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Blunt Renal Injuries

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Epidemiology, Etiology, Pathophysiology

Epidemiology and Etiology

Kidneys are the most injured genitourinary organ in external trauma, and it is estimated that 1–5% of all traumas and 10% of abdominal traumas sustain a renal injury [1–4]. In a series consisting purely of blunt abdominal trauma mechanism, 15% of patients were found to have an injury to the kidneys [5]. Of all patients who sustain genitourinary trauma, over half of them involve the kidney [6]. A population-based study found the incidence of renal trauma to be 4.9 per 100 000 population ≥16 years of age in the United States [4]. The majority of these patients were young and male, with 72% between the ages of 16 and 44 and 75% male. In an analysis of pediatric genitourinary injuries, renal injuries were found to make up 3.5% of the cohort, but the incidence has not been defined [7].

There is variation in the etiology of renal trauma based on geographical location; series from Low and Middle-Income Countries (LMIC) suggest that the rates of penetrating trauma are high, with the majority of blunt trauma caused by road traffic accidents, assault, and falls [8–11]. In the More Economically Developed Countries (MEDC), the vast majority (90–95%) of renal injury is sustained by blunt trauma, which is caused by motor vehicle collisions (63%), falls (14%), sports injuries (11%), pedestrian accidents (4%), motorcycle crashes (2%), assault (2%), and the remaining from other causes [6, 12, 13]. In a recent blunt renal trauma series, 80% of injuries were found to be grade I–II renal injuries, 9.5% grade III, 8.1% grade IV, and 2.7% grade IV [5]. Thus, imaging all renal injuries is unnecessary, and criteria have been developed (see below). Table 1.1 summarizes the large (n > 100) series with emphasis on blunt injuries.

Pathophysiology

Blunt trauma injury to the kidney is thought to occur as a result of kinetic energy transmission, often as a consequence of rapid deceleration forces or direct interaction of structures in the environment with the soft tissues and bones of the flank and then the

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Table 1.1 Demographics of renal trauma.

SERIES[a]	[6]	[14]	[15]	[1][b]	[4]	[16]	[5][b]	[17]	[18]	[19]
Year published	1984	1986	1995	2001	2003	2012	2012	2013	2013	2014
Renal injury (N)	154	132	2254	227	6231	1505	221	338	9002	105
Renal injury (%)	2.9	3.25	n/a	1.4	1.2	n/a	n/a	n/a	n/a	n/a
Blunt (%)	93.5	95.4	89.8	93.4	81.6	95.0	100	96.2	82.0	96.1
Penetrating (%)	6.5	4.6	10.2	6.6	18.4	5.0	0	3.9	17.8	3.9
Grade IV–V (%)	n/a			14.6			10.9	29.3	21.1	23.5
Initial non-operative management among *all* trauma (%)		92.6	92.6	n/a	88.6	94.5	n/a	92.6	86.8	98.0
Initial non-operative management among *blunt* trauma (%)			98.3	89.5/92.9?	96.3		92.3	92.6	94.4	
Nephrectomy (%) among *all* trauma	3.8	3.2			7.9	3.1	n/a	7.1	8.6	1.9
Nephrectomy (%) among *blunt* trauma			0	7.2	3.3		5.4	7.4	4.7	

Blank cells indicate missing data.
[a] Series with N < 100 not included.
[b] Data showing grade and management of blunt renal injuries only.

kidney. Studies using animal models have shown that the kidney has viscoelastic properties and that damage occurs as a result of stresses that cause tissue deformations exceeding an impact energy threshold of 4 J [20, 21]. A three-dimensional animal model also demonstrated that the primary site of load-bearing, where injuries result from, is the junction between the renal pelvis and the renal cortex [21]. Research has also demonstrated that the kidney with a fluid-filled structure (i.e. ureteropelvic junction obstruction, hydronephrosis, or renal cyst) may be more prone to rupture due to the hydrostatic pressure and resulting distribution of forces within the kidney [20, 22].

Children may have a higher risk of significant renal injury from blunt trauma and this is thought to be related to the proportionately larger kidney for their body size as compared to that of adults, the possibility of children retaining fetal lobulations that may predispose to parenchymal disruption, and the pediatric kidney having less protection due to lower perirenal fat content, weaker abdominal muscles, and less ossification of the rib cage [23, 24].

The proportion of patients with renal trauma found to have congenital anomalies varies, depending on different series, ranging from 1 to 23% [23]. One series that reviewed 193 pediatric renal trauma patients found that just over 8% of patients had a congenital anomaly [25]. Data regarding renal trauma and congenital anomalies is somewhat mixed, with most studies suggesting that congenital anomalies increase the risk of significant renal injury and decrease the possibility of renal salvage, while other series suggest that there is no effect on morbidity or mortality [25-30]. Overall consensus is that pre-existing renal anomalies likely increase the vulnerability of kidneys in blunt renal trauma [4, 30]. They may also complicate the management of a renal laceration involving the collecting system or parenchyma (e.g. horseshoe kidney with complex arterial vasculature, UPJ (ureteropelvic junction) obstruction, etc.).

