Grading Abdominal Trauma: Changes in and Implications of the Revised 2018 AAST-OIS for the Spleen, Liver, and Kidney

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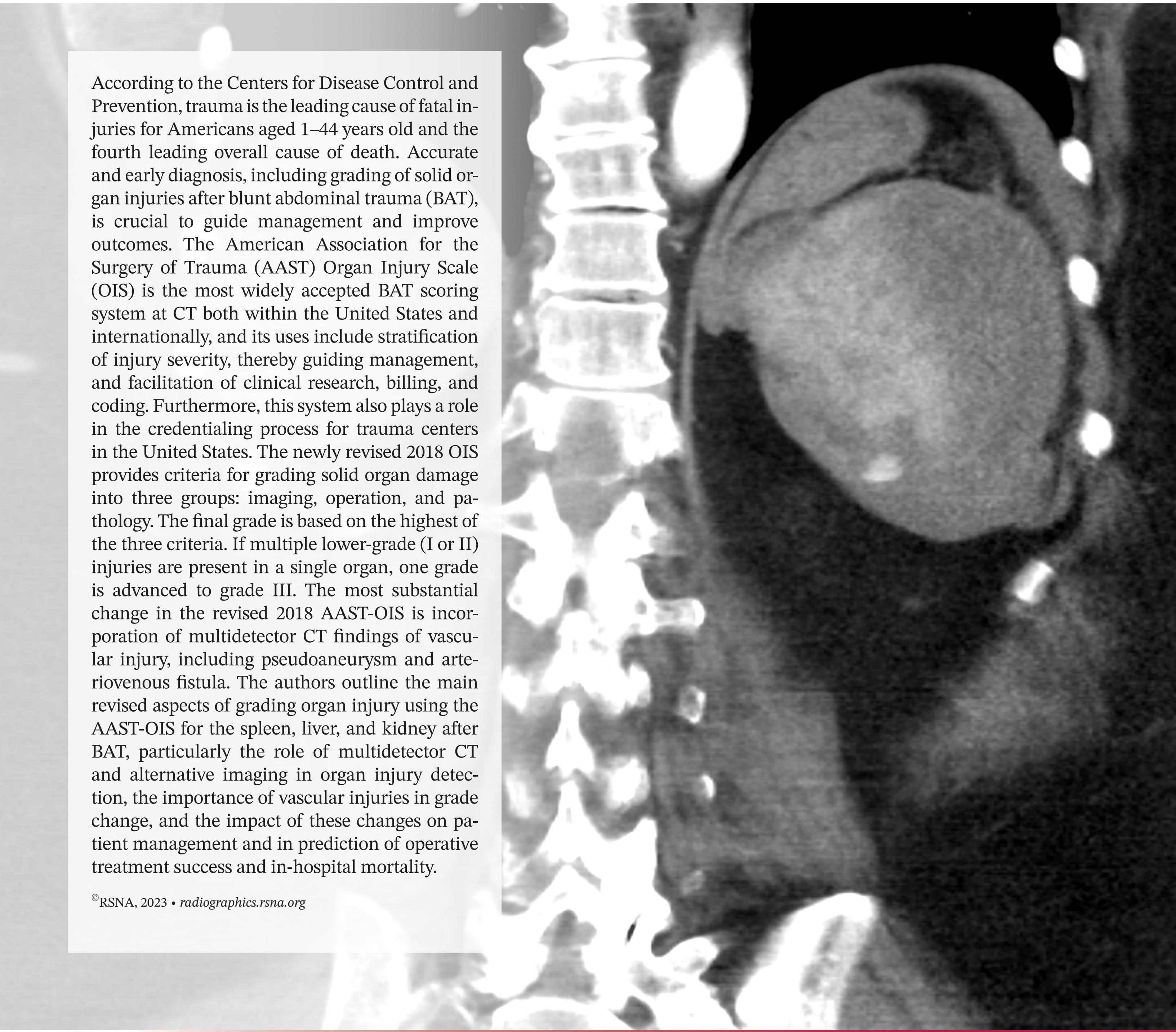

According to the Centers for Disease Control and Prevention, trauma is the leading cause of fatal injuries for Americans aged 1–44 years old and the fourth leading overall cause of death. Accurate and early diagnosis, including grading of solid organ injuries after blunt abdominal trauma (BAT), is crucial to guide management and improve outcomes. The American Association for the Surgery of Trauma (AAST) Organ Injury Scale (OIS) is the most widely accepted BAT scoring system at CT both within the United States and internationally, and its uses include stratification of injury severity, thereby guiding management, and facilitation of clinical research, billing, and coding. Furthermore, this system also plays a role in the credentialing process for trauma centers in the United States. The newly revised 2018 OIS provides criteria for grading solid organ damage into three groups: imaging, operation, and pathology. The final grade is based on the highest of the three criteria. If multiple lower-grade (I or II) injuries are present in a single organ, one grade is advanced to grade III. The most substantial change in the revised 2018 AAST-OIS is incorporation of multidetector CT findings of vascular injury, including pseudoaneurysm and arteriovenous fistula. The authors outline the main revised aspects of grading organ injury using the AAST-OIS for the spleen, liver, and kidney after BAT, particularly the role of multidetector CT and alternative imaging in organ injury detection, the importance of vascular injuries in grade change, and the impact of these changes on patient management and in prediction of operative treatment success and in-hospital mortality.

EMERGENCY RADIOLOGY

Supplemental Material

Quiz questions for this article are available through the Online Learning Center.

CME

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Abbreviations: AAST = American Association for the Surgery of Trauma, OIS = Organ Injury Scale

TEACHING POINTS

- While CT is the ideal test in patients in stable condition with suspected intra-abdominal injuries, Extended Focused Assessment with Sonography for Trauma (EFAST) US is frequently used as the initial screening test in all patients after abdominal trauma.
- The main changes brought on by the 2018 update are that splenic vascular injuries or active bleeding confined within the capsule are now included in grade IV. It is also important to note that addition of the arterial phase recommended in this version is responsible for increased detection of vascular injuries.
- The major change in the 2018 revision was removal of equivalent Couinaud segments for grading parenchymal disruption. Furthermore, grade VI—previously used to describe hepatic avulsion—was discontinued as it is a nonsurvivable injury, making V the highest grade in liver injuries, a feature now shared by the three organs.
- The previously used term *nonexpanding* has been discontinued in the 2018 update for both subcapsular and perinephric hematomas, as conclusive demonstration of nonexpansion is not possible with a single radiologic examination.
- Validation of the AAST-OIS 2018 revision revealed that it has led to an increase in heterogeneity for grade IV renal injuries, an improvement in the ability to predict the need for operative treatment, and a decline in the correlation with in-hospital mortality for both splenic and hepatic trauma.

Introduction

Trauma is the leading cause of fatal injuries for Americans aged 1–44 years old (1). The 2018 revision of the American Association for the Surgery of Trauma (AAST) Organ Injury Scale (OIS) is the newest version of the most widely accepted scoring system for blunt abdominal trauma, and it provides criteria for grading solid organ damage into three groups: imaging, operation, and pathology. The most substantial change in the revised 2018 AAST-OIS is incorporation of multidetector CT findings of vascular injury, including pseudoaneurysm and arteriovenous fistula (2).

In this article, we describe the 2018 AAST-OIS for the liver, spleen, and kidney; changes from the prior versions; and implications for management and outcomes.

Validation of AAST-OIS 2018

One of the strongest motivators for updating trauma grading systems is to improve their ability to predict mortality and guide management. Validation is essential to understand whether these goals were achieved.

In 2020, Morell-Hofert et al (3) systematically reviewed the CT images of 703 patients with blunt splenic and hepatic injury to evaluate the clinical significance of the change in grade according to the 1994 AAST-OIS compared with the revised 2018 AAST-OIS and found that the latter was superior for predicting the need for primary or secondary operative treatment in both splenic and hepatic trauma but inferior for prediction of in-hospital mortality. In splenic trauma, reclassification to the 2018 AAST-OIS resulted in changes in individual injury severity in 28.1%, while in liver trauma, reclassification resulted in changes in 1.9% (3). In 2021, Hemachandran et al (4) conducted a retrospective review of 527 patients who sustained blunt abdominal trauma and underwent dual-phase CT. They concluded that over 40% of the splenic vascular injuries were detected only in the arterial phase, and its addition led to a change in the grade in 11.7% of patients.

As for renal trauma, in 2021 Keihani et al (5) reviewed the CT studies of 322 patients and graded them according to both the original 1989 AAST-OIS and the revised 2018 AAST-OIS classifications. They found that approximately one-third of injuries initially classified as grade III with the 1989 version were upgraded to grade IV when the 2018 revision was used, and a significant number of injuries classified as grade V were downgraded, thereby leading to heterogeneity of grade IV injuries in the 2018 version. Graphical representations of the reclassifications described in this section are shown in Figure 1.

Trauma Grading History

Knowledge of the experiences that led to development and implementation of trauma scales throughout history is crucial to understand the motivations that influence their changes (Fig 2). The Abbreviated Injury Scale (AIS) was introduced in 1971 for the American Medical Association Committee on Medical Aspects of Automotive Safety to improve vehicle safety, as an ordinal scale that divides injuries into six categories based on the degree of threat to life, from minor to not survivable (6). The AIS served as the foundation for future trauma scoring scales by providing the lexicon used to describe and define the severity of injuries through summary scores.

In 1974, the Injury Severity Score (ISS) was introduced for a better description of severity and probability of death in patients with multiple injuries. It is based on division of the whole body into six anatomic regions, with an AIS score assigned per region. If multiple injuries are present within the same region, the most severe score is assigned. The ISS is calculated by adding up the sum of the scores of the three most severely injured regions (7). The severity scale has been shown to correlate well not only with patient mortality, but also morbidity and length of hospital stay (8).

The Abdominal Trauma Index (ATI) model, which is based on risk stratification, was developed in 1981 for penetrating trauma (9), and later, in 1990, was updated for blunt trauma (10). The ATI is calculated by assigning a risk factor (from 1 to 5) to each organ injured and multiplying this number by a severity of injury estimate (from 1 to 5). The sum of the individual organ scores is taken to determine the final ATI score, which ranges from 0 to 200. The risk of postoperative complications increases with ATI scores greater than 25 (9,10).

In 1987, the AAST formed an OIS committee to create a more comprehensive classification to facilitate clinical research, risk stratify patients for quality measures, and assist with billing and coding. The first AAST-OIS guidelines classifying injuries to the spleen, liver, and kidney were published in 1989 (11) and later updated for the spleen and liver in 1994

