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SPECIAL SECTION : UROTHELIAL DISEASE

Computed tomography (CT) in the evaluation of bladder and ureteral trauma: indications, technique, and diagnosis

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Abstract

Introduction Trauma to the genitourinary system includes blunt and penetrating injuries to bladder and ureters. These are rare injuries and are overlooked as other abdominal and pelvic injuries often take priority. Delayed diagnosis can lead to significant morbidity and mortality. Computed tomography has taken a central role in the imaging of the ureters and bladder.
Methods This article reviews the anatomic relationships, mechanisms of injury, and clinical presentation to help physicians determine when bladder and ureteral injuries should be suspected and further imaging should be pursued. Radiologic evaluation of bladder and ureteral injury with CT cystography and CT urography, respectively, will be reviewed.
Conclusion CT cystography and CT urography are effective tools in identifying potentially serious injuries to the genitourinary system. Timely recognition of these injuries can be crucial for the overall management and prognosis.

Keywords Bladder · Ureter · Trauma · Injury · Urography · Cystography

Introduction

Trauma to the genitourinary system includes blunt and penetrating injuries to the bladder and ureters. Bladder injuries frequently occur in the setting of high-energy trauma; however, it is an uncommon injury, accounting for 2–4% of abdominal injuries that require surgery [1–4]. Similarly, traumatic ureteral injuries are a rare event, seen in 1–2.5% of genitourinary injuries [5, 6]. Studies have suggested that bladder and ureteral injuries are often missed early on in multi-trauma patients, because attention is focused on acutely life-threatening injuries [7, 8]. Associated injuries may lead to mortality rates of up to 44% [9, 10]. Delayed diagnosis of bladder and ureteral injuries can lead to significant morbidity and mortality. A thorough understanding of the relevant anatomy, mechanisms of injury, and clinical presentation can inform the clinicians and radiologists when to suspect bladder or ureteral injuries, as these injuries can be missed if appropriate imaging (CT cystography and CT urography for bladder and ureteral injuries, respectively) is not performed. The prompt recognition and management of traumatic injuries to the bladder and ureters can help reduce morbidity and mortality.

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Bladder injury

Bladder anatomy

A thorough understanding of the pelvic anatomy and fascial planes as they relate to the bladder is crucial when evaluating and characterizing bladder trauma and patterns of extravasation on CT cystography. These classifications can steer clinical management.

In infants and young children, both the distended and non-distended bladder lie almost entirely within the abdomen, with the peritoneum extending from the fundus to the level of the bladder neck in newborns. The bladder begins to enter the pelvis at about age 6, but does not reach adult position until after puberty [11, 12].

In adults, the bladder is almost entirely situated in the anteroinferior pelvis, and enters the greater pelvis when full. The bladder is anchored in place at its neck by various

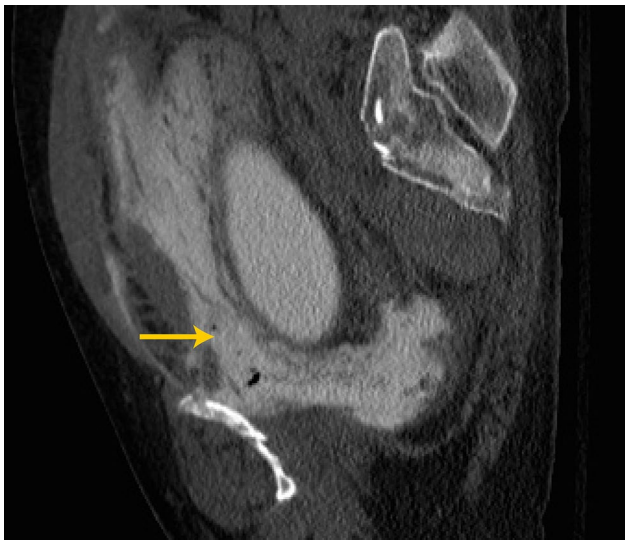

Fig. 1 47-year-old woman pedestrian struck by motor vehicle found to have extraperitoneal bladder rupture. On sagittal reconstruction from CT cystogram, contrast seen pooling in the space of Retzius (arrow)

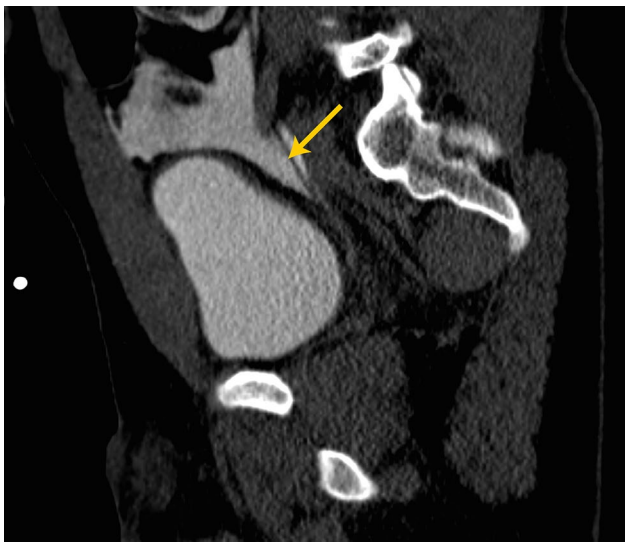

Fig. 2 18-year-old man who fell from 3 stories and found to have intraperitoneal bladder rupture. Sagittal reconstruction from CT cystography demonstrating contrast layers along the peritoneal reflections, including the rectovesical pouch (arrow)

ligaments [12]. The anterior perivesical space, between the anterior bladder and the pubic symphysis, is known as the space of Retzius. This is a common location for extraperitoneal rupture related to injury to the pubic bone (Fig. 1) [13].

In males, the posterior peritoneal reflection is called the rectovesical pouch, and the bladder is separated from the rectum by the rectovesical fascia (Fig. 2) [12]. In females, the posterior peritoneal reflection is called the vesicouterine pouch, and the fundus of the bladder is adjacent to the anterosuperior wall of the vagina [12].

The superior aspect of the bladder is called the dome and is covered by peritoneum. The extent of the peritoneal reflection anteriorly and posteriorly can vary from patient-to-patient [13, 14]. For this reason, injury to the anterosuperior aspect of the bladder can be either intraperitoneal or extraperitoneal, based on the extent of the patient's peritoneal reflection. The dome is the most mobile and weakest part of the bladder due to the looser area around the urachal attachment [12, 13]. This leaves the bladder susceptible to rupture when the bladder is full.

Inferiorly, the neck of the bladder is secured in place by various ligaments with the pelvic fascia. In men, the puboprostatic ligaments anchor the bladder base to the pubic bones, while the pubovesical ligaments do the same in women [12, 13]. The urogenital diaphragm lies inferior to the bladder. The superior fascia of the urogenital diaphragm is also called the triangular ligament and forms the anterior half of the perineum [13]. The triangular ligament is continuous with the pelvic fascia, the obturator fascia, and the endopelvic visceral fascia and when disrupted can lead to leakage of contrast into the perineum [12, 13]. The inferior fascia of the urogenital diaphragm continues into Colle's fascia, which then continues as Scarpa's fascia anteriorly, dartos fascia inferiorly, and fascia lata of the thigh inferolaterally [12, 13]. Complicated bladder lacerations involving the bladder neck can lead to disruption of the urogenital diaphragm, which can result in contrast extravasation into the perineum with superior fascia disruption and the scrotum, penis, anterior abdominal wall, and thigh with inferior fascia disruption (Fig. 3a–c) [15].

Bladder injury classification

Classification of bladder injury in the clinical setting is critical for determining management [9]. CT cystography is used to classify bladder injuries into 5 patterns: bladder contusion (type 1), intraperitoneal rupture (type 2), interstitial rupture (type 3), simple extraperitoneal rupture (type 4a), complex extraperitoneal rupture (type 4b), and combined intra- and extraperitoneal rupture (type 5) [9, 13, 15]. Although not commonly used for radiologic descriptions, it is important to be aware of the American Association for the Surgery of Trauma (AAST) classification of urinary bladder injury, which includes 5 grades: hematoma (grade 1a), partial thickness tear (grade 1b), extraperitoneal < 2 cm wall laceration (grade 2), extraperitoneal ≥ 2 cm or intraperitoneal < 2 cm (grade 3), intraperitoneal ≥ 2 cm (grade 4), and intra- or extraperitoneal laceration extending to bladder neck or urethral orifice [15].

