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REVIEW ARTICLE

# The American Association for the Surgery of Trauma Organ Injury Scale 2018 update for computed tomography-based grading of renal trauma: a primer for the emergency radiologist

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## Abstract
The most widely used trauma injury grading system is the Organ Injury Scale (OIS) by the American Association for the Surgery of Trauma (AAST). The AAST OIS for renal trauma was revised in 2018 to reflect necessary updates based on decades of experience with computed tomography (CT)–based injury diagnosis and, specifically, to better incorporate vascular injuries, which were not comprehensively addressed in the original OIS. In this review article, we describe CT findings of the AAST OIS for the kidney according to the 2018 revision, with an emphasis on real-world application, and highlight important differences from the prior grading scheme. Routine use of this grading system allows for a standardized classification of the range of renal injuries to aid in management, adding value in the imaging care of trauma patients.

**Keywords** Kidney · Renal · Trauma · Injury · Computed tomography

## Introduction

The most widely used trauma injury grading system is the Organ Injury Scale (OIS) by the American Association for the Surgery of Trauma (AAST), which was originally published in 1989 with the aim to stratify injury to the liver, spleen, and kidney for patient outcomes research [1]. Like the Abbreviated Injury Scale (AIS) that preceded it, the OIS assigned a numerical grade from 1 to 5, from least to most severe injury. The first iteration of the OIS was devised prior to the widespread adoption of computed tomography (CT) in the diagnosis of organ trauma; therefore, this classification system was based solely on intraoperative findings. In the intervening years, the AAST has published injury scales for several other organs and updated its OIS for the liver and spleen in 1994 in light of new patient outcomes data and partly on the basis of an increasing recognition of the value of CT in diagnosing solid organ injury [2].

Increasingly, contrast-enhanced CT (CECT) has been adapted as a proxy for surgical findings in estimating an OIS grade and is in part responsible for facilitating a growing paradigm shift from one dominated by surgical intervention to that of nonoperative management for abdominopelvic trauma [3]. Correlation between CECT findings and surgical findings for renal injury, in specific, has been shown to be relatively strong [4, 5]. Santucci et al. conducted a retrospective review of 2467 patients and found that the original AAST OIS for the kidney correlated with need for surgical intervention. Surgery was performed in 0% patients with grade I injury, 15% in grade II, 76% in grade III, 78% in grade IV, and 93% in grade V. Nephrectomy was performed in 0% patients with grade I injury, 0% in grade II, 3% in grade III, 9% in grade IV, and 86% in grade V [5].

However, the original OIS did not fully take into account vascular injury in its classification system. As renal vascular injury is now quickly and accurately detected on CECT and image-guided embolization has emerged as an effective means for managing certain cases, the AAST OIS

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Committee convened a panel in 2015 to revise the injury rating scales for the kidney, liver, and spleen to better account for vascular injury, expanding on preliminary revisions proposed by Buckley and McAnich in 2011 [6]. This revised classification was published in 2018 [7] and is the first comprehensive revision for the kidney since the original OIS nearly 30 years before (Fig. 1).

The primary aim of this article is to describe the imaging findings of the AAST OIS for the kidney according to the 2018 revision, with an emphasis on important differences from the prior grading scheme (Table 1). This article also reviews the mechanisms of renal injury, imaging indications, and protocols used in the initial assessment of renal trauma patients and explores clinical management.

