Renal Injuries

19

Silvia Lucarini, Alessandro Castellani, Elena Bertelli, Monica Marina Lanzetta, Simone Agostini, Margherita Trinci, and Vittorio Miele

19.1 Introduction

The kidneys are two symmetrical retroperitoneal organs, wrapped in retroperitoneal fat and located at the sides of the lumbar spine; their upper pole is at the level of twelfth dorsal vertebrae, and the lower one is at the third lumbar vertebrae.

The right kidney is slightly moved in lower than the left kidney, for the presence of the liver.

A fibrous capsule wraps the kidney; the parenchyma is formed externally from the cortical part and an inner medulla part. The medial surface of the kidney has a concave incision called hilum, through which arteries, veins, and lymph vessels and ureter enter and exit.

The right kidney is related to the liver, right flexure of the colon, and duodenum. The left kidney gets into relationship with the stomach, pancreas, duodenal-jejunal flexure and spleen, and colon (left flexure). They report, above, with their adrenal gland and posteriorly with the muscles of the back abdomen.

The kidney is involved in 8–10% of abdominal trauma cases, with 245,000 cases/year/world, and it is the most frequently injured organ in genitourinary trauma (80%), followed by external genital organs, bladder, urethra, and ureter. The incidence of renal trauma is about 4.9 per 10,000 of the population [1]. Three quarters of patients with renal trauma are male. In most of the cases, renal involvement occurs in blunt trauma (approximately 90%) [2–4]. The most common causes of blunt trauma are motor vehicle accidents, followed by direct blow to the flank or abdomen during a fight, sport activities or an assault, and a fall from a height [5–7]**.** Car accidents are associated with renal injuries in 43% of cases, whereas motorcycle accidents are more frequently associated with male external genital organs injuries and urethra; in this latter type of accidents, renal injuries occur in 28% of cases [8]. The incidence of renal injuries due to penetrating trauma, such as gunshot, stab wounds, or iatrogenic injuries during renal biopsies or other medical procedures, is low (approximately 10% of renal traumas) but could be associated with more severe renal damage and is frequently associated with injuries to other organs [9–11]**.**

There are predisposing conditions that can expose a blunt trauma patient to a kidney injury, including hydronephrosis, cystic diseases, horseshoe kidney, and nephroblastoma. Another factor

S. Lucarini, M.D., Ph.D. (✉) • A. Castellani
E. Bertelli • M.M. Lanzetta • S. Agostini • V. Miele
Department of Radiology, Careggi University Hospital, L.go G. A. Brambilla 3, 50134 Florence, Italy
e-mail: slucarini@iol.it; lucarinis@aou-careggi.toscana.it

M. Trinci
Department of Emergency Radiology, S. Camillo Hospital, Rome, Italy

V. Miele, M. Trinci (eds.), *Diagnostic Imaging in Polytrauma Patients*,
https://doi.org/10.1007/978-3-319-62054-1_19

that exposes the kidney to traumatic injuries is its mobility on the pedicle that exposes it to stretching injuries.

In both blunt and penetrating trauma, multiorgan involvement is common (80–90% of patients with penetrating trauma, 75% of those with blunt trauma). The associated lesions by frequency are lung contusion, 46%; splenic injury, 39%; liver injury, 34%; bone damage, 27%; adrenal injury, 7%; and intestinal perforation, 4%. Especially in these cases of multiorgan involvement, contrast-enhanced CT is essential for a complete trauma evaluation.

Isolated renal trauma is rare and is usually classified as a minor injury [6, 12]. While blunt trauma may result in contusion or laceration of the parenchyma or the renal hilum due to sudden deceleration or a crush injury, penetrating ones produce direct damage on the parenchyma, the collecting system, or the vascular structures and involve the peritoneum [10, 13, 14]. Moreover, penetrating injuries are at higher risk of bacterial growth within the hematoma or urine leakage due to the non-sterile condition, and in some cases, a surgical debridement or a nephrectomy could be mandatory [15, 16].

Imaging assessment depends primarily on the hemodynamic status of the patient, because if the patient is hemodynamically unstable, an immediate damage control laparotomy is usually performed. In case of stable patients, the imaging strategy depends on the mechanism of injury and on clinical and laboratory findings.

Renal trauma can occur with a quite wide range of severity; therefore, different kinds of treatment are needed. In the past two decades, important advances have been made in diagnostic imaging and in polytrauma patient management, and therefore the focus has slowly passed from a mainly surgical to a more conservative approach, since urgent surgical exploration often leads to nephrectomy and endovascular embolization is gaining importance in treating ongoing bleeding [17].

Renal trauma management depends widely on lesion type and extension. The radiologist plays an essential role in distinguishing kidney lesions that need surgical or interventional treatment from the ones needing a conservative approach.

Nowadays, two main classifications exist, which are used for the management of traumatic renal injuries: the one developed by the American Association for the Surgery of Trauma (AAST) (Table 19.1), surgical-based, which grades the severity of renal injuries from 1 (minor contusion) to 5 (shattered kidney), and the one proposed by Federle, a CT-based classification, more popular among radiologists, which considers some aspects not included in the AAST grading system (Table 19.2) [18–22].

Of course these two classification systems present several overlaps and don't include all the

Table 19.1 American Association for Surgery of Trauma (AAST) renal injury classification

Grade[a]	Type	Description
I	Parenchyma	Microscopic or gross hematuria; urological studies normal (contusion)
	Hematoma	Non-expanding subcapsular hematoma
II	Parenchyma	Laceration <1 cm in depth, without collecting system rupture
	Hematoma	Non-expanding perirenal hematoma confined to retroperitoneum
III	Parenchyma	Laceration >1 cm in depth without collecting system rupture
IV	Parenchyma	Laceration with collecting system rupture
	Vascular	Main renal artery/vein injury with contained hemorrhage
V	Parenchyma	Shattered kidney
	Vascular	Avulsion of renal hilum that devascularized kidney

Obtained permission from Wolters Kluwer

[a]Advance one grade for bilateral injuries up to grade III

Table 19.2 Federle classification

Category	Type	Injury
I	Minor injury	Renal contusion; intrarenal and subcapsular hematoma; minor laceration with limited perinephric hematoma without extension in the collecting system or medulla; small subsegmental cortical infarct
II	Major injury	Major renal laceration through the cortex extending to the medulla or collecting system with or without urine extravasation; segmental renal infarct
III	Catastrophic injury	Multiple renal lacerations; vascular injury involving the renal pedicle
IV	Ureteropelvic injury	Avulsion (complete transaction); laceration (incomplete tear)

Reproduced with permission from Razali MR, Azian AA, Amran AR, Azlin S (2010) Computed tomography of blunt renal trauma. Singapore Med J 51:468–473; quiz 474

possible conditions; therefore, the communication between radiologist and surgeon is of vital importance to define the grade and severity of the kidney injury.

Moreover, the AAST classification is the most and widely accepted, and it's based on accurate assessment at autopsy, laparotomy, or radiologic study. This grading system is widely used in the urological setting. Increasing grade correlates with the need for nephrectomy and dialysis and with mortality. Grades I through III can be managed conservatively as they heal spontaneously. Grades IV and V with collecting system disruption and vascular injury usually require intervention.

This classification has some limitations, like it does not consider vascular injuries associated with low-grade injuries. There are some proposals for changes, including a sub-stratification of the intermediate-grade injury into low-risk (likely to be managed nonoperatively) and high-risk cases (likely to benefit from angiographic embolization or surgery) [23]. Another suggestion is to comprise all collecting system injuries and segmental arterial and venous injuries in grade IV injuries, while including only hilar injuries (comprising thrombotic events) in grade V injuries [24].

As we have already said, the Federle classification is based on CT findings; however, both classifications, although based on different criteria, have common points and in fact agree that the most serious lesions are those involving the excretory system and/or the vascular one.

Conservative management has become the treatment of choice for the majority of renal injuries, especially in blunt trauma [25, 26]**.** In particular, a nonoperative approach can be performed in hemodynamically stable patients with:

- Grade I and II injuries
- Most of grade III injuries
- Grade IV with a devitalized fragment or with urinary extravasation
- Grade V with unilateral main arterial injury, comprising unilateral complete blunt arterial thrombosis

In penetrating trauma a selective nonoperative management is generally accepted [27, 28]:

- In stab wounds if the patient is stable and the site of penetration is posterior to the anterior axillary line
- In gunshot injuries if they don't involve the renal hilum or are accompanied by signs of ongoing bleeding, ureteral injuries, or renal pelvis lacerations with a successful outcome in approximately 50% of stab wounds and up to 40% of gunshot wounds [29, 30]

Nowadays angiography and embolization represent essential techniques in the nonsurgical treatment of traumatic kidney lesions. Superselective embolization has shown to increase significantly the chances to preserve the kidney and its function.

Embolization has a fundamental role in the conservative management of active bleeding, arteriovenous fistula, and pseudoaneurysm, and it seems to be most beneficial in the setting of high-grade renal trauma (AAST > 3).

In the management of high-grade renal trauma, embolization can be successful in up to 94.9% of grade III, 89% of grade IV, and 52% of grade V injuries and has decreased significantly nephrectomy [31–33].

Indications to operative management are limited, reserving surgery in case of shuttered kidney. The hemodynamic instability and the unresponsiveness to aggressive resuscitation due to renal hemorrhage are indications for surgical exploration, irrespective of the mode of injury [34, 35].

The exploration aims to control the hemorrhage and to save the kidney. Other indications are the mechanism of trauma; the presence of an expanding perirenal hematoma, identified at exploratory laparotomy performed for associated injuries; and the presence of multiorgan involvement which led the patient to hemodynamic instability.

Endourological techniques are indicated for the management of persistent extravasation or urinoma.

Inconclusive imaging and a preexisting abnormality or an incidentally diagnosed tumor may require surgery even after minor renal injury [36]. The overall exploration rate for blunt trauma is less than 10% [37] and may be even lower, as the conservative approach is increasingly adopted [38].

19.2 Radiological Diagnosis

The purpose of diagnostics imaging is to identify the renal lesion, to evaluate prognostic factors, and to give an indication of the patient's management.

Currently the indications for the different diagnostic imaging modalities are controversial and depend on several things, such as the hemodynamic status of the patient, on the presence of associated lesions, and on the type and locations of the trauma.

Unstable patients are immediately examined with FAST (focused assessment with sonography for trauma), an abdominal ultrasound (US) protocol performed bedside in the emergency room for the detection of free peritoneal fluid [39].

Patients involved in a high-energy accident, in stable condition or whose vital functions have been stabilized, are rapidly examined with a whole-body computed tomography (CT) [40].

The management of patients with mild-/low-energy trauma is controversial: the clinical presentation and the mechanism of injury are fundamental for the decision to immediately perform CT or assess the patient with sonography, conventional radiography, and clinical observation [41–44].

In 2014 the American Urological Association (AUA) released new guidelines, amended in 2017 [45], for management of patients with a suspect of renal trauma.

CT with administration of intravenous contrast material is recommended in adults with blunt trauma and one of the following cases [2, 10, 46, 47]:

- Gross hematuria: represents the main initial indicator of a significant renal lesion, although it is not correlated with the degree of injury
- Microscopic hematuria in the presence of shock (systolic blood pressure < 90 mmHg)
- A mechanism of injury (e.g., rapid deceleration or high-speed collisions)
- A physical examination concerning for renal injury: contusion or flank ecchymosis, fracture of the last ribs or thoracolumbar spine, and open wound of the abdomen, of the flank, or of the lower part of the thorax, in case of expanding mass of the flank that may be a hematoma or urinoma, regardless of the presence or absence of hematuria
- In case of retroperitoneal fluid, nausea, vomit, or paralyzed ileum

A diagnostic evaluation is mandatory also in all cases of penetrating traumas, because in those situations there is a poor correlation between the presence of hematuria and the severity of the injuries [48].