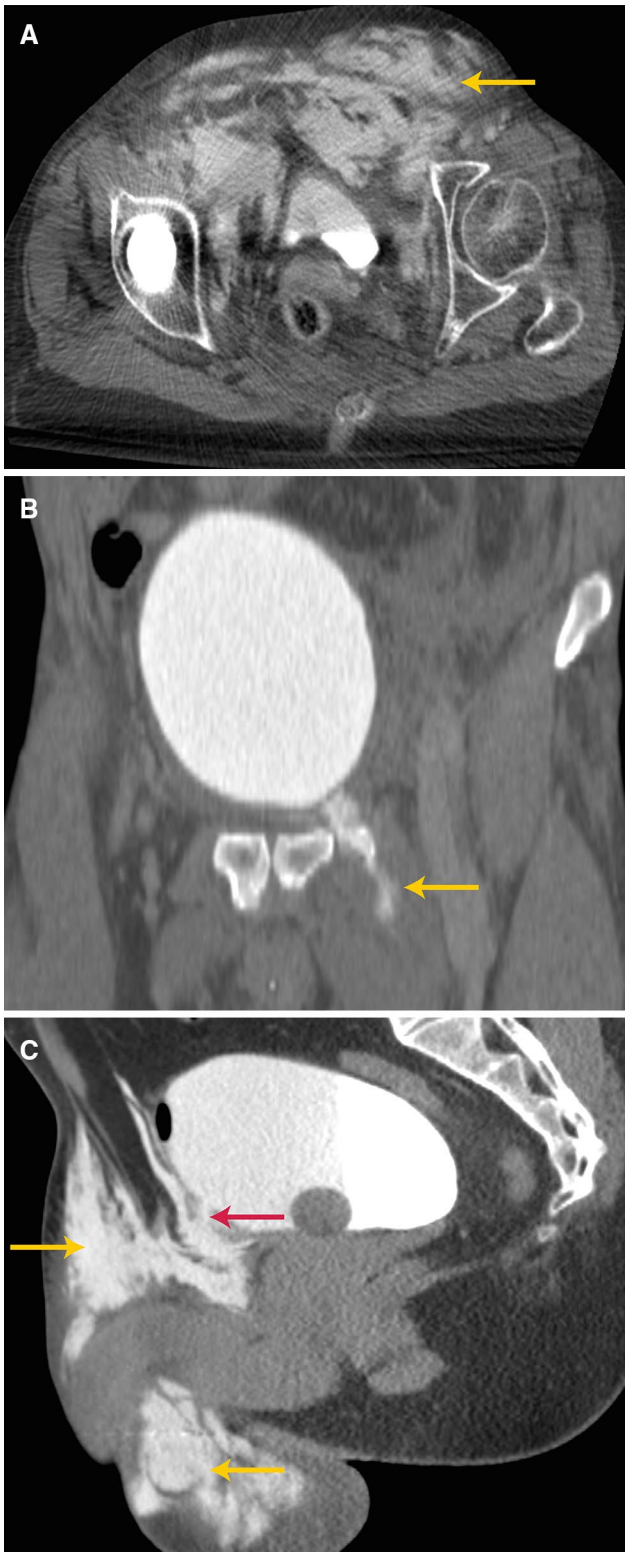

Fig. 3 **a**–**c** Three separate patients where the fascia of the urogenital diaphragm is violated and CT cystography demonstrating contrast leakage in the rectus abdominus muscles (**a**; arrow), the anteromedial thigh (**b**; arrow), and anterior abdominal wall and scrotum (**c**; yellow arrows). Defect in the anterior bladder wall (**c**; red arrow)

Mechanisms of bladder injury

Mechanisms of injury can be separated into two broad categories: blunt trauma and penetrating trauma. Blunt trauma accounts for 67–86% of bladder ruptures, while penetrating injuries represent 14–33% [7, 16]. In a review of 8565 documented bladder injuries in the U.S. National Trauma Data Bank, blunt trauma was the mechanism in 85% of bladder injuries [4].

Blunt trauma related bladder injuries are associated with pelvic fracture in 70–100% of patients; however, only 3 to 10% of pelvic fractures had a concomitant bladder injury [1, 6, 13, 17–21]. Given the bladder's anatomic location, it is prone to rupture with pelvic fractures [22, 23]. Pelvic fractures can lead to several proposed methods of bladder injury: bone fragments lacerating the bladder, avulsion from severe displacement of the fractured pelvis, rupture of ligamentous attachment, and direct force (Fig. 4a–f) [15]. Rupture of ligamentous attachments of the bladder can also lead to bladder injury in the absence of pelvic fracture. Additionally, Carroll et al. found that only 35% of bladder lacerations occur in the area of fracture, while the majority occur opposite to the area of fracture [2]. Thus, implying that direct force led to a burst-type injury of the bladder. Motor vehicle collisions are by far the most common cause of blunt bladder trauma accounting for nearly 50%, while pedestrian struck by vehicle, fall from substantial height (Fig. 5a, b), crush injuries, and blows to the abdomen comprise the remaining etiologies [6, 21, 24, 25].

Penetrating trauma is thought to cause up to 50% of bladder injuries in patients without pelvic fractures [7]. Among penetrating injuries, gunshot wounds (GSW) are by far the most common, accounting for nearly 80% of penetrating bladder injuries, while stab wounds account for the remaining 20% (Fig. 6a, b) [3, 4, 21]. Patients with penetrating injuries from GSW often have both entry and exit bladder wounds [19, 26]. Additionally, associated rectal or bowel injuries are often seen [3, 4, 26].

Iatrogenic bladder injuries are relatively common (Fig. 7a–c). Bladder injuries are most commonly seen during obstetric and gynecological procedures, primarily hysterectomy; however, they have also been reported with trocar placement for emergent laparoscopy, orthopedic repair of adjacent structures (pelvic fractures), and placement of intrauterine devices [6, 27].

When to suspect bladder wall rupture

Evaluation of clinical history, physical examination findings, and laboratory values is crucial to determining the pre-test probability of bladder injury, and if bladder imaging should be pursued [25]. Although clinical signs of bladder trauma can be non-specific, a triad of gross hematuria, suprapubic

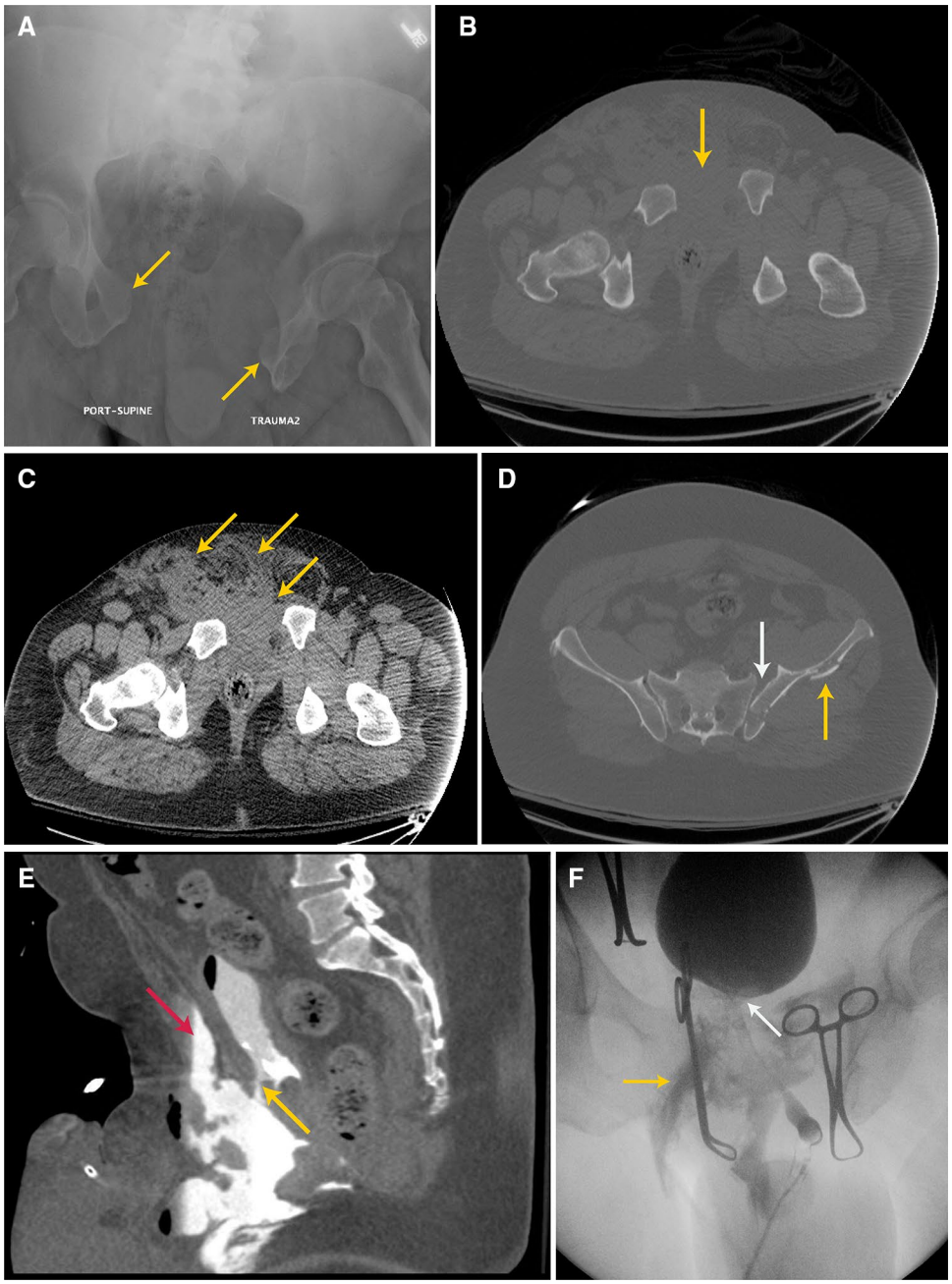

Fig. 4 **a–f** Extraperitoneal bladder rupture. 42-year-old man s/p pedestrian hit by a truck, AP radiograph (**a**) demonstrating comminuted open-book pelvic fractures. Axial CT abdomen and pelvis shows large pubic diastasis (**b**; arrow), hematoma (**c**; arrows), and left SI joint diastasis (**d**; white arrow) with a comminuted left iliac wing fracture (**d**; yellow arrow). Sagittal reconstruction from CT cystogram demonstrates a defect along anterior wall of bladder (**e**; yellow arrow) with layering extraperitoneal contrast (**e**; red arrow). A retrograde urethrogram (RUG) demonstrates contrast leaking from the bladder wall defect (**f**; white arrow) and extravasating into the into the space of Retzius (**f**; yellow arrow)

pain/tenderness, and difficulty or inability to void are often seen [16]. The two most common signs of bladder injury are gross hematuria (> 25 RBC/HPF), present in 80–100% of patients, and abdominal tenderness (approximately 60% of presentations) [15, 19, 28]. Other signs include shock, abdominal distention, microscopic hematuria (< 25 RBC/HPC), lower abdominal bruising, and blood at the urethral meatus [1, 15].