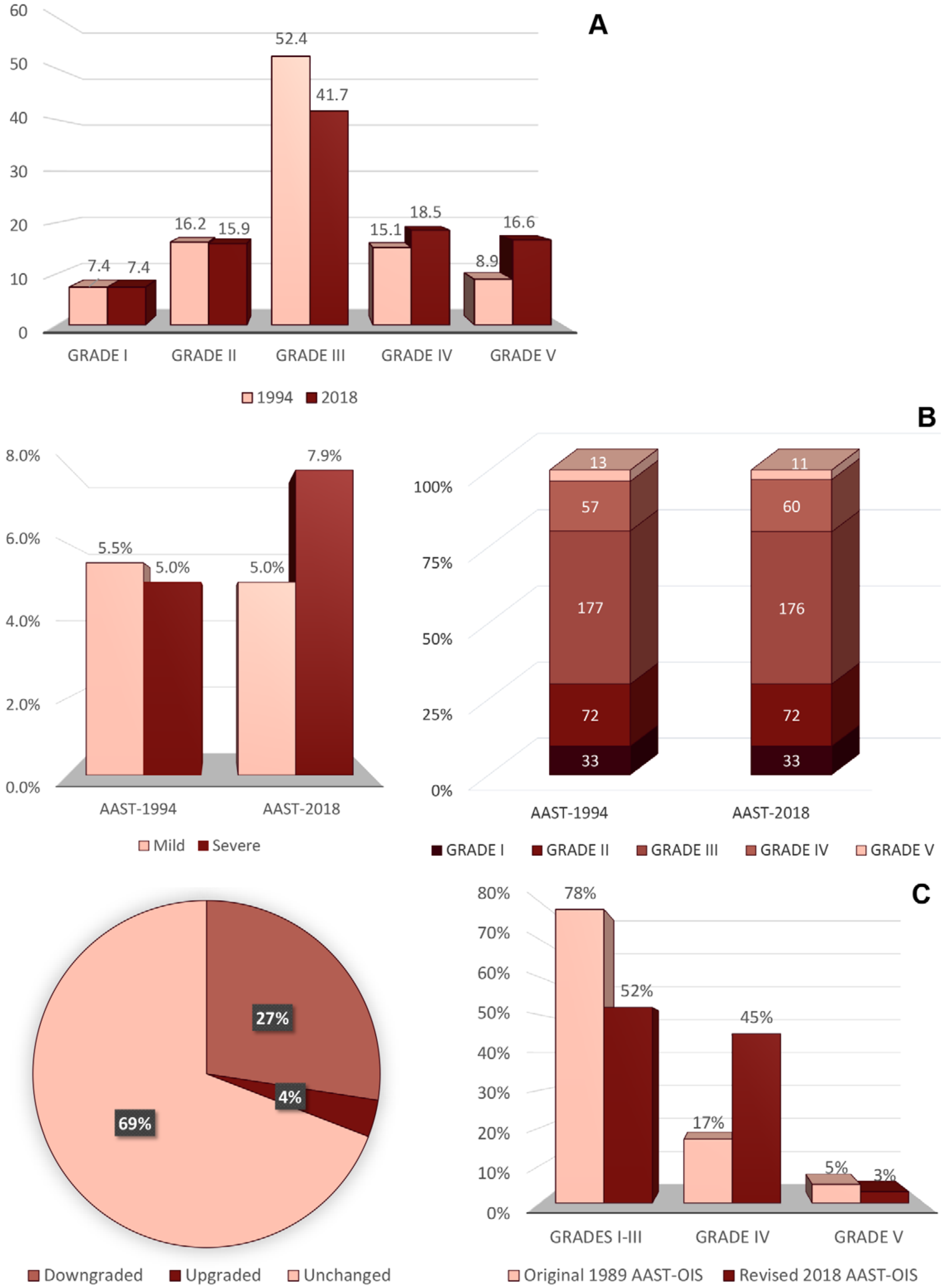


Figure 1. Validation of the AAST-OIS 2018 version. **(A)** Comparison of the splenic trauma grades using the 1994 version and the revised 2018 AAST-OIS in the 703-patient cohort analyzed by Morell-Hofert et al (3). **(B)** Comparison of the hepatic trauma grades using the 1994 version and the revised 2018 AAST-OIS in the 703-patient cohort analyzed by Morell-Hofert et al (3). **(C)** Comparison of the renal trauma grades using the original 1989 and the revised 2018 AAST-OIS in the 322-patient cohort analyzed by Keihani et al (5).

(12). The main changes in the revised 1994 AAST-OIS included the following: global downgrading of hematomas for both spleen and liver, acknowledging their relatively benign course with the advent of widespread CT scanning for blunt abdominal trauma; addition of Couinaud's segmental liver anatomy to facilitate quantification of lobar parenchymal disruption, employing internationally familiar terminology; application of more rigorous criteria for grades IV and V hepatic injuries, recognizing the need to further delineate the operative challenges of these advanced injuries; and restricting the advancement of one grade for multiple injuries within an OIS to grade III (12).

Imaging Tools

Initial management of any trauma patient begins with stabilization and identification of any life-threatening injuries as described in Advanced Trauma Life Support (ATLS) protocols. Blunt abdominal trauma can have a wide range of

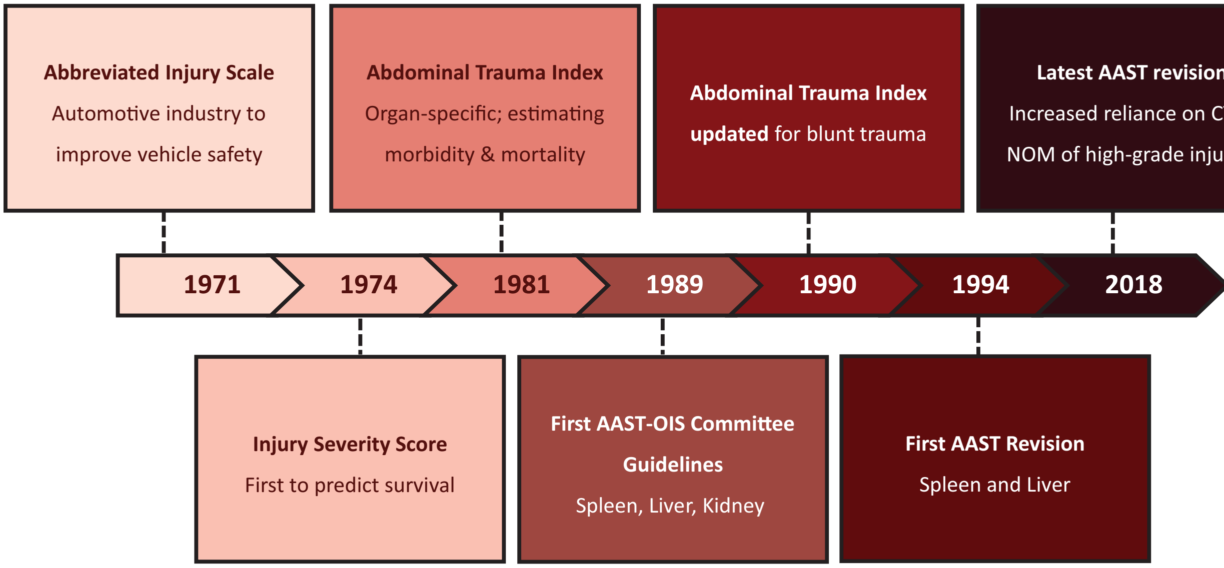


Figure 2. Schematic representation shows the main historical events in the creation of trauma grading scales. *NOM* = nonoperative management.

manifestations, and it is crucial to consider the mechanism of injury, presence of extra-abdominal injuries, physical examination results, and laboratory findings (13).

While CT is the ideal test in patients in stable condition with suspected intra-abdominal injuries, Extended Focused Assessment with Sonography for Trauma (EFAST) US is frequently used as the initial screening test in all patients after abdominal trauma, especially those who are too hemodynamically unstable to undergo CT, and it addresses a broad array of pathologic conditions capable of causing instability, including hemoperitoneum, hemopericardium, hemothorax, and pneumothorax.

Multidetector CT

Multidetector CT is the reference standard for depicting abdominal trauma, with sensitivity for detection of visceral organ injury approaching 96%–100% (14). Intravenous iodinated nonionic contrast agent should be used. Close collaboration between the trauma and radiology teams ensures the best overall imaging evaluation, with the lowest radiation dose and contrast material load.

The 2018 AAST injury scale advocates use of dual-phase CT (ie, arterial and portal venous phases) for optimal overall performance. The arterial phase is performed 25–30 seconds after intravenous injection of contrast material, and it is superior for pseudoaneurysm detection. It is important to note that the spleen has heterogeneous parenchymal enhancement in the arterial phase, which should not be mistaken for splenic lacerations or contusions. The portal venous phase is performed 65–80 seconds after injection and provides superior detection of active bleeding and parenchymal disruption (15,16).

Several studies have shown that comparable image quality can be achieved using a biphasic intravenous contrast material injection protocol with single multidetector CT acquisition with less radiation and reduction in acquisition time, which is especially important in the younger cohort of patients (17). Regardless of whether an arterial phase is included or whether a single or split-bolus protocol is used, images should be immediately reviewed by the radiologist to decide whether delayed imaging (performed approximately 9 minutes after the portal venous phase) is needed (18). Some of the indications for delayed imaging include renal lacerations grade II or higher, substantial amount of fluid around the renal pelvis, macroscopic hematuria, pelvic fractures, or suspected bladder injury. Among the top reasons to not include delayed imaging in the standard protocol for all trauma patients is the attempt to limit radiation and the need to be time efficient in critically ill patients, in whom delayed phase imaging may be later performed if needed (19). Axial CT images of the arterial and portal venous phases and the split-bolus protocol are shown in Figure 3.

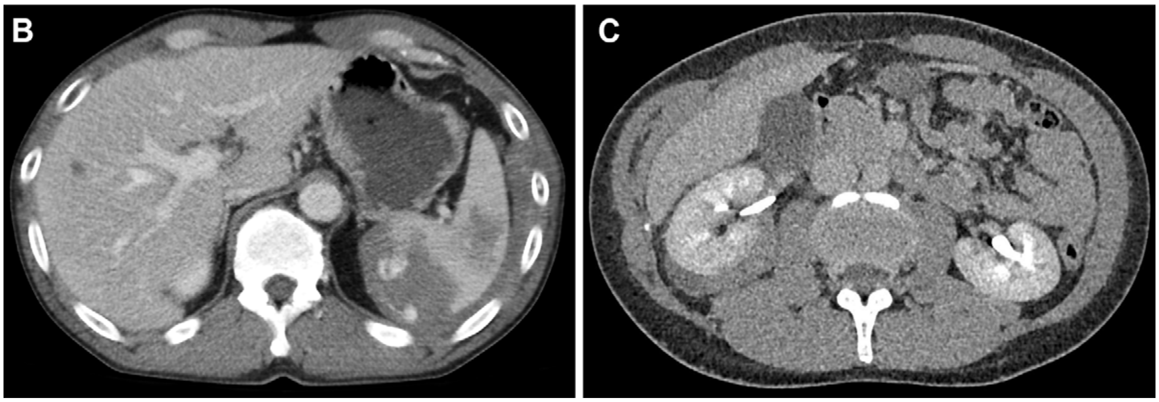
Alternative Imaging Tools

US plays a vital role in assessment of trauma patients who are too hemodynamically unstable to undergo CT, as it is performed at the bedside and is cost-effective. Extended Focused Assessment with Sonography for Trauma (EFAST) US is aimed at identifying free intraperitoneal or pericardial fluid and contributes to timely diagnosis of potentially life-threatening hemorrhage (17).

Angiography and angioembolization are highly effective in controlling bleeding after blunt injury, which may be related to active extravasation, traumatic pseudoaneurysm, or arteriobiliary, arteriovenous, or portobiliary fistula. Gelfoam (Pfizer), Ivalon, particles, and coils are some of the embolization materials that can be used either alone or in combination (20). Gelfoam and Ivalon usually produce only transient hemostasis in patients who have received multiple blood transfusions.

Contrast-enhanced US has been shown to be almost as sensitive as contrast-enhanced CT in detection of traumatic injuries in patients with low-energy isolated abdominal trauma, with sensitivity and specificity of greater than 90% (21,22). Advantages such as portability, safety of the contrast agent, and lack of ionizing radiation exposure make contrast-enhanced US a

Figure 3. Multidetector CT phases used in trauma imaging. **(A)** The arterial phase is performed 25–30 seconds after intravenous contrast material injection. All structures that receive their blood supply from the arteries will show optimal enhancement. There is incidental note of a small liver hypoattenuation, likely a hepatic cyst. **(B)** During the portal venous or hepatic phase, the liver parenchyma enhances through blood supply by the portal vein, and appropriate timing includes mild enhancement of the hepatic veins. Of note, the small liver hypoattenuation is again seen, and there is evidence of a moderate- to high-grade splenic injury. **(C)** The delayed phase is performed approximately 9 minutes after the portal venous phase if renal lacerations grade II or higher, a significant amount of fluid around the renal pelvis, macroscopic hematuria, pelvic fractures, or suspected bladder injury are present.



promising tool, especially in fertile women and pediatric patients. The cost of contrast media, operator dependence, lack of panoramic imaging, difficulty of exploring some deep regions, and poor ability to demonstrate injuries to the urinary tract are some of its limitations (22).

Dual-energy CT is another promising tool that gathers information through two absorption measurements at two-photon spectra, allowing characterization of various materials depending on their differential attenuation. It has been shown to improve visualization and detection of lacerations and hematomas in solid organs and viscera (eg, bowel) after abdominal trauma by using iodine-selective imaging and low–kiloelectron volt virtual monoenergetic imaging (23,24).

MRI has limited utility in the acute trauma setting due to its time-consuming and expensive nature. Furthermore, although the AAST-OIS is more commonly used for blunt abdominal trauma, it may also be used for firearm-related injuries, or gunshot wounds (GSWs), which lead to injury through laceration and crushing, cavitation, or shock waves (25). In this setting, bullets and metal fragments containing steel or nickel may become dangerous if near critical structures due to heating and movement of these fragments (20).

Nevertheless, MRI may occasionally have a place as an alternative to CT, in follow-up of patients with major solid organ injuries or as an additional tool for solving equivocal CT findings. For example, MR cholangiopancreatography (MRCP) may be crucial in diagnosis of injuries to the biliary system (eg, bile leak or biliary-peritoneal fistula) or pancreas (26,27). Use of MRI avoids repeated radiation and contrast medium exposures, which may be an especially important consideration in younger patients (28).

2018 AAST-OIS Updates

The following sections focus on describing the AAST-OIS for splenic, hepatic, and renal trauma and the main changes brought on by the 2018 revision, with emphasis on the imaging findings. A summary of these changes is provided in the Table.

Splenic Trauma

The spleen is the most injured abdominal organ in blunt abdominal trauma, accounting for approximately one-third of all abdominal organ injuries (29,30). Given the risk for infection after splenectomy, splenic preservation is the standard of care (29). Up to 90% of isolated splenic injuries are managed nonoperatively, and up to 80% of high-grade injuries can be managed with angioembolization (30,31). The most common causes of splenic trauma include motor vehicle collisions and pedestrian accidents. Motorcycle accidents, sports injuries, gunshot or stab-related injuries, and assaults are other frequent culprits in adults (31).