Gross or microscopic hematuria is usually present in 95% of renal trauma, but its absence doesn't preclude the presence of kidney injure, for example, it can be absent in 24% of patients with renal artery thrombosis, and in approximately 30% of urinary tract junction lesions, these lesions, moreover, are major injuries.

Although no exact indications have been given in the AUA 2014 guidelines for patients with penetrating renal trauma, the most accepted one is to perform a CT in the presence of hematuria or in a clinical suspect of a urinary tract lesion.

The Urogenital Trauma guidelines of European Association of Urology (EAU) released in 2013 and updated until 2017 are similar to the AUA ones [2, 46].

Some authors affirm that patients with microscopic hematuria and systolic blood pressure >90 mmHg have a very low risk of major renal injury (incidence of 0.2%) [48], so they could not require a diagnostic imaging evaluation.

Renal injuries, especially high-grade ones, seem to be more frequent in children, and these can also occur for minor trauma [49]; this is because of the anatomy of pediatric patient. In fact, the kidney in children is larger compared to the rest of the body, and it can maintain fetal lobulation that could easier lead to parenchymal disruption; a child's kidney is also less protected because it has less perirenal fat, and the abdominal wall thickness is less than that of the adult [37, 50].

In pediatric patients the diagnostic imaging choice is controverted. Due to the capability of children to maintain their blood pressure, instead of adults, some centers recommend a CT scan in case of suspected renal involvement in pediatric blunt trauma with any degree of hematuria following significant abdominal trauma.

In pediatric blunt renal trauma, CT is indicated when the RBC value in the urine is >50 per HPF and in penetrating trauma when the RBC value in the urine is >5 per HPF [10].

19.2.1 Ultrasonography (US)

Ultrasound, just for its well-known advantages, which consist of low cost, lack of ionizing radiations, and its portability with the possibility to be rapidly performed at patient's bedside, among others, is the most largely available imaging modality in emergency department.

Apart from its use in the emergency room with FAST (focused assessment with sonography for trauma) to highlight the presence of hemoperitoneum, ultrasound is often the first imaging of choice in evaluating a patient with localized low-energy trauma. In fact a standard ultrasound technique is able not only to detect free fluid but also to demonstrate a parenchymal lesion. In the specific case of kidney, the deep retroperitoneal position and the body type of patient can influence the detection of the lesion; moreover, the operator's experience and patient's collaboration are other factors that may affect the outcome of the exam. For these reasons US demonstrates high sensitivity for the detection of free intra-abdominal fluid; in the same study, it is reported more than CT exam for small amount, but fairly low sensitivity (even below 50%) for the detection of abdominal solid organ traumatic lesions [51].

Some studies report that the US, practiced in an emergency environment, has very low sensitivity in the detection of parenchymal renal injury (less than 22% in minor lesion) and perirenal collections [51–55]. The American College of Radiologists (ACR) Renal Trauma guidelines consider US usually not appropriate in renal trauma [46]. It also cannot be a reliable diagnostic tool for major vascular injuries and renal function.

Contrast-enhanced ultrasound (CEUS) in traumatic patients has been shown to be more sensitive than US for the detection of solid organ injuries, improving the identification and grading of traumatic abdominal lesions with levels of sensitivity and specificity similar to CT (up to 95%) [56]. With CEUS is also easier demonstrated even small amount of perirenal fluid and sometimes is possible to detect active bleeding. The principal limit of CEUS is the impossibility to evaluate the excretory phase, because microbubbles are not excreted into the collecting system; therefore, CEUS cannot demonstrate injuries to the urinary system: renal pelvis or ureter [57–60].

For these reasons both basic ultrasound and CEUS may not be the only investigations to evaluate a patient with trauma. Their role, especially that of CEUS, is to identify patients with a positive traumatic injury response and to send them a CT diagnostic completion test, differentiating them from negative traumatic injury patients who, if in agreement with the clinic, cannot continue the radiological diagnostic iter.

In this way it decreases the unnecessary radiation exposure, using the US-CEUS as a screening tool to select patients who require a CT or not.

This is very important especially in selected series of patients, such as pediatric patients, young women in reproductive age, and low-energy trauma patients, or in the follow-up of stable patients with kidney injury [39, 41, 61].

An US exam is performed using a convex-array multifrequency 3.5–8 MHz probe. During the US exam, a parenchymal renal injury can be seen as a slightly hyperechoic area with no defined margins that may be difficult to detect in renal parenchyma. Often even in case of minor trauma a surrounding hematoma is visible, as well as a recent hyperechogeneous hematoma, which sometimes can be confused with renal parenchyma (Fig. 19.1).

Over time, hematoma loses its echogenicity, becoming hypo-anecdotal and decreasing its volume (Fig. 19.2).

Usually CEUS exam, in case of low-energy localized renal trauma or during a follow-up of known injuries, is performed using a convex-array multifrequency 3.5–8 MHz probe after a previous basal ultrasound. CEUS uses second-generation ultrasound contrast agents and needs dedicated software operating at low mechanical index.

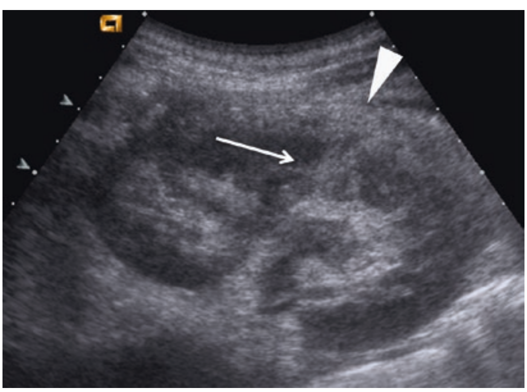

Fig. 19.1 Ultrasound shows injured left kidney, with a hyperechoic parenchymal area at the medium of the kidney, corresponding to the lesion (*arrow*); there is a hyperechoic hematoma surrounding the kidney (*arrowhead*)

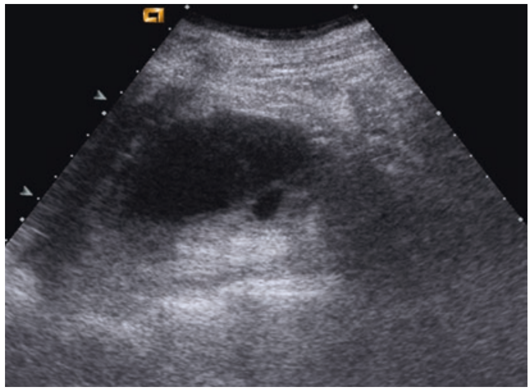

Fig. 19.2 Ultrasound shows a non-recent subcapsular hematoma, which appears as an hypoechoic mass compressing renal parenchyma

Like any contrastographic examination, the informed consent of the patient is required.

After contrast agent administration with quick bolus, the renal cortex enhances immediately in arterial phase (10–30 s), very brightly and evenly, and the pyramids enhance diffusely from the periphery to the center over about 30 s. The homogeneous phase of the kidneys generally lasts 2–2.5 min: this homogeneous phase (venous phase or nephrographic phase) is still the most effective for detection of traumatic injuries. At CEUS exam the injured area is detected as anechoic surrounded by normal strongly hyperechogenic renal parenchyma (Fig. 19.3). Perirenal or subcapsular hematoma is easily seen as perirenal hypo-anechoic zone, in case of subcapsular hematoma, with the typical imprint on the kidney profile (Fig. 19.4). In case of active bleeding, it is possible to detect in the injured area the hyperechoic spots. As we already said, it is impossible evaluate the excretory system [53, 60].

When a renal lesion is detected at US or CEUS complete, the examination of the patient performing a CT with intravenous contrast medium is recommended.

Eco-color-Doppler imaging can be useful in monitoring vascular posttraumatic complications

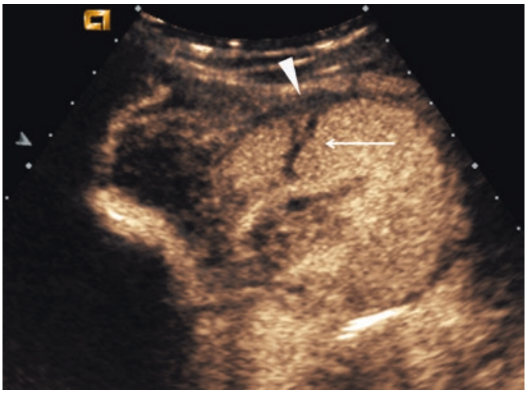

Fig. 19.3 CEUS, axial view of the kidney, shows the renal injury as linear anechoic area. Note the small perirenal hematoma as a subtle fluid collection surrounding the kidney (*arrowhead*)

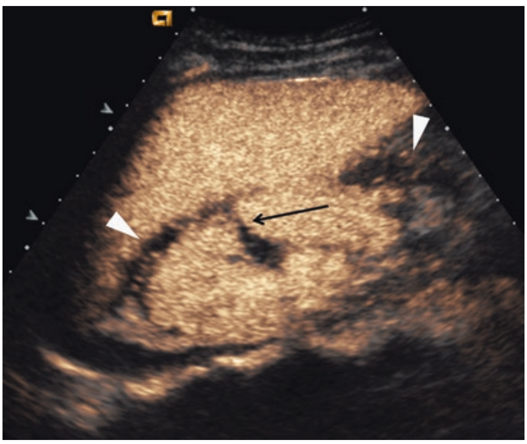

Fig. 19.4 CEUS shows a deep laceration of renal parenchyma (*black arrow*). Perinephric hematoma is seen as a hypoechoic fluid collection surrounding the kidney (*arrowheads*)

such as pseudoaneurysms, arteriovenous fistulas, and arterial or venous renal thrombosis.

19.2.2 Multidetector Computed Tomography (MDCT)

With the technological development in the past two decades, contrast-enhanced MDCT has gained a central role in the evaluation of stable polytrauma patients, becoming the first choice examination. Integration of whole-body CT into the initial management of polytrauma patients significantly increases the probability of survival and a better prognosis [62].

CT can quickly and accurately identify and grade renal injury [63], can establish the condition of the contralateral kidney, and can demonstrate injuries to other organs.

In the setting of renal trauma, multiphase CT allows the most comprehensive assessment of the injured kidney. The standard protocol consists in an abdominal pre-contrast acquisition from the diaphragm to the pubic symphysis, followed by a post-intravenous contrast exam in arterial phase (delay around 40 s) and venous nephrographic phase (delay around 80 s). A pyelographic phase (at 5–10 min or more) is practiced only in the suspected urinary tract injury, e.g., in the presence of collections to differentiate an active bleeding from a urinoma (Fig. 19.5) [64, 65].

A volume of nonionic contrast medium of 100–150 mL is injected at a rate of 2–4 mL/s through an 18–20-gauge needle.

Concerns regarding contrast media worsening outcomes via renal parenchymal toxicity are likely unwarranted, with low rates of contrast-induced nephropathy seen in trauma patients [66].

However, in practice, trauma patients usually undergo standardized whole-body imaging protocols; it may happen that, caused by critical patient's condition, it is not possible to perform an excretory phase; and in this case if there is suspicion that renal injuries have not been fully evaluated, repeating renal imaging when it is possible should be considered.

19.2.3 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is not commonly used imaging modality in trauma patients, due to the time needed for examination, the difficulty to manage a traumatized patient in MR room, the limited access to the patient during the acquisition of imaging, the need for MRI-safe equipment, and the logistical challenges of moving a trauma patient to the MRI suite. Anyway the diagnostic accuracy of MRI in renal trauma is similar to that of CT with the benefit due to the

Fig. 19.5 CT exam in a patient with a urine leakage from pyelo-ureteral tract, with huge urinoma. (**a**) Arterial phase and (**b**) axial and (**c**) coronal MPR in excretory phase. Note the importance of the late excretory phase that allows to differentiate a perirenal collection, e.g., hematoma from urinoma

lack of radiations exposure [67, 68]**.** Due to the lack of radiations, MRI can be useful, especially in the assessment of pediatric patients and young women, in cases in which the use of iodine contrast material is contraindicated or in follow-up of renal and urinary tract lesions, since with the administration of gadolinium the extravasations of urine can be visualized [69–71].