As described earlier, pelvic fractures are often seen with bladder trauma. In a series by Morey et al., all patients with bladder injury had gross hematuria, and nearly all had pelvic fractures (85%) [25]. Quagliano et al. showed that as many as 32% of patients with both gross hematuria and pelvic fracture were also found to have bladder injury [29]. Gross hematuria in the absence of pelvic fracture can be seen in up to 25% of intraperitoneal rupture [7]. According to the American Urological Association (AUA) Core Trauma Guidelines, pelvic fracture with only microscopic hematuria has a less than 1% chance of concomitant bladder injury [30]. Thus, an absolute indication for imaging is the presence of both gross hematuria and pelvic fracture, while relative indications are gross hematuria without pelvic fracture and even less so microscopic hematuria with pelvic fracture [28]. Specific pelvic injuries that are

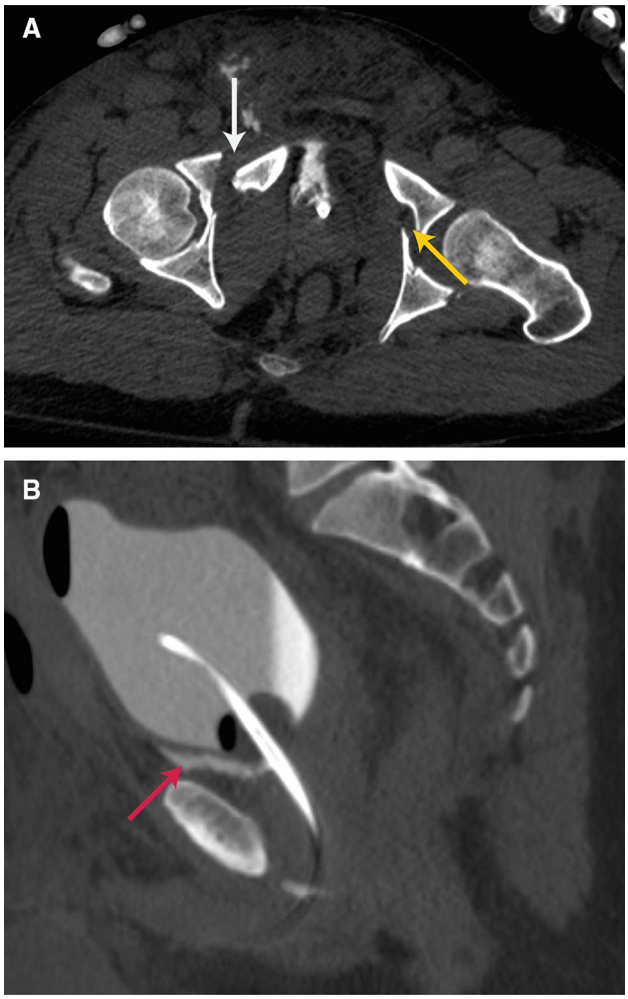

Fig. 5 **a**, **b** 45-year-old man with a fall from a tree. Axial CT cystography demonstrating comminuted acetabular (**a**; yellow arrow) and inferior pubic rami fractures (**a**; white arrow). Sagittal reconstruction from CT cystogram demonstrates an extraperitoneal bladder rupture (**b**; arrow)

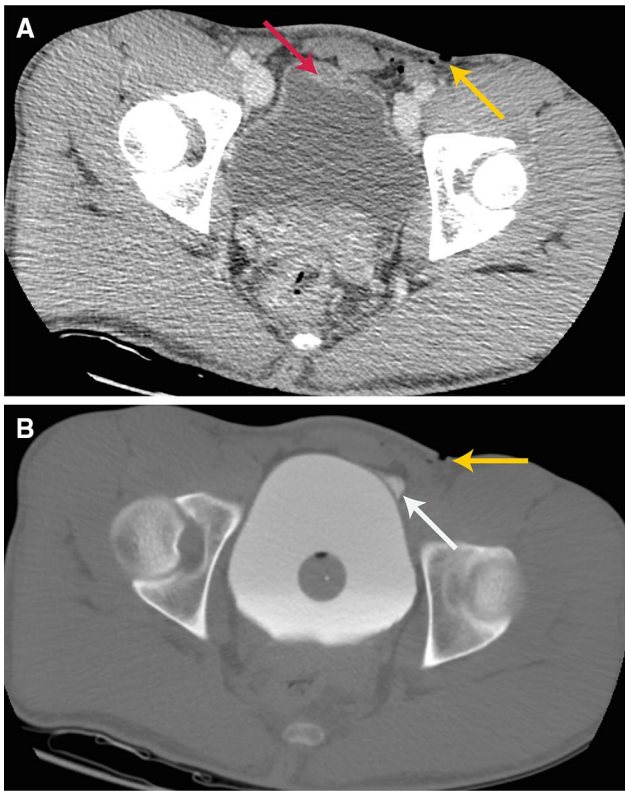

Fig. 6 **a**, **b** 23-year-old man presenting with stab wound to the left inguinal region. Contrast-enhanced CT abdomen and pelvis demonstrating cutaneous defect seen in the left inguinal region from stab wound (**a**, **b**; yellow arrow). Intramural hematoma seen in the anterior bladder wall (**a**; red arrow). CT cystography shows contrast pooling in the left perivesical space (**b**; white arrow), indicating extraperitoneal bladder leak

associated with bladder injuries include diastasis of symphysis pubis or sacroiliac joints, iliac fracture, and displaced fractures of the pubic rami or obturator ring [28]. Isolated acetabular fracture is the only pelvic fracture that is not associated with bladder injury [31].

Microhematuria alone is a poor predictor of bladder rupture, and is more commonly seen with bladder contusions [19]. Therefore, cystographic evaluation for these patients is not routinely recommended. However, imaging can be considered in patients with isolated microscopic hematuria in the setting of additional clinical symptoms, including suprapubic pain or voiding difficulties [25, 32]. Urethral rupture can be seen in up to 17% of patients with bladder injury [17, 33]. Blood at the urethral meatus indicates the presence of possible urethral injury. These patients should first undergo a retrograde urethrogram prior to catheterization [1].

Patients with penetrating trauma must be evaluated for injury based on the location of penetration. Multi-detector CT plays a crucial role in evaluating the trajectory of a penetrating injury. Damage associated with penetrating injury is a result of a complex interaction between physical characteristics of the penetrating object, kinetic energy, and variable trajectory, particularly with ballistic injury [34]. With ballistic injury, the cavity created by the bullet is considerably larger than the bullet itself due to the kinetic energy imparted on adjacent tissues [34]. Additionally, determining the trajectory can be difficult, with possible ricocheting and fragmentation of the bullet, which can lead to non-linear and unpredictable trajectories [34]. Given these factors, imaging should be carefully evaluated and a trajectory leading to or near the bladder should raise suspicion of a bladder injury.

Pao et al. demonstrated that all patients with bladder rupture had pelvic fluid on standard contrast-enhanced computed tomography (CT) (Fig. 8a, b) [35]. The absence of fluid indicated the absence of rupture [31, 35, 36]. This

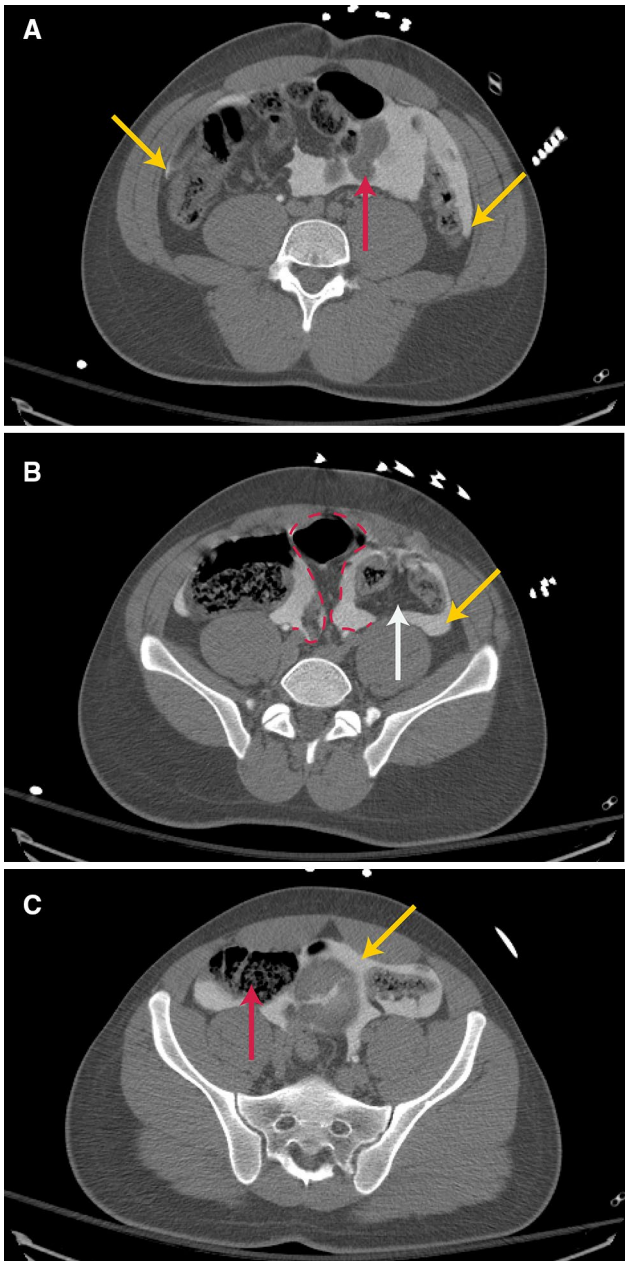

Fig. 7 **a**–**c** Intraperitoneal bladder rupture. 55-year-old man with iatrogenic trauma from laparoscopic colorectal surgery. Axial CT cystography demonstrating contrast leaking from the bladder into the peritoneum (**a**, **c**; yellow arrows) and interdigitating between loops of bowel (**a**, **c**; red arrow). A decompressed air-filled bladder is outlined in red (**b**)

pelvic fluid in the region of the bladder is likely to represent urine, hematoma, or both. In the absence of pelvic fluid on CT, particularly without gross hematuria or pelvic fracture, CT cystography is not needed [31]. The presence of pelvic fluid alone is not as strong positive predictor of bladder injury as orthopedic, bowel, or vascular injury, which can also lead to similar CT findings. Of note, the absence of

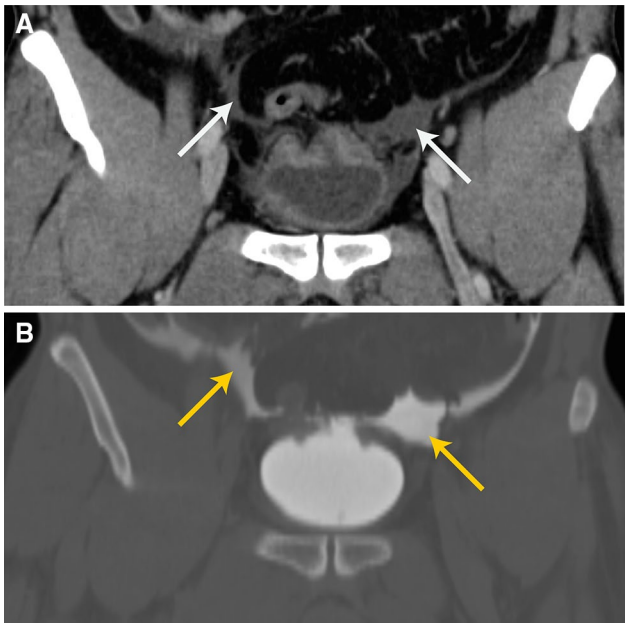

Fig. 8 **a**, **b** 35-year-old man motor vehicle collision driver presenting with suprapubic pain and abdominal guarding. Coronal reconstruction of CT abdomen and pelvis revealed low attenuation fluid in the peritoneal space (**a**; arrows). Bladder rupture was suspected, and a CT cystography reveals intraperitoneal bladder rupture, with contrast layering along the peritoneal reflections (**b**; arrows)

pelvic fluid is a strong negative predictor for bladder rupture, but not all bladder injuries. Mucosal laceration and bladder wall contusions are unlikely to have significant abnormalities on CT or cystography despite clinical symptoms, such as hematuria [16].