Diagnosis

Workup

A complete history, including the crash mechanics and velocity of impact as well as known pre-existing renal disease or abnormality, should be obtained if possible. For example, renal injury frontal and side impact collisions may be impacted by direct contact from seatbelt and steering column [31]. Seatbelt use and airbag deployment are also important characteristics to note; absence of a seatbelt is associated with higher probability of thoracoabdominal injury [32]. Compared to individuals who did not have airbag deployment with vehicle collision, those with frontal and side airbags have a 46 and 53% decrease in renal injury, respectively [33]. Vehicle characteristics are important given the association of increased crash test rating (i.e. safer car) with lower likelihood of thoracoabdominal injury [32].

Blunt trauma caused by a blow to the flank, rib fracture, or rapid deceleration injury should make clinicians suspicious for possible renal injury. Such mechanisms include injuries related to sports (in particular ice hockey, soccer, and football), ski and snowboarding, and motor vehicle versus pedestrian. Signs of renal injury from blunt trauma that may be noted on physical examination include gross hematuria, flank hematoma, and abdominal or flank tenderness. Vital signs are important to obtain and monitor both in the field and upon arrival at the hospital, as hemodynamic stability drives evaluation and management of renal trauma. Laboratory examinations, including a creatinine, hematocrit, and urinalysis with microscopic analysis to evaluate for hematuria, should be obtained.

Radiographic Evaluation

The American Urological Association (AUA) has released guidelines to provide indications for imaging of suspected renal trauma [34]. Patients sustaining blunt injury that require diagnostic imaging are those who have gross hematuria, or those who have a systolic blood pressure of less than 90 mmHg with microscopic hematuria. Additionally, any patients who are stable but have a mechanism of injury (e.g. fall from a great height) or physical examination (see above) findings concerning renal injury should also be imaged, as trauma patients may have renal injury, even in the absence of hematuria or shock [14, 35]. Based on the AUA Urotrauma Guidelines, children should be imaged with the same modality and criteria as adults.

If imaging is obtained, a contrast enhanced CT (computed tomography) abdomen pelvis with immediate and delayed images is recommended, in order to visualize the kidney parenchyma and collecting system and to look for evidence of bleeding or urinary extravasation. The immediate phase is typically an arterial or early venous phase, which highlights the renal parenchyma and can be useful for evaluating for parenchymal laceration, intravascular contrast extravasation, and hematoma. The delayed phase, typically obtained at 10–15 minutes after contrast administration, is useful to evaluate the collecting system of the kidney and the ureter. In addition, subtle findings on initial venous imaging such as perinephric stranding, hematoma, and low-density retroperitoneal fluid may prompt imaging with delayed phase to evaluate for a ureteropelvic or ureteral injury; a large medial urinoma or contrast extravasation on delayed images without distal ureteral contrast visualized is concerning for a renal pelvis or ureteral avulsion injury [36, 37].

Evaluating the size of a perinephric hematoma, the presence of intravascular contrast extravasation, and a medial laceration on CT can be useful, as these factors can predict bleeding complications and help guide management, as discussed in the management section (below).

Renal injuries are classified by the Organ Injury Scaling of the American Association for Surgery of Trauma (AAST) [38] (Table 1.2, Figures 1.1 and 1.2). Grade I injuries are renal contusions or subcapsular hematomas without parenchymal laceration. Grade II injuries involve perirenal hematomas of the renal retroperitoneum or parenchymal renal lacerations that extend for less than 1 cm. Once the laceration extends for greater than 1 cm into the renal parenchyma, this becomes a grade III injury, with an elevation to grade IV if there is collecting system involvement (i.e. urinary contrast extravasation from the renal collecting system). Grade IV injuries also include contained hilar vascular injuries, such as injury to the main renal artery or vein. Grade V injuries are so-called "shattered" kidneys and renal hilar avulsion injuries that cause devascularization of the kidney. Revisions have been proposed to this classification in order to include previously undescribed injuries and reclassify other injuries to facilitate more appropriate alignment of classification and management/outcomes, particularly in order to better classify vascular (such as segmental vessel injury) and collecting system injuries, though these revisions have not been formally accepted [40–43].

Table 1.2 2018 American Association for the Surgery of Trauma (AAST) organ injury scale [38].