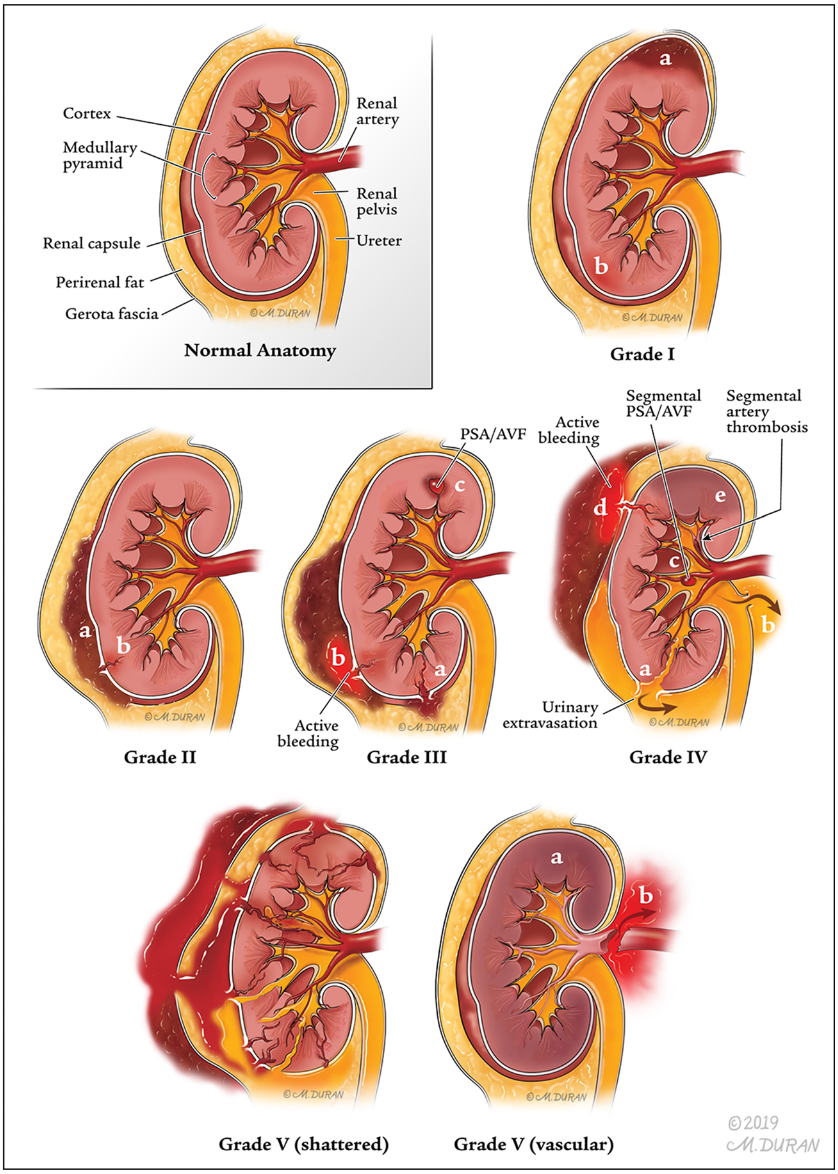


Fig. 1 The American Association for the Surgery of Trauma (AAST) Organ Injury Scale (OIS) for the kidney (2018 revision): Normal anatomy: for illustrative purposes only, the renal vein has been removed. Grade I: (a) subcapsular hematoma and/or (b) parenchymal contusion without laceration. Grade II: (a) perirenal hematoma confined to Gerota fascia; (b) renal parenchymal laceration ≤ 1 cm in depth without urinary extravasation. Grade III: (a) renal parenchymal laceration > 1 cm in depth without urinary extravasation; (b) active bleeding arising from the kidney and contained by Gerota fascia; (c) pseudoaneurysm (PSA)/arteriovenous fistula (AVF) arising from the kidney and contained by Gerota fascia. Grade IV: (a) parenchymal laceration extending into the urinary collecting system with urinary extravasation; (b) renal pelvis laceration (illustrated) and/or complete ureteropelvic disruption; (c) segmental renal vein or artery PSA/AVF; (d) active bleeding extending beyond Gerota fascia into the retroperitoneum or peritoneal cavity; (e) segmental or complete kidney infarction due to vessel thrombosis without active bleeding (note that only segmental artery thrombosis and infarction are illustrated). Grade V: shattered kidney with loss of identifiable parenchymal renal anatomy; devascularized kidney (a) with (b) active bleeding; main renal artery or vein laceration or avulsion of hilum (main renal artery laceration illustrated in (b)). © 2019 Mica Duran

Table 1 Description of CT features associated with each AAST OIS grade in the 2018 revision. The last column emphasizes the new elements in the revised grading scheme

| AAST grade | CT criteria in the revised grading system | New features in the revised grading system |
|---|---|---|
| I | - Isolated parenchymal contusion<br>- Subcapsular hematoma | - Removes *microscopic or macroscopic hematuria without imaging abnormality*<br>- Removes term *nonexpanding* from subcapsular hematoma |
| II | - Renal parenchymal laceration ≤ 1 cm in depth without extension to collecting system<br>- Perirenal hematoma contained by Gerota fascia | - Removes term *nonexpanding* from perirenal hematoma |
| III | - Renal parenchymal laceration > 1 cm without extension to collecting system<br>- Any low-grade injury with associated vascular injury or active bleeding contained by Gerota fascia | - Adds *vascular injury*, defined as AVF or pseudoaneurysm<br>- Includes active bleeding within Gerota fascia |
| IV | - Parenchymal laceration extending to collecting system<br>- Renal pelvis laceration or complete ureteropelvic laceration<br>- Segmental renal artery or vein intimal injury/thrombus<br>- Active bleeding beyond Gerota fascia into the retroperitoneum or peritoneum<br>- Segmental or complete renal infarction due to vessel thrombosis in the absence of active bleeding | - Incorporates isolated renal collecting system injury<br>- Includes active bleeding beyond Gerota fascia<br>- Removes bleeding injuries to the main renal artery and vein (laceration or avulsion of hilar vessels now included in Grade V) |
| V | - Main renal artery or vein laceration or avulsion from renal hilum<br>- Complete organ devascularization with active bleeding<br>- Shattered kidney | - Adds active bleeding in setting of complete renal infarction in distinction from Grade IV |

## Mechanism of injury

Located high in the retroperitoneum, the kidneys are relatively protected by the peritoneum anteriorly and the paravertebral muscles, spine, and rib cage posteriorly [4, 8]. The kidneys are confined within the perirenal (or perinephric) space, bounded anteriorly by Gerota fascia and posteriorly by the Zuckerkandl fascia, which together makes up the renal (alternatively perirenal) fascia. Gerota fascia variably refers to just the anterior layer, or both anterior and posterior layers, of the renal fascia. Gerota fascia, as used in the OIS and this review, refers to both anterior and poster layers conjointly.

Up to 80–90% of renal injuries occur in the setting of blunt trauma. The vast majority of these injuries are due to high-speed motor vehicle collisions, and a direct blow or fall from height accounts for far fewer [9]. Although the mechanism of injury in blunt renal trauma is incompletely understood, it likely results from shear injury related to rapid acceleration and deceleration forces. Rapid deceleration produces tension on the renal pedicle from relative forward motion of the kidney against a fixed hilum, which can lead to vascular laceration, thrombosis, and/or ureteropelvic disruption. By contrast, rapid acceleration may produce injury by means of collision of the kidney with adjacent, posteriorly located osseous structures, usually the spine or ribs [10].

Penetrating renal trauma mainly consists of firearm or stabbing injuries, accounting for 10–20% of all renal injuries [4]. Although penetrating trauma is much less common than blunt injury, these are more likely to result in severe renal injury, accounting for up to 68% of high-grade renal injuries compared with up to 25% due to blunt mechanisms [8]. Penetrating injuries through the anterior abdomen have a higher association with renal hilar injuries than through posterior approach wounds, which are more likely to disrupt the renal parenchyma [4, 8, 11].