Imaging techniques

Conventional retrograde cystography has been considered the reference standard for evaluation of bladder trauma; however, CT cystography has taken its place as CT imaging has become more commonly used in imaging trauma patients.

In the past, some have suggested that clamping the Foley catheter for 20 min after IV contrast given for conventional CT abdomen and pelvis can be used to evaluate bladder trauma. However, it is now widely accepted that conventional CT is not reliable in evaluating bladder trauma, and injuries due to under distention of the bladder may be missed [3, 36–39]. This method is unreliable because it relies on the patient's ability to excrete contrast, which can be limited by poor renal function, possible injury to the upper collecting system, and mixing with urine or hemorrhage [3]. Additionally, this method requires a 20-min delay, and this may not be feasible in the acute trauma setting [11].

Cystography should not be performed until concomitant urethral injury has been excluded. If there is suspicion of urethral injury (blood at the urethral meatus, high riding prostate, penile swelling, blood in the vaginal vault), retrograde urethrogram should be performed. If findings are normal, a Foley catheter may be placed; however, if abnormal a suprapubic catheter should be placed [17, 33, 40]. This is often performed in the operating room, and bladder injuries can be evaluated at that time.

Conventional retrograde cystography is performed by instilling approximately 350 ml of contrast by gravity via Foley catheter. Lower quantities of contrast may produce false negatives [1, 41]. Only AP films are required, however, oblique views and fluoroscopic evaluation can be used in difficult cases [1, 2, 17]. It is crucial to have scout, filled, and post-drainage radiographs to visualize possible extravasated contrast behind the distended bladder, as approximately 10% of cases are diagnosed on post-drainage films [13, 15, 42]. When properly preformed, retrograde cystography has proved to be 100% accurate [1].

Conventional retrograde cystography and CT cystography have been shown to be equivalent when done properly, both with high sensitivity and specificity for bladder injuries (intraperitoneal and extraperitoneal) [29, 30, 41]. Despite similar efficacies, CT cystography has become the mainstay due to several logistical reasons. CT of the abdomen and pelvis has become routine in evaluating pelvic fracture or intraabdominal injury in high-energy trauma patients. Since these patients already require CT, CT cystography saves time without sacrificing accuracy [1, 3, 9]. Additionally, on CT cystography, the distended bladder does not obscure visualization of extravasation of contrast from the bladder. Morgan et al. found that there were no cases of bladder rupture that were only visualized on post-drainage CT cystography series, indicating that post-drainage images are not required [31].

An understanding of indications, protocol and procedural technique for CT cystography is critical for accurate diagnosis in the acute setting [43]. If there is suspicion of bladder injury, CT cystography is performed after routine CT abdomen and pelvis [35]. The presence or absence of pelvic fluid on CT abdomen and pelvis can inform the decision to continue with CT cystography [35]. A Foley catheter should be placed, once urethral injury is excluded, and drained prior to instilling with contrast. This is important as urine or hematoma within the bladder may limit visualization of the contrast. Approximately 300–400 ml of 3–5% iodinated contrast solution should be infused with gravity to reduce the risk of false negatives [3, 43]. The infusion should be stopped if the infusion stops dripping with gravity or the patient experiences worsening pain. Images should be attained with the patient in the supine position and taken from the iliac crests to the greater trochanters. Multi-planar reformations should be performed in the coronal and sagittal planes. Again, post-drainage images are not required.

There are several potential pitfalls in imaging technique and interpretation. Failure to drain the bladder prior to instilling the contrast can result in unopacified urine along the bladder wall [43]. Incomplete bladder distention leads to a limited evaluation. Bladder diverticuli can be misdiagnosed as a perforation (Figs. 9a–c and 10a–c) [13, 44]. A

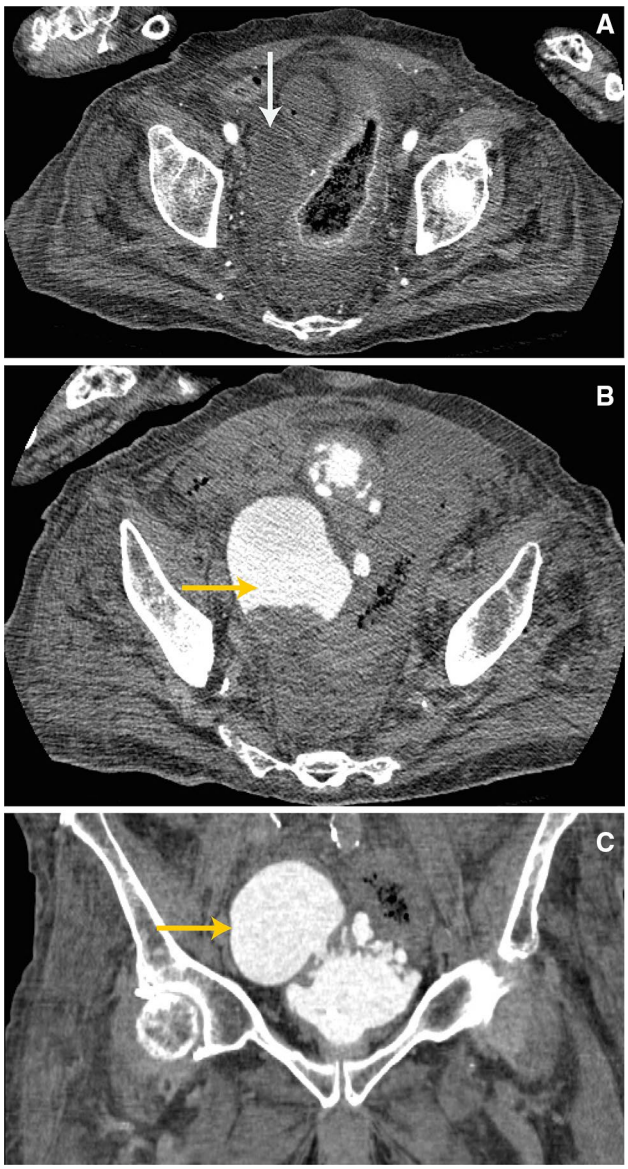

Fig. 9 **a–c** 90-year-old man presents to ED from nursing home for abdominal pain. Contrast-enhanced CT of the abdomen and pelvis showing a peripherally-enhancing fluid collection, 6.3 cm×7.5 cm (**a**; white arrow), which was believed to be an abscess on initial presentation. Foci of air were also seen adjacent to the bladder wall. CT cystography was requested, which shows multiple diverticuli with the largest along the right posterolateral aspect of the bladder, corresponding to the peripherally-enhancing fluid collection on axial and coronal reconstruction (**b**, **c**; yellow arrow)

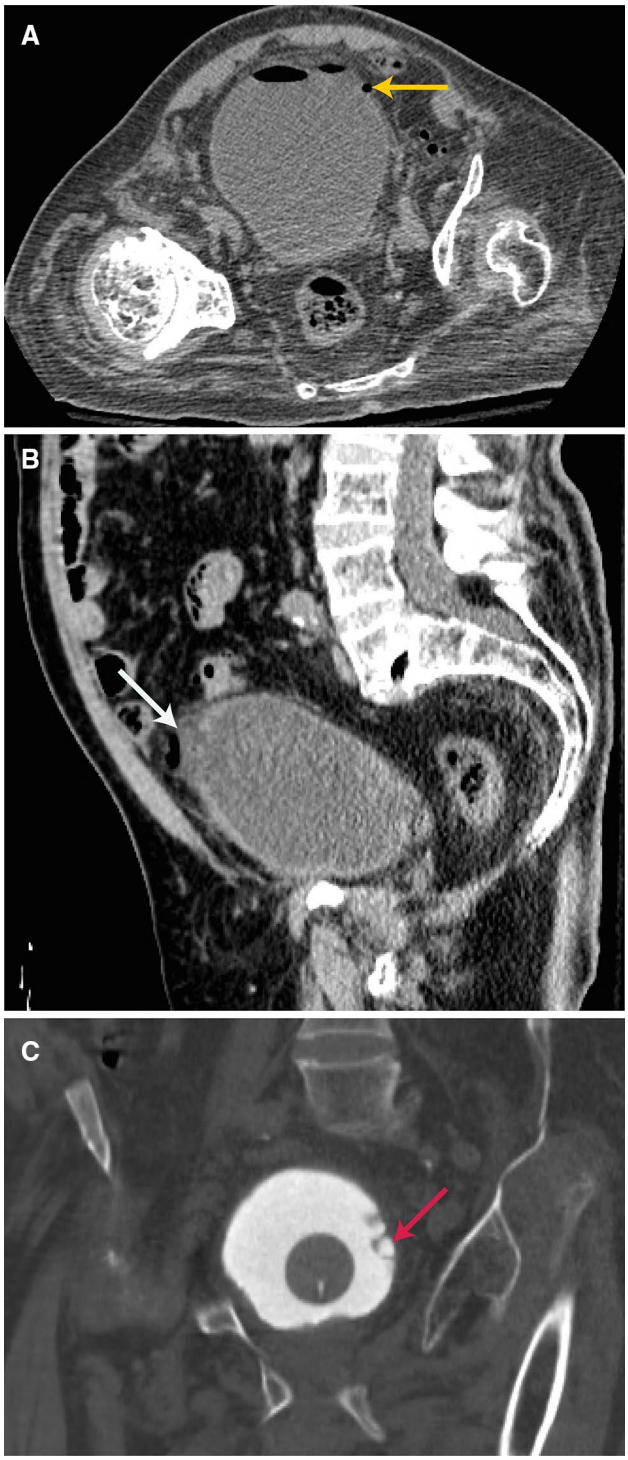

Fig. 10 **a**–**c** 96-year-old man presents to the emergency department for abdominal pain. CT of the abdomen and pelvis showing foci of air adjacent to bladder lumen (**a**; arrow), as well as a possible defect at the anterior bladder wall (**b**; arrow). CT cystography shows multiple diverticuli (**c**; arrow) which opacify with contrast