19.2.4 Urography, Angiography, and Scintigraphy

Intravenous urography is nowadays an obsolete imaging modality for the evaluation of renal trauma. It can be used only in rare situations, if the MDCT is not available or in the operating room, in hemodynamically unstable patients taken to the operating room without imaging, to confirm the contralateral renal function if nephrectomy is considered. The technique consists of an injection of intravenous contrast (2 mL/kg) followed by a single plain film taken after 10–15 min [46, 72]. In doubt or positive cases, MDCT is anyway necessary once the patient is stable.

Angiography has only a therapeutic role in renal vascular lesions in stable patients. This topic will be treated in Chap. 22.

Kidney scintigraphy with Tc-99m glucoheptonate, Tc-99m mercaptoacetyltriglycine, or Tc-99m-diethylenetriamine penta-acetic acid can be useful in the follow-up of renal injuries, to counsel the patient on the expected renal function [65].

It can be used also in studying the renal function in patients with contraindications to contrast media or in very selected cases.

19.3 Renal Trauma Classification

Renal trauma management depends widely not only on the detection of renal parenchyma lesion but also on the presence of bleeding parenchymal lesions or direct damage to the vascular peduncle or compromise of the urinary excretory system. The presence of these kinds of injury, detected at CT exam, completely changes management from nonoperative to operative. The CT exam with intravenous contrast medium can show accurately not only the presence of a renal injury and its grade but also can allow the identification of a preexisting renal condition mimicking trauma and can explore the contralateral kidney and the presence of concomitant lesions of other organs.

Therefore the radiologist plays an essential role in the management of traumatic patient and regarding renal trauma distinguishing kidney lesions that need interventional/surgical treatment from the ones needing only a conservative approach.

Since this manuscript is mainly intended for an imaging-based audience, we take into consideration the Federle classification dividing traumatic renal injury in two principal categories of injury: minor and major—anyway the two principal classifications will be considered for the description of the different kidney lesion.

19.3.1 Category I: Minor Traumatic Lesions

This category comprises minor renal contusions and lacerations which don't extend to the collecting system or medulla, subcapsular hematomas with less than 1 cm or more than 1 cm of thickness but without urinary excretal delay, and perinephric hematomas without active bleeding comprised in the perinephric adipose space and small subsegmental cortical infarcts.

Category I corresponds in the AAST renal injury scale to grades I and II. It includes most of kidney injuries (75–85%), which generally are treated conservatively.

19.3.1.1 Imaging Findings

Renal Contusion

Contusion represents a self-limiting blood extravasation (hematoma) in the renal parenchyma (grade I AAST; type I Federle). These minor injuries will spontaneous resolve and follow-up imaging is not required.

At an early US examination (within 1 h from trauma), it can appear as an oval or round hyperechoic area, with margins that after being undefined at the beginning become more and more distinct; rarely it is large enough to lead to a mass effect, alter the cortical profile, or determine a dilatation of nearby chalices (Fig. 19.6). The echogenicity of renal contusions reduces in a few days until becoming isoechoic within 2 weeks, generally without leaving sequelae. Anyway contusion has to be suspected when a trauma patient presents hematuria without significant alterations or abnormalities of the urinary tract at US. On CEUS kidney contusion lesion can appear as a hypoechoic area without clear delimitation [50, 53, 59, 71].

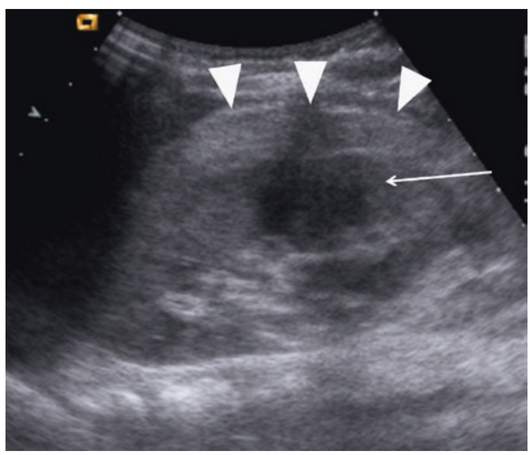

Fig. 19.6 Minor lesion: US shows the lower pole renal contusion as a non-well-defined inhomogeneous parenchymal (*arrow*); note the surrounding perirenal hematoma as a hyperdense collection (*arrowheads*), not compressing the renal profile

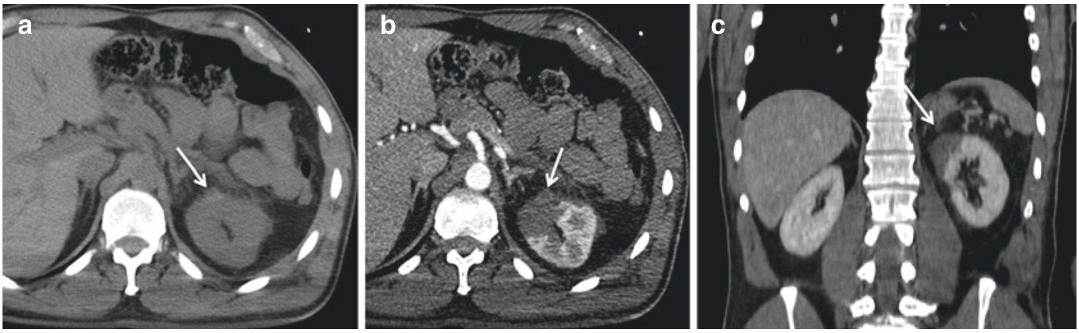

Fig. 19.7 Renal contusion seen on MDCT. Unenhanced CT scan (**a**) shows an iso-hyperdense area, which is better delineated on post-contrast images (**b**) and coronal reconstruction (**c**) as a hypodense area

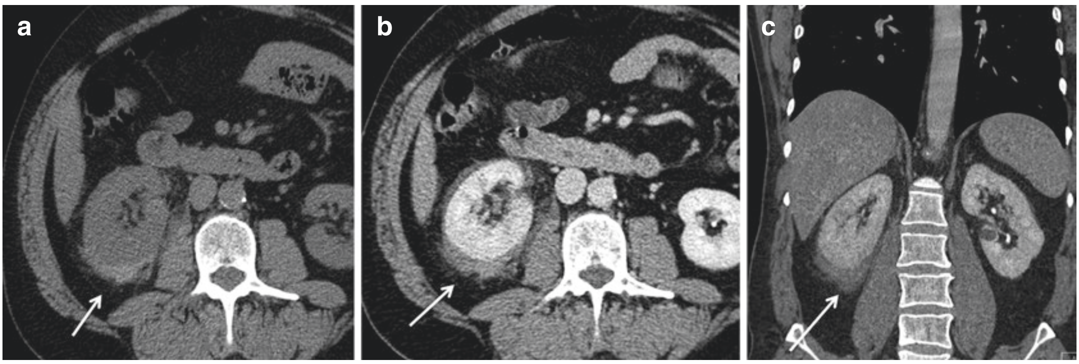

Fig. 19.8 Subcapsular hematoma seen on MDCT unenhanced scan (**a**) as a hyperdense area, without expanding signs on post-contrast images (**b** and **c**)

Compared to US, MDCT is more sensible in detecting renal contusion. On unenhanced images, it may be slightly hyperdense (due to the accumulation of acute blood products); in enhanced phases contusion appears as an ill-defined hypoattenuating lesion. Sometimes renal contusions can be seen as focal areas of striated nephrogram and as hyperdense areas in the excretory phase, due to small iodinated urine extravasations in the intraparenchymal collecting system. These lesions have to be distinct from segmental infarction that is usually linear or wedge-shaped sharply defined non-enhancing areas [21, 64, 65, 73, 74] (Fig. 19.7).

Subcapsular Hematoma

Subcapsular hematoma is a collection of clotted blood situated under the renal capsule. It is quite rare due to the tight adherence of renal capsule and cortex (grade I AAST; type I Federle). On US it is seen at the beginning as hyperechoic lenticular lesion, which is distributed along the external kidney surface, confined between the cortex and the capsule, determining a compressive effect on the renal parenchyma. Over time, it becomes a hypo-/anechoic lesion and reduces its thickness. On CEUS a subcapsular hematoma appears as a nonhomogeneous fluid collection without enhancement surrounding the kidney [41, 43, 53, 59].

On CT, acute hematomas are seen as a round or elliptical fluid hyperdense collection (>35–55 UH) [21, 64] on unenhanced scan, with an oval or crescent shape which imprints the underlying renal parenchyma; if the fluid collection is of greater size, it can have a biconvex shape and causes a delay in the nephrographic phase (Fig. 19.8). The Federle classification, unlike the AAST, evaluates the presence of any delay or reduction of parenchymal vascularity due to hematoma compression. In case of a chronic and prolonged compression and distortion of the renal parenchyma and vessels, a reduction of the blood flow to the kidney occurs resulting in activation of the renin-angiotensin system with development of hypertension, also known as "Page kidney phenomenon." Surgical treatment of the renal compression is indicated in these cases [21, 64].

Superficial and Deep Laceration

Superficial renal laceration (< 1 cm depth) is a tear of the renal parenchyma that involves only the cortical zone, often associated with contusion. Instead a deep laceration (>1 cm depth) passes through the cortical zone extending to the medullary one. A laceration appears as irregular or linear parenchymal defects that may contain clot (grade I–III AAST; type I Federle) [74].

Superficial or deep renal lacerations appear as defects in the renal parenchyma without involvement of the collecting system and typically resolve spontaneously, without the need for follow-up imaging, especially in case of superficial laceration [21]. If it extends only to the renal cortex, it is classified as AAST grade II, and if it goes until the medullar part, without comprising the collecting system, it is classified as AAST grade III and may need follow-up imaging.

On US it is difficult to observe, and it can be suspected if a subcapsular or perirenal hematoma is seen; it can be evident as a hyperechoic line or an undefined area of the kidney profile. On CEUS laceration is seen as a linear or branched hypoechoic streak, perpendicular to the surface of the kidney [59] (Fig. 19.9). The rapid enhancement can generate questions of interpretation that can possibly be solved only with a second injection of contrast agent [75]. An injection of too high a dose of contrast media will have a negative effect due to the intense enhancement, potentially masking the presence of lacerations [61].

On MDCT it is seen as a hypodense linear or irregular streak on unenhanced scan; after contrast material administration, it is visualized as a less or unenhanced area; therefore, sometimes the differential diagnosis with a segmental or subsegmental infarct can be difficult (Fig. 19.10).

Perirenal Hematoma

Perirenal hematoma is a hemorrhagic extravasation in the perirenal adipose tissue, within Gerota's fascia, which normally represents the result of a laceration of the renal capsule. Usually it is not creating a distortion of the kidney's profile (from grade II AAST; type I Federle). This kind of finding is treated conservatively. Sometimes the hematoma can be very large and dislocate the kidney.