Grade	Description of Injury
I	Subcapsular hematoma and/or parenchymal contusion without laceration
II	Perirenal hematoma confined to Gerota fascia
	Renal parenchymal laceration ≤1 cm depth without urinary extravasation
III	Renal parenchymal laceration >1.0 cm parenchymal depth without collecting system rupture or urinary extravasation
	Any injury in the presence of a kidney vascular injury or active bleeding contained within Gerota fascia
IV	Parenchymal laceration extending into urinary/collecting system with urinary extravasation
	Renal pelvic laceration and/or complete ureteropelvic disruption
	Segmental renal vein or artery injury
	Active bleeding beyond Gerota fascia into retroperitoneum or peritoneum
	Segmental or complete kidney infarction(s) due to vessel thrombosis without active bleeding
V	Main renal artery or vein laceration or avulsion of hilum
	Devascularized kidney with active bleeding
	Shattered kidney with loss of identifiable parenchymal renal anatomy

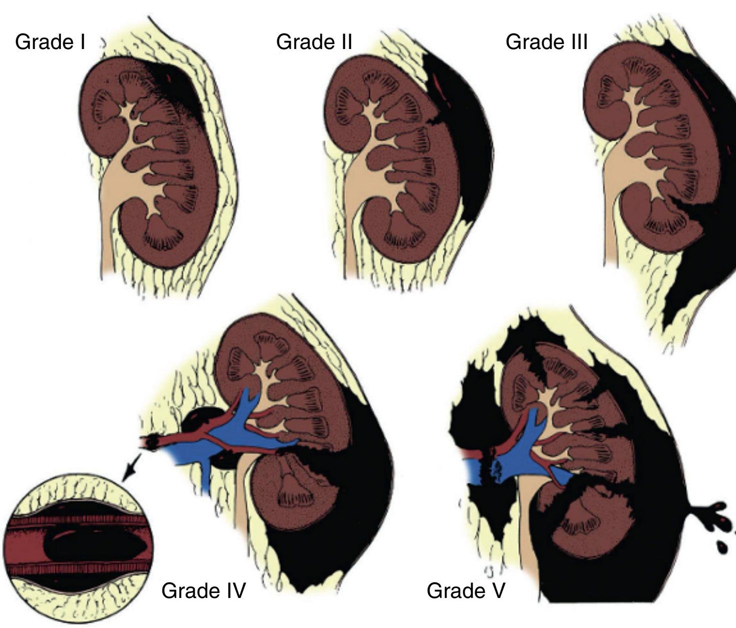

Figure 1.1 American Association for the Surgery of Trauma (AAST) Organ Injury Severity Score for the Kidney. *Source:* from Campbell-Walsh, 10th Edition with permission [39].