Ballistic injuries, in particular, carry a high morbidity and mortality. Direct tissue damage occurs along the ballistic track from crush injury caused by the leading edge of the projectile [12]. The energy from the projectile also results in a temporary cavitation along the bullet track, leading to more extensive injury in the surrounding tissues as a result of crushing shear forces [12, 13]. Given its destructive tendencies, ballistic trauma often necessitates operative intervention to identify injured structures, control hemorrhage, and debride devitalized tissue, which carries a high risk for infection [9, 13].

## Indications for imaging in renal trauma

Hematuria is a characteristic feature of renal trauma and can be divided into microscopic (> 5 red blood cells (RBC)/high-powered field (HPF)) and macroscopic (visible to the human eye). Although greater than 95% of patients with renal injuries present with > 5 RBC/HPF, it is important to recognize that major renal injuries may be present in patients without hematuria, such as might occur in vascular pedicle or ureteropelvic injuries, and, accordingly, the degree of hematuria does not always correlate with the severity of renal injury [14–16].

Although imaging indications may vary by institution, CECT evaluation of the genitourinary system should generally be performed in trauma patients with (a) macroscopic hematuria, (b) microscopic hematuria combined with either shock (< 90 mmHg systolic blood pressure) or other significant abdominal injuries necessitating imaging, or (c) significant blunt trauma with injuries commonly associated with renal trauma, such as posterior flank hematoma, spine, or rib fractures as detected on trauma bay plain radiography, or rapid deceleration injuries even in the absence of hematuria [9]. Stable patients with penetrating flank wound or concern for retroperitoneal trajectory, specifically involving the flank or lower thorax, should also be evaluated with CECT regardless of the presence of hematuria. Although pediatric patients are more likely to sustain renal injury in the setting of trauma, there is currently no consensus on applying a lower threshold for imaging children compared with adults [17, 18].

## Imaging protocols in renal trauma

In most institutions, hemodynamically stable patients with suspected renal injury are evaluated with dual-phase CECT of the abdomen and pelvis (including chest when thoracic injury is present), consisting of an arterial and portal venous phase, as part of an evaluation for associated injury to other organ systems. When using a fixed time-delay protocol, an arterial phase of the abdomen and pelvis is attained with an approximately 15–25-s delay. The arterial phase, which results in a corticomedullary pattern of parenchymal enhancement, is helpful in detecting arterial injury, but is relatively insensitive for characterizing parenchymal or collecting system injury. A subsequent portal venous phase of the abdomen and pelvis using a 70–80-s delay results in a late corticomedullary or early nephrogenic phase, is then obtained to assess for solid organ injury, as the kidneys enhance more uniformly and parenchymal injury will be maximally conspicuous. This phase is especially helpful in characterizing arterial injuries as either active bleeding (active extravasation) or pseudoaneurysm/arteriovenous fistula (AVF) (contained vascular injury), and in assessing for the presence of venous injuries.

Active bleeding is usually apparent on the arterial phase as an irregular focus of extravascular contrast with attenuation similar to that of the aorta. On later phases, this focus will increase in size, but its attenuation will remain relatively constant. An AVF is usually indistinguishable from a pseudoaneurysm on CECT unless simultaneous arterial and venous enhancement occurs in the region of injury on the arterial phase [15]. These types of vascular injury appear as a rounded focus of extravascular contrast with no change in morphology between phases of contrast; however, its attenuation will follow approximately that of the aorta for each corresponding phase. Venous bleeding will not be apparent on the arterial phase, but will become evident on either the portal venous or excretory phases, and will follow the attenuation of adjacent venous structures. Venous thrombosis will manifest as an intraluminal filling defect on the portal venous phase. A 5-min delay (excretory phase) of the abdomen and pelvis is obtained in those patients in whom collecting system injury is suspected on the basis of microscopic or gross hematuria, lacerations extending to the collecting system on portal venous phase, or significant perirenal or periureteral fluid, including hematoma [9].

## AAST grading of renal trauma

As previously noted, the revised OIS for renal trauma differs from the earlier version primarily in that it takes into account vascular injury identified on CECT. As such, grades I and II, which are not characterized by gross vascular injury, are similar between the two versions. The revised system distinguishes two types of vascular damage based on their CECT appearance. Since pseudoaneurysms and AVFs are usually indistinguishable on CECT, Kozar et al. group these together as *vascular injury*, whereas *active bleeding* is characterized as a separate entity. In addition, *vessel thrombosis* is treated as a unique type of vascular injury [7]. In order to avoid confusion, we refer to pseudoaneurysm and AVF as *contained vascular injury* in this review where Kozar et al. use *vascular injury.* Active bleeding and vessel thrombosis will be referred to as such. Where it appears in this manuscript, the term *vascular injury* is used in the conventional sense of the full range of vascular damage. As in the original OIS, the presence of bilateral low-grade injuries results in an upstaging by one grade, up to a grade III. It is important to emphasize that the imaging descriptions that follow constitute the consensus interpretation of the revised AAST OIS by the authors of this review and do not necessarily represent the intentions of the members of the OIS Committee.

### Low-grade AAST renal injuries

**Grade I** Grade I injury consists of either an isolated *parenchymal contusion* or *subcapsular hematoma* (Fig. 2). Microscopic or macroscopic hematuria without imaging abnormality, a feature of grade I in the original OIS, has been removed in the new version [1, 7]. On the nephrogenic phase of CECT, a *contusion* generally appears as an ill-defined, rounded, or ovoid hypoattenuating focus within the renal parenchyma. Regions of clotted blood may appear isodense to normal renal parenchyma [16]. The detection of a contusion will be limited on the corticomedullary phase typical of an arterial phase acquisition due to suboptimal enhancement of the renal pyramids. Excretory phase CECT reveals a focal *delayed nephrogram* of hyperattenuation from retained parenchymal contrast [16]. A contusion should be discriminated from a segmental infarct, which would indicate a grade IV injury. An infarct is typically wedge-shaped with the apex directed towards the renal hilum on CECT and will remain hypodense even on delayed imaging [16] (Fig. 6). On