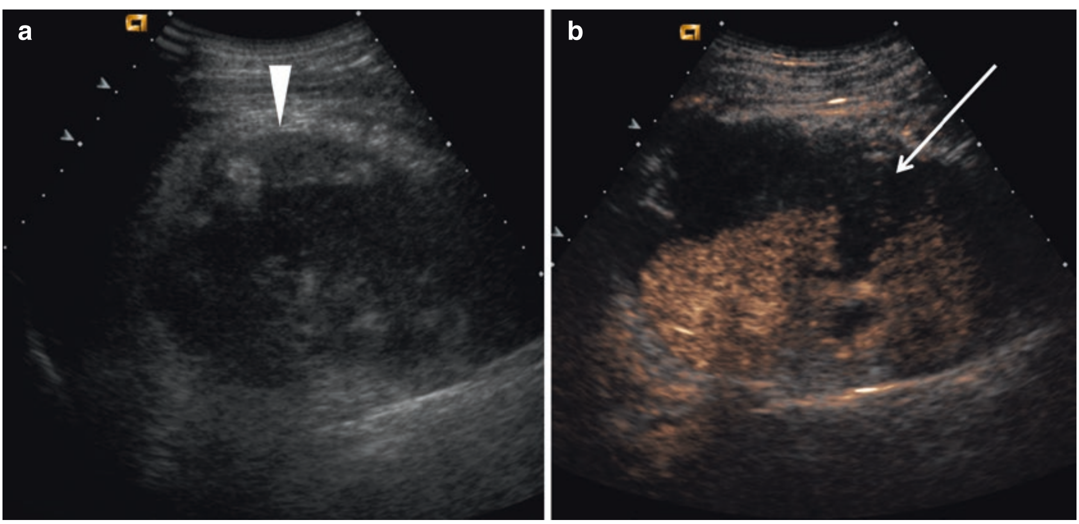

Fig. 19.9 (**a**) US shows a large perirenal hematoma (*arrowhead*); it isn't appreciable the renal parenchymal injury. (**b**) CEUS demonstrates a deep parenchymal laceration at the lower pole of the kidney (*arrow*)

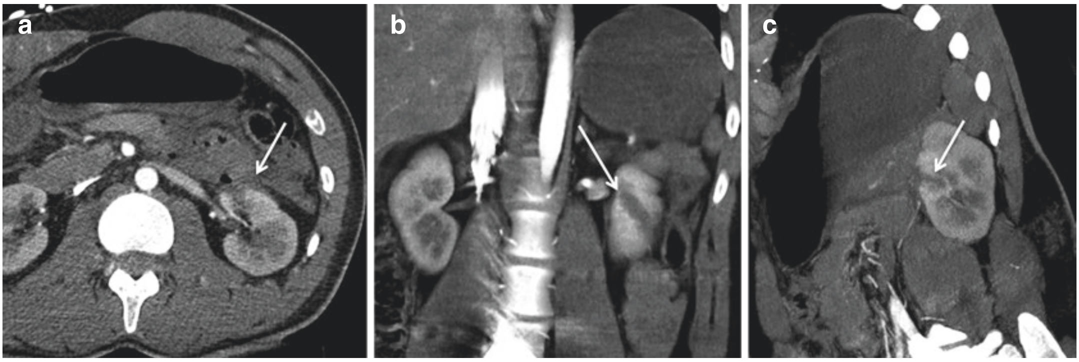

Fig. 19.10 Superficial laceration seen as a hypodense streak on post-contrast images (**a**), better visualized on 3D (**b**) and sagittal (**c**) reconstructions

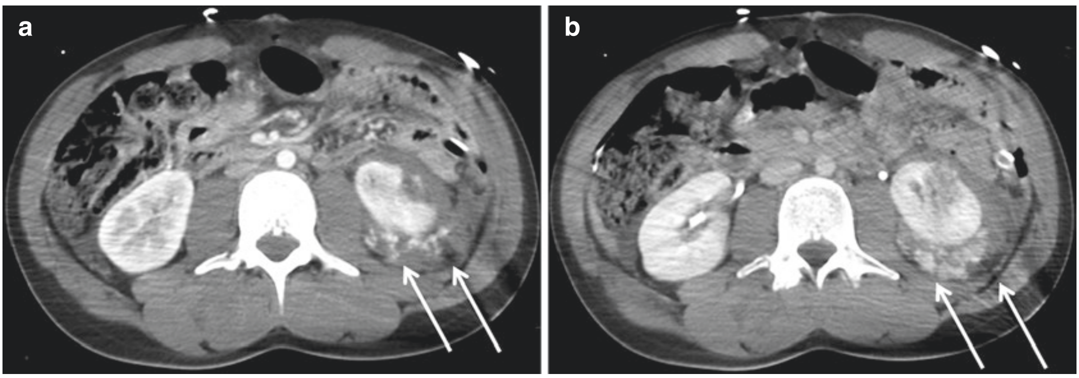

Fig. 19.11 Contrast-enhanced CT scans in arterial phase (**a**) and venous phase (**b**) show the lower pole parenchymal injury, with perirenal hematoma; in both arterial and venous phases, active bleeding is evident (*arrows*)

Ultrasound is not sensible in distinguishing between acute hematoma and the perirenal fat tissue density, since both are hyperechoic. On CEUS the adipose tissue shows a low enhancement and can therefore be differentiated from the non-enhancing fluid collection.

On MDCT in basal phase, an acute perirenal hematoma is seen as a hyperdense collection more irregular in shape than subcapsular hematoma. The perirenal fascia can be thickened if it is infiltrated by the hematic collection [18, 65]. After contrast intravenous medium, the hematoma will be hypodense; in case of active bleeding, hyperdense foci or pooling of contrast medium will be seen in the hematoma (Fig. 19.11).

Subsegmental Kidney Infarct

Subsegmental infarct is caused by traction or stretching and consequent thrombotic occlusion of an accessory, subsegmental, or capsular renal artery; it normally heals with a scar and doesn't require treatment (no AAST grade, type I Federle).

On US examination no distinguishing signs are present. Eco-color Doppler instead can give important information regarding vascularization and can identify the infarcted area. With CEUS a wedge-shaped region of absent vascularization can be identified.

The main imaging technique is MDCT, which shows a small hypo-perfused parenchymal wedge-shaped area and hypodense and with well-delineated margins, more often seen on the

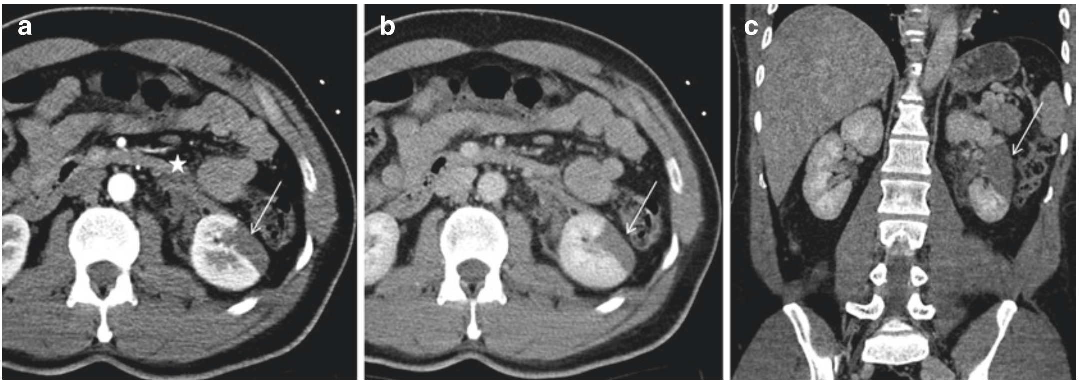

Fig. 19.12 Segmental infarct of the kidney is seen as a wedge-shaped hypodense area on post-contrast images (*arrow*); the infarct is caused by dissection/thrombosis of the renal artery with is never opacified (*star*)

lower polar region, and compared with renal contusions, it is more well defined and demarcated (Fig. 19.12) [18].

19.3.2 Category II: Major Traumatic Injuries

Renal injuries comprised in this category can necessitate an interventional/surgical approach; this category includes vascular injuries and/or deep laceration extending to collecting system or urinary tract injuries with iodate urine extravasation. AAST grade IV comprises lacerations affecting the collector system with urine outflow, renal pelvis laceration or complete ureteropelvic destruction, and arterial lesions or segmental veins; AAST grade V comprises renal vascular peduncle injury, devascularized kidney, venous thrombosis, and shattered kidney.

The management of these lesions is variable, in the majority of cases needing just conservative treatment but occasionally requiring surgical exploration depending on the hemodynamic status and the evolution of the injury. Usually in case of devascularized kidney or shattered one, surgical management is requested.

19.3.2.1 Imaging Findings

Major Laceration

Major laceration of the renal parenchyma or incomplete renal fracture appears as deep cleft which runs through the renal cortex and medulla reaching the collecting system and can be associated to a hematoma and/or a urinary extravasation (urinoma) confined to the perirenal or pararenal fat tissue (grade IV AAST; type II Federle) [76, 77].

Major lacerations appear similar to minor lacerations but are wider, usually more numerous, and larger.

On CT exam multiplanar reconstructions can be useful in better visualizing the extension of the lacerations and their relationship with the collecting system.

Major lesions usually are associated with an extensive perinephric hematoma, a blood collection which infiltrates the perirenal fat tissue and can have a mass effect and dislocation of the kidney, altering the renal contour, the nearby muscle, or the organ shape (such as the psoas muscle or the colon); it can also diffuse toward the abdominal aorta, becoming bilateral. If it trespasses Gerota's fascia, it becomes a paranephric hematoma, with thickening of Gerota's fascia (Fig. 19.13).

When in the case of kidney injury we find peripheral fluid, we must always ask ourselves what kind of fluid is it, blood or urine. An excretory phase should always be performed to exclude an involvement of the collecting system and to demonstrate the presence of a retroperitoneal urinoma, a urine extravasation into the retroperitoneum due to a laceration of the collecting system, or a transection of the ureteropelvic junction,

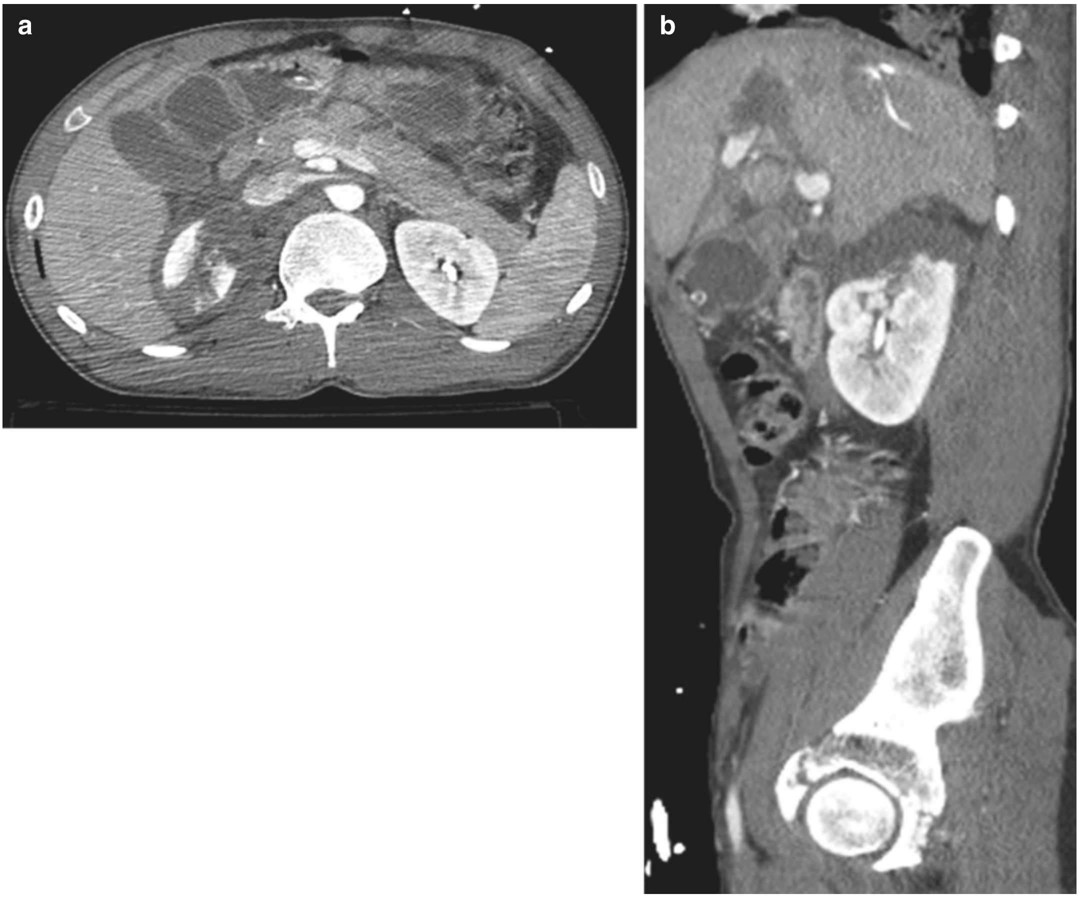

Fig. 19.13 Contrast-enhanced CT, axial scan (**a**), and sagittal reconstruction (**b**) show a deep laceration of the upper pole of the right kidney, associated with retroperitoneal hematoma

causing lipolysis of the surrounding fat with resultant encapsulation of urine. In fact, when the laceration extends into the renal collecting system, extravasation of excreted contrast material will be present on delayed views.