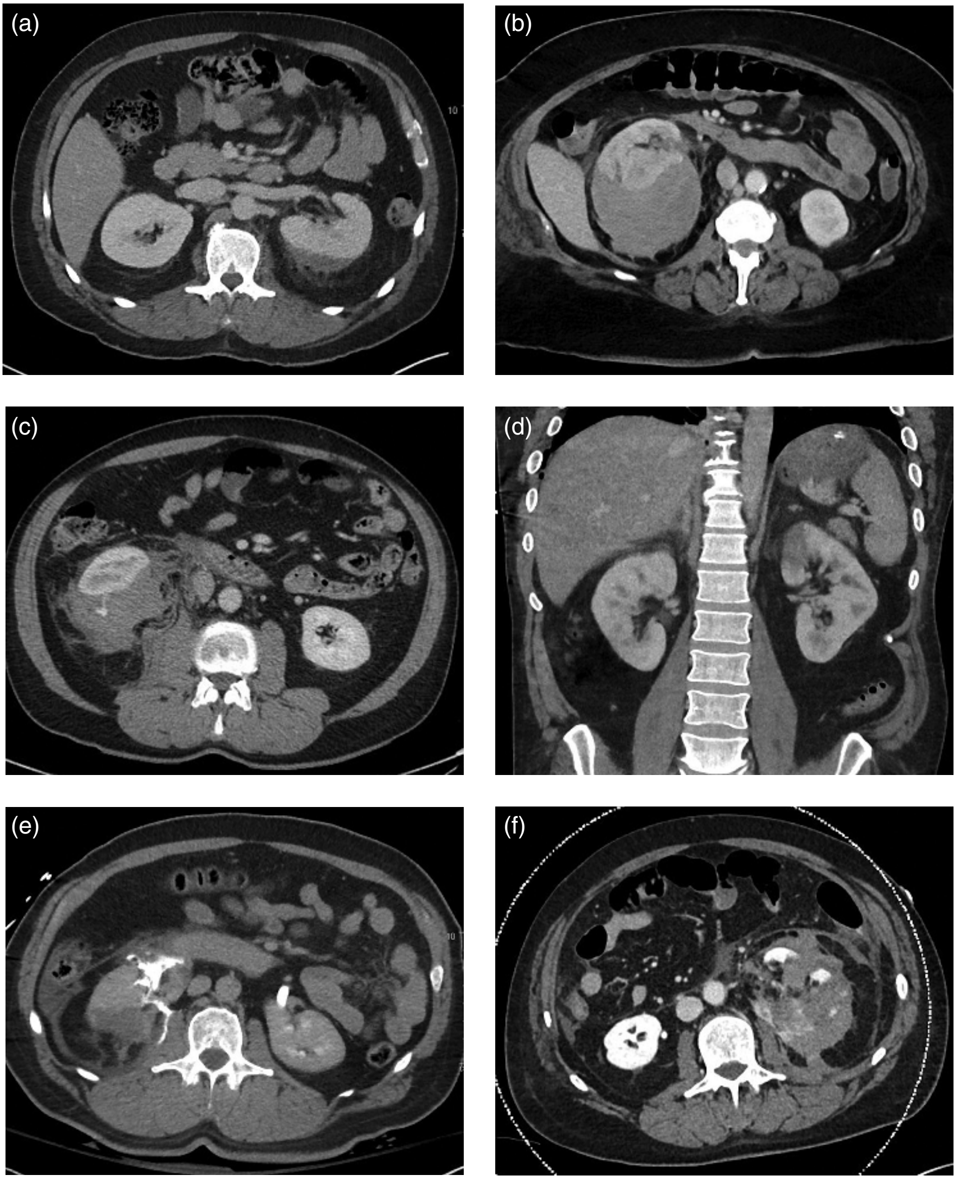

Figure 1.2 CT images of renal injuries including: (a) axial view of a left subcapsular hematoma (AAST Grade I); (b) a large right perinephric hematoma and a 2-cm parenchymal laceration (Grade III); (c) intravascular contrast extravasation into a right perinephric hematoma (Grade III); (d) coronal view of a left upper pole perfusion defect consistent with a segmental vascular injury (Grade IV); (e) a right medial parenchymal laceration with urinary contrast extravasation (Grade IV); and (f) a shattered left kidney with hematoma, contrast extravasation and multiple parenchymal fragments (Grade V). *Source:* courtesy of Alex Skokan, MD.

If CT is not available, or if the patient is brought directly to the operating room for exploration without first obtaining imaging, and renal injury is suspected due to hematuria or a perinephric hematoma, a one-shot intravenous pyelogram (IVP) can be useful, primarily to confirm the presence of a contralateral kidney, and secondarily to identify injury of the kidney of interest, although it is much less sensitive to detect injuries than CT (see image) [44]. A one-shot IVP is obtained by administering 2 ml/kg IV bolus of contrast with a single x-ray of the abdomen obtained 10–15 minutes later. The radiographic image quality can be limited by under-resuscitation, hypotension, significant edema, or renal dysfunction. One study evaluated the quality and usefulness of one-shot IVP in the operative setting, finding that the average quality score was 3.84/5 with only 1/50 studies found to be unintelligible, and the majority (66%) were good or of excellent quality. The average usefulness score was 3.96/5, with only 1 imaging study considered worthless and the majority (72%) considered important or critical for determining urological management.

Other imaging modalities such as ultrasound, radionucleotide scintigraphy, and angiography are not recommended for initial evaluation of renal injuries but may be useful during subsequent management.

Management

Non-operative Management

Patients with high-grade renal injuries who are hemodynamically stable can be managed non-operatively, involving hospital admission, intensive care monitoring, bed-rest, hydration, and serial hematocrit checks [34]. Over time, data have shown that the majority of renal injuries can be safely managed in a non-operative manner, with the potential benefits of preserving renal function and limiting morbidity [45].

Most stable patients with urinary extravasation can be managed non-operatively initially, as long as they do not have concern for a renal pelvis or ureteropelvic junction injury. Management may involve bladder drainage in order to facilitate collecting system drainage and/or antibiotics, although evidence is lacking to support these. Urinary extravasation can resolve spontaneously without intervention, with rates of spontaneous resolution near to 90% [46–48]. Guidelines support initial non-operative management of patients with urinary extravasation, given the possibility of spontaneous resolution and avoiding risks of injury during stent placement, risks of anesthesia, and the possibility of retained stents due to patients being lost to follow-up [34]. If there is any concern for complications with non-operative management (such as fever, enlarging urinoma, ileus, infection) or the urinary extravasation is found to be persistent on repeat imaging, ureteral stent placement is indicated. Some of these patients will require additional drainage with a nephrostomy tube and/or perinephric drain [47-48].

The AUA Urotrauma Guidelines suggest that patients who sustain high-grade injury (AAST IV-V) that are managed non-operatively should undergo repeat imaging after 48 hours or earlier, if needed, given the higher risk of complications and possibility of requiring future intervention [34]. In addition, conservatively managed patients who have clinical signs of complications – such as fevers, persistent severe pain, dropping hematocrit, hemodynamic instability, worsening flank or abdominal pain – should also undergo repeat imaging [34].

Repeat imaging may be tailored, based on an individuals' specific injury [49]. A recent analysis of repeat imaging in patients with grade IV and V renal trauma at three Level 1 trauma centers over 19 years (1999–2017) demonstrated that in asymptomatic patients, one in eight patients would need to undergo repeat imaging to identify a patient who needs surgical intervention. The primary goal of repeat imaging is to evaluate for complications and to evaluate clinical deterioration. Hence, it may be more worthwhile to obtain repeat imaging in patients who have signs of bleeding or history of collecting system injury as in this study. Stable patients with grade I–III injuries generally do not require repeat imaging. Repeat imaging with ultrasound instead of CT has also been advocated, based on studies showing that imaging of asymptomatic patients would not have altered clinical decision-making and concerns that standardized repeat imaging with CT exposes patients to unnecessary radiation exposure, and drives up healthcare costs, and ultrasound has been shown to be an effective alternative for detecting clinically relevant complications [20, 50, 51].

