primary realignment and urethroplasty range from 80-95% in adults, with similar results in pediatric series. Continence success rates are generally unfavorable if the urethral defect extends into the bladder neck, regardless of timing of repair. **Recurrent strictures occur in approximately 10-30%**, but may respond to simple incision or dilation, with up to 90% success with internal urethrotomy for post-anastomotic strictures.[119,120] Recurrent strictures not responsive to internal urethrotomy will require repeat urethroplasty, with or without buccal mucosal grafting with good outcomes in children and adults.

The major long-term complications associated with male posterior urethral injury are incontinence, urethral stricture and erectile dysfunction. Short strictures can be incised endoscopically, but longer strictures, or those that failed prior incisions, should undergo open urethroplasty.[121,122] Erectile dysfunction can occur in up to 70% of boys with significant prostatic urethral injury or urethral defect larger than 2.5cm.[123] The risk of incontinence and erectile dysfunction has been shown to most closely correlate to the degree of initial injury rather than the timing or type of repair performed.[97]

6. Abbreviations

- **CT** – computerized tomography
- **Hpf** – high powered field
- **IVP** – intravenous pyelogram
- **MRI** – magnetic resonance imaging
- **RBC** – red blood cell
- **UPJ** – ureteropelvic junction

Presentations

Pediatric Trauma Presentation 1

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