On B-mode US images, urinoma can be seen as a hypo-anechoic area surrounding the kidney, resembling a fluid collection.

On enhanced MDCT, as said before, the retroperitoneal urinoma can be visualized in the excretory phase (at least 4–5 min after contrast media administration) due to the urine extravasation, markedly hyperdense (Fig. 19.14), although often a later scan can be needed (8–15 min from contrast media administration).

The management of this kind of lesions is variable, affected patients are usually treated conservatively, and there may be a need to place a stent, but occasionally require surgical exploration depending on hemodynamic status and the evolution of the injury.

The presence of a voluminous perirenal hematoma or small blood clots can block the urinary extravasation right after trauma, leading to a non-immediate visualization of it; often it is then diagnosed in a CT scan performed after 6–12 h, the time in which the blood clot dissolves permitting the urine to exit. The patient with an expanding perinephric hematoma and a decrease in hematocrit often requires intervention.

When intense contrast enhancement occurs within a laceration or an adjacent hematoma during the early phase of the CT examination, the

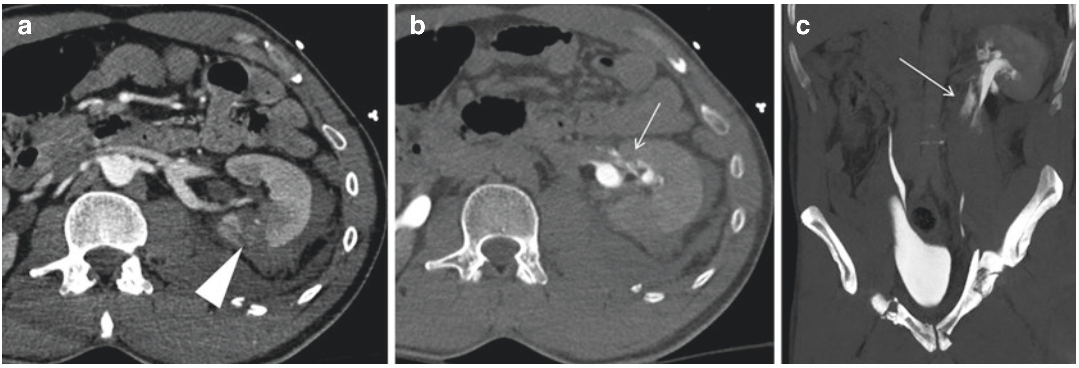

Fig. 19.14 Axial CT scan in arterial (**a**) and excretory (**b**) phase and coronal reconstruction (**c**) show the deep laceration (*arrowhead*) seen as a hypodense cleft on post-contrast images (**a**); the excretory phase on axial (**b**) and better on coronal (**c**) plane show collective system involvement with urine extravasation (*arrows*)

diagnosis of traumatic false aneurysm or active hemorrhage should be considered. Active hemorrhage tends to track into surrounding tissues and has a linear or flame-like appearance, whereas false aneurysms tend to be more focal and rounded. Extravasation of vascular contrast medium appears with attenuation values of 80–370 HU, is typically within 10–15 HU of the aorta or adjacent major artery, and is generally surrounded by lower-attenuation clotted blood. This finding is an important indicator that a patient may be about to pass from hemodynamic stability to decompensation. In one series, 38% of patients with this finding became hypotensive during or immediately after the CT examination. Patients in stable condition with active vascular extravasation should be referred for angiographic embolization [78–80].

The isolated urine extravasation doesn't represent anymore an indication for surgical exploration, reserved only to very extensive lesions, since most of urinary leaks tend to resolve spontaneously and need just a "watch-and-wait" approach. However, in 37% of cases, an endoscopic ureteral stent placement is needed (nephrostomic catheter or ureteral double J); in other cases the urinoma can get infected due to the urinary stasis, needing a percutaneous drainage.

Follow-up CT or MRI may be necessary to assess interval change in the appearance of the injury [21, 71].

Segmental Infarct

Segmental infarct appears as a sharply demarcated, dorsal, or ventral segmental region of decreased enhancement of the parenchyma (type II Federle); it is present in approximately 10% of renal injuries and seen on MDCT as a wedge-shaped, sharply demarcated hypodense lesion involving the renal parenchyma, with a subcapsular basis and the apex toward the hilum; it is caused by a traumatic dissection and/or thrombosis of segmental vessels (AAST V) (see Fig. 19.12). Vascular thrombosis and a segmental area of parenchymal infarction can be seen also with Doppler and with CEUS as feeling defect in the vessel or an area of anechoic parenchyma surrounded by the normally hyperechoic vascular parenchyma.

Management is usually conservatory, but if it involves more than 50% of the renal parenchyma, a surgical debridement is indicated.

19.3.3 Catastrophic Lesions

These lesions (type III Federle) consist in vascular injury involving the vascular pedicle (AAST V); they represent approximately 5% of all renal injuries and thus generally require an interventional intravascular and/or surgical approach.

Part of this group is multiple severe lacerations generating three or more devascularized fragments (shattered kidney) and arterial and/or venous vascular pedicle lesions.

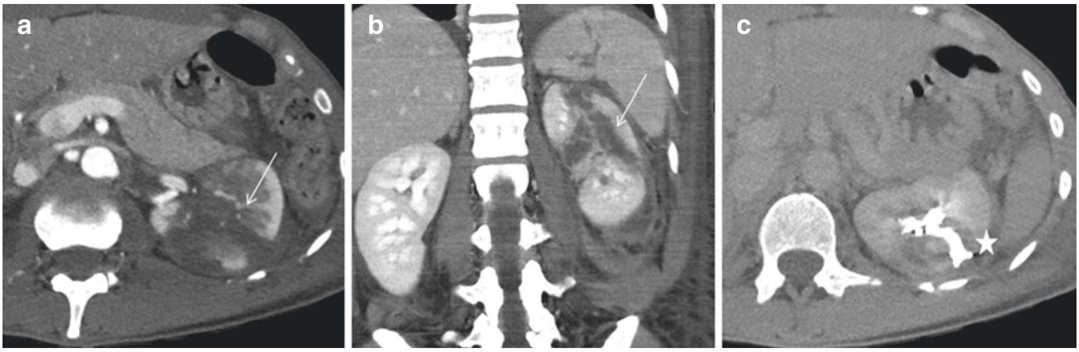

Fig. 19.15 Shattered kidney: multiple deep clefts (*arrow*) are identified on post-contrast images (**a**), (**b**) and (**c**); in the excretory phase in (**c**), an important involvement of the collective system is seen, with abundant urine extravasation trough the clefts (star).

For this category of lesions, the leading imaging modality is MDCT with contrast media administration, due to its capability to visualize the active bleeding differentiating it from urine extravasation.

19.3.3.1 Imaging Findings

Shattered Kidney

The shattered kidney and renal pedicle avulsion represent some of the most severe renal injuries, since they determine a complete devascularization of the kidney, leading to a nephrectomy.

The term shattered kidney refers to gross renal parenchymal disruption by multiple lacerations; these injuries are frequently associated with multiple areas of renal infarction [73].

In rare cases (hemodynamic stability, non-expanding perinephric hematoma, scarce or absent urine extravasation), an interventional approach can be attempted, with a vascular embolization and a percutaneous drainage of the hematoma.

On MDCT in a shattered kidney, the gland has lost its normal morphology and structure, with multiple deep clefts passing through the renal parenchyma and collecting system, creating devitalized fragments due to a lack of vascular supply; these non-enhancing segments may not be depicted because of the presence of a large perinephric hematoma, which appears hypodense (Fig. 19.15). Within this hematoma, often foci of active arterial bleeding can be visualized as a patchy hyperdense area (with a density of 85–370 HU; mean, 132 HU) that is best appreciated at dynamic contrast-enhanced CT.

Vascular Injury Involving the Renal Pedicle

The most significant vascular injury following blunt trauma is thrombosis of the main renal artery. The other vascular injuries comprise vein thrombosis and renal artery avulsion [81].

Deceleration forces dislocate the kidneys in the retroperitoneal adipose space, causing a stretching and tearing of the intima and the formation of an intimal flap, which leads to the formation of blood clots and arterial thrombosis; in blunt trauma, this rarely is complete. More often a segmental or subsegmental infarction occurs. The renal artery occlusion occurs in higher percentage of cases at the proximal-medial third of the kidney with a distal distribution.

On MDCT the non-visualization of the whole kidney, correlated to the absence of perinephric hematoma, should give the suspect of main renal artery thrombosis (Fig. 19.16) although other causes should be excluded, such as renal vascular spasm due to severe contusion, renal pedicle avulsion, or high-grade urinary obstruction. If the thrombus is detectable, it appears as an endovascular filling defect, hyperdense on unenhanced CT images, and hypodense on enhanced scans. A “cortical rim sign” can be rarely observed (it usually is seen after at least 8 h), in which the peripheral cortex and renal capsule show a higher enhancement, as perfusion is maintained by the renal capsular artery (Fig. 19.17).

If this kind of condition is depicted, the treatment decision has to be chosen also keeping in mind a 2 h time limit for revascularization.

Fig. 19.16 Contrast-enhanced axial CT scan, arterial phase, shows the complete ischemia of the right kidney (*white arrow*), due to renal artery thrombosis (*black arrowhead*). Note the huge intraparenchymal hepatic hematoma (*white arrowheads*) and the subcutaneous emphysema (*asterisk*)

Renal vein thrombosis is a rare condition in blunt trauma; the vein is dilated and not compressible during the ultrasound evaluation; in acute conditions, the thrombus is hypoechoic and difficult to visualize. In case of complete renal vein thrombosis, the eco-color-Doppler examination doesn't show any flow, and several signs can be associated, such as kidney enlargement, the absence of intraparenchymal flow, and the presence of a collateral venous system at the kidney hilum. On MDCT an endovascular filling defect (in case of partial thrombosis) or absent filling (complete thrombosis) of the distended renal vein is seen, associated with nephromegaly, delayed nephrographic progression, reduced nephrogram (Fig. 19.18), or delayed excretion of contrast material into the collecting system due to the acute venous hypertension.