Indications for Intervention

As per AUA guidelines, "the surgical team must perform immediate intervention (surgery or angioembolization in selected situations) in hemodynamically unstable patients with no or transient response to resuscitation" [34]. Intervention is also required in the face of an enlarging or pulsatile perinephric hematoma seen on exploratory laparotomy, suspected renal pedicle avulsion, or a ureteropelvic junction disruption [52]. Depending on the clinical circumstances, these patients may require surgery or angioembolization. Several studies have evaluated high-risk criteria for bleeding associated with renal trauma, finding that intravascular contrast extravasation, perinephric hematoma of more than 3.5 cm in distance from the parenchymal edge to the hematoma edge, and medial renal laceration are risk factors associated with surgery for hemodynamic instability and the presence of two or more of these risk factors predicts the need for intervention [41–43, 53]. Studies have also evaluated these predictors for angiographic embolization, finding that perirenal hematoma size and intravascular contrast extravasation are indicators for embolization [54]. One study showed that patients without intravascular contrast extravasation and who have a perirenal hematoma rim distance of less than 25 mm are unlikely to benefit from angioembolization, and that combining CT scan-specific criteria such as intravascular contrast extravasation, perirenal hematoma size, and discontinuity of Gerota's fascia, can be predictive of the need for renal embolization [55]. Intravascular contrast extravasation alone is not an indication for angioembolization or other interventions. It is important to consider the hemodynamic status of the patient and blood transfusion requirements.

Building on these single institution series, the Multi-institutional Genito-Urinary Trauma Study Group created a nomogram to predict bleeding interventions after high-grade renal injury [56]. The variables in the nomogram (Figure 1.3) include mechanism of injury, hemodynamic status, associated injuries, and the following radiographic features: intravascular contrast extravasation; para-renal hematoma; and hematoma size.

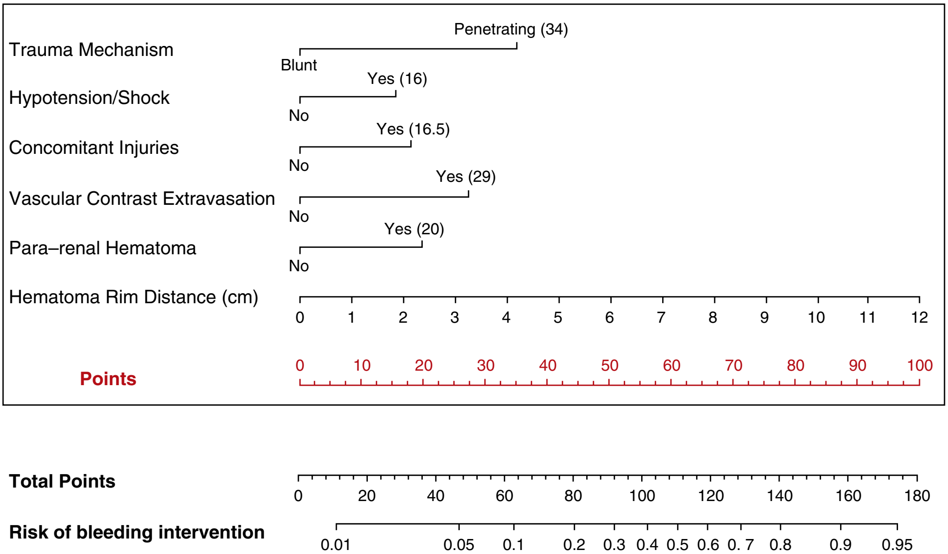

Figure 1.3 Nomogram predicting bleeding interventions after high-grade renal injury. Points are awarded for "Yes" responses for the first 5 parameters; the Hematoma Rim Distance is scored by tracing a line down to the Points scale in red. Total Points is based on the sum of the first 5 scores and the points from the scale in red. Source: from the MiGUTS Study, with permission [56].

With an area under the ROC (receiver operator characteristic) curve of 0.83, the nomogram performed better than AAST grade alone (which was not included in the nomogram). The nomogram, once externally validated, could provide a means to incorporate imaging data into decision-making on renal trauma management. Future work will be necessary to determine how to apply the nomogram in clinical care settings. Potential applications include its use to triage patients to ICU (intensive care unit) versus floor care for isolated grade III and IV injuries; ensure appropriateness of transfer from a lower to higher trauma designation hospital; to select treatment of bleeding with embolization versus transfusion alone; and support decisions for operative management [57].

Non-operative Versus Operative Management

Published series of blunt trauma patients suggest that when patients are matched by grade and mechanism injury in an operative cohort compared to a more conservatively managed cohort, the rate of nephrectomy is lower, complication rates are similar, and length of hospital stay is shorter with non-operative management [45–47]. Further supporting these data, hospitals that have changed their policy toward renal trauma management to adopt a non-operative approach have shown significant (two- to six-fold) decreases in renal exploration and nephrectomy without seeing an increase in complications [46, 58, 59].