Although the spleen is usually at least partially protected by the rib cage, inspiration can displace it to a more subcostal position, making it more vulnerable. The splenorenal ligament connects the bare area of the spleen at the hilum with the left anterior pararenal space. Therefore, injury to the splenic hilum can result in a retroperitoneal bleed in the anterior pararenal space. Fusion of the left anterior renal fascia with the gastrosplenic ligament and of the posterior renal fascia with the diaphragm results in communication between the left perinephric space and the left subphrenic extraperitoneal space.

The peritoneum covers most of the spleen except for the splenic hilum (32). Splenic lobules, notches, and clefts are normal anatomic variants due to fetal remnants. They have

Summary of Changes in the 2018 AAST-OIS for the Spleen, Liver, and Kidney

Grade	Spleen	Liver	Kidney
I	No changes	No changes	Clinical descriptors for renal contusions have been removed Contusions recognized as visible at MDCT Term *nonexpanding* has been removed
II	Lack of trabecular vessel involvement has been removed as a requirement for lacerations, making size the only requirement for distinguishing between grade II and III injuries	No changes	Term *nonexpanding* has been removed Term *renal retroperitoneum* replaced by "hematoma confined within Gerota's fascia" Size of the laceration is now inclusive of 1 cm
III	Trabecular vessel involvement has been removed as a consideration for lacerations Term *expanding* for both subcapsular and parenchymal hematomas has been removed	Inclusion of vascular injuries with active bleeding contained within the liver parenchyma Term *expanding* for both subcapsular and parenchymal hematomas has been removed	Incorporates vascular injury (pseudoaneurysms and arteriovenous fistulas) and active bleeding
IV	Inclusion of splenic vascular injuries or active bleeding within capsule	Removal of equivalent Couinaud segments for parenchymal disruption Inclusion of vascular injuries with active bleeding extending beyond the liver parenchyma into the peritoneum	Incorporates renal pelvis laceration and complete ureteropelvic disruption Active bleeding is explicitly categorized Injuries to the main renal vessels, excluding thrombosis, are now grade V injuries (previously grade IV) Segmental vascular compromise and infarction have been included but previously were not described Infarction as a sequela of vascular thrombosis has been added
V	Inclusion of splenic vascular injuries with active bleeding extending beyond the spleen into the peritoneum	Removal of equivalent Couinaud segments for parenchymal disruption Removal of grade VI (previously used to describe hepatic avulsion), thereby making grade V the highest grade in liver injuries	Active bleeding included In addition to avulsion at the renal hilum, the main renal artery or vein injury descriptor now also includes "laceration" All main renal vascular injuries, excluding thrombosis, are reserved for grade V injuries

Note.—The changes for the liver and spleen are in comparison with the revised 1994 AAST-OIS, while the changes for the kidney are in comparison with the original 1989 AAST-OIS. MDCT = multidetector CT.

no clinical significance and should not be misinterpreted as splenic laceration in the setting of trauma (33). As with renal trauma, injuries can be the result of acceleration, deceleration, or compression.

2018 AAST-OIS Splenic Grading.—2018 AAST-OIS grade I injuries (Figs 4, 5; Movie 1) include subcapsular hematoma spanning less than 10% of the surface area and capsular tear extending less than 1 cm in depth. No major changes were made to this grade in the revised version.

Grade II injuries (Figs 4, 6; Movie 2) include subcapsular hematoma spanning 10%–50% of the surface area, intraparenchymal hematoma measuring less than 5 cm in diameter, and capsular tears with 1–3 cm of parenchymal depth extension. Trabecular vessel involvement is no longer a consideration when assessing lacerations, making size and depth the only responsible factors for classification between grades II and III.

Grade III injuries (Figs 4, 7; Movie 3) include subcapsular hematoma spanning greater than 50% of the surface area, ruptured subcapsular or parenchymal hematoma, intraparenchymal hematoma greater than or equal to 5 cm, and capsular tear with greater than 3 cm of parenchymal depth extension. The main changes were removal of trabecular vessel involvement as a consideration when assessing lacerations and discontinuation of the term *expanding* for both subcapsular and parenchymal hematomas.

Grade IV injuries (Figs 4, 8; Movie 4) include lacerations involving segmental or hilar vessels producing major devascularization (>25% of spleen); any injury in the presence of splenic vascular injury (eg, arteriovenous fistula or pseudoaneurysm); or active bleeding confined within the splenic capsule. Intraparenchymal pseudoaneurysms have a similar appearance to active hemorrhage at initial scanning but either wash out or do not increase in size in delayed phases and follow the blood pool in all phases. Arteriovenous fistula cannot be differentiated from pseudoaneurysm at CT. In contrast, active hemorrhage appears as high-attenuation material (80–95 HU) due to extravasation of intravenous contrast media that increases in size at delayed imaging.

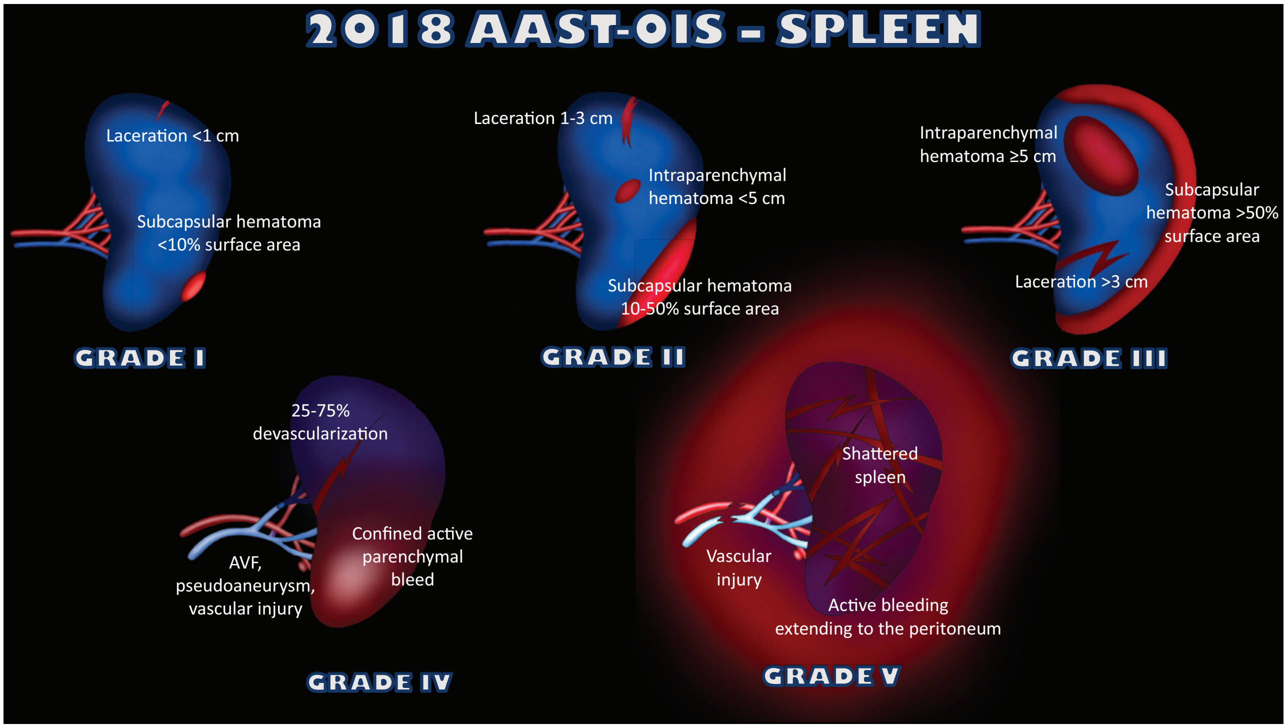


Figure 4. Schematic representation shows the revised 2018 grading for splenic injuries. *AVF* = arteriovenous fistula.

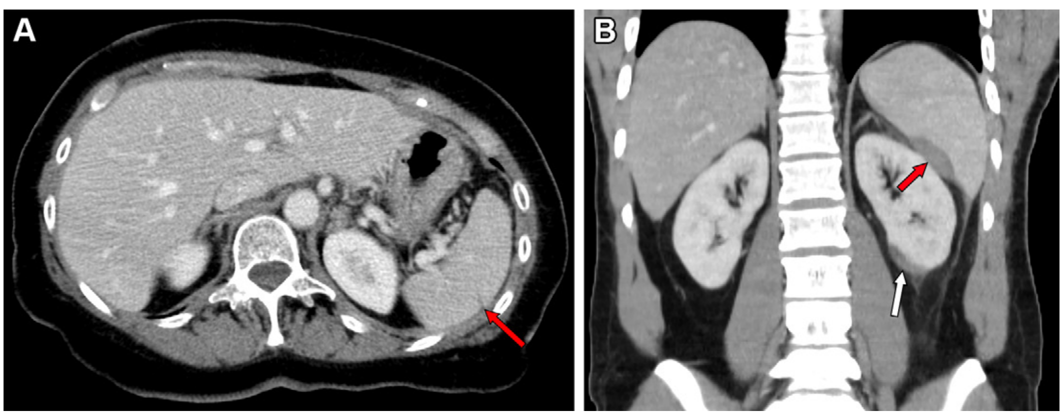


Figure 5. Grade I splenic injuries according to the revised 2018 AAST-OIS. **(A)** Axial contrast-enhanced CT image in a 42-year-old man after a bicycle accident shows a small splenic laceration measuring approximately 1 cm in depth (arrow). Of note, in the trauma setting, streak artifact from the arms or increased image noise is not uncommon, as patients are often in pain, have altered mental status, or have multiple injuries, which may make them unable to lie still in the appropriate position for optimal imaging quality. **(B)** Coronal contrast-enhanced CT image in a 28-year-old man after a motor vehicle collision shows a small subcapsular hematoma (red arrow) spanning less than 10% of the splenic surface area. Note also the small left lower pole subcapsular renal hematoma (white arrow).

The main changes brought on by the 2018 update are that splenic vascular injuries or active bleeding confined within the capsule are now included in grade IV. It is also important to note that addition of the arterial phase recommended in this version is responsible for increased detection of vascular injuries. In the acute phase, splenic infarction is characterized by ill-defined areas of decreased attenuation, but over time the region of infarction becomes more sharply demarcated with volume loss. In the chronic phase, fibrosis or calcification may occur (34).

Grade V injuries (Figs 4, 9; Movie 5) include shattered spleen and any injury in the presence of splenic vascular injury with active bleeding extending beyond the spleen into the peritoneum. According to the 2018 update, any vascular injury extending beyond the spleen is considered grade V, while previously only vascular injuries causing splenic devascularization were included.

Management.—Nonoperative management is preferred in most low-grade injuries (grades I–III) and select hemodynamically stable high-grade injuries (grades IV and V) (35). The presence of active hemorrhage is the most important predictor for failure of nonoperative management. Contraindications to nonoperative management include hemodynamic instability after