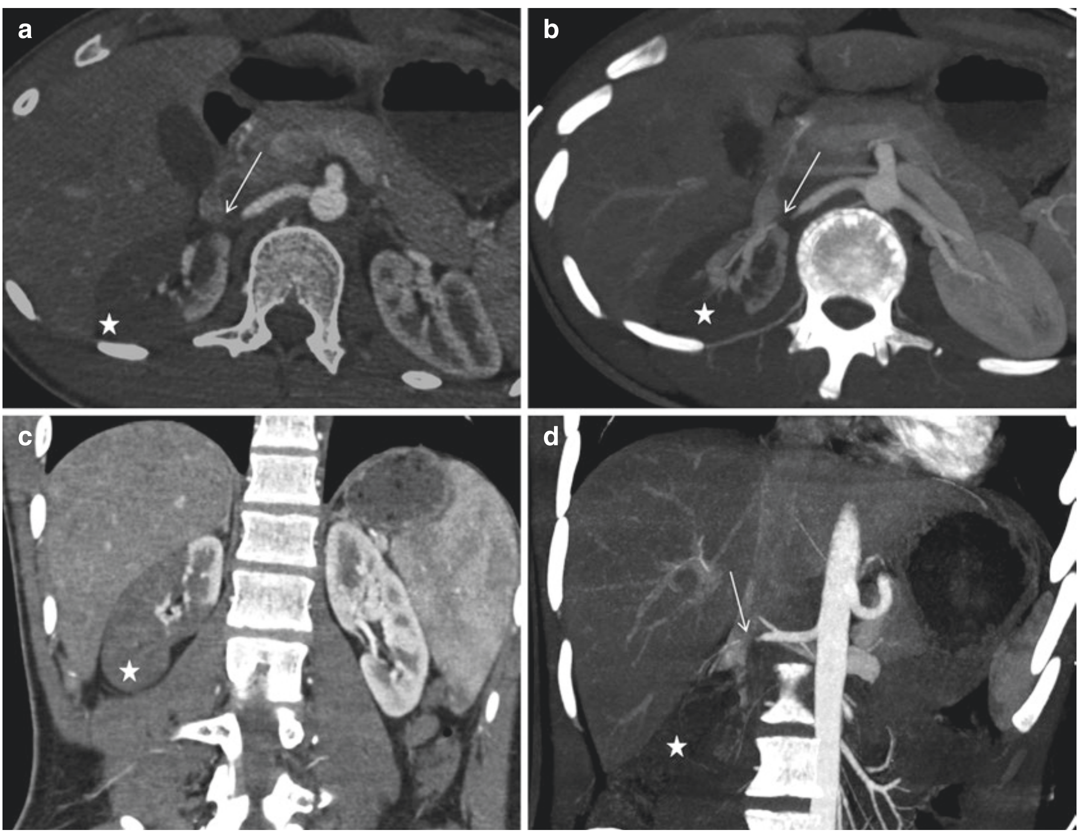

Fig. 19.17 Contrast-enhanced CT (**a**–**d**) demonstrates the absence of vascularization of most of the right kidney on post-contrast images (*star*), caused by thrombosis of the main renal artery seen as a filling defect (*arrow*) on the arterial phase (**a** and **d**)

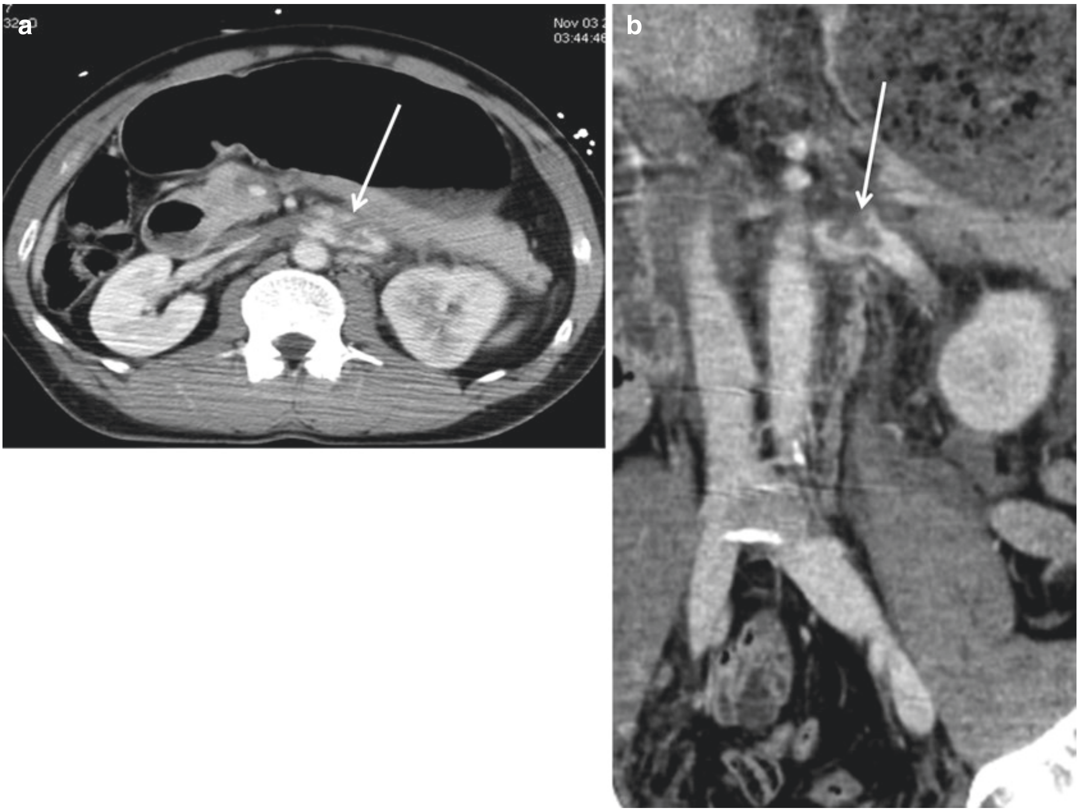

Fig. 19.18 Contrast-enhanced CT, axial scan (**a**), and coronal reconstruction (**b**) show the filling defect in the left renal vein (*arrows*), due to partial thrombosis. The left kidney has a reduced parenchymal enhancement with respect to the right kidney

Avulsion of the renal artery is a rare life-threatening condition in blunt trauma, not often seen on CT, due to the hemodynamical instability of the patient; caused by tearing of the tunica muscularis and adventitia, it is associated with global renal infarction (seen on CT as a completely or largely devascularized kidney) (see Fig. 19.16) and large perinephric hematoma (mainly distributed medially to the renal hilum), with important contrast material extravasation between the kidney and the aorta, which becomes larger in the venous phase, with a higher density than the one of the aorta (active arterial bleeding). In case of renal vein avulsion, the perinephric hematoma is self-limiting due to the compression of the perirenal adipose tissue. Renal enhancement is usually delayed and reduced, but uniformly present. In case of avulsion of the renal hilum, a total absence of parenchymal enhancement is found at MDCT and CEUS [61, 82].

19.3.4 Ureteropelvic Junction Injuries

This group comprises ureteropelvic junction injuries, a rare consequence of blunt trauma. In case of sudden deceleration and hyperextension, the relative mobility in the retroperitoneal space of the kidney compared to the aorta and vertebrae can cause traction and tension on the renal pedicle.

A predisposing condition is congenital or secondary obstructive uropathy, which causes chronic renal pelvis dilatation.

Keep in mind that in 30% of cases, these injuries occur in the absence of hematuria and the diagnosis may be delayed.

This kind of damage is mentioned in Category IV of the Federle classification, corresponding to grade V of the AAST injury scale.

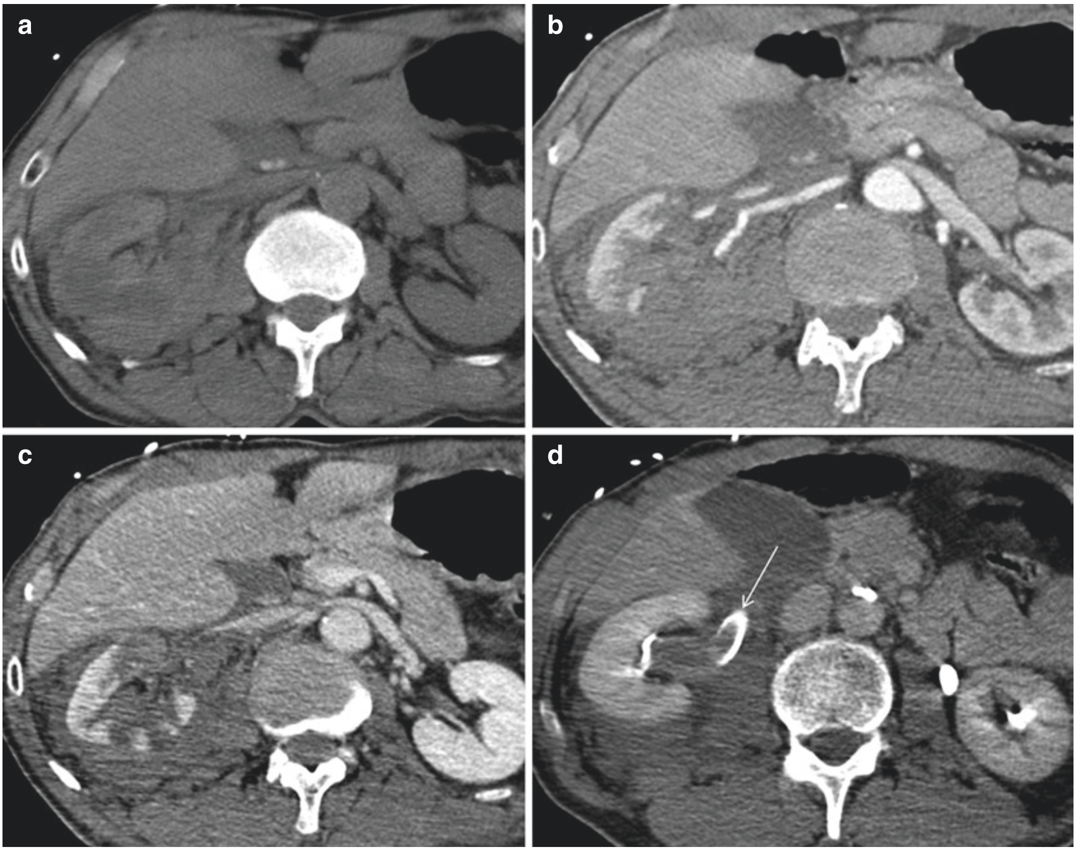

Fig. 19.19 Renal pedicle injury: perirenal hematoma and inhomogeneous parenchyma are already seen on direct scan (**a**); on arterial phase (**b**) an incomplete vascularization of the kidney is seen, with multiple deep clefts, better visualized on venous phase (**c**); in the excretory phase, the urine runs along the renal pelvis toward the ureter, surrounding it (**d**) (*arrow*)

The ureteropelvic junction can be completely transected (avulsion) or incompletely teared (laceration). In these cases an excretory phase imaging is necessary to visualize correctly the injury; in fact in both situations, urine extravasation surrounding the ureteropelvic junction is present (circumrenal urinoma), typically without hematoma, and the presence of contrast material in the ureter distal to the ureteropelvic junction helps differentiate laceration from avulsion (Fig. 19.19). However, when neither CT nor intravenous urography unequivocally demonstrates ipsilateral ureteral filling, retrograde pyelography should be performed [21].

Treatment of avulsion of the ureteropelvic junction is always surgical; laceration can also be treated in some cases conservatively with or without stent placement.

19.4 Other Nonclassified Renal Injuries

Contained vascular lesions such as pseudoaneurysm and arteriovenous fistulae are lesions that can be identified on CT imaging, but are not classified in the AAST or Federle injury scale.

Pseudoaneurysm or false aneurysm occurs when all three layers of the arterial wall (intima, media, and adventitia) are disrupted and the blood pool is external to the vessel, without an own wall but contained by the surrounding connective tissue.

On eco-color-Doppler ultrasound, a pulsatile flow sign is seen within the lesion (with a swirling pattern), and documentation of the to-and-fro flow with spectral Doppler is essential to make diagnosis.

On MDCT it is identified as a round or oval area, with a size between 5 mm and 5 cm, of vascular origin, and hyperdense in the arterial phase, next to the vessel, with a decrease in attenuation in the following post-contrast phases, similar to the aorta. This behavior is useful to distinguish it from active bleeding, which increases in size and retain a higher attenuation than the aorta on delayed imaging.