In comparing series of grade IV blunt injuries that were managed non-operatively versus those who underwent exploration, higher rates of exploration are associated with higher rates of nephrectomy [45]. Finally, there are published series of patients who have sustained blunt grade V injuries, usually complex parenchymal lacerations (e.g. shattered kidney), who have been managed non-operatively. One such series showed a decreased rate of transfusions, shorter ICU length of stay, and fewer complications for the conservatively managed patients [60]. A recent series showed that just over 50% of grade V injuries were able to be managed non-operatively [61].

Predictors of Failure of Non-Operative Management in Blunt Renal Trauma

Of patients with blunt trauma that are managed non-operatively, some will ultimately require intervention. One series evaluated 154 patients (74.8%) with grade IV and V blunt renal trauma, who were initially managed non-operatively, with a non-operative management failure rate of 7.8% [62]. The vast majority of the patients who failed non-operative management did so because of their kidney injury and none of these patients had complications as a result of delayed operative management. The mean time to failure was just over 24 hours and the majority (83.3%) failed due to hemodynamic instability. Independent predictors based on multivariate analysis found that those who were older than 55 years of age or who were injured as a result of a motor vehicle collision were more likely to fail non-operative management.

Patients with a devitalized parenchymal segment were more likely to require delayed surgical intervention in a series of grade IV and V blunt renal injuries [46]. Of 40 patients with grade III–V blunt renal injury initially managed non-operatively, the risk of delayed nephrectomy in three was associated with grade IV injuries and secondary hemorrhage which necessitated intervention [8].

Management of Renal Trauma in Children

Many studies have evaluated management of renal trauma in children, with the consensus being that most cases of pediatric renal trauma can be safely managed non-operatively [63–67]. Rates of delayed intervention vary from very low to as high as 30–40% [64, 68–70]. In one series of 16 patients managed non-operatively, 44% required intervention with a mean time to intervention of 11 days; collecting system clot and larger urinoma were significant predictors of failure of non-operative management [70]. Consistent with findings in adults, another group found that medial contrast extravasation among grade IV renal injuries was a significant predictor of failure of non-operative management [71].

Given the lack of age specific guidelines, pediatric blunt renal trauma guidelines were established recently by the Eastern Association for Surgery of Trauma and Pediatric Trauma society [72]. These guidelines advocate for nonoperative management in high-grade trauma sustained by hemodynamically stable patients based on synthesis of evidence. For those undergoing intervention, angioembolization is highly recommended. Finally, routine blood pressure monitoring is recommended after injury.

Operative Technique

Absolute criteria for renal exploration include life-threatening hemorrhage with hemodynamic instability, renal pedicle avulsion, and expanding, pulsatile, or uncontained retroperitoneal hematoma [25]. Renal exploration and repair in the acute injury setting is accomplished through a midline abdominal incision. While prior literature supported early

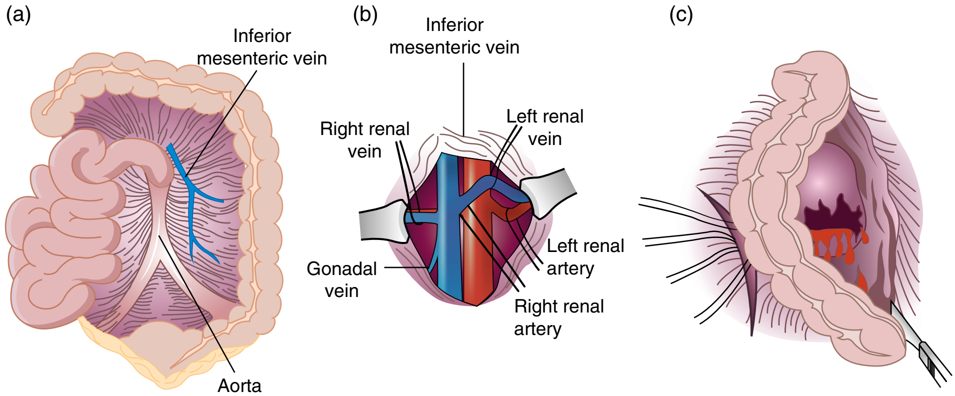

Figure 1.4 Surgical approach to renal vessels and hilum. (a) Relationship between the aorta, posterior peritoneum, and inferior mesenteric vein. (b) Window in posterior peritoneum made between aorta and inferior mesenteric vein demonstrating each renal artery and vein. (c) After vascular exposure and isolation, exploration of Gerota fascia obtained by incising the peritoneum lateral to the descending colon (for a left-sided injury). *Source:* from Campbell-Walsh, 10th Edition, with permission [39].