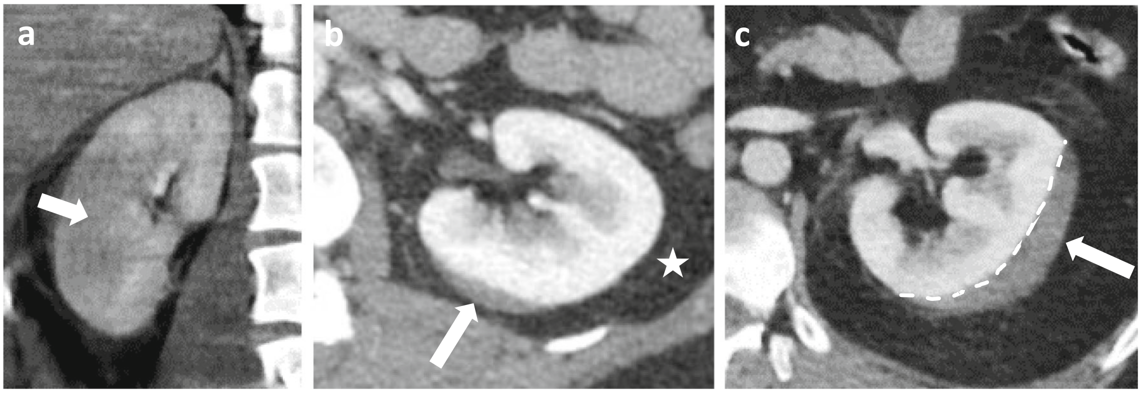


**Fig. 2** AAST grade I injury in three different patients. **a** Coronal CECT with ill-defined hypoenhancement in the interpolar region and inferior pole, indicative of parenchymal contusion without laceration (arrow). **b** Axial CECT demonstrates a focal crescentic hemorrhagic collection along the posterior margin of the kidney, compatible with a subcapsular hematoma (arrow); note that the perinephric fat (white star) is clear. **c** Larger subcapsular hematoma (arrow). Note the conformity of the hematoma peripherally to the convex margin of the fibrous renal capsule that contains it, and the mass effect it exerts on the enhancing renal parenchyma, deforming and flattening it (dashed line)

unenhanced CT, a contusion may range from nonapparent (isodense) to hyperdense, depending on the presence of clotted blood.

A *subcapsular hematoma* is characterized by a well-demarcated fluid collection measuring unclotted (30–50 HU) or clotted (50–70 HU) blood, in a location between the renal capsule peripherally and the renal parenchyma internally on both CECT and unenhanced CT. This collection is generally eccentric, crescentic, or biconvex and exerts mass effect on the underlying parenchyma, resulting in a flattened or depressed contour [9, 15, 16]. While the revised OIS still includes nonexpanding subcapsular hematoma in the operative criteria, the term nonexpanding is not included in the new imaging-based criteria since the expansion of a hematoma is more likely to be observed over the course of an operation than on imaging [1, 7]. An expanding hematoma at surgery implies ongoing bleeding and, as such, would represent a higher grade of injury.

**Grade II** Grade II injury consists of either a *renal parenchymal laceration measuring ≤ 1 cm in depth without extension to the renal collecting system*, or a *perirenal hematoma contained by Gerota fascia* (Fig. 3). Parenchymal lacerations appear as irregular, linear, or branching hypoattenuating regions on portal venous phase of CECT. As with infarcts and hematomas, lacerations will not enhance. On CECT, the integrity of the collecting system can be inferred by identifying normal enhancing tissue between the deepest extent of a laceration and the urine-containing collecting system; nevertheless, the absence of renal collecting system involvement can be ensured only on excretory phase imaging by the absence of extravasation of excreted contrast.

A *perirenal hematoma* is characterized on both CECT and unenhanced CT as a hyperattenuating, ill-defined fluid collection located between the renal capsule and Gerota fascia and implies rupture of the renal capsule. Although this type of hematoma can occur in isolation, it most often occurs along with lacerations and/or vascular injury [15]. A perirenal hematoma may cross the midline and extend deep into the pelvis while still being contained by Gerota fascia [9, 15]. Care must be taken when evaluating perirenal fluid in the region of the renal hilum. While fluid in the region may simply represent medial extension of a perirenal hematoma (≥ grade II), blood from renal vascular injury (≥ grade III), or extravasated urine (≥ grade IV) can have a similar appearance [15]. As in grade I, the term *nonexpanding* has been removed from the new OIS when applied to the feature of *perirenal hematoma.* The revised OIS makes mention of only *perirenal hematoma* confined to Gerota fascia [1, 7].

**Grade III** Grade III injury is characterized by a *laceration > 1 cm but not involving the collecting system* or *any low-grade injury in the presence of associated kidney contained vascular injury or active bleeding contained within Gerota fascia* (Fig. 4). Collecting system integrity can be inferred when a laceration clearly does not extend to the collecting system and can only be ensured when delayed imaging demonstrates absence of extravasation of excreted contrast [9]. The criterion of vascular injury contained within Gerota fascia is new in the 2018 OIS revision, whereas the grade III laceration component is unchanged [1, 7].