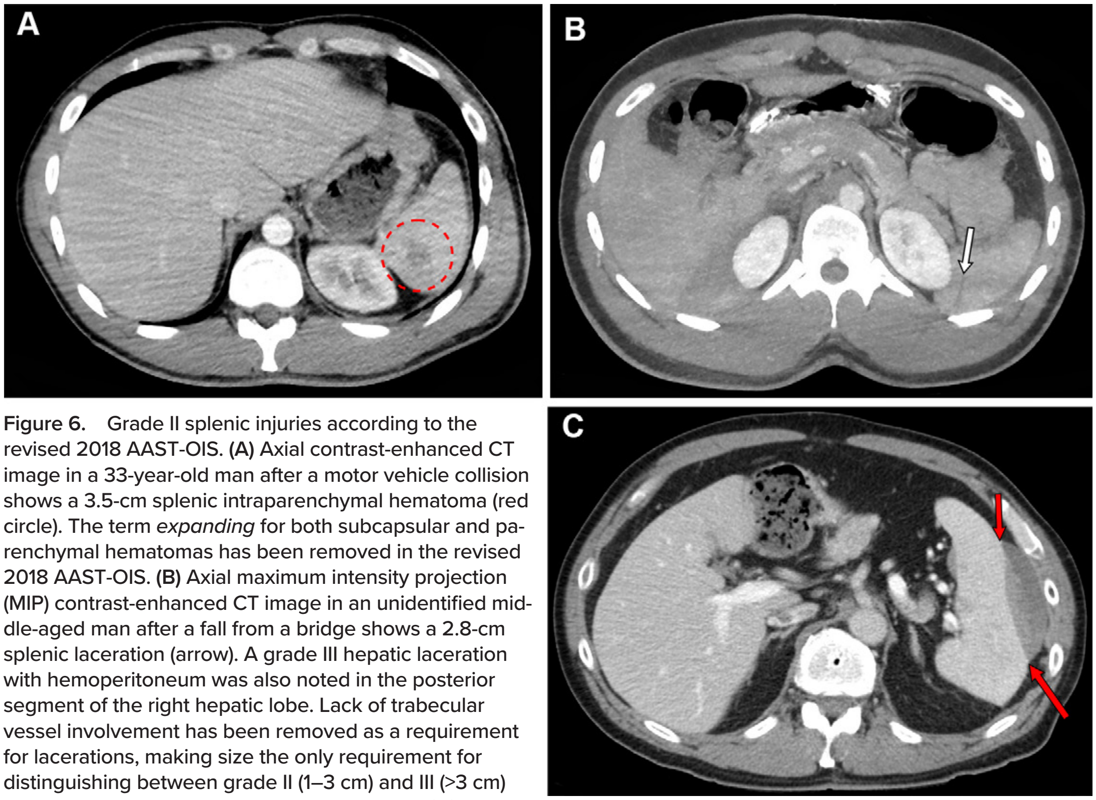


Figure 6. Grade II splenic injuries according to the revised 2018 AAST-OIS. **(A)** Axial contrast-enhanced CT image in a 33-year-old man after a motor vehicle collision shows a 3.5-cm splenic intraparenchymal hematoma (red circle). The term *expanding* for both subcapsular and parenchymal hematomas has been removed in the revised 2018 AAST-OIS. **(B)** Axial maximum intensity projection (MIP) contrast-enhanced CT image in an unidentified middle-aged man after a fall from a bridge shows a 2.8-cm splenic laceration (arrow). A grade III hepatic laceration with hemoperitoneum was also noted in the posterior segment of the right hepatic lobe. Lack of trabecular vessel involvement has been removed as a requirement for lacerations, making size the only requirement for distinguishing between grade II (1–3 cm) and III (>3 cm) injuries in the revised 2018 AAST-OIS version. **(C)** Axial contrast-enhanced CT image in a 39-year-old man after a motorcycle crash shows a subcapsular hematoma (arrows) spanning approximately 30% of the splenic surface area. An axial cine clip of this patient is shown in Movie 2.

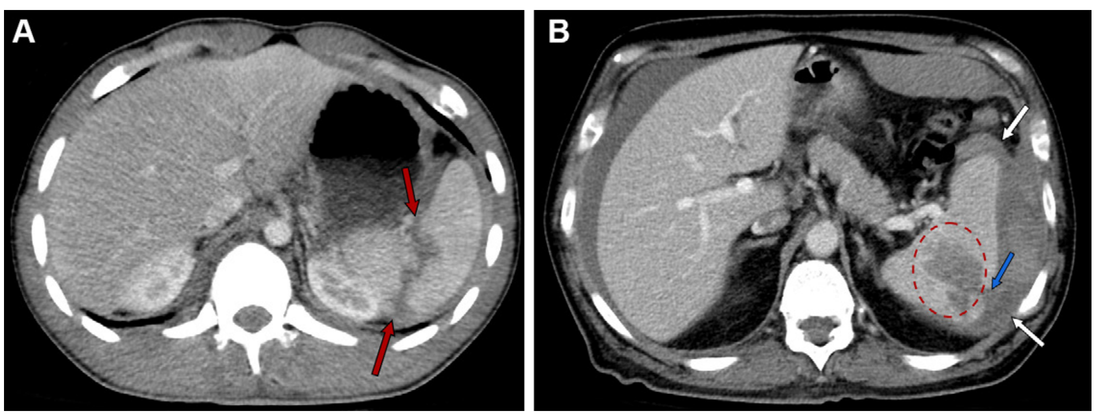


Figure 7. Grade III splenic injuries according to the revised 2018 AAST-OIS. **(A)** Axial contrast-enhanced CT image in a 37-year-old man after a high-speed motor vehicle collision shows an approximately 6-cm splenic laceration (arrows). Trabecular vessel involvement has been removed as a requirement for lacerations, making size the only requirement for distinguishing between grade II (1–3 cm) and III (>3 cm) injuries in the revised 2018 AAST-OIS version. The patient underwent splenic artery angiography, which revealed active extravasation from a superior splenic branch, which was embolized with coils. Given the high-grade nature of the laceration, the mid splenic artery was empirically embolized with an 8-mm Amplatzer Vascular Plug Version 2 (Abbott). An axial cine clip of this patient is shown in Movie 3. **(B)** Axial contrast-enhanced CT image in a 45-year-old man after a motor vehicle collision shows an intraparenchymal splenic hematoma (red circle), which communicates (blue arrow) with a large subcapsular splenic hematoma (white arrows) spanning over 50% of the splenic surface area. The subcapsular hematoma has ruptured, and there is blood extending to the peritoneum. The patient underwent angiography, which revealed no significant active extravasation or contained vascular injuries at the time of the procedure. The mid splenic artery was empirically embolized with Concerto coils (Medtronic) and one Azur coil (Terumo) with good angiographic results. The patient made a full recovery.

initial resuscitation, other indication for surgery, and inability to provide serial monitoring or urgent embolization or abdominal exploration should the need arise (31). Splenic artery embolization (SAE) has been shown to reduce both laparotomy and complication rates but should be reserved for high-grade injuries and visible vascular disease or active bleeding (35).

According to the 2018 revision, any injury in the presence of a splenic vascular injury (pseudoaneurysm or arteriovenous

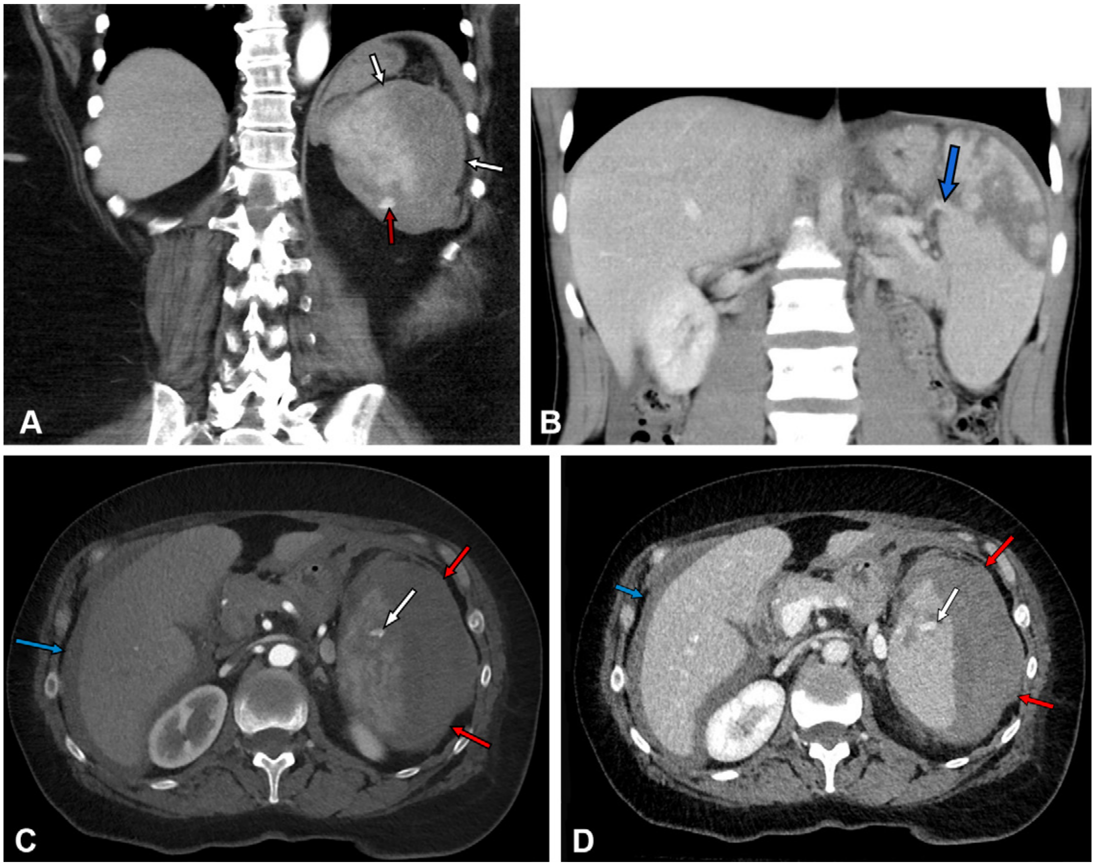


Figure 8. Grade IV splenic injuries according to the revised 2018 AAST-OIS. **(A)** Coronal contrast-enhanced CT image in a 27-year-old woman after a motor vehicle collision shows active contrast material extravasation (red arrow) consistent with bleeding contained within the splenic capsule (white arrows). Inclusion of splenic vascular injuries or active bleeding within the capsule was one of the main changes brought on by the AAST-OIS 2018 revision. The patient underwent angiography, which revealed no significant active extravasation or contained vascular injuries at the time of the procedure. Nevertheless, the mid splenic artery was empirically embolized with an 8-mm Amplatzer Plug II with good angiographic results. The patient made a full recovery. **(B)** Coronal contrast-enhanced CT image in a 15-year-old boy shows a large laceration of the upper pole of the spleen involving segmental vessel damage (arrow) and resulting in greater than 25% devascularization. An axial cine clip of this patient is shown in Movie 4. **(C, D)** Axial contrast-enhanced CT images in the arterial **(C)** and portal venous **(D)** phases in a 47-year-old man after a motor vehicle collision show a large subcapsular splenic hematoma (red arrows) and a small contrast material–attenuation focus within the spleen (white arrow), which follows the blood pool in both the arterial and portal venous phases. This focus showed washout at delayed imaging, compatible with contained vascular injury. Perihepatic bleeding is also noted (blue arrow). Inclusion of splenic vascular injuries or active bleeding within the capsule was one of the main changes brought on by the AAST-OIS 2018 revision.

fistula) or active bleeding confined within the splenic capsule is grade IV, while active bleeding extending beyond the spleen into the peritoneum is grade V. This division has facilitated recognition of patients who may benefit from SAE (36). The sensitivity, specificity, and accuracy of CT in predicting the need for SAE have been reported to be between 80% and 90% (37). Complications may include abscess formation, delayed splenic rupture, delayed hemorrhage, splenic necrosis, pancreatitis, pseudoaneurysm, postsplenectomy infection, splenosis, and thrombocytosis (38).

Liver Trauma

The liver is the second most frequently injured abdominal organ and the most common cause of death in severe abdominal trauma, with reported mortality rates of 5%–15% (39,40). The most common causes are motor vehicle collisions, followed by pedestrian accidents, falls from a height, and gunshot or stab wounds. The right lobe is injured three times more often than the left (39), and laceration is the most common type of liver injury (40).

Like in the organs described earlier, injuries can be categorized into acceleration, deceleration, and compression. Acceleration injuries to the right lobe are usually caused by lateral right or anterior-to-posterior trauma. The former leads to lacerations between the anterior and posterior lobes, which may extend to the retrohepatic vena cava and major hepatic vein in severe cases, and the latter causes lacerations at the Cantlie line, given the fixed inferior vena cava position. Acceleration injuries in the left lobe occur when forces are delivered to the front of the chest, displacing the liver posteriorly. The left hepatic vein and left branches of the portal vein or hepatic bile duct may be affected in severe cases.

Deceleration injuries occur when a rapidly moving body is suddenly stopped, but the liver keeps moving and collides against the chest wall or posterior abdominal wall, leading to crushing injuries or lacerations in the affected region, usually

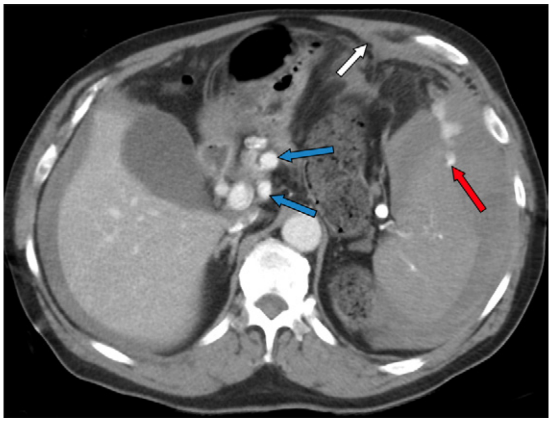


Figure 9. Grade V splenic injuries according to the revised 2018 AAST-OIS. Axial contrast-enhanced CT image in a 67-year-old man after a motor vehicle collision shows extensive parenchymal disruption, hemoperitoneum (white arrow), and active extravasation beyond the spleen and into the peritoneum (red arrow). Extensive periportal collaterals (blue arrows) are noted related to portal hypertension from chronic liver disease. The patient was treated with exploratory laparotomy and splenectomy. An axial cine clip of this patient is shown in Movie 5.