vascular control, more recent literature is inconclusive on this approach [73-77]. Surgical exploration often results in nephrectomy [4]. The renal vessels can be isolated before Gerota's fascia is opened in order be able to rapidly occlude hilar vessels if significant bleeding is encountered; some advocate that this technique may lead to a lower rate of nephrectomy, whereas other data have shown no difference in nephrectomy rate, transfusion requirements, or blood loss with potential for increased operative time [76, 77]. If early vascular control is desired, an incision can be made in the mesentery medial to the inferior mesenteric vein and extended to the ligament of Treitz in order to expose the aorta [78] (Figure 1.4). The left renal vein will be visualized first as it passes anterior to the aorta and the renal arteries can then be identified posterior to the left renal vein, and the right renal vein will be identified anterior to the right renal artery. Once the hilar vessels have been isolated, the colon can then be reflected medially by incising the peritoneum lateral to the colon and exposing Gerota's fascia. The kidney can then be fully exposed in order to identify any injuries. The other approach to the renal hilum involves initial reflection of the colon and its mesentery, keeping out of Gerota's fascia, followed by isolation of the renal hilum for early vascular control, and renorrhaphy, partial nephrectomy, or nephrectomy.

Repair of the kidney depends on the injuries present, and should involve debridement of nonviable tissue, suture ligation of individual bleeding vessels to obtain hemostasis, watertight closure of any collecting system defects, and closure or re-approximation of the parenchymal defect when possible. If parenchymal closure is difficult, techniques such as thrombin-soaked Gelfoam bolsters or omental interposition or pedicle flap may be helpful.

In terms of renovascular injuries, segmental arterial and venous injuries can be managed with suture ligation, realizing that ligation of segmental arteries will result in ischemia to the corresponding renal parenchyma. Repair of the main renal artery and vein should be attempted when safe with 4-0 or 5-0 prolene suture; however, many injuries of the main hilar vessels will result in nephrectomy (Figure 1.5).

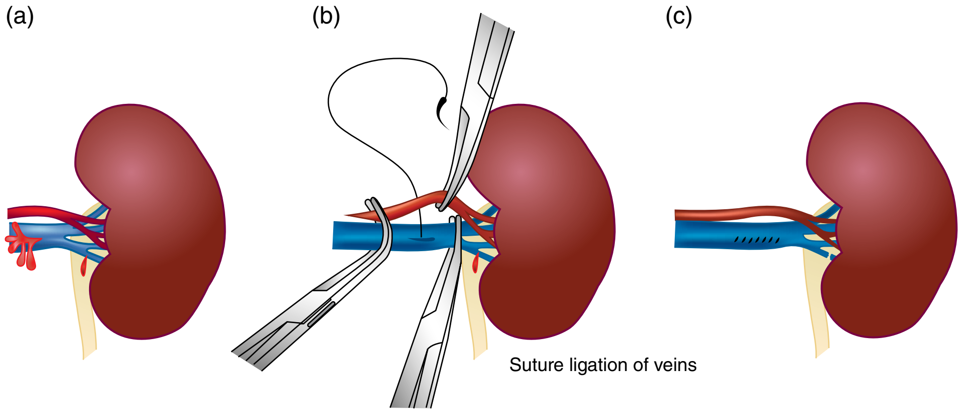

Figure 1.5 Surgical management of vascular injuries. (a) Schematic showing injury to different portions of the renal vein. Injuries are repaired (b) or divided (c), depending on location and size. *Source:* from Campbell-Walsh, 10th Edition, with permission [39].

Issues in Operative Technique for Blunt Trauma

Renal trauma may be incompletely staged and this can be an important determinant for renal exploration. If exploration occurs before complete staging has been accomplished, a one-shot IVP or retrograde pyelograms can be performed in the operating room (see above), or the kidney and/or ureters can be directly inspected during an abdominal exploration [79].

In cases of renal trauma, it is important to have familiarity with damage control maneuvers. It is particularly important in patients who do not have life-threatening renal injury. In cases of uncontrolled bleeding, vascular control is paramount. Renal pedicle access by blunt dissection over psoas fascia allows for application of a large vascular clamp. Once this is done, then the kidney can be evaluated and nephron sparing techniques can be applied. Another consideration is in cases where the patient is unstable for kidney exploration and repair in the setting of active bleeding. In this case, packing the renal fossa with delated intervention is an alternative to nephrectomy. This would allow for appropriate staging in patients who were initially unstable for imaging. This staging may allow for the patient to have non-operative management and/or angioembolization.

Complications and Follow-Up

Complications after renal trauma are reported to be rare, occurring in about 5% of cases in modern series, although true rates of long-term complications are difficult to define given the lack of long-term follow-up in the trauma population [25]. One retrospective series of grade IV and V blunt renal trauma evaluated the incidence of complications among patients who underwent immediate intervention versus those who were conservatively managed, subdividing the conservatively managed patients into successes and failures of conservative management [62]. Most were successfully managed conservatively. Of those who underwent successful conservative management ($n = 142$), 10.6% developed urinoma

Table 1.3 Long-term follow-up recommendations.