## High-grade AAST renal injuries

**Grade IV** High-grade renal injuries include grades IV and V and are characterized by varying degrees of complex parenchymal disruption, violation of the renal collecting system, and/or severe vascular injury. In the revised OIS, grade IV injuries include any of the following: (1) *parenchymal laceration extending to involve the collecting system;* (2) *renal pelvis laceration or complete ureteropelvic laceration;* (3) *contained vascular injury involving a segmental renal artery*

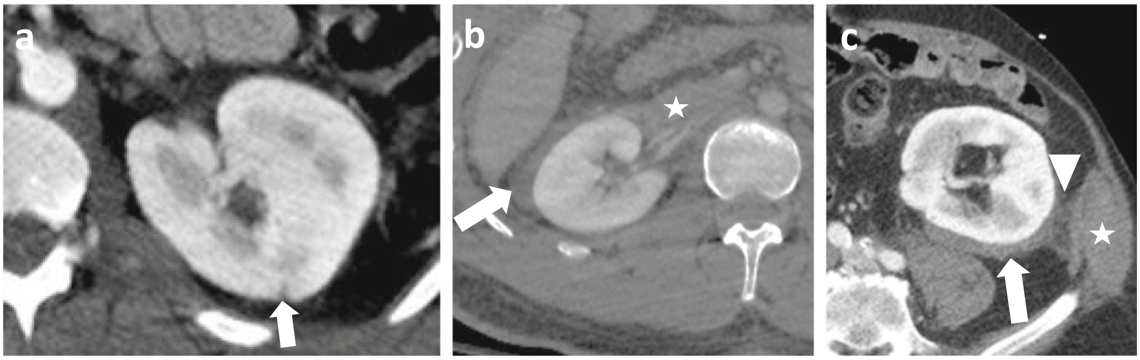


**Fig. 3** AAST grade II injury in three different patients. **a** Axial CECT demonstrating a superficial (< 1 cm in length) parenchymal laceration (white arrow) in the posterior aspect of the kidney clearly sparing the collecting system. **b** Axial CECT demonstrating perirenal hematoma contained within Gerota fascia. Hemorrhage nearly fills the hepatorenal fossa (arrow) and extends anteromedially along the hilar vasculature. **c** Axial CECT with left lower quadrant renal transplant subcapsular hematoma (white arrow) with characteristic crescentic shape, perinephric hematoma (arrow head), and intramuscular hematoma in the left lateral abdominal wall (star). Due to anatomic differences in renal transplants (e.g., the lack of Gerota fascia, other retroperitoneal anatomical structures), the AAST criteria must be conceptually modified by the interpreting radiologist for these cases; however, using the grading system allows standardized communication and treatment of these vulnerable patients who often have only a single functioning kidney

*or vein;* (4) *active bleeding beyond Gerota fascia into the retroperitoneum or peritoneum;* or (5) *segmental or complete renal infarction due to vessel thrombosis in the absence of active bleeding* (Figs. 5 and 6). The revised classification for grade IV injury differs in several important ways from the original version: (a) isolated renal collecting system injury is now incorporated; (b) bleeding injuries to the main renal artery and vein are not specifically described (laceration or

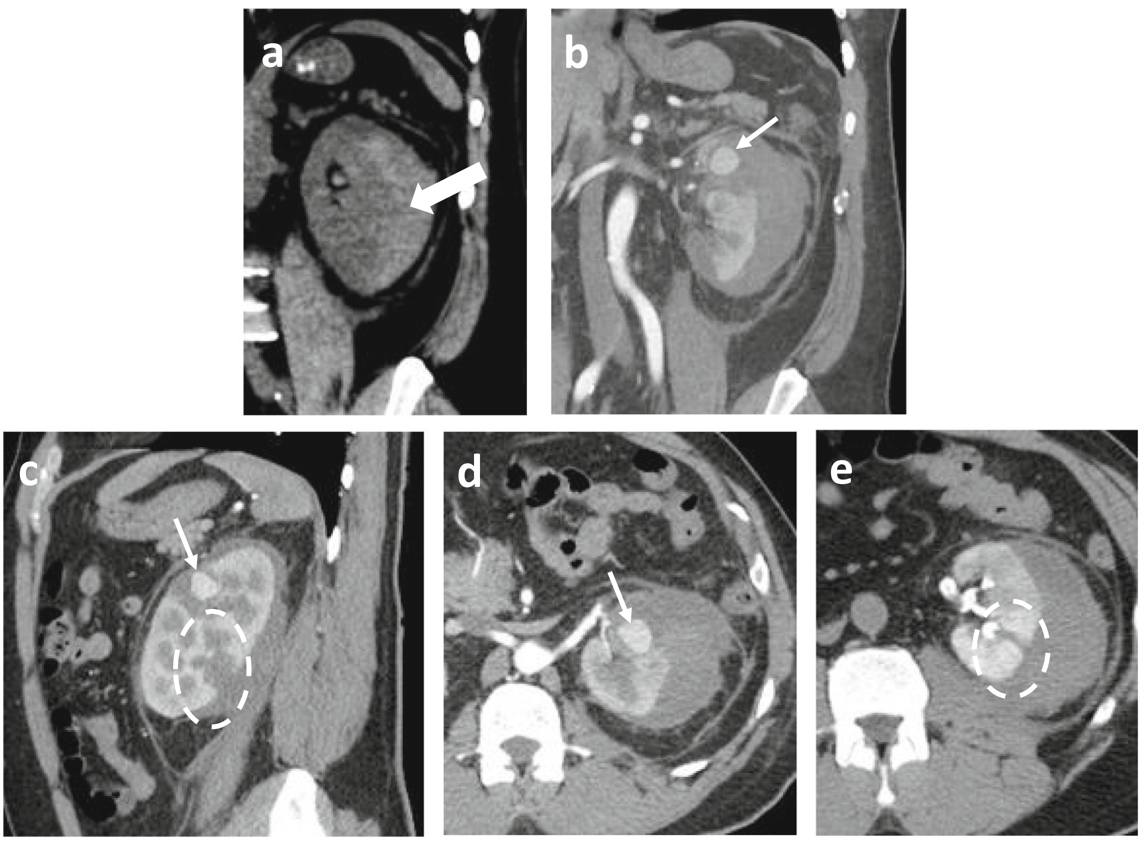


**Fig. 4** AAST grade III injury in following a motorcycle collision in a patient with flank pain and gross hematuria. **a** Coronal non-contrast CT demonstrates crescentic high density collection along the lateral margin of the kidney (arrow), compatible with a subcapsular hematoma. Note that the vascular injury shown in **b**–**d** is not visible without contrast. **b**–**d** Coronal (**b**), sagittal (**c**), and axial (**d**) CECT demonstrates a large, contained smoothly marginated pool of contrast in the superior renal pole, consistent with pseudoaneurysm (arrow in **b**–**d**). There are deep parenchymal lacerations (> 1 cm), which extend through the cortex and medullae (dashed circle **c** and **e**). **e** Excretory phase image demonstrates a deep laceration extending to the renal hilum; however, the absence of urinary extravasation excludes renal collecting system violation