Pseudoaneurysms of the main renal artery branches may require embolization, in contrast to the ones of the main renal artery that require surgical treatment by stent positioning.

An arteriovenous fistula is an abnormal connection between an artery and a vein, which on eco-color-Doppler imaging may be visualized directly, with an abnormal high-velocity flow.

On MDCT it is seen as an early intensity of the renal vein, which is usually larger in diameter and lower attenuation on the parenchymal phase due to the “stolen effect” of the enhanced blood. Differential diagnosis with pseudoaneurysm can be difficult and only resolved by angiography.

19.5 Traumatic Injuries to Kidneys with Preexisting Abnormalities

A kidney with a preexisting abnormality is at increased risk for injury [83]. An underlying renal disorder may be first brought to medical attention because the severity of the patient’s symptoms is disproportionate to the degree of injury suffered.

Trauma to an abnormal kidney occurs more frequently in children than in adults. Such injuries include disruption of the renal pelvis or ureteropelvic junction in patients with hydronephrosis or an extrarenal pelvis intracystic hemorrhage or rupture of a renal cyst with or without communication with the collecting system, rupture of a tumor, laceration of poorly protected ectopic or horseshoe kidneys (Fig. 19.20) [50, 53], and laceration of fragile, infected kidneys.

CT provides more specific and clinically useful information than excretory urography in this context [84].

19.6 Complications

Complication of renal injury mostly occurs within 1 month from the traumatic event with a wide range from 3 to 33% of all kidney injuries. Early complications include urinoma, urinary fistula, infected urinoma or perinephric abscess, pseudoaneurysm, delayed bleeding, persistent hematuria, and hypertension.

Late complications include A-V fistula, hydronephrosis, delayed hypertension, calculus formation, and chronic pyelonephritis.

Low-grade lesions usually resolve completely without complications, and high-grade lesions instead often result in the formation of one or more scars, which can be responsible of obstructive conditions, with urinary stasis, calculi, or infection.

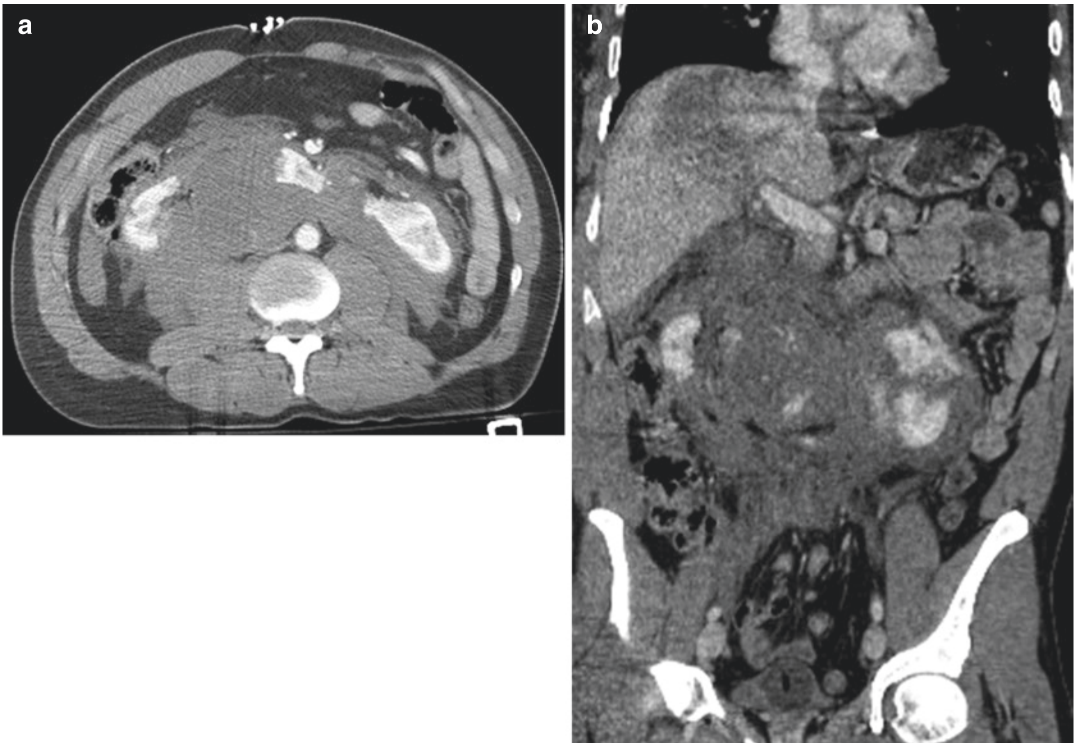

Fig. 19.20 Contrast-enhanced CT, axial scan (**a**), and coronal reconstruction (**b**) show a complete fracture of the middle part of a horseshoe kidney, with huge retroperitoneal hematoma

References

1. Wessells H, Suh D, Porter JR, et al. Renal injury and operative management in the United States: results of a population-based study. J Trauma. 2003;54:423–30. doi:10.1097/01.TA.0000051932.28456.F4.
2. Morey AF, Brandes S, Dugi DD III, et al. Urotrauma: AUA guideline. J Urol. 2014;192:327–35. doi:10.1016/j.juro.2014.05.004. Epub 20 May 2014.
3. Safir MH, McAninch JW. Diagnosis and management of trauma to the kidney. Curr Opin Urol. 1999;9:227–31.
4. Bruce LM, Croce MA, Santaniello JM, et al. Blunt renal artery injury: incidence, diagnosis, and management. Am Surg. 2001;67:550–4; discussion 555–6.
5. Lee YJ, Oh SN, Rha SE, Byun JY. Renal trauma. Radiol Clin North Am. 2007;45:581–92, ix. doi:10.1016/j.rcl.2007.04.004.
6. Park SJ, Kim JK, Kim KW, Cho KS. MDCT findings of renal trauma. AJR Am J Roentgenol. 2006;187:541–7. doi:10.2214/AJR.05.0543.
7. Jankowski JT, Spirnak JP. Current recommendations for imaging in the management of urologic traumas. Urol Clin North Am. 2006;33:365–76. doi:10.1016/j.ucl.2006.04.004.
8. Paparel P, N'Diaye A, Laumon B, et al. The epidemiology of trauma of the genitourinary system after traffic accidents: analysis of a register of over 43000 victims. BJU Int. 2006;97:338–41. doi:10.1111/j.1464-410X.2006.05900.x.
9. Kansas BT, Eddy MJ, Mydlo JH, Uzzo RG. Incidence and management of penetrating renal trauma in patients with multiorgan injury: extended experience at an inner city trauma center. J Urol. 2004;172:1355–60.
10. Santucci RA, Wessells H, Bartsch G, et al. Evaluation and management of renal injuries: consensus statement of the renal trauma subcommittee. BJU Int. 2004;93:937–54. doi:10.1111/j.1464-4096.2004.04820.x.
11. Shariat SF, Jenkins A, Roehrborn CG, et al. Features and outcomes of patients with grade IV renal injury. BJU Int. 2008;102:728–33; discussion 733. doi:10.1111/j.1464-410X.2008.07638.x. Epub 24 Apr 2008.
12. Smith J, Caldwell E, D'Amours S, et al. Abdominal trauma: a disease in evolution. ANZ J Surg. 2005;75:790–4. doi:10.1111/j.1445-2197.2005.03524.x.
13. Sangthong B, Demetriades D, Martin M, et al. Management and hospital outcomes of blunt renal artery injuries: analysis of 517 patients

from the National Trauma Data Bank. J Am Coll Surg. 2006;203:612–7. doi:10.1016/j.jamcollsurg.2006.07.004. Epub 27 Sep 2006.
14. Najibi S, Tannast M, Latini JM. Civilian gunshot wounds to the genitourinary tract: incidence, anatomic distribution, associated injuries, and outcomes. Urology. 2010;76:977–81; discussion 981. doi:10.1016/j.urology.2010.01.092.
15. Goldman SM, Sandler CM. Urogenital trauma: imaging upper GU trauma. Eur J Radiol. 2004;50:84–95. doi:10.1016/j.ejrad.2003.11.018.
16. Broghammer JA, Fisher MB, Santucci RA. Conservative management of renal trauma: a review. Urology. 2007;70:623–9. doi:10.1016/j.urology.2007.06.1085.
17. Santucci RA, Fisher MB. The literature increasingly supports expectant (conservative) management of renal trauma-a systematic review. J Trauma. 2005;59:493–503.
18. Razali MR, Azian AA, Amran AR, Azlin S. Computed tomography of blunt renal trauma. Singap Med J. 2010;51:468–73; quiz 474.
19. The American Association of Surgery for the Surgery of Trauma. Injury scoring scale. http://www.aast.org/Library/TraumaTools/injuryscoringscales.aspx
20. Moore EE, Shackford SR, Pachter HL, et al. Organ injury scaling: spleen, liver, and kidney. J Trauma. 1989;29:1664–6.
21. Kawashima A, Sandler CM, Corl FM, et al. Imaging of renal trauma: a comprehensive review. Radiographics. 2001;21:557–74. doi:10.1148/radiographics.21.3.q01ma11557.
22. Federle MP, Kaiser JA, McAnninch JW, et al. The role of computed tomography in renal trauma. Radiology. 1981;141:455–60. doi:10.1148/radiology.141.2.7291573.
23. Dugi DD III, Morey AF, Gupta A, et al. American Association for the Surgery of Trauma grade 4 renal injury substratification into grades 4a (low risk) and 4b (high risk). J Urol. 2010;183:592–7. doi:10.1016/j.juro.2009.10.015. Epub 16 Dec 2009.
24. Buckley JC, McAninch JW. Revision of current American Association for the Surgery of Trauma renal injury grading system. J Trauma. 2011;70:35–7. doi:10.1097/TA.0b013e318207ad5a.
25. Holmes JF, McGahan JP, Wisner DH. Rate of intra-abdominal injury after a normal abdominal computed tomographic scan in adults with blunt trauma. Am J Emerg Med. 2012;30:574–9. doi:10.1016/j.ajem.2011.02.016.
26. Alsikafi NF, McAninch JW, Elliott SP, Garcia M. Nonoperative management outcomes of isolated urinary extravasation following renal lacerations due to external trauma. J Urol. 2006;176:2494–7. doi:10.1016/j.juro.2006.08.015.
27. Jansen JO, Inaba K, Resnick S, et al. Selective non-operative management of abdominal gunshot wounds: survey of practise. Injury. 2013;44:639–44. doi:10.1016/j.injury.2012.01.023. Epub 15 Feb 2012.
28. Buckley JC, McAninch JW. Selective management of isolated and nonisolated grade IV renal injuries. J Urol. 2006;176:2498–502; discussion 2502. doi:10.1016/j.juro.2006.07.141.
29. Hope WW, Smith ST, Medieros B, et al. Non-operative management in penetrating abdominal trauma: is it feasible at a Level II trauma center? J Emerg Med. 2012;43:190–5. doi:10.1016/j.jemermed.2011.06.060. Epub 1 Nov 2011.
30. DuBose J, Inaba K, Teixeira PG, et al. Selective non-operative management of solid organ injury following abdominal gunshot wounds. Injury. 2007;38:1084–90. doi:10.1016/j.injury.2007.02.030.
31. Lanchon C, Fiard G, Arnoux V, et al. High grade blunt renal trauma: predictors of surgery and long-term outcomes of conservative management. A Prospective Single Center Study. J Urol. 2016;195:106–11. doi:10.1016/j.juro.2015.07.100. Epub 6 Aug 2015.
32. Shoobridge JJ, Bultitude MF, Koukounaras J, et al. A 9-year experience of renal injury at an Australian level 1 trauma centre. BJU Int. 2013;112(Suppl 2):53–60. doi:10.1111/bju.12003.
33. van der Wilden GM, Velmahos GC, Joseph DK, et al. Successful nonoperative management of the most severe blunt renal injuries: a multicenter study of the research consortium of New England Centers for Trauma. JAMA Surg. 2013;148:924–31. doi:10.1001/jamasurg.2013.2747.
34. Armenakas NA, Duckett CP, McAninch JW. Indications for nonoperative management of renal stab wounds. J Urol. 1999;161:768–71.
35. Glass AS, Appa AA, Kenfield SA, et al. Selective angioembolization for traumatic renal injuries: a survey on clinician practice. World J Urol. 2014;32:821–7. doi:10.1007/s00345-013-1169-1.
36. Schmidlin FR, Iselin CE, Naimi A, et al. The higher injury risk of abnormal kidneys in blunt renal trauma. Scand J Urol Nephrol. 1998;32:388–92.
37. McAninch JW, Carroll PR, Klosterman PW, et al. Renal reconstruction after injury. J Urol. 1991;145:932–7.
38. Hammer CC, Santucci RA. Effect of an institutional policy of nonoperative treatment of grades I to IV renal injuries. J Urol. 2003;169:1751–3. doi:10.1097/01.ju.0000056186.77495.c8.
39. Valentino M, Ansaloni L, Catena F, et al. Contrast-enhanced ultrasonography in blunt abdominal trauma: considerations after 5 years of experience. Radiol Med. 2009;114:1080–93. doi:10.1007/s11547-009-0444-0.
40. Poletti PA, Wintermark M, Schnyder P, Becker CD. Traumatic injuries: role of imaging in the management of the polytrauma victim (conservative expectation). Eur Radiol. 2002;12:969–78. doi:10.1007/s00330-002-1353-y. Epub 15 Mar 2002.
41. Sessa B, Trinci M, Ianniello S, et al. Blunt abdominal trauma: role of contrast-enhanced ultrasound (CEUS) in the detection and staging of abdominal traumatic lesions compared to US and CE-MDCT. Radiol Med. 2015;120:180–9. doi:10.1007/s11547-014-0425-9. Epub 25 Jun 2014.
42. Catalano O, Aiani L, Barozzi L, et al. CEUS in abdominal trauma: multi-center study. Abdom Imaging. 2009;34:225–34. doi:10.1007/s00261-008-9452-0.