large pelvic hematoma can cause incomplete bladder distension and lead to missed intraperitoneal rupture [13, 43, 44]. Intraperitoneal hematoma at the bladder dome can initially prevent contrast extravasation through bladder dome rupture [13, 43, 44]. Large extraperitoneal rupture can cause incomplete distention, and lead to missed concomitant intraperitoneal rupture. Bone fragments, radiopaque foreign bodies, and oral or IV contrast (from visceral or vascular injury) near the bladder can complicate the evaluation of extravasation from the bladder [43]. Bladder dome laceration can be missed when CT reformations are not reviewed [13, 43, 44]. Proximal urethral injuries can mimic a complex extraperitoneal bladder injury [13, 43, 44].

In resource-limited environments, bedside sonography with retrograde instillation of normal saline has been suggested in hemodynamically-unstable patients [45]. The detection of peritoneal fluid in the presence of normal viscera or failure to visualize the bladder despite instillation of saline is highly suggestive of bladder rupture [45].

Imaging classification of bladder injury

CT cystographic classification of bladder injury classifies bladder injuries into 5 injury patterns: bladder contusion (type 1), intraperitoneal rupture (type 2), interstitial rupture (type 3), simple extraperitoneal rupture (type 4a), complex extraperitoneal rupture (type 4b), and combined intra- and extraperitoneal rupture (type 5) [9, 13, 15].

A normal CT cystogram will show a homogeneously hyperattenuating, thin- walled, well-distended bladder with no evidence of extravasated contrast material.

Type 1: bladder contusion

Bladder contusion is defined as incomplete or non-perforating tear in the bladder mucosa without loss of bladder wall continuity. Hematuria may be present, but CT cystography will typically appear normal. CT cystography can sometimes show mild focal wall thickening [43]. This is a diagnosis of exclusion, and the true prevalence is unknown, but is thought to be the most common form of bladder injury [19]. These injuries are typically self-limiting and require no specific therapy [13].

Type 2: intraperitoneal rupture

Intraperitoneal rupture accounts for 10–39% of major bladder injuries [9, 46, 47]. Intraperitoneal ruptures typically occur following high-energy blunt trauma to the lower abdomen of a patient with a distended bladder [48, 49]. This type of trauma results in a horizontal tear along the

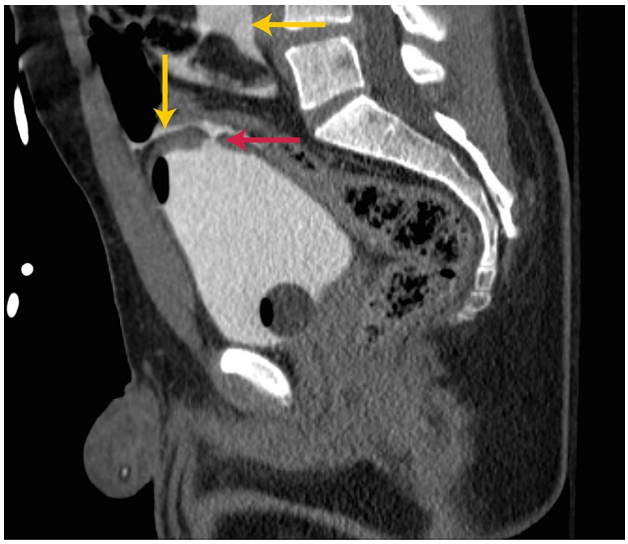

Fig. 11 18-year-old man found to have intraperitoneal bladder rupture after falling down three stories. CT cystography demonstrating a defect at the bladder dome (red arrow) and contrast pooling in the intraperitoneal space and interdigitating between bowel loops (yellow arrows)

peritoneal potion at the bladder dome leading to intraperitoneal extravasation (Fig. 11) [13, 50]. The bladder dome is particularly susceptible to rupture with blunt trauma to a distended bladder because it is the weakest portion of the bladder [18, 32]. Intraperitoneal extravasation is diagnosed by contrast material around loops of bowel, intraperitoneal viscera, and in the pericolic gutters [9]. Surgery is the mainstay of therapy (Figs. 12a–c, 13a, b, and 14a, b).

Type 3: interstitial rupture

Interstitial bladder rupture is an uncommon injury and is described as a dissection of the bladder wall without complete perforation (intact serosa) [13, 51]. On CT cystography, it can be seen as intramural hemorrhage and intramural contrast extravasation within the bladder wall without transmural extension (Fig. 15) [9, 43]. Prolonged bladder rest with an indwelling Foley catheter is the recommended treatment with no required follow-up imaging [11].

Type 4: extraperitoneal rupture

Extraperitoneal bladder ruptures are the most common ruptures accounting for 55–90% of major bladder injuries (Fig. 16a–c) [9, 46, 47].

Type 4A: simple extraperitoneal rupture

In simple extraperitoneal rupture, contrast extravasation is limited to the pelvic extraperitoneal space [11]. Contrast

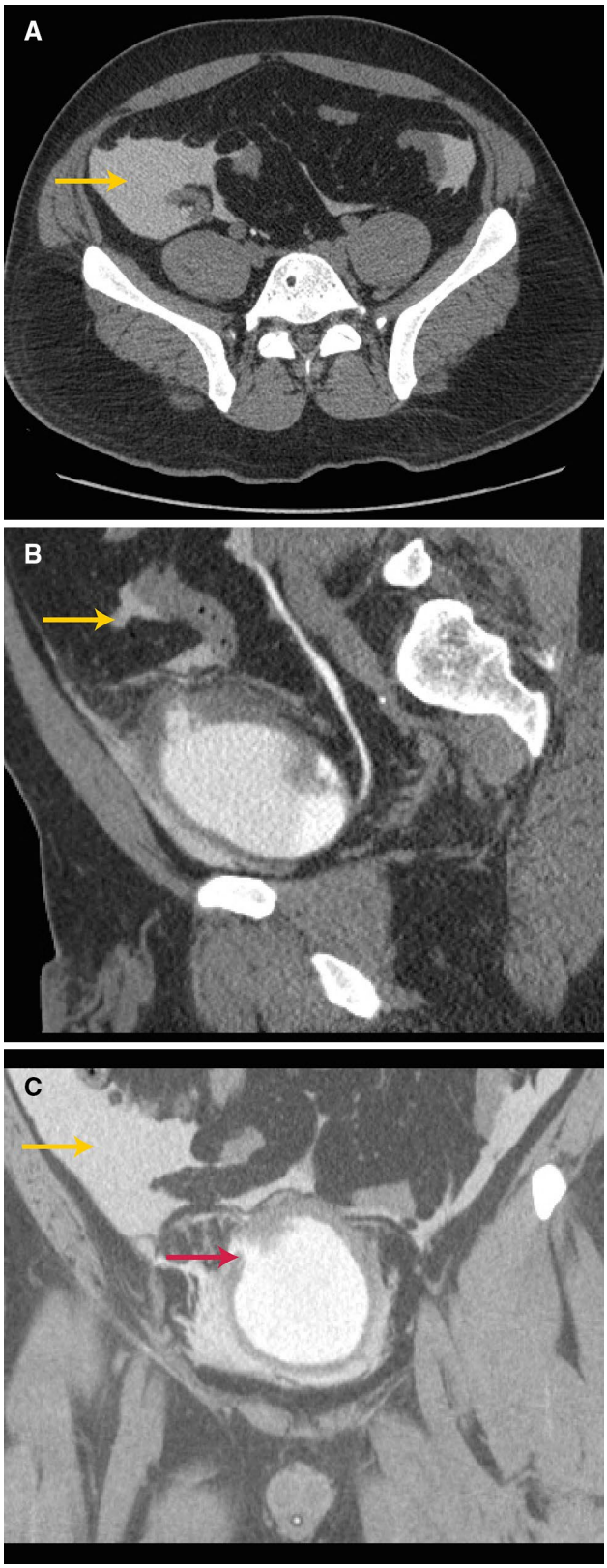

Fig. 12 **a–c** 29-year-old man was involved in a high-speed motor vehicle collision. CT cystography reveals contrast pooling into the intraperitoneal space (**a–c**; yellow arrow). Sagittal reconstruction revealed a defect (**c**; red arrow) along the right anterior bladder wall. Patient went to operating room for intraperitoneal bladder repair, where a 10 cm midline bladder rupture was seen