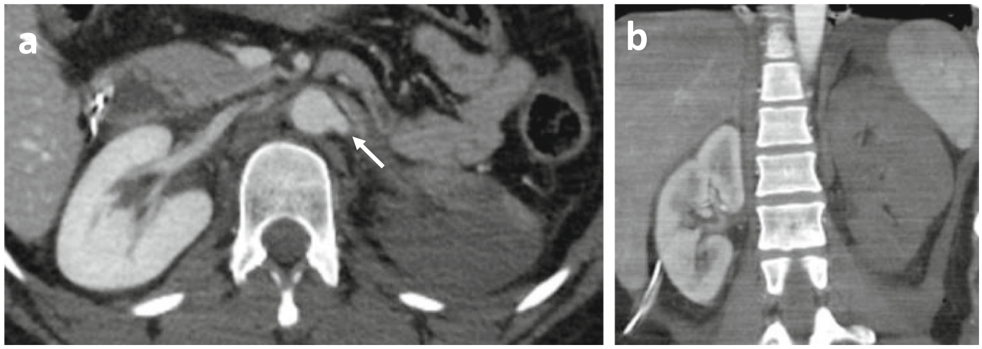

**Fig. 5** AAST grade IV injury. Axial (**a**) and coronal (**b**) CECT demonstrating abrupt occlusion of the proximal left renal artery (arrow in **a**), likely due to thrombosis or dissection, resulting in devascularization of the left kidney. Note the absence of blood products or active bleeding from the vascular injury. If active bleeding were present, this would reflect a grade V injury

avulsion of the hilar vessels is now included under grade V); and (c) active bleeding beyond Gerota fascia is introduced as a feature [1, 7].

Renal collecting system violation does not enter into the OIS until grade IV. As mentioned with respect to the lower grades, while collecting system involvement can be suggested when a parenchymal laceration appears to extend to or through renal calyces, pelvis, or ureteropelvic junction, it can only be ascertained on imaging by the presence of extravasation of excreted contrast during the excretory phase. Complete ureteropelvic avulsion will completely disrupt the lumen, leading to the absence of excreted contrast in the excluded distal portion of the ureter but presence of excreted contrast in the area of injury. In the case of partial pelvic or