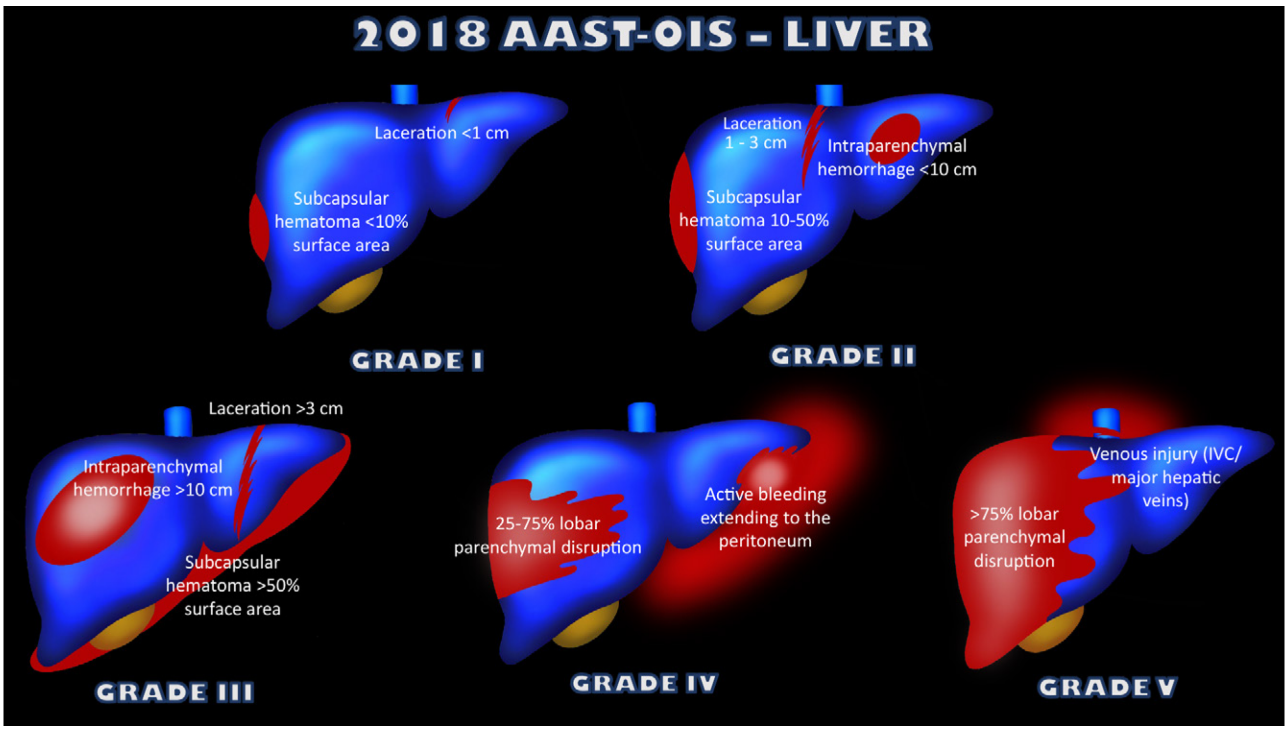


Figure 10. Schematic representation shows the revised 2018 AAST-OIS for liver injuries. *IVC* = inferior vena cava.

the right lobe. Compression injuries lead to lacerations at the anterior or posterior sides of the right hepatic lobe, given its larger size and fixed position, making it unable to escape the anterior and posterior walls of the rib cage (39).

2018 AAST-OIS Liver Grading.—2018 AAST-OIS grade I injuries (Figs 10, 11; Movie 6) include subcapsular hematoma spanning less than 10% of the surface area and capsular lacerations extending less than 1 cm in parenchymal depth.

Grade II injuries (Figs 10, 12; Movie 7) include subcapsular hematoma spanning 10%–50% of the surface area, intraparenchymal hematoma measuring less than 10 cm in diameter, and capsular tears extending 1–3 cm in depth and less than or equal to 10 cm long. No major changes were made to either grade I or II.

Grade III injuries (Figs 10, 13; Movie 8) include subcapsular hematoma spanning greater than 50% of the surface area, ruptured subcapsular or parenchymal hematoma, parenchymal hematoma greater than 10 cm, lacerations greater than 3 cm in depth, and vascular injuries with active bleeding contained within liver parenchyma. The major change in the 2018 revision was inclusion of vascular injuries with active bleeding contained within the liver parenchyma. Furthermore, the term *expanding* has been discontinued for both subcapsular and parenchymal hematomas (2). Evidence of contrast material extravasation extending from the liver parenchyma into the peritoneum will upgrade the injury to grade IV. Delayed images may help distinguish active bleeding, which would demonstrate persistence and increase the size of high-attenuation material, from a pseudoaneurysm, which would be characterized by "washout of contrast attenuation" approximating the blood pool attenuation.

Grade IV injuries (Figs 10, 14; Movie 9) include parenchymal disruption involving 25%–75% of a hepatic lobe and vascular injuries with active bleeding extending from the liver parenchyma into the peritoneum. The major changes in the

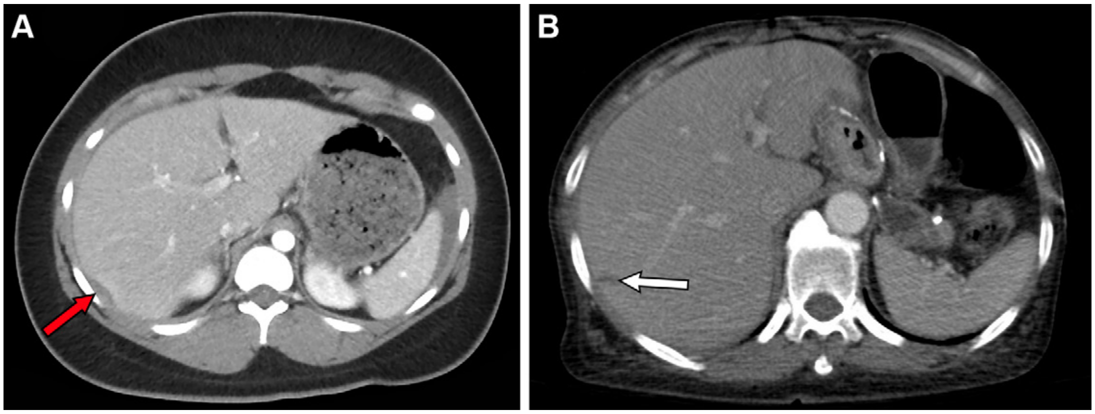


Figure 11. Grade I liver injuries according to the revised 2018 AAST-OIS. (A) Axial contrast-enhanced CT image in a 21-year-old woman after a motor vehicle collision shows a small subcapsular hematoma (arrow) along segment VI, measuring 2.2 × 0.7 cm (<10% of the liver surface) with no associated hepatic laceration. The patient also suffered a bucket handle omental injury with arterial bleeding (not shown), which required exploratory laparotomy and omentectomy. The subcapsular hematoma was successfully managed conservatively. (B) Axial contrast-enhanced CT image in a 48-year-old woman after a motor vehicle collision shows a hepatic laceration measuring less than 1 cm in depth (arrow). An axial cine clip of this patient is shown in Movie 6.

2018 revision were inclusion of vascular injuries with active bleeding extending from the liver parenchyma into the peritoneum and removal of equivalent Couinaud segments—an anatomic classification system that divides the liver into eight independent functional units—for grading parenchymal disruption.

Grade V injuries (Figs 10, 15; Movie 10) include parenchymal disruption of greater than 75% of the hepatic lobe and juxtavenous hepatic injuries (ie, retrohepatic vena cava or central major hepatic veins). The major change in the 2018 revision was removal of equivalent Couinaud segments for grading parenchymal disruption. Furthermore, grade VI—previously used to describe hepatic avulsion—was discontinued as it is a nonsurvivable injury, making V the highest grade in liver injuries, a feature now shared by the three organs.

Management.—Nonoperative management is appropriate for most mild to moderate (grade I–III) and one-third of severe (grade IV or V) liver injuries (41). The most important factors affecting management are hemodynamic status, associated injuries, and grade and presence of other organ or visceral injuries (41). Multidetector CT must be immediately available and performed in hemodynamically stable or stabilized patients and under the supervision of the trauma team. Delayed phase CT helps in differentiating patients with active bleeding from those with contained vascular injuries, and angiography or angioembolization decreases the rate of laparotomy and complications (14,41).

Complications may include delayed hemorrhage, abscess formation, posttraumatic pseudoaneurysm, hemobilia, and biliary complications (eg, biloma, bile leakage, biliary strictures, and bile peritonitis). Interventional radiology plays a key role in management of many of these complications (40).

Renal Trauma

Injuries to the genitourinary system occur in 10% of patients with blunt abdominal trauma, with the kidney being the most injured genitourinary organ (42,43). Renal trauma may occur in isolation or in association with other visceral injuries (44) and may be the result of blunt (80%–90%) or penetrating (10%–20%) trauma (43), with the latter associated with more severe injuries and multiorgan involvement (45). It is most common in young males (45) after motor vehicle collisions (43). Additional mechanisms include falls, sports, pedestrian accidents, assaults, gunshots, or stab wounds (45).

Findings that should raise suspicion for renal trauma include hematuria, flank or upper abdomen pain or hematomas, abdominal tenderness or distention, palpable mass, ecchymosis or abrasions, rib fractures, hypotension, and shock. Hematuria may be absent in ureteral tears, vascular pedicle injury, or ureteropelvic injuries (42,43). The mechanism of injury can be direct or indirect, with the former occurring due to rapid acceleration leading to contusions, lacerations, or hematomas, and the latter resulting from rapid deceleration causing renal compression against the spine or thoracic cage, potentially leading to avulsion at the ureteropelvic junction (UPJ), avulsion of the renal pedicles, vascular dissection, laceration, or thrombosis. In external compression injuries, both mechanisms can be seen. The 2018 AAST-OIS provides a score-based assessment of renal injuries, with specific emphasis on the vascular injuries based on the multidetector CT findings.

2018 AAST-OIS Renal Grading.—2018 AAST-OIS grade I injuries (Figs 16, 17; Movie 11) include parenchymal contusions and subcapsular hematomas without laceration. Renal contusions appear as ill-defined patchy areas of poor contrast enhancement during the portal venous phase that become isoattenuating in the delayed phase. In contradistinction, segmental infarctions appear as a wedge-shaped sharply defined area of reduced or absent enhancement during the portal venous phase, which persists in the delayed phase (44). The 2018 update reflects that contusions can be visualized at multidetector CT (19), which were previously diagnosed clinically (ie, microscopic or gross hematuria with otherwise normal results of urologic studies) (11).

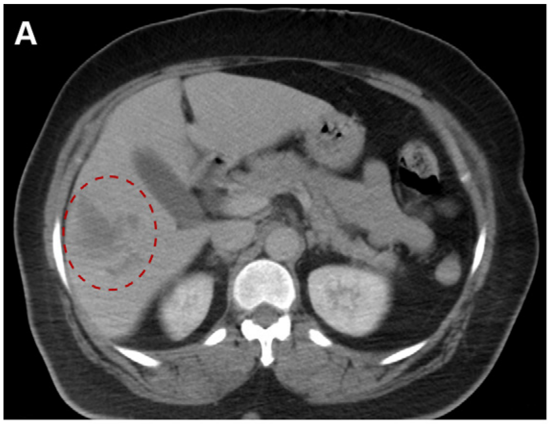


Figure 12. Grade II liver injuries according to the revised 2018 AAST-OIS. **(A)** Axial contrast-enhanced CT image in a 35-year-old man after a motorcycle collision shows an intraparenchymal hepatic hematoma (red oval) measuring approximately 4 cm in maximal dimension. **(B)** Axial contrast-enhanced CT image in a 29-year-old woman after falling down the stairs shows a laceration (arrows) in the left liver lobe measuring almost 3 cm in depth. There is no subcapsular hematoma or active bleeding. An axial cine clip of this patient is shown in Movie 7. **(C)** Axial contrast-enhanced CT image in a 47-year-old man after a motor vehicle collision shows a subcapsular hepatic hematoma (arrows) spanning approximately 40% of the liver's surface area.