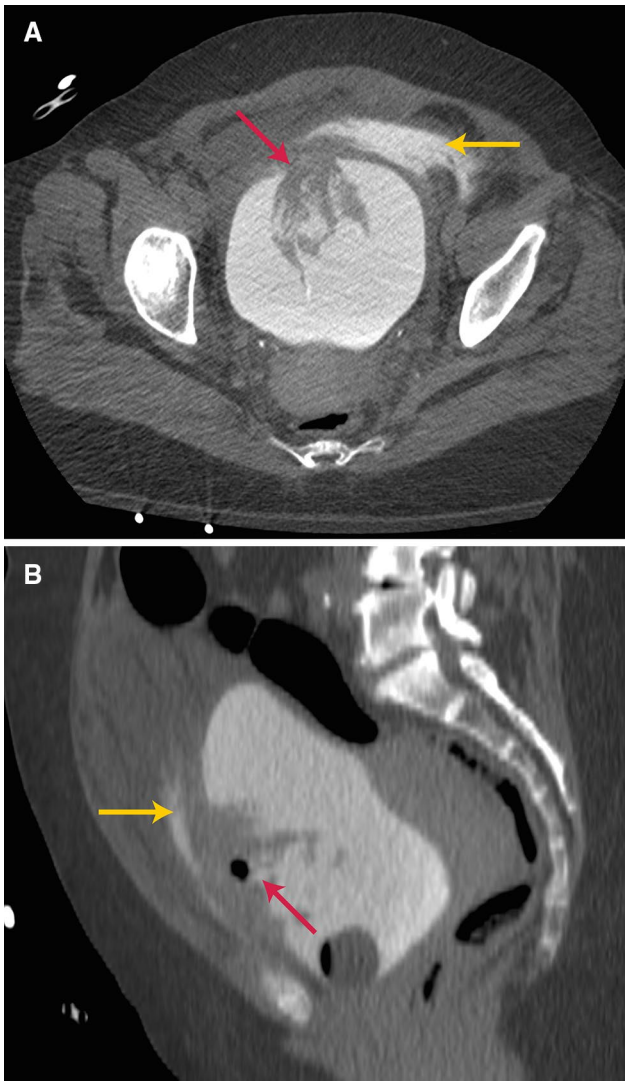

Fig. 13 **a**, **b** 55-year-old man fell down 5 concrete steps. Gross hematuria in the Foley catheter was noted. Axial (**a**) and sagittal (**b**) reconstruction from CT cystography demonstrating a large anterior bladder wall defect (**a**, **b**; red arrow), with contrast seen pooling in the pelvic extraperitoneal space (**a**, **b**; yellow arrow). The patient was taken to operating room, and was noted to have a 8 cm longitudinal bladder perforation

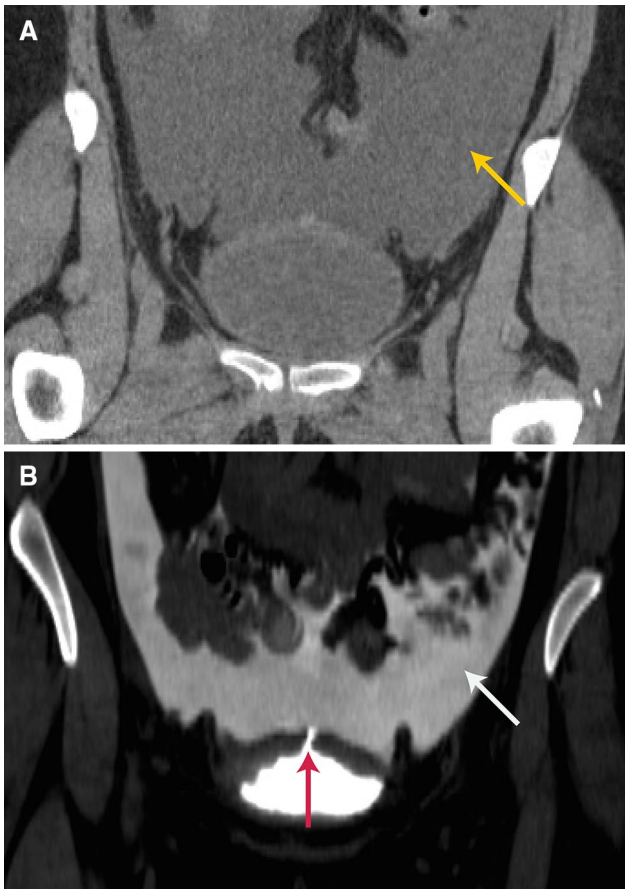

Fig. 14 **a**, **b** 27-year-old woman presenting with abdominal pain. On coronal reconstruction from initial abdominopelvic CT, free fluid seen in the intraperitoneal space (**a**; arrow). Coronal reconstruction from CT cystography showing a defect at the bladder dome (**b**; red arrow), and contrast leakage into the intraperitoneal space (**b**; white arrow)

extravasation into anterior perivesical space, or space of Retzius, surrounds the bladder in the form of a molar tooth, known as the "molar tooth" sign (Fig. 17a, b). On conventional retrograde cystography, small lacerations are best seen on post-drainage films as a full bladder can obscure extravasated contrast [19, 52, 53].

Type 4B: complex extraperitoneal rupture

In complex extraperitoneal rupture, contrast extravasation may extend into the perineum, anterior abdominal wall, penis, scrotum, or thigh [11]. As discussed earlier, the presence of communication with these spaces implies that the fascial planes (superior and inferior fascia of the urogenital diaphragm) in the pelvis has been disrupted (Fig. 18a–c). Extravasation can also extend upward within the retroperitoneum to the perinephric spaces. The extent and pattern of extravasation is dependent of the size of injury, location of injury, and volume of contrast material. Due to variable extravasation patterns, complex injuries isolated extraperitoneal injuries can be misdiagnosed as a combined intra- and extraperitoneal injury or having a co-existing urethral injury [29].

Type 5: combined intra- and extraperitoneal injury

Combined intra- and extraperitoneal bladder rupture accounts for 5–8% of major bladder injury [11, 46, 47]. These injuries will have extravasation characteristics of both intra- and extraperitoneal rupture (Fig. 19a, b). However,

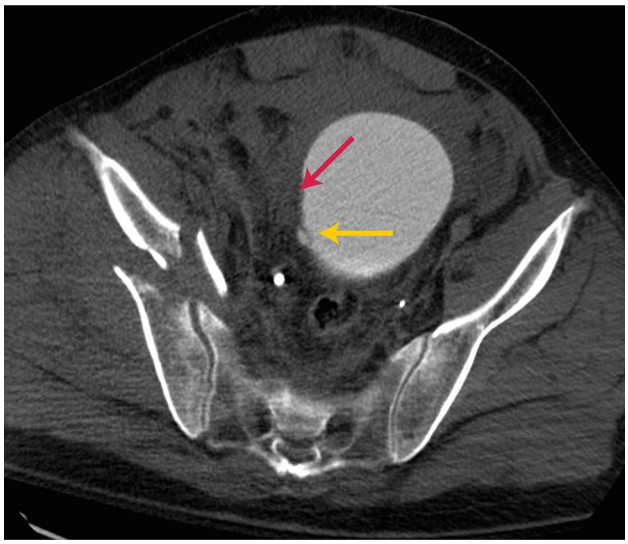

Fig. 15 50-year-old man fell down a flight of stairs. Pelvic radiograph (not shown) revealed a displaced right iliac wing and right superior pubic ramus fractures (which are also seen on CT). CT cystography demonstrates intramural contrast without leakage into the perivesical space (red arrow). Thickening of the bladder wall can also be seen when there is an intramural hematoma (yellow arrow). Extraperitoneal hematomas are also present anterior to the bladder

there are reported cases of combined injury that only demonstrated one component on cystography [13].

Management of bladder injury

The prognosis for bladder rupture is excellent if diagnosed and managed early [11, 13]. The determination of operative or non-operative management is based on several factors. All penetrating injuries are managed surgically. The management of blunt trauma is more nuanced.

A major distinction that must be made is the type of injury, intraperitoneal or simple extraperitoneal rupture. Isolated extraperitoneal injury can generally be treated conservatively with 10 days of Foley catheter drainage, assuming the catheter is draining properly, hematuria resolves, and there is no evidence of clot retention [11, 54]. A majority of tears close within 10 days and nearly all close within 3 weeks [11, 54]. Non-operative management is as effective as operative management in most patients with simple extraperitoneal rupture [30]. Intraperitoneal ruptures requires open repair, as they are often much larger than cystography suggests and are unlikely to heal with conservative management, which can lead to severe and sometimes fatal complications, particularly sepsis [1, 15]. Combined injuries are treated with open repair of both the intra- and extraperitoneal ruptures [2].

There are several exceptions to the distinction above. If there is a bone fragment projecting into the bladder rupture, open repair is preferred [55]. When the bladder neck, prostate, rectum, or vagina is injured, open repair is required [11, 46, 56]. If conservative management has failed with persistent contrast extravasation, excessive bleeding or sepsis,

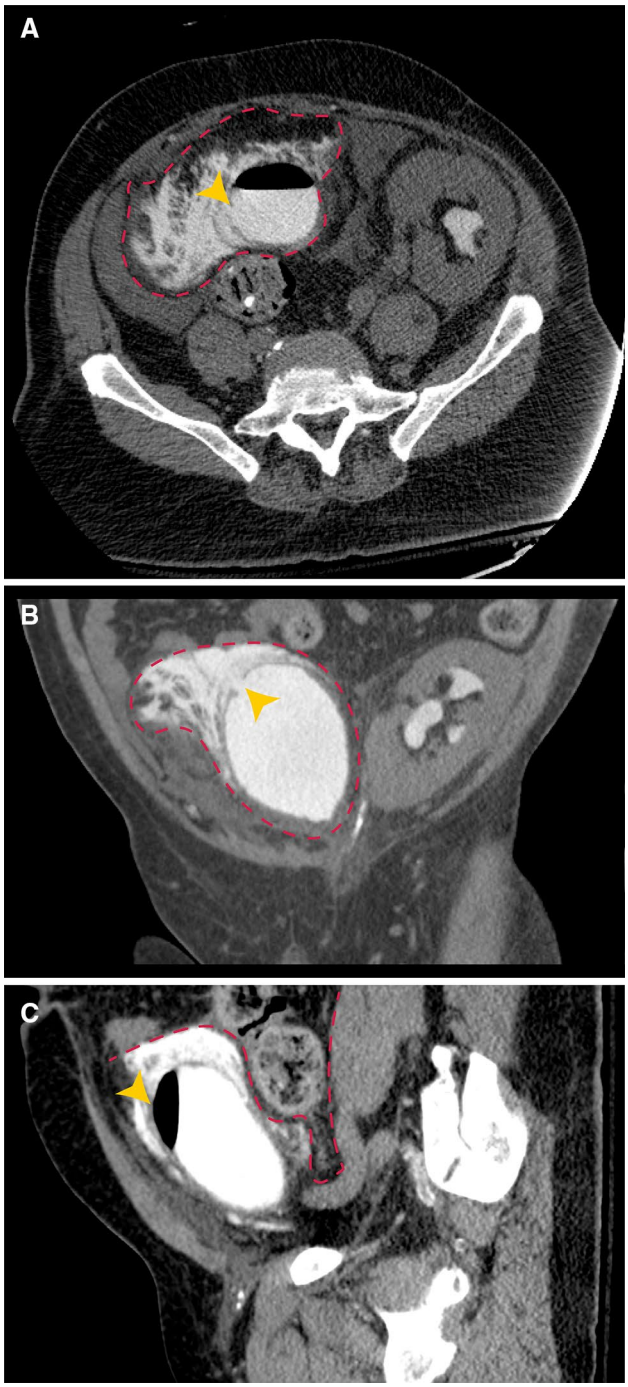

Fig. 16 **a**–**c** Extraperitoneal bladder rupture. 69-year-old man after fall from ladder. Axial CT cystography demonstrating contrast leaking from a bladder wall defect (**a**; arrow head) into the surrounding extraperitoneal space. Coronal (**b**) and sagittal (**c**) reconstruction demonstrates the anterior bladder wall defect (**b**, **c**; arrowhead) and the contrast spilling into the extraperitoneal pelvis. Incidental left pelvic kidney in noted (**a**, **b**)