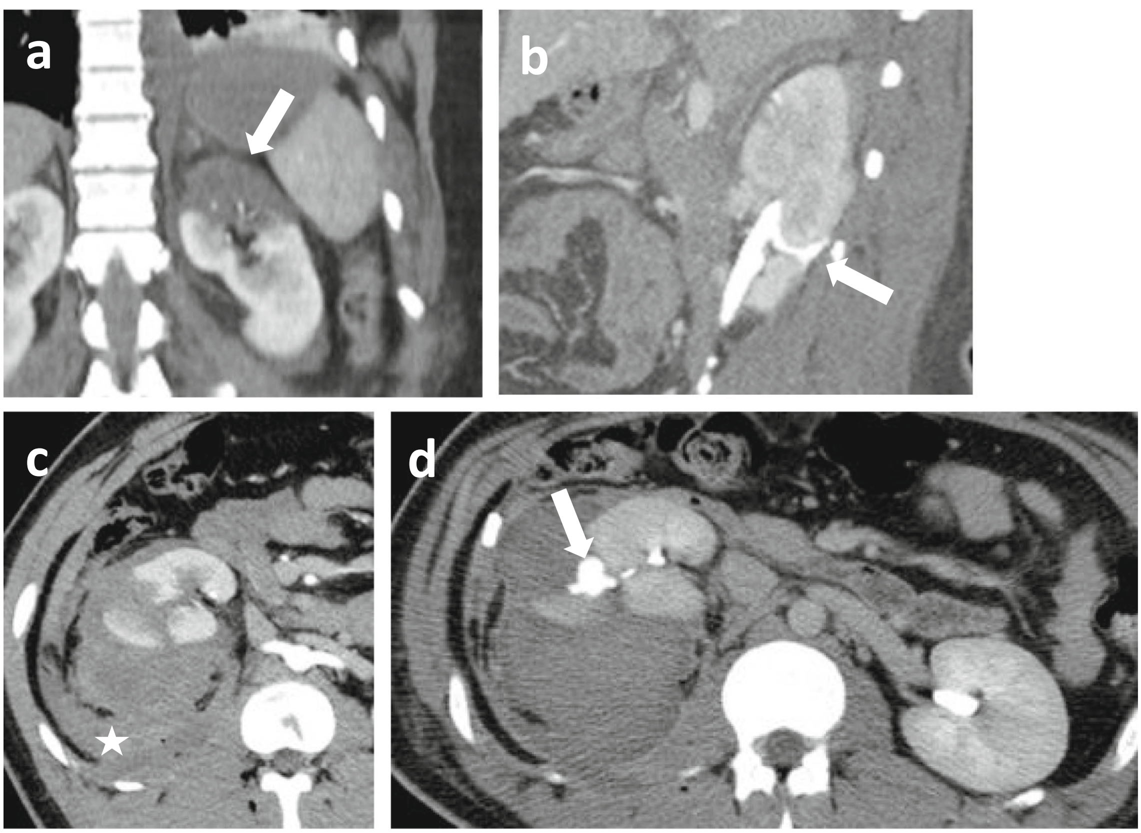

**Fig. 6** AAST grade IV injury in three different patients. **a** Coronal CECT with a wedge-shaped region of non-enhancing parenchyma in the superior renal pole, in keeping with traumatic segmental renal artery injury with occlusion and subsequent segmental infarction (arrow). In such cases, the affected segmental artery may not be apparent; the characteristic appearance of the segmental parenchymal infarct is evidence of arterial injury. **b** Different patient following a stabbing; dual-phase imaging including excretory phase demonstrates urinary extravasation through a deep parenchymal laceration (arrow). **c**, **d** Images from the same patient following motor vehicle collision. Massive perirenal hematoma with extension beyond Gerota fascia (**c**, star) into the posterior pararenal space and multiple deep lacerations (**c**) with urinary extravasation present on excretory phase imaging (arrow, **d**)

ureteropelvic tears, excreted contrast may still be visible in the distal ureter since the majority of the lumen remains intact [9].

The bleeding-type vascular injury included in grade IV reflects severe shearing injury to segmental or main renal arteries, leading to uncontained hemorrhage into the retroperitoneum or peritoneal cavity. This complication can lead to life-threatening hemodynamic instability, exsanguination, and even death [7]. Shearing forces can alternatively result in arterial intimal tearing, dissection, and, ultimately, thrombosis without active bleeding, resulting in segmental or main renal vessel thrombosis and subsequent segmental or complete kidney infarction, respectively [9]. The authors note that controversy exists in the trauma imaging literature as to whether an isolated segmental renal infarct should be considered a high-grade injury, as it rarely, if ever, results in intervention or clinical renal functional loss [19]. Contained segmental vein or artery vascular injury (pseudoaneurysm or AVF) is also included in grade IV.

**Grade V** Grade V injury comprises the most severe form of renal vascular and renal parenchymal damage and includes (1) *main renal artery or vein laceration or avulsion from the renal hilum;* (2) *complete organ devascularization with active bleeding;* and (3) *shattered kidney* (Fig. 7). Renal pedicle trauma is unique to grade V vascular injury and accounts for up to 5% of all renal trauma [9]. This includes avulsion of the renal hilum with laceration of the main renal artery or vein [7]. Laceration of the main renal vessels often results in active bleeding with devascularization of the entire kidney, warranting emergent nephrectomy.

Grade V injury also includes a *shattered kidney*, which, due to numerous lacerations, results in the formation of multiple fragments and loss of identifiable renal parenchyma [7]. The distinction between a shattered kidney and multiple lacerations of a lower injury grade is subjective, but the term *shattered* implies a degree of tissue destruction that precludes any meaningful healing and may include multiple areas of devitalized parenchyma, injury to the collecting system, and severe vascular damage with active arterial bleeding [8, 9].

## Management of renal injuries

### The evolving management of renal trauma

Historically, the management of renal trauma was determined solely on the basis of hemodynamic stability and grade of injury. If the patient was hypotensive, an operative intervention was mandated. Management of stable patients was then determined by injury grade, reserving operations for patients with grade V injuries. In contemporary practice, the improved ability to closely monitor a patient's hemodynamic status and success with nonoperative endovascular techniques, nonoperative management is feasible even in the highest grade of injury. The decision to carefully monitor a patient with a grade V injury instead of immediately proceeding to surgical exploration, in specific, is made in conjunction with interventional radiologists, who can perform endovascular treatment to attempt hemostasis; trauma surgeons, who are able to take a patient to the operating suite at a moment's notice; and a urologist, who is able to help manage the non-emergent complications that may arise.

### Expectant management

For most hemodynamically stable patients, the American Urological Association guidelines recommend observation regardless of AAST grade [20]. Almost all grade I and II, and some grade III, parenchymal renal injuries are treated

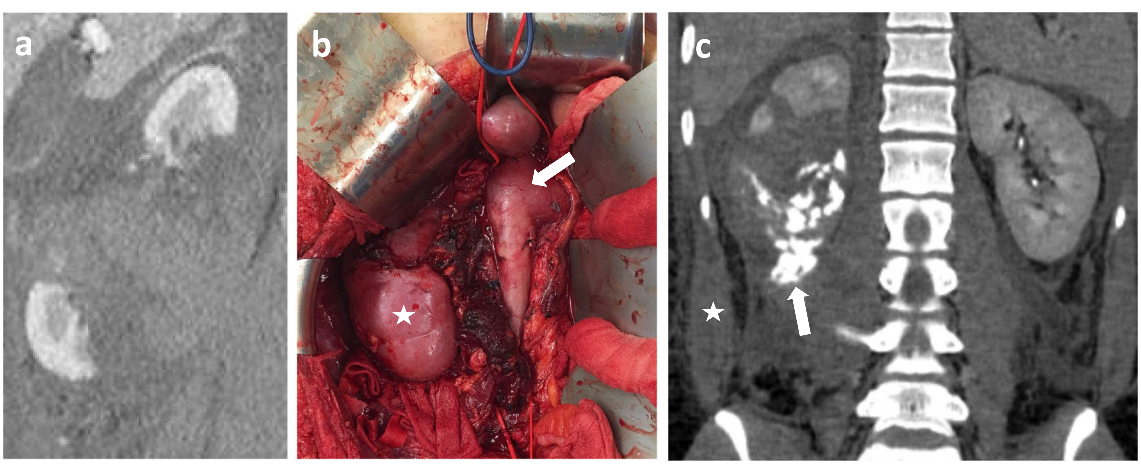


**Fig. 7** AAST grade V injury in two separate patients. **a** Sagittal CECT of a patient with transected kidney demonstrates complete devascularization of the interpolar region of the right kidney. **b** Intraoperative photograph of the same patient as (**a**) demonstrating transection of the kidney, with small superior pole attached to the IVC (arrow), which was subsequently repaired. The inferior pole is in the left-lower corner (star). No distinct arterial supply to the inferior pole could be identified. Superior pole parenchyma was well-vascularized, but was avulsed from the entire collecting system. Nephrectomy was performed. **c** Coronal CECT in a separate patient

nonoperatively with bed rest, analgesia, and hydration, as complications are exceedingly rare [21–23]. In isolation, low-grade renal injuries may not even warrant hospital admission, as they often fully heal without intervention and without loss of renal function or significant, if any, morphological abnormalities on subsequent imaging [15, 24].