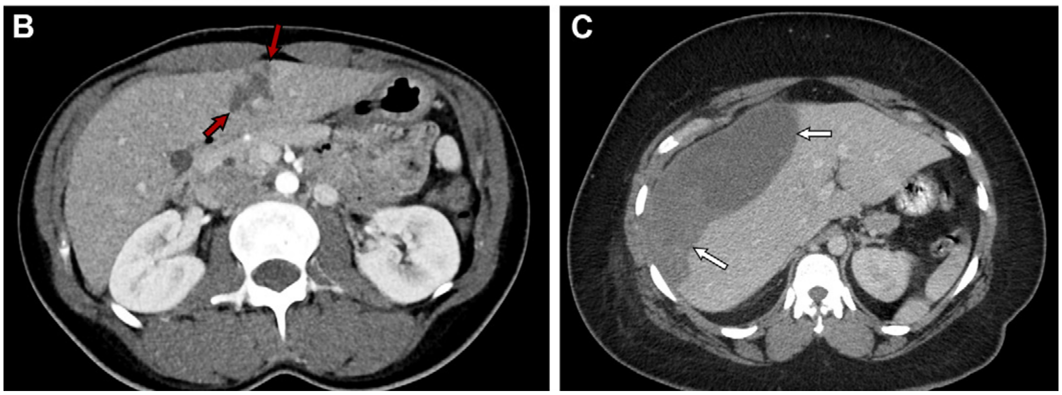
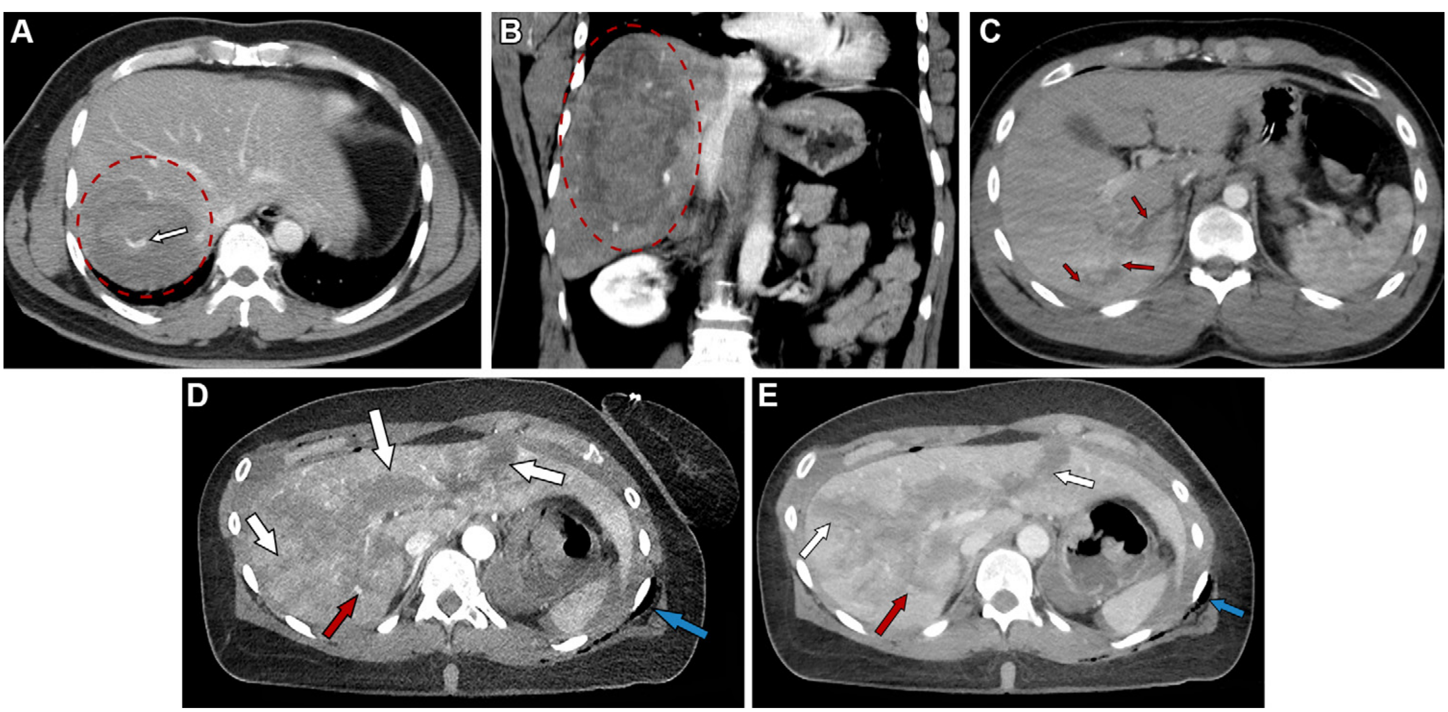


Figure 13. Grade III liver injuries according to the revised 2018 AAST-OIS. **(A, B)** Axial **(A)** and coronal **(B)** contrast-enhanced CT images in a 45-year-old man after a motor vehicle collision show a large intraparenchymal hematoma in the posterior right lobe (red circle in **A**, red oval in **B**) measuring 5.5 × 3.3 × 10.1 cm with active extravasation (arrow in **A**) and no capsular disruption. Inclusion of vascular injuries with active bleeding contained within the liver parenchyma was one of the changes brought on by the AAST-OIS 2018 revision. An axial cine clip of this patient is shown in Movie 8. According to the AAST-OIS 2018 revision, the term *expanding* was removed for both subcapsular and parenchymal hematomas. **(C)** Axial contrast-enhanced CT image in a 37-year-old woman after a motor vehicle collision shows a hepatic laceration (arrows) measuring approximately 7 cm in length and over 3 cm in depth. **(D, E)** Axial arterial **(D)** and portal venous **(E)** phase contrast-enhanced CT images in a 45-year-old woman after a motor vehicle collision show multiple large liver lacerations (white arrows) and a contrast material–attenuation focus (red arrow), which partly washes out in the portal venous phase and does not increase in size, suggestive of a contained vascular injury. However, the patient underwent angiography, which failed to reveal the injury. The patient was managed conservatively, but her hematocrit level continued to drop. Second-look angiography 2 days after presentation revealed a large contained vascular injury, which was successfully embolized. Also note the air adjacent to the rib cage (blue arrow) and the hemoperitoneum.



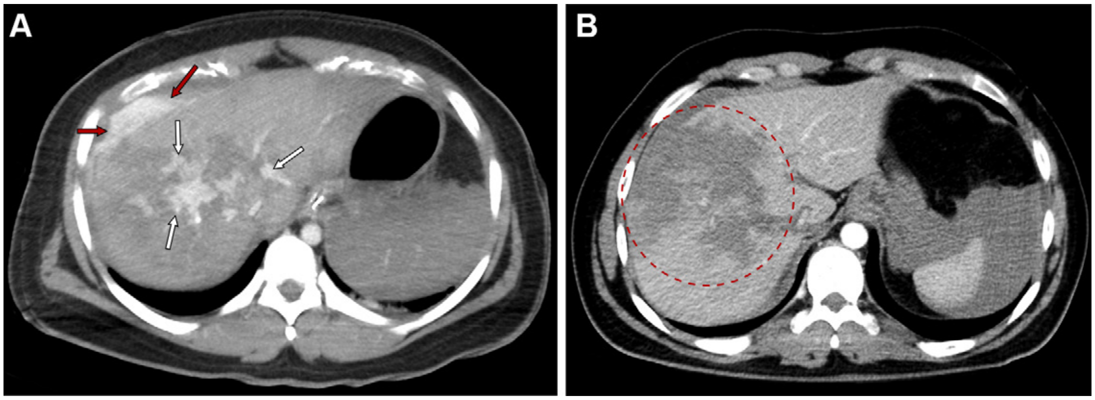


Figure 14. Grade IV liver injuries according to the revised 2018 AAST-OIS. (A) Axial contrast-enhanced CT image in a 46-year-old man after a pedestrian-versus-motor-vehicle collision shows major disruption of the right hepatic lobe, with active contrast material extravasation both within the liver parenchyma (white arrows) and extending into the peritoneum (red arrows). Inclusion of vascular injuries with active bleeding extending beyond the liver parenchyma into the peritoneum was one of the major changes included in the AAST-OIS revision. An axial cine clip of this patient is shown in Movie 9. (B) Axial contrast-enhanced CT image in a 21-year-old man after a fall off a train platform while intoxicated shows approximately 50% disruption of the right hepatic lobe (red oval). Hemoperitoneum is present, with fluid in the perihepatic and perisplenic regions. According to the AAST-OIS 2018 revision, the Couinaud segments are no longer used for quantifying parenchymal disruption.

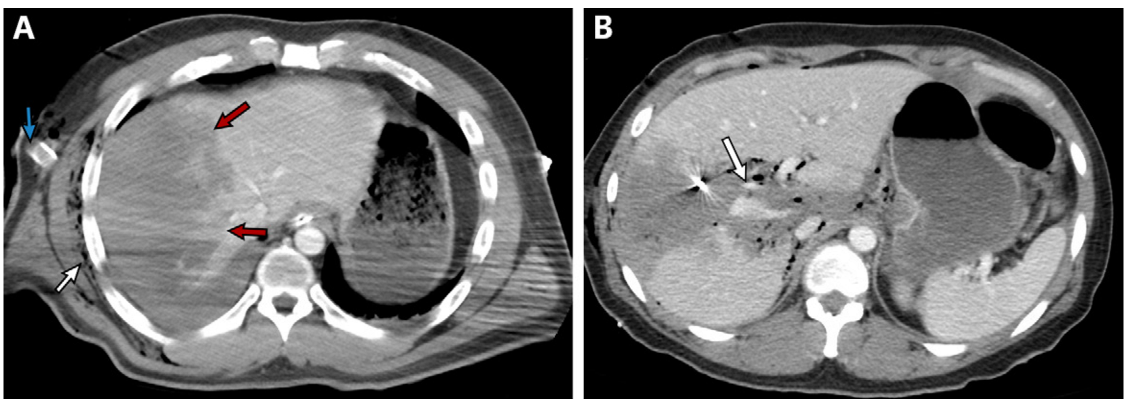


Figure 15. Grade V liver injuries according to the revised 2018 AAST-OIS. (A) Axial contrast-enhanced CT image in a 43-year-old man after a motor vehicle collision shows over 75% right lobe parenchymal disruption (red arrows). A partially visualized right-sided chest tube (blue arrow) and subcutaneous emphysema of the right chest wall (white arrow) are also noted. According to the AAST-OIS 2018 revision, the Couinaud segments are no longer used for quantifying parenchymal disruption. (B) Axial contrast-enhanced CT image in a 35-year-old woman after a gunshot wound shows a ballistic trajectory extending from the right hepatic margin to the hepatic hilum, transecting the inferior vena cava; contrast material extravasation (arrow), streak artifact from the metallic ballistic fragments, and air are noted along the bullet's trajectory. An axial cine clip of this patient is shown in Movie 10.

Subcapsular hematomas are nonenhancing, usually hyperattenuating, superficial, crescentic or lentiform fluid collections contained within the renal capsule. When large, they may cause mass effect on the underlying renal parenchyma, and, in rare cases, compress the kidney sufficiently to reduce renal perfusion and result in hypertension, a condition called Page kidney. The distinction between subcapsular (less common; superficial, crescentic or lentiform) and perinephric (poorly defined; do not usually deform the shape of the renal parenchyma even when large) hematomas should be made, as the latter represent grade II injuries. The previously used term *nonexpanding* has been discontinued in the 2018 update for both subcapsular and perinephric hematomas (2), as conclusive demonstration of nonexpansion is not possible with a single radiologic examination (46).

Grade II injuries (Figs 16, 18; Movie 12) include perirenal hematomas confined to the Gerota fascia and lacerations less than or equal to 1 cm in depth without urine leak. The term *renal retroperitoneum* was replaced by "confined to Gerota's fascia." Furthermore, lacerations smaller than 1 cm and those measuring exactly 1 cm in depth are now included in grade II injuries, as opposed to the prior version, which included only lacerations smaller than 1 cm in depth.