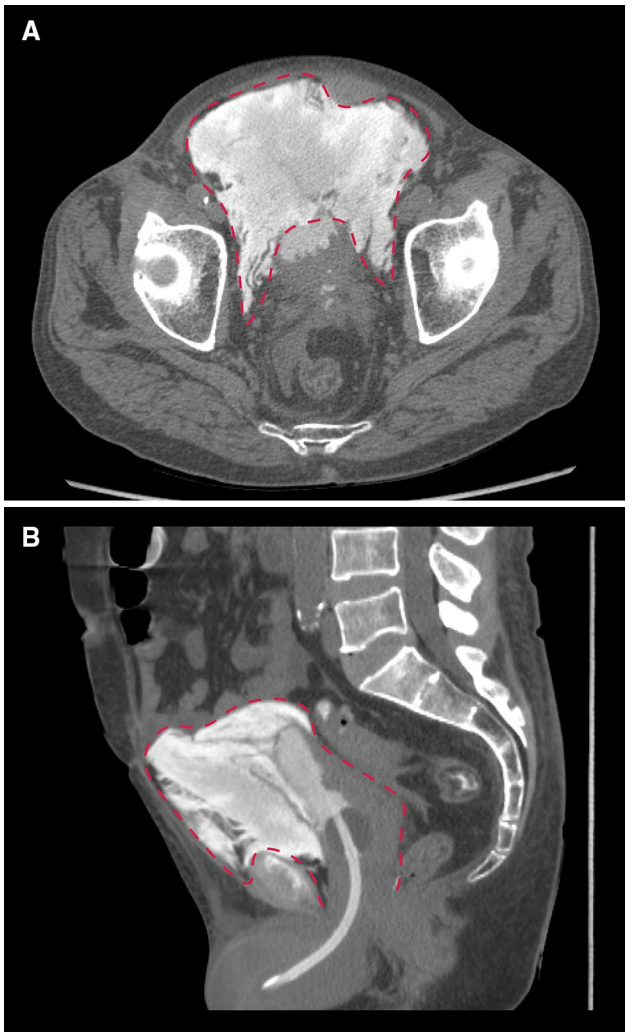

Fig. 17 **a**, **b** "Molar tooth" sign. 39-year-old man after fall from a roof. Axial (**a**) and sagittal reconstruction (**b**) from CT cystography demonstrates contrast extravasating from the ruptured bladder in the space of Retzius, and surrounding the bladder and the preperitoneal structures in the shape of a "molar tooth" (**a**; red outline)

surgical management is recommended [15]. If the patient is undergoing open reduction of pelvic fracture, the bladder is repaired at the same time as this will stop urinary leakage and decrease the risk of hardware infection.

After surgical bladder repair, a postoperative cystogram is recommended in 7–14 days [57]. For those patients managed conservatively, interval cystogram is recommended to assess for resolution of urine extravasation prior to removing the Foley catheter [4, 58].

Complications of bladder injury

The complications of bladder injury can be separated into two broad categories: delayed diagnosis and post-management (operative or non-operative).

Delayed diagnosis can lead to significantly increased morbidity and mortality. Complications due to persistent urine leakage can include sepsis, peritonitis, abscess formation, urinoma, uremia, metabolic imbalance (peritoneal reabsorption of urine electrolytes), and formation of urinary fistulas [15, 43].

After surgical repair, patients can suffer from continued leakage, clot retention, local infection, urethral stricture, or dysuria [1, 54, 59]. Complications from conservative management include urethral stricture, bladder hyperreflexia, urethrocutaneuous fistula, failure to heal, and sepsis (Fig. 20a, b) [1, 54].

Ureteral injury

Ureteral anatomy

Ureters are retroperitoneal bilateral tubular structures that connect the renal pelvis to the bladder. The ureters start at the ureteropelvic junction (UPJ) posterior to renal vasculature, and travel inferiorly passing over the psoas muscle before inserting into the bladder. The ureters measure 22–30 cm in length and are divided into the upper (proximal) segment, which extends from the UPJ to where it crosses the sacroiliac joint, the middle ureter where it passes over the pelvic rim, and distal ureter which extends from the iliac vessels to the bladder [5]. The blood supply to the upper third of the ureter stems from the aorta and renal artery, while the middle and lower segment is supplied by the iliac, lumbar, and sacral vessels [5]. The ureters are relatively protected by the retroperitoneum, which makes traumatic injuries a rare event.

Ureteral injury classification

Ureteral injuries account for 1–2.5% of the urologic trauma [5, 6]. Ureteral injuries stem from either penetrating or blunt trauma. Compared to blunt trauma, penetrating injuries to the ureters account for the majority of ureteral injuries [60–62]. While hematuria is considered a hallmark for an underlying genitourinary abnormality including trauma in the proper clinical context, it is often not present with ureteral trauma. The American Association for the Surgery of Trauma has developed a scoring scale for grading ureteral injuries. Grade I injury involves a hematoma [60, 63]. Grade II injury involves a ureteral laceration injury with less than 50% transection [60, 63]. Grade IV involves complete ureteral transection with < 2 cm devascularization [60, 63]. Grade V is an avulsion of the ureter with > 2 cm devascularization [60, 63]. This grading system plays a substantial role in guiding management of ureteral injuries, which can present as either blunt or penetrating trauma.

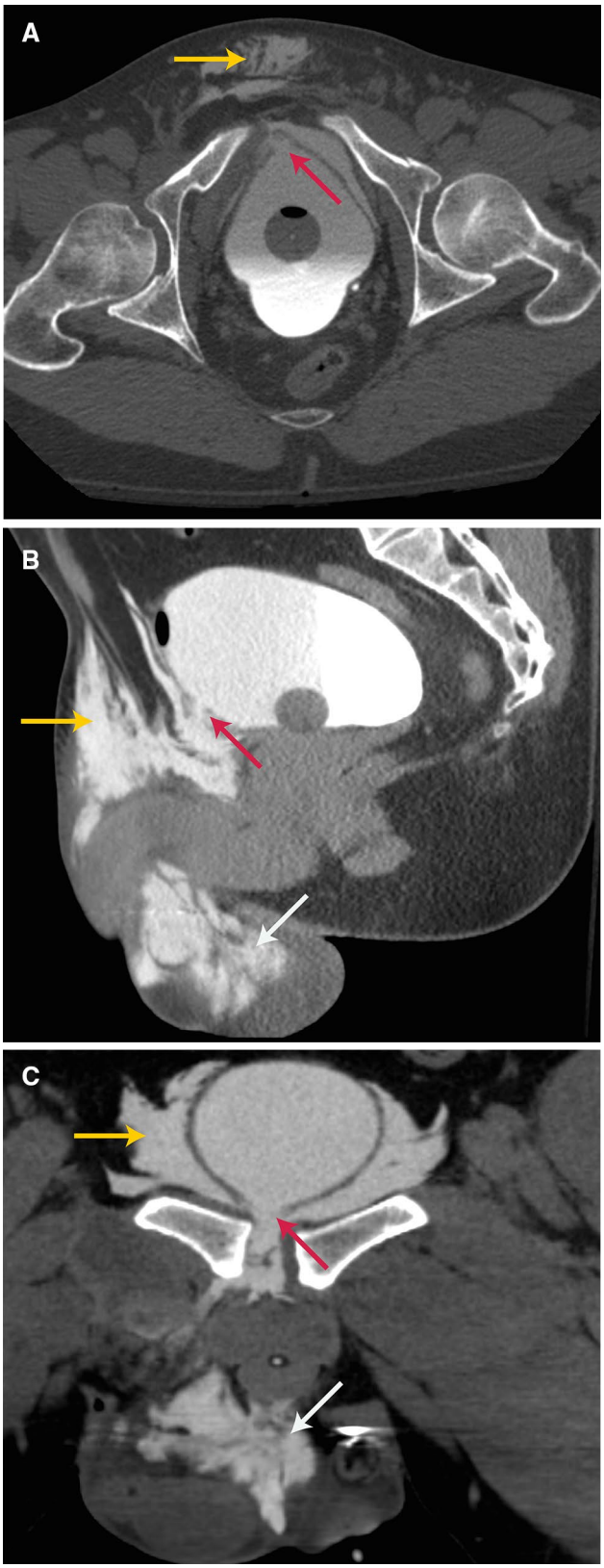

Fig. 18 **a**–**c** 42-year-old man presented to emergency department following a motorcycle crash. Patient complained of pain in his lower abdomen. The pelvic radiograph (not shown) revealed an open-book pelvic fracture. Axial (**a**), sagittal (**b**), and coronal (**c**) reconstructions from CT cystography shows a 6 mm defect in the anterior bladder wall (**a**–**c**; red arrows), with contrast leakage into the extraperitoneal paravesical space (**c**, yellow arrow). Contrast tracks into the anterior abdominal wall (**a**, **b**; yellow arrow) and scrotum (**b**, **c**; white arrow). Patient was managed with Foley catheter decompression

Mechanisms of ureteral injury

Penetrating injuries to the ureters account for the majority of traumatic ureteral injuries ranging from stab or gunshot injuries. Gunshot injuries account for 91% of penetrating injuries, while stab wound injuries account for about 5% [64]. There are two widely accepted mechanisms of penetrating injuries. The first and most common is direct transection of the ureter from penetrating injury [4, 5, 64, 65]. A bullet fired can directly transect the ureter. The second commonly accepted mechanism is a blast injury, where a penetrating bullet can cause a shock wave to adjacent tissue and disrupt the intramural blood supply [5, 64]. This is, in turn, leads to thrombosis and ischemia of the blood supply, resulting in eventual necrosis [5, 64]. The mid and distal ureter are the most common sites of penetrating injury. Blast effect may not be apparent right away and should on the radar several days following post-injury [5]. Commonly injured vasculature in penetrating trauma are venous structures, with the iliac vein being the most common [5].