Follow-up imaging for grade I and II injuries has not been shown to affect outcomes and is generally not indicated [10, 25, 26], although each should be tailored to individual patient management. Follow-up imaging in high-grade injuries managed expectantly should generally be performed after at least 48 h and should include excretory phase imaging to assess for complications, including persistent urine leak, contained vascular injury, or ongoing hemorrhage [8]. This timeframe allows for AVFs to develop or urinomas to become clinically significant. If there is a high clinical suspicion of active bleeding (labile blood pressures, need for slow continuous transfusions, or downward trending hemoglobin levels), a repeat CECT should be performed earlier. Radionuclide scintigraphy should also be considered to document renal function in high-grade injuries regardless of treatment approach [8].

### Endovascular and endoscopic management

Over the past 20 years, there has been a shift towards nonoperative management even in high-grade renal injuries, given successful outcomes of nonoperative approaches, including endovascular embolization in treating less severe vascular injury [27–29].

Pseudoaneurysms and AVFs associated with grade III injuries may be treated with endovascular embolization if the patient is hemodynamically stable. Additional imaging features that may predict the need for embolization include perirenal hematoma size of greater than 3.5–4 cm, intravascular contrast extravasation, medial site of injury, and high complexity of renal lacerations [30–35]. Ultimately, the decision to confirm the presence of vascular injury with angiography and subsequently treat with an endovascular approach is decided in consultation with the trauma surgical team. The management of renal vascular injuries with embolization is geared towards minimizing the need for nephrectomy [36].

Over 80% of collecting system injuries not involving the renal pelvis or ureter will resolve spontaneously. Persistent urinary extravasation can be managed by minimally invasive urinary diversion with ureteral stenting or with percutaneous nephrostomy when stent placement fails. Both can be performed under light sedation. Additional indications for stent placement include persistent pain, blood clot in the renal pelvis, hydronephrosis with the possibility of pre-existing partial obstruction at the ureteropelvic junction (UPJ), and ureteropelvic injury without avulsion noted on open repair [8].

Persistent urinary leak may be complicated by the development of a urinoma, which can be treated with percutaneous catheter drainage. Drainage is indicated for enlarging or infected urinomas, fever, fistulas, increasing pain, or ileus [8, 20]. Drainage should be achieved via ureteral stent and may be supplemented by percutaneous urinoma drain, percutaneous nephrostomy, or both [20].

### Operative management

Traditionally, the four absolute indications for surgical exploration include the following: life-threatening hemorrhage, renal pedicle avulsion (including ureteropelvic avulsion), shattered kidney, and rapidly expanding retroperitoneal hematoma [8, 15]. Renal exploration may also be considered in patients who fail non-invasive management or for grade III and IV lacerations if there is significant devitalized tissue or concomitant pancreatic or bowel injuries, as these injuries may be associated with higher risk of delayed complications, including secondary bleeding from an AVF or pseudoaneurysm, urinoma or perinephric abscess, or renal hypertension [8].

Operative management includes either early control of bleeding with the repair of the main renal artery or vein or partial or total nephrectomy, depending on the severity of injury. High-grade renal injuries are associated with higher nephrectomy rates, approaching almost 100% in unstable patients [8, 28, 37–40]. Reasons for such a high total nephrectomy rate are multifactorial. Should an unstable patient with high-grade injury present at an institution where a specialist in renal reconstruction is not available, the operation of choice is nephrectomy. Furthermore, attempts at grade V renal artery repair have been associated with a nearly 100% failure rate as well as a 15-fold increase in fatality, delayed nephrectomy, and hypertension, and as such, nephrectomy is the treatment of choice [8]. Repair of main renal vein injuries, however, carries a better prognosis with the possibility of salvaging the kidney [8]. Renal salvage is otherwise considered when experts in renal reconstruction are available, when the patient is stable enough to undergo such a procedure, and when the patient is dependent on the injured kidney (previous contralateral nephrectomy, horseshoe kidney, congenital agenesis of the contralateral kidney, etc.). Intra-operatively, it is not always feasible to know the patient's past history, and surgeons sometimes must rely on direct inspection of the contralateral side to evaluate for the presence and function of the uninjured kidney.

### Management of penetrating injuries

Renal stab wounds can often be managed conservatively with the goal of preserving renal function and limiting morbidity. Nephrectomy has been associated with renal failure in 28% of patients [8]. A study by Armenakas et al. reported successful management of 54% of renal stab wounds nonoperatively

[41]. Gunshot wounds to the kidneys may also be conservatively managed in the absence of signs of concomitant bowel injury, exsanguination, or a grade V vascular injury warranting surgery [8]. Based on published data, up to 50% of grade III and IV ballistic injuries may be managed nonoperatively [42, 43].

## Conclusion

Renal injuries are relatively common, occurring in 10% of blunt abdominal trauma. Radiologists should be familiar with the 2018 update to the AAST OIS renal injury grading system, which emphasizes CECT-based injury classification and more completely incorporates vascular injuries to assess organ injury severity and inform a management approach. Routine use of this grading system allows standardized classification and management of renal injuries, adding value in the imaging care of trauma patients.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Informed consent** This article contained no human subjects and is not primary research, and informed consent is not applicable in this situation.

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