In contrast to subcapsular hematoma, perinephric hematoma occurs after laceration of the renal capsule, with blood accumulating between the renal parenchyma and Gerota fascia. Its attenuation varies according to the age, from hyperattenuating in the acute and subacute stages to progressively iso- or hypoattenuating in the chronic stage (44). The presence of a low-attenuation perinephric fluid collection in the acute

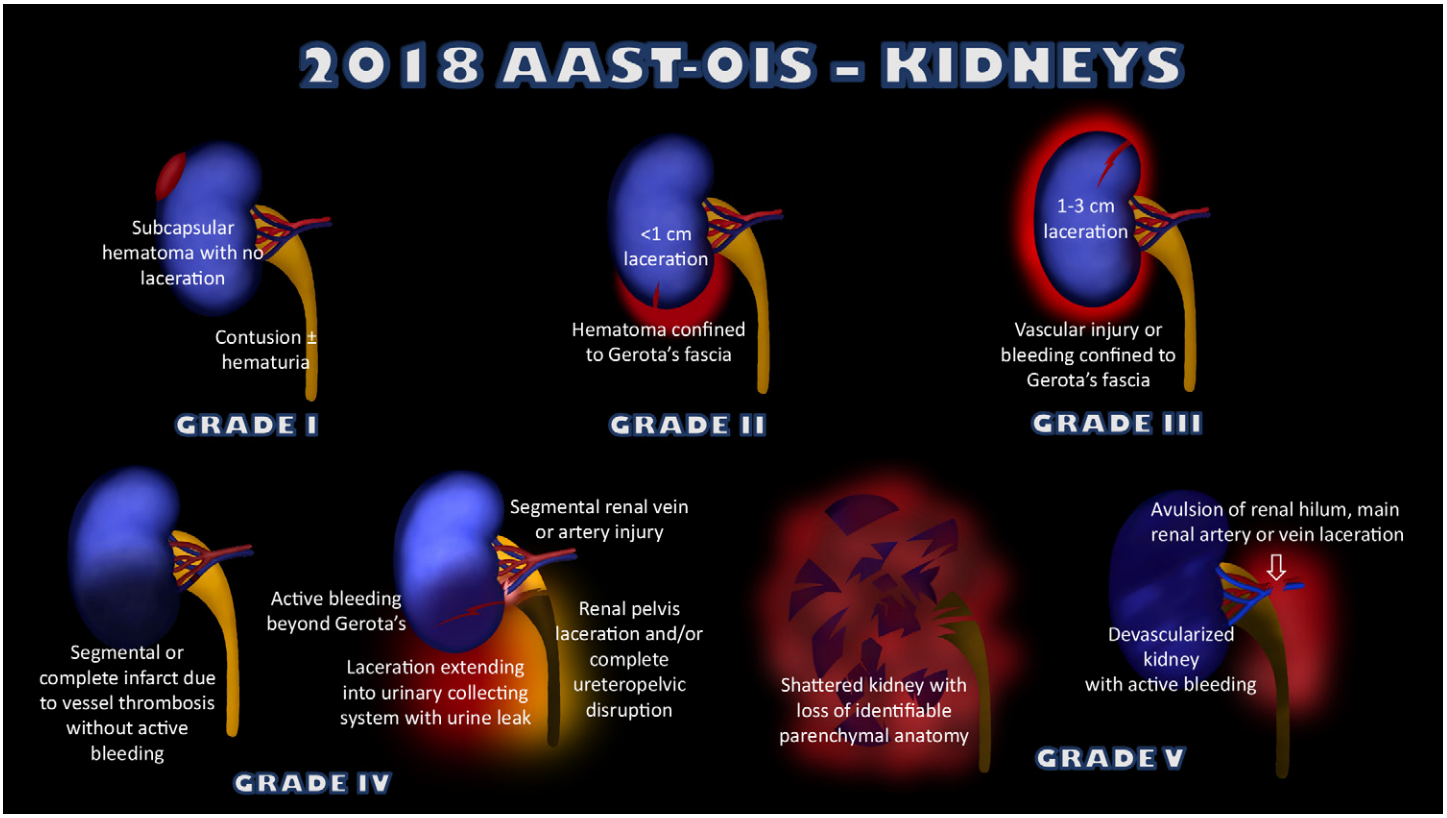


Figure 16. Schematic representation shows the revised 2018 AAST-OIS for renal injuries.

setting should prompt evaluation with delayed phase imaging, as it may represent urine leak due to a collecting system injury, which denotes a higher grade of injury (19). The margins of a perinephric hematoma are poorly defined compared with those of subcapsular hematomas, and it does not usually deform the shape of the renal parenchyma, even when large.

For a renal parenchymal laceration to be classified as grade II, it must be superficial (≤1 cm), and there must be no associated active bleeding or urine leak. Active bleeding would upgrade the injury to grade III, which represents a change from the original 1989 version. Urine leak, which is better evaluated with CT urography, would upgrade the injury to grade IV (19).

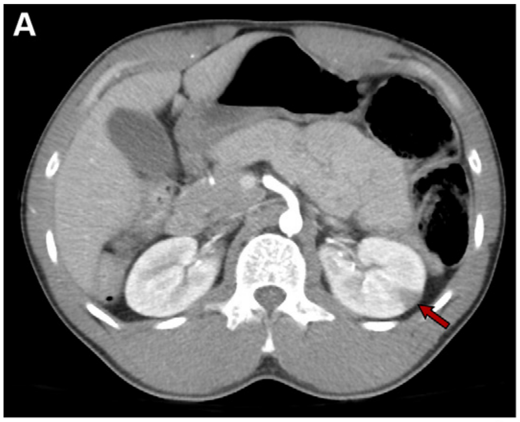
Grade III injuries (Figs 16, 19; Movie 13) include parenchymal lacerations greater than 1 cm in depth without collecting system rupture or urine leak and any injury in the presence of a vascular injury or active bleeding contained within the Gerota fascia. The main change introduced by the 2018 revision is that vascular injuries and active bleeding within the Gerota fascia are now classified under this grade. Active bleeding is defined by focal or diffuse vascular contrast enhancement (VCE) that increases in size and attenuation in the delayed phase, and, if present, it must be contained within the Gerota fascia.

Vascular injuries include pseudoaneurysm and arteriovenous fistula, which at imaging manifest as a focal collection of VCE that shows decreasing attenuation at delayed imaging (19). Early enhancement of the renal vein during the arterial phase and increased caliber of the renal vein are findings strongly suggestive of an arteriovenous fistula. Well-marginated ovoid or round collections that follow the arterial blood pool and appear as washout on delayed phase images are characteristic findings of a pseudoaneurysm (44).

Lacerations deeper than 1 cm are included under grade III if there is no evidence of urine leak. This includes renal fracture (ie, laceration connecting two cortical surfaces) if the collecting system remains intact.

Grade IV injuries (Figs 16, 20; Movies 14, 15) include parenchymal laceration extending into the urinary collecting system with urine leak, renal pelvis laceration or complete ureteropelvic junction (UPJ) disruption, segmental renal vein or artery injury, active bleeding beyond the Gerota fascia into the retroperitoneum or peritoneum, and segmental or complete kidney infarction due to vessel thrombosis without active bleeding. The main changes to grade IV include the inclusion of segmental vascular injuries, active bleeding beyond the Gerota fascia, and segmental or complete parenchymal infarction in the absence of active bleeding.

Lacerations are included under this grade if there is evidence of urine leak manifesting as an uncontained collection with low attenuation in the arterial or portal phase and high attenuation (matching that of the collecting system) in the delayed phase. Renal pelvis laceration or complete UPJ disruption can manifest as urine leak medial to an intact lateral calix on delayed images. In complete avulsion, there is no passage of excreted contrast material into the distal ureter, which may also be seen in partial tears. If free fluid is noted adjacent to the UPJ, delayed imaging is of the utmost importance in identifying these injuries (13).



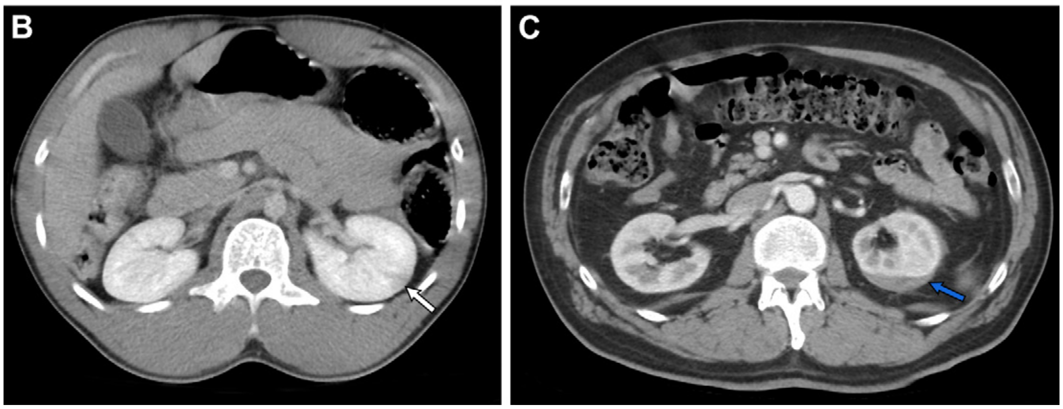


Figure 17. Grade I renal injuries according to the revised 2018 AAST-OIS. **(A, B)** Axial contrast-enhanced CT images in a 24-year-old man after a motorcycle collision show a left renal ill-defined region of hypoattenuation (arrow) in the portal venous phase **(A)** that becomes almost isoattenuating in the delayed phase **(B)**, consistent with a renal contusion. The AAST-OIS 2018 revision recognizes contusions as a finding visible at CT, and clinical descriptors suggestive of the diagnosis have been removed. **(C)** Axial contrast-enhanced CT image in a 68-year-old man after a fall from a bicycle shows a left subcapsular hematoma (arrow) with no evidence of laceration. The term *nonexpanding* has been removed in the AAST-OIS 2018 revision. An axial cine clip of this patient is shown in Movie 11.

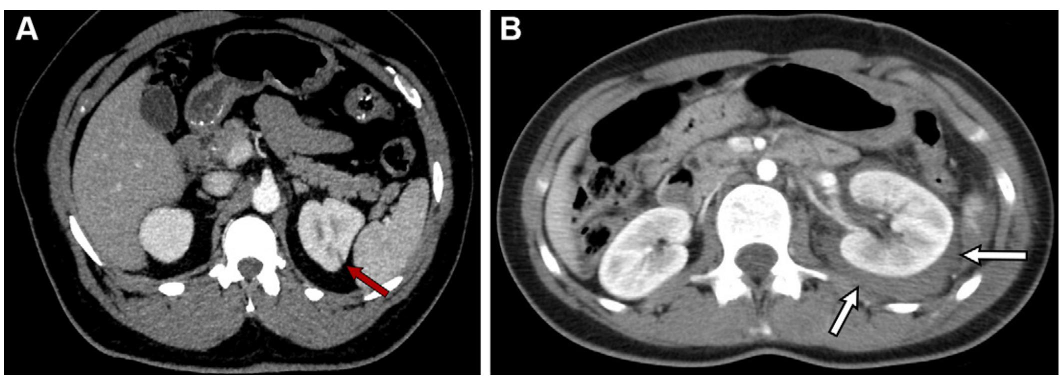
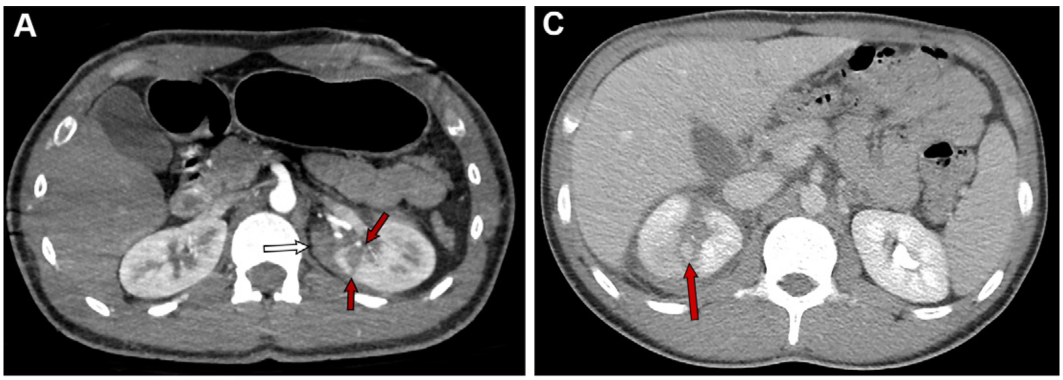


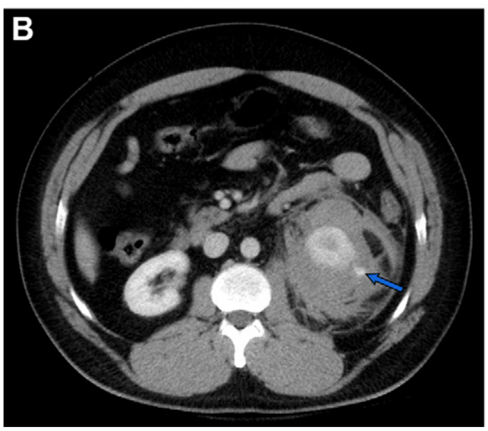
Figure 18. Grade II renal injuries according to the revised 2018 AAST-OIS. **(A)** Axial contrast-enhanced CT image in a 29-year-old man shows a lucency less than 1 cm in depth (arrow) in the left kidney, consistent with a laceration. There is no evidence of urine leak, as this would automatically upgrade injuries to at least grade IV. According to the revised 2018 AAST-OIS, lacerations smaller than 1 cm and those measuring exactly 1 cm in depth are now included in grade II injuries, as opposed to the prior version, which included only lacerations smaller than 1 cm in depth. An axial cine clip of this patient is shown in Movie 12. **(B)** Axial contrast-enhanced CT image in a 45-year-old woman after a motor vehicle collision shows a perirenal hematoma (arrows) confined to the Gerota fascia. According to the revised 2018 AAST-OIS, the term *renal retroperitoneum* is replaced by “hematoma confined within Gerota’s fascia.”