Blunt trauma to the ureters is less common than penetrating trauma, but a high clinical concern should remain. Blunt trauma to the ureters is believed to be caused by rapid deacceleration at fixed attachment points, with the ureteropelvic junction being the most common site of blunt trauma [64]. Blunt trauma may disrupt the integrity via bony pelvic fractures or compression by bony structures [5]. Unlike penetrating injuries, arterial structures are likely to be injured with renal artery being the most common [64].

Iatrogenic ureteral injuries can occur during a variety of abdominopelvic and retroperitoneal surgical procedures (gynecologic, obstetric, vascular, colorectal, and urologic), as well as endoscopic procedures (ureteral stones) [32, 66]. Gynecologic procedures account for the majority of iatrogenic ureteral injuries [32, 67, 68]. The incidence of injury may also be lower in laparoscopic versus open colorectal procedures [69].

Imaging technique and evaluation

Multi-detector computerized tomography (CT) has become the mainstream imaging modality used to evaluate traumatic ureteral injuries in addition to evaluating abdominal and pelvic solid parenchymal organs. CT

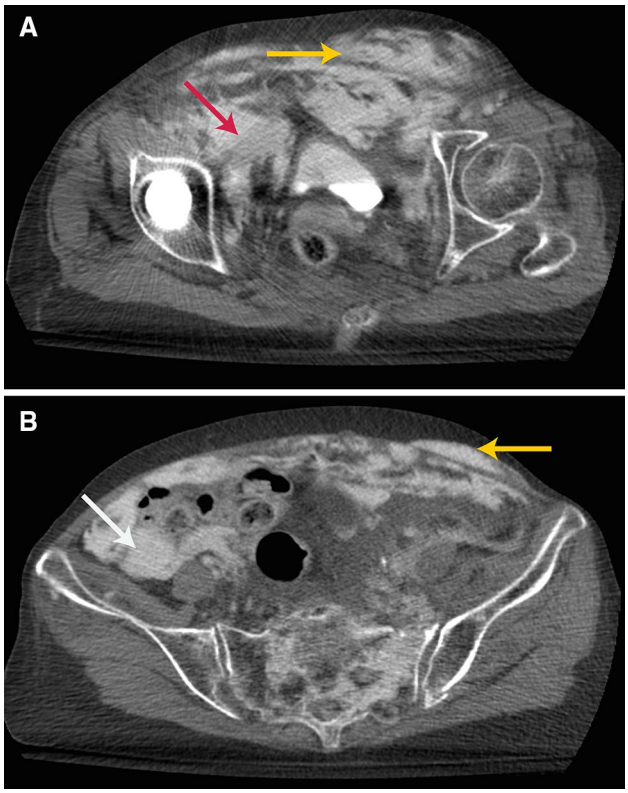

Fig. 19 **a**, **b** 68-year-old man struck by a car while crossing street. CT cystography demonstrating a complex extraperitoneal rupture, with contrast pooling in the paravesical space (**a**; red arrow), and traversing into the soft tissues of the anterior abdominal wall (**a**, **b**; yellow arrow). Contrast is also seen in the right paracolic gutter (**b**; white arrow) and intercalating between loops of bowel

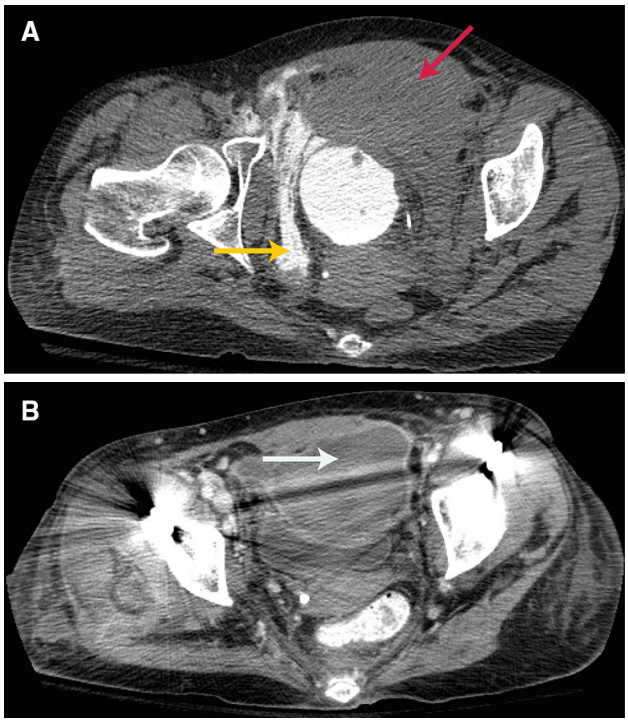

Fig. 20 **a**, **b** 47-year-old woman hit by car. On CT cystography she was found to have pelvic ring fractures and extraperitoneal bladder rupture (**a**; yellow arrow), with an adjacent pelvic hematoma (**a**; red arrow). 2 weeks later during her hospital course, the patient became septic, and was found to have an abscess in the region of the previously seen hematoma on CT abdomen and pelvis (**b**; white arrow), also noting new pelvic orthopedic hardware

urography is most commonly used when suspected traumatic or iatrogenic ureteral injury is suspected [32]. CT urography allows for the opacification of the collecting with contrast extravasation raising suspicion for ureteral injury (Fig. 21a, b). CT urography generally consists of three phases, including non-enhanced, nephrogenic, and excretory phase [32, 64]. CT images before and after administration of 100–125 ml of IV contrast are obtained with coronal and sagittal reformations to determine the extent of injury. Delayed sequences, which are obtained 5–20 min after IV contrast administration are essential to diagnosing ureteral injuries as it allows for opacification of the collecting system and enables to demonstrate contrast extravasation pinpointing ureteral injury [5, 32, 64]. Laceration of the ureter will typically present with contrast extravasation with opacification of the distal ureter, while in ureteral transection the distal ureter will not be opacified [32].

Complications of ureteral injury

Delayed diagnosis of ureteral injuries can lead to complications including urinomas, periureteral abscess, and strictures [5]. Urinomas are collections of urine with water attenuation on CT, which can be seen in the subcapsular or perirenal spaces or extend into the intraperitoneal cavity [32]. A ureteral stricture is defined as fixed ureteral narrowing with proximal dilation and lack of distal opacification [32, 70]. Ureteral strictures are most often iatrogenic, but can be seen in post-traumatic settings with narrowing of the ureter and lack of opacification distal to the site of the tapered ureter [32]. Partial stricture could present with a subtler demonstration of focal narrowing and proximal dilation, with opacification of the distal ureter. A potential mimic of ureteral narrowing is peristalsis which presents as lack of an opacified ureter; however, proximal ureteral dilation is absent [70]. Prompt diagnosis of a ureteral injury can prevent or decrease the severity of complications associated with ureteral trauma.

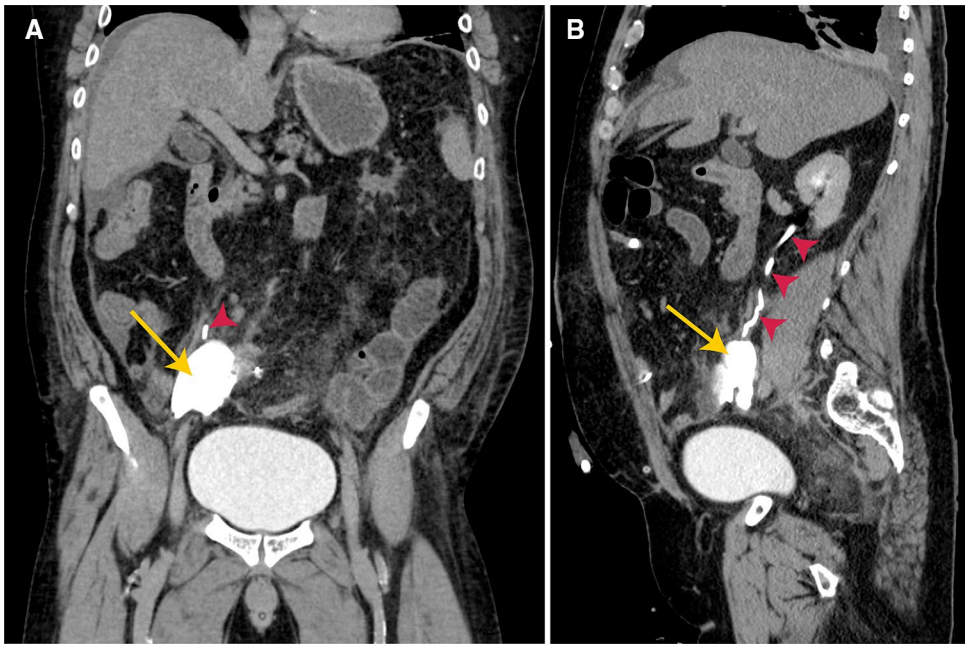

Fig. 21 **a**, **b** Ureteral transection. 60-year-old man after iatrogenic trauma during laparoscopic colostomy takedown and lysis of adhesions. Coronal (**a**) and sagittal (**b**) CT images demonstrating contrast leaking from the right ureter (**a**, **b**; arrow), with an intact proximal ureter (**a**, **b**; arrowheads)

Conclusion

Traumatic injury to the bladder and ureters rarely occurs alone, and often takes a backseat as other abdominopelvic injuries take precedence. However, recognizing the presentation and imaging findings of blunt as well as penetrating traumatic injuries to the bladder and ureter is important for the care and prognosis of the patient.

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