43. Pinto F, Miele V, Scaglione M, Pinto A. The use of contrast-enhanced ultrasound in blunt abdominal trauma: advantages and limitations. Acta Radiol. 2014;55:776–84. doi:10.1177/0284185113505517.
44. Pinto F, Valentino M, Romanini L, Basilico R, Miele V. The role of CEUS in the assessment of haemodynamically stable patients with blunt abdominal trauma. Radiol Med. 2015;120:3–11. doi:10.1007/s11547-014-0455-3. Epub 21 Aug 2014.
45. Morey AF, Brandes S, Dugi DD III, et al. Urotrauma: AUA guideline. Copyright © 2014 American Urological Association Education and Research, Inc.®; (published 2014–amended 2017). http://www.auanet.org/guidelines/urotrauma-(2014-amended-2017)
46. Sheth S, Casalino DD, Remer EM, et al. Appropriateness criteria: renal trauma. American College of Radiology; 2012.
47. McCombie SP, Thyer I, Corcoran NM, et al. The conservative management of renal trauma: a literature review and practical clinical guideline from Australia and New Zealand. BJU Int. 2014;114(Suppl 1):13–21. doi:10.1111/bju.12902.
48. Mee SL, McAninch JW, Robinson AL, et al. Radiographic assessment of renal trauma: a 10 years prospective study of patient selection. J Urol. 1989;141:1095–8.
49. Kurtz MP, Eswara JR, Vetter JM, et al. Blunt abdominal trauma from motor vehicle collisions from 2007 to 2011: renal injury probability and severity in children versus adults. J Urol. 2017;197:906–10. doi:10.1016/j.juro.2016.07.085. Epub 16 Dec 2016.
50. Miele V, Piccolo CL, Trinci M, Galluzzo M, Ianniello S, Brunese L. Diagnostic imaging of blunt abdominal trauma in pediatric patients. Radiol Med. 2016;121:409–30. doi:10.1007/s11547-016-0637-2.
51. Valentino M, Serra C, Zironi G, et al. Blunt abdominal trauma: emergency contrast-enhanced sonography for detection of solid organ injuries. AJR Am J Roentgenol. 2006;186:1361–7. doi:10.2214/AJR.05.0027.
52. Körner M, Krötz MM, Degenhart C, et al. Current role of emergency US in patients with major trauma. RadioGraphics. 2008;28:225–42. doi:10.1148/rg.281075047.
53. Miele V, Piccolo CL, Galluzzo M, et al. Contrast-enhanced ultrasound (CEUS) in blunt abdominal trauma. Br J Radiol. 2016;89:20150823. doi:10.1259/bjr.20150823. Epub 8 Jan 2016.
54. Kitrey ND, Djakovic N, Gonsalves M, et al. EAU guidelines on urological trauma. Updated 2017. uroweb.org/guideline/urological-trauma/
55. Poletti PA, Platon A, Becker CD, et al. Blunt abdominal trauma: does the use of a second-generation sonographic contrast agent help to detect solid organ injuries? AJR Am J Roentgenol. 2004;183:1293–301. doi:10.2214/ajr.183.5.1831293.
56. Regine G, Atzori M, Miele V, et al. Second-generation sonographic contrast agents in the evaluation of renal trauma. Radiol Med. 2007;112:581–587. Epub 11 June 2007. doi:10.1007/s11547-007-0164-2.
57. Valentino M, De Luca C, Galloni SS, et al. Contrast-enhanced US evaluation in patients with blunt abdominal trauma. J Ultrasound. 2010;13:22–7. doi:10.1016/j.jus.2010.06.002. Epub 8 Jul 2010.
58. Mihalik JE, Smith RS, Toevs CC, et al. The use of contrast-enhanced ultrasound for the evaluation of solid abdominal organ injury in patients with blunt abdominal trauma. J Trauma Acute Care Surg. 2012;73:1100–5. doi:10.1097/TA.0b013e31825a74b5.
59. Cagini L, Gravante S, Malaspina CM, et al. Contrast enhanced ultrasound (CEUS) in blunt abdominal trauma. Crit Ultrasound J. 2013;5(Suppl 1):S9. doi:10.1186/2036-7902-5-S1-S9.
60. Menichini G, Sessa B, Trinci M, Galluzzo M, Miele V. Accuracy of Contrast-Enhanced Ultrasound (CEUS) in the identification and characterization of traumatic solid organ lesions in children: a retrospective comparison with baseline-US and CE-MDCT. Radiol Med. 2015;120:989–1001. doi:10.1007/s11547-015-0535-z. Epub 31 Mar 2015.
61. Valentino M, Serra C, Pavlica P, Barozzi L. Contrast-enhanced ultrasound for blunt abdominal trauma. Semin Ultrasound CT MR. 2007;28:130–40.
62. Huber-Wagner S, Lefering R, Qvick LM, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet. 2009;373:1455–61. doi:10.1016/S0140-6736(09)60232-4.
63. Heller MT, Schnor N. MDCT of renal trauma: correlation to AAST organ injury scale. Clin Imaging. 2014;38:410–7. doi:10.1016/j.clinimag.2014.02.001. Epub 24 Feb 2014.
64. Dane B, Baxter AB, Bernstein MP. Imaging genitourinary trauma. Radiol Clin North Am. 2017;55:321–35. doi:10.1016/j.rcl.2016.10.007. Epub 27 Dec 2016.
65. Gross JA, Lehnert BE, Linnau KF, et al. Imaging of urinary system trauma. Radiol Clin North Am. 2015;53:773–88, ix. doi:10.1016/j.rcl.2015.02.005. Epub 9 Apr 2015.
66. Colling KP, Irwin ED, Byrnes MC, et al. Computed tomography scans with intravenous contrast: low incidence of contrast-induced nephropathy in blunt trauma patients. J Trauma Acute Care Surg. 2014;77:226–30. doi:10.1097/TA.0000000000000336.
67. Ku JH, Jeon YS, Kim ME, et al. Is there a role for magnetic resonance imaging in renal trauma? Int J Urol. 2001;8:261–7.
68. Leppäniemi A, Lamminen A, Tervahartiala P, et al. MRI and CT in blunt renal trauma: an update. Semin Ultrasound CT MR. 1997;18:129–35.
69. Sarani B, Powell E, Taddeo J, et al. Contemporary comparison of surgical and interventional arteriography management of blunt renal injury. J Vasc Interv Radiol. 2011;22:723–8. doi:10.1016/j.jvir.2011.01.444.
70. McAninch JW, Santucci RA. Renal and ureteral injuries. In: Gillenwater JY, Grayhack JT, Howards SS, Mitchell ME, editors. Adult and pediatric urology.

Philadelphia: Lippincott Williams & Wilkins; 2002. p. 451–83.
71. Miele V, Piccolo CL, Sessa B, Trinci M, Galluzzo M. Comparison between MRI and CEUS in the follow-up of patients with blunt abdominal trauma managed conservatively. Radiol Med. 2016;121:27–37. doi:10.1007/s11547-015-0578-1. Epub 8 Jan 2016.
72. Morey AF, McAninch JW, Tiller BK, et al. Single shot intraoperative excretory urography for the immediate evaluation of renal trauma. J Urol. 1999;161:1088–92.
73. Harris AC, Zwirewich CV, Lyburn ID, et al. CT findings in blunt renal trauma. Radiographics. 2001;21:S201-14. https://doi.org/10.1148/radiographics.21.suppl_1.g01oc07s201
74. Ramchandani P, Buckler PM. Imaging of genitourinary trauma. AJR Am J Roentgenol. 2009;192:1514–23. doi:10.2214/AJR.09.2470.
75. Scialpi M, Mazzei MA, Barberini F, et al. Traumi del surrene. In: Miele V, Scaglione M, Grassi R, Rotondo A, editors. Diagnostica per immagini del trauma maggiore. Milano: Elsevier Masson; 2010. p. 193–203.
76. Knudson MM, Maull KI. Nonoperative management of solid organ injuries. Past, present and future. Surg Clin North Am. 1999;79:1357–71.
77. Brandes SB, McAninch JW. Reconstructive surgery for trauma of the upper urinary tract. Urol Clin North Am. 1999;26:183–99, x.
78. Shanmuganathan K, Mirvis SE, Sover ER. Value of contrast-enhanced CT in detecting active hemorrhage in patients with blunt abdominal or pelvic trauma. AJR Am J Roentgenol. 1993;161:65–9. doi:10.2214/ajr.161.1.8517323.
79. Jeffrey RB Jr, Cardoza JD, Olcott EW. Detection of active intraabdominal arterial hemorrhage: value of dynamic contrast-enhanced CT. AJR Am J Roentgenol. 1991;156:725–9. doi:10.2214/ajr.156.4.2003435.
80. Shanmuganathan K, Mirvis SE, Reaney SM. Pictorial review: CT appearances of contrast medium extravasations associated with injury sustained from blunt abdominal trauma. Clin Radiol. 1995;50:182–7.
81. Regine G, Stasolla A, Miele V. Multidetector computed tomography of the renal arteries in vascular emergencies. Eur J Radiol. 2007;64:83–91. doi:10.1016/j.ejrad.2007.06.007.
82. Cokkinos D, Antypa E, Stefanidis K, et al. Contrast-enhanced ultrasound for imaging blunt abdominal trauma—indications, description of the technique and imaging review. Ultraschall Med. 2012;33:60–7. doi: 10.1055/s-0031-1273442. Epub 24 Jan 2012.
83. Pollack HM, Wein AJ. Imaging of renal trauma. Radiology. 1989;172:297–308.
84. Rhyner P, Federle MP, Jeffrey RB. CT of trauma to the abnormal kidney. AJR Am J Roentgenol. 1984;142:747–50. doi:10.2214/ajr.142.4.747.