Segmental vascular injuries can manifest as wedge-shaped infarctions. Active bleeding extending beyond the Gerota fascia into the anterior or posterior perirenal space or the peritoneal cavity is evidenced by fluid in these spaces, which increases in size and attenuation at delayed imaging (47). It is important to note that active extravasation should not be due to main renal artery or vein laceration, as these would upgrade the injuries to grade V. Vessel thrombosis leading to segmental or complete renal infarction is also included in grade IV.

Grade V injuries (Figs 16, 21; Movie 16) include shattered kidney with loss of identifiable parenchymal anatomy, main renal artery or vein laceration or avulsion of the hilum, and devascularized kidney with active bleeding. Shattered kidney results in multiple fragments and is usually associated with urine leak and active bleeding. Loss of parenchymal identification is now required for its diagnosis (2). Hilar vascular injuries are rare and may result in retroperitoneal hematomas with possible active bleeding. CT angiography, CT venography, and conventional angiography can be useful for identification of

Figure 19. Grade III renal injuries according to the revised 2018 AAST-OIS. **(A)** Axial image from the combined phase of single-pass split-bolus contrast-enhanced CT in a 28-year-old man after a motorcycle collision shows a left renal laceration (red arrows) with no urine leak during the delayed phase (not shown); a small perirenal hematoma is also noted (white arrow), which is confined to the Gerota fascia. An axial cine clip of this patient is shown in Movie 13. **(B)** Axial contrast-enhanced CT image in a 37-year-old man after a motor vehicle collision shows a large left perinephric hematoma and active bleeding (arrow) contained within the Gerota fascia. This patient also suffered a grade IV splenic injury (not shown). He was treated with splenic artery embolization with an 8-mm Amplatzer Vascular Plug at presentation and with left renal upper pole artery embolization with coils approximately 2 days later due to lack of improvement in hemodynamic status. According to the revised 2018 AAST-OIS, vascular injuries (pseudoaneurysms and arteriovenous fistulas) and active bleeding are now included under grade III renal injuries. **(C)** Axial delayed phase contrast-enhanced CT image in a 15-year-old boy with flank pain and gross hematuria after he fell and hit his abdomen on the corner of a plastic step shows a globular structure (arrow) within the right kidney, which was the same size as a contrast material–attenuation focus noted in the arterial phase (not shown), compatible with a contained vascular injury. The patient underwent angiography, which confirmed the diagnosis of a pseudoaneurysm, which was successfully treated with coil embolization. Note the extensive perirenal hematoma surrounding the right kidney and the lack of contrast material within the right renal pelvis.





patients with suspected hilar vascular injuries (19). In contrast with the devascularization seen in grade IV injuries that result from thrombosis, grade V injuries are characterized by devascularization with active bleeding.

Management.—Most renal injuries can be managed nonoperatively, with bed rest, frequent examinations, and monitoring of vital signs, hematuria, and hemoglobin level. AAST renal injury grading is critical to determine which patients may benefit from more aggressive management (42,48,49). In grade III injuries with active bleeding, angioembolization should be considered, depending on the hemodynamic status (Movies 17–19) (50). Perirenal hematoma size, contrast material extravasation, and medial renal laceration site have been associated with increased need for urgent hemostatic intervention but are not included in the 2018 update (51). Vessel thrombosis is now classified under grade IV (while other main renal vessel injuries are grade V), as it has been shown to correlate with lower risk and does not require acute intervention (51,52).

A growing number of studies advocate for the value of renal preservation in the setting of high-grade trauma. As such, a multidisciplinary team involving interventional radiology, urology, and trauma surgeons is therefore crucial, as studies have shown significant differences in management approaches (53,54). Complications of renal trauma may include urinoma, urinary fistula, perinephric abscess, hydronephrosis, recurrent pyelonephritis, kidney stone formation, pseudoaneurysms, arteriovenous fistulas, and hypertension (50,55).

Conclusion

Given the short time since the publication and implementation of the AAST-OIS 2018 revision, evidence regarding its impact is still limited. However, according to the currently available literature, validation of the AAST-OIS 2018 revision revealed that it has led to an increase in heterogeneity for grade IV renal injuries, an improvement in the ability to predict the need for operative treatment, and a decline in the correlation with in-hospital mortality for both splenic and hepatic trauma. The radiologist should keep in mind that multidisciplinary cooperation and appropriate grading of injuries according to the latest update are essential in management of and prognosis for these critically ill patients, to further understand the implications of the revision, and to guide future updates. Possible future directions may include addition of alternative imaging modalities (eg, contrast-enhanced US, dual-energy CT), incorporation of machine learning algorithms to support mortality prediction or facilitate management decisions, and integration of three-dimensional printing in

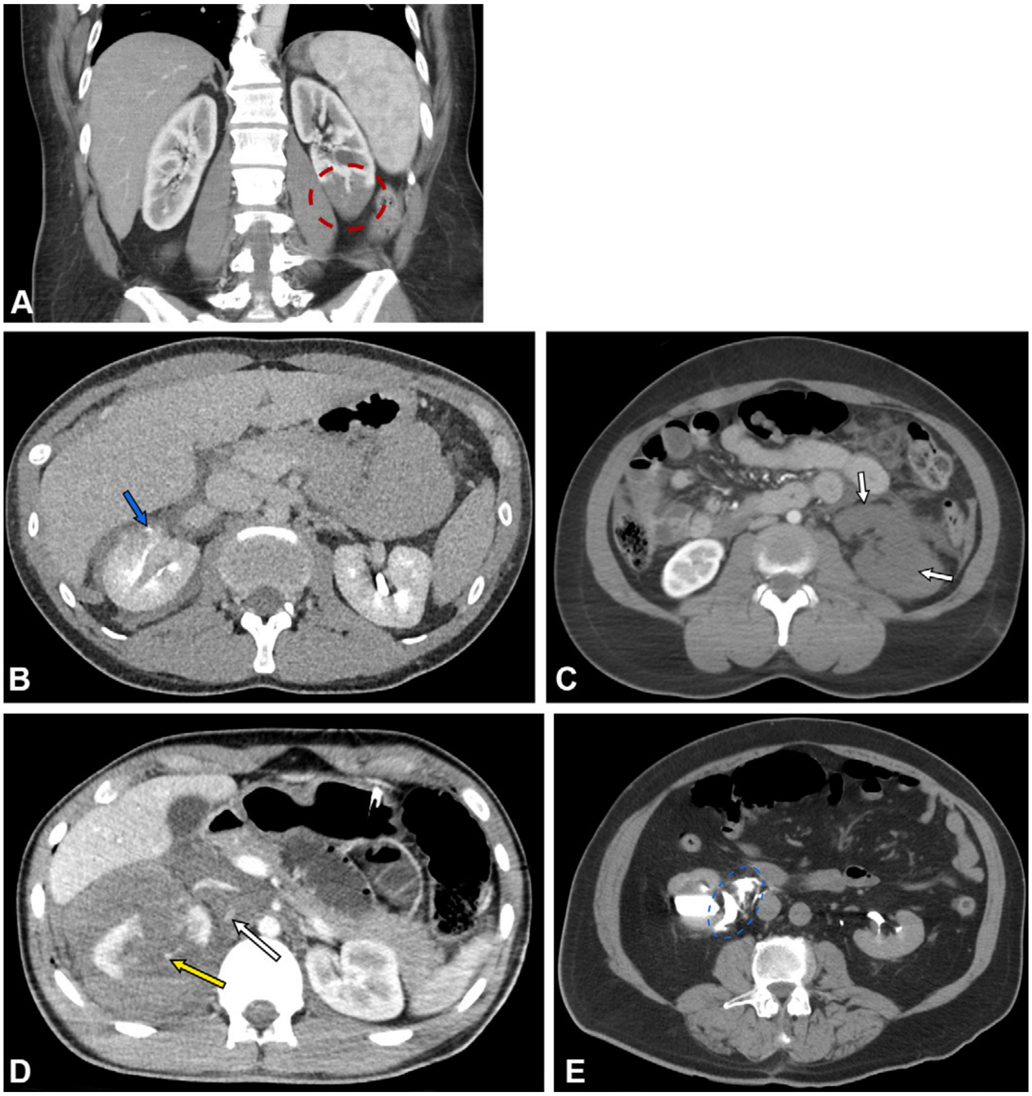


Figure 20. Grade IV renal injuries according to the revised 2018 AAST-OIS. **(A)** Coronal contrast-enhanced CT image in a 31-year-old man after a motor vehicle collision shows a left lower pole renal infarction (red oval), suggesting segmental vascular injury. According to the revised 2018 AAST-OIS, segmental vascular compromise and infarction and/or infarction as a sequela of vascular thrombosis are now classified under grade IV injuries. **(B)** Axial delayed phase contrast-enhanced CT image in a 26-year-old man after a car-versus-pedestrian collision shows a laceration of the right kidney extending from the anterior aspect, through the renal pelvis, and to the posteromedial aspect with contrast material extending beyond the collecting system (arrow), consistent with urine leak. No contrast material extravasation was noted during the arterial or portal venous phase to suggest active bleeding. The patient was managed conservatively with a good outcome. According to the revised 2018 AAST-OIS, renal pelvis laceration and complete ureteropelvic disruption are now included under grade IV injuries. An axial cine clip of this patient is shown in Movie 14. **(C)** Axial contrast-enhanced CT image in a 45-year-old woman after a motor vehicle collision shows complete left kidney infarction (arrows) with no evidence of active bleeding. The patient also suffered multiple other injuries (not shown), including a shattered spleen, liver laceration, pancreatic transection, and fractures of the transverse processes of the L1 and L4 vertebrae. The patient underwent multiple surgeries for the remaining injuries, but the kidney injury was managed conservatively. However, long-term follow-up revealed no functional recovery of the left kidney. **(D)** Axial contrast-enhanced CT image in a 16-year-old boy after a tree branch fell on him shows multiple severe right kidney lacerations, a large amount of blood extending beyond the Gerota fascia, and contrast material extravasation suggestive of active bleeding both within (yellow arrow) and beyond (white arrow) the Gerota fascia into the retroperitoneum. **(E)** Axial delayed phase contrast-enhanced CT image in a 71-year-old man after a fall shows contrast material extending into the right perinephric space (blue oval) and down to the right retroperitoneum, with no contrast material in the distal right ureter (not shown), diagnostic of a complete ureteropelvic disruption. The patient was managed with ureteral stent placement with a good response. An axial cine clip of this patient is shown in Movie 15.

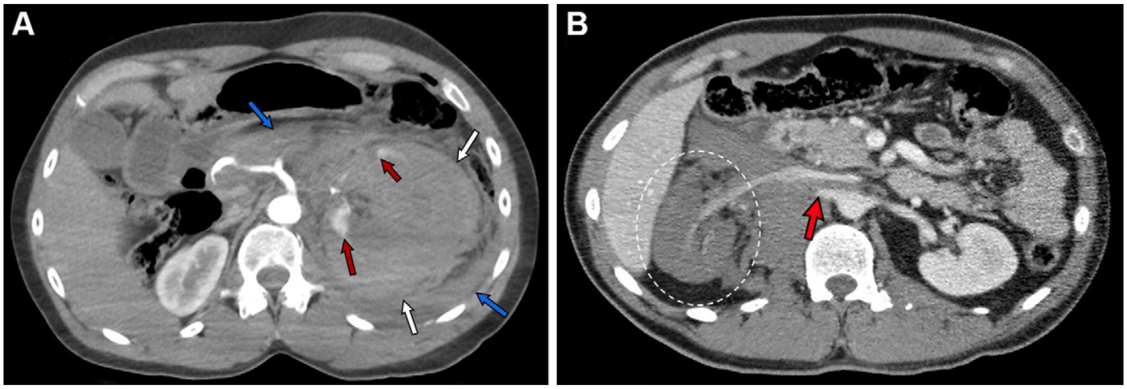


Figure 21. Grade V renal injuries according to the revised 2018 AAST-OIS. (A) Axial contrast-enhanced CT image in a 55-year-old man after a front-end motor vehicle collision at 45 mph shows a shattered left kidney with two small fragments (red arrows) but loss of identifiable renal parenchymal anatomy, and bleeding extending from the Gerota fascia (white arrows) into the peritoneum and retroperitoneum (blue arrows). The patient underwent exploratory laparotomy and left nephrectomy. (B) Axial contrast-enhanced CT image in a 34-year-old man after being crushed between two vehicles shows avulsion of the right renal hilum, right renal artery laceration (arrow), extensive retroperitoneum, and a devascularized right kidney (white oval). Additionally, he suffered a right 10th rib fracture and injuries to the duodenum and transverse mesocolon. The patient underwent right nephrectomy, and avulsion of the hilum and renal artery transection were confirmed during surgery. Absence of exuberant active contrast material extravasation was related to vasospasm and compression by the hematoma. According to the revised 2018 AAST-OIS, all main renal vascular injuries, excluding thrombosis, are reserved for grade V injuries.

assessment of and surgical planning for high-grade or multiple-organ injuries.

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