AUA [34]	EAU [81, 82]	SIU/WHO [30]
Periodic monitoring of blood pressure up to a year after injury. Do not recommend routine DMSA (dimercaptosuccinic acid) or other functional nuclear scans.	Physical exam, urinalysis, "individualized radiological investigation," serial blood pressure monitoring, and determination of renal function. Follow-up should continue until healing is complete and lab findings have stabilized. Monitoring may need to be continued for years to evaluate for latent renovascular hypertension.	No specific recommendations, but consensus statement does cite a study that recommends that all grade IV/V injuries follow-up with documentation of renal function by quantitative assessment

(n = 15) and 16.9% had hematuria (n = 24). Of those who failed conservative management (n = 12), 8.3% developed urinoma (n = 1) and 8.3% had persistent hematuria (n = 1).

Short-term monitoring and follow-up of trauma patients as previously specified is intended to detect complications and offer appropriate additional interventions. In terms of long-term follow-up, there is no consensus and most trauma series do not have the luxury of long-term follow-up, given the difficulty in following up the acutely injured population [80]. Follow-up recommendations are outlined in Table 1.3.

Secondary Hemorrhage

Delayed hemorrhage can be a life-threatening complication of renal trauma that can arise as a result of the parenchymal injury itself, segmental arterial bleeding, or ruptured arterio-venous fistulas (AVFs) or pseudoaneurysm. One series of grade III–IV blunt injuries managed conservatively showed a 13–25% rate of delayed bleeds, with the caveats that this number varies significantly by series and the majority of the literature on delayed bleeds is derived from cases of penetrating trauma [83-85]. Delayed bleeds occur most commonly in the first 2–3 weeks after trauma, although case reports have described trauma-associated bleeds occurring as late as 15 or 20 years after the initial insult [83-84]. Renal trauma from stab wounds demonstrate the onset of secondary hemorrhage in the 2–36 day time-frame [30, 85].

Most often, delayed hemorrhage is caused by AVF or pseudo-aneurysm [30]. The occurrence of pseudoaneurysm after blunt renal trauma has been described in several case reports but is a rare event [83, 86–88]. Pseudoaneurysms are believed to form within the surrounding tissue after an arterial injury, likely due to shear stress in blunt renal trauma, where the space around the vascular injury is temporarily tamponaded by coagulation. Eventually, the intravascular and extravascular space may recannulate after degradation of the clot and necrosis of the surrounding tissue, leading to the formation of a pseudoaneurysm which can then grow and rupture [88, 89].

AVF after blunt trauma is also a rare event and has been reported in several case reports [89–92]. The fistula is thought to form as a result of injury to an arterial and venous vessel in close proximity to one another, usually within the renal parenchyma. Initially the bleeding may be tamponaded by a clot; as the hematoma resorbs the arterial bleeding can resume, draining into the nearby lacerated vein [30].

New-onset or worsening hematuria, flank pain or mass, a hematocrit drop, or even new-onset hypertension, should raise suspicion of a delayed bleed. CT angiogram or conventional angiography is the preferred imaging modality, although diagnosis can be made with ultrasound in some cases. Depending on the etiology, either surgical management or super-selective embolization is employed, with the goal of controlling the bleeding while preserving as much renal function as possible [93, 94]. Complications of embolization can include abscess, infarction, renal insufficiency, and pulmonary embolization of coils [25, 84, 94, 95].

Urinary Extravasation and Perinephric Abscess

AUA guidelines recommend that clinicians perform urinary drainage in the presence of complications such as enlarging urinoma, fever, increasing pain, ileus, fistula, or infection [34].

Renal injuries with urinary extravasation at initial presentation can for the most part be managed conservatively given the high rates (90%) of spontaneous resolution, although repeat imaging is intended to evaluate for persistent leaks, urinomas, or perinephric abscesses that require additional intervention such as stenting or percutaneous drainage [30, 46–48, 98]. Patients with devitalized renal parenchyma in conjunction with urinary extravasation tend to have increased morbidity and may require more aggressive management [80, 96–98]. Furthermore, patients with concomitant injuries, such as pancreatic or colonic injuries, may also have a higher likelihood of developing complications [25, 99–101].

In practice, approximately 29% of patients with high-grade renal trauma undergo ureteral stent placement [102]. To date, there are no standard guidelines on duration of stent and Foley placement for high-grade renal trauma. In a single center series, an indwelling stent for six to eight weeks was associated with favorable outcomes [103]. Generally, maintaining a Foley catheter while a stent is in place helps with healing by preventing antegrade reflux of urine to the kidney, minimizing pressure in the collecting system, and enhancing urinoma drainage. Percutaneous drains may be necessary in cases of increasing urinoma size, complexity, and/or infection [34].

Renal Insufficiency

The lack of long-term follow-up after renal trauma makes it difficult to determine the true rates of renal insufficiency after trauma. One study evaluating pediatric blunt renal trauma patients managed conservatively found that the decline in percentage of renal function of the injured renal unit correlated to the severity of renal injury, with $44.7 \pm 8.4\%$ residual function for grade II–III injuries, $41.8 \pm 9.2\%$ residual function for grade IV injury, and $29.5 \pm 7.9\%$ residual function for grade V injuries [104]. Notably, all patients had normal serum creatinine at follow-up. This group re-assessed renal function for a subset of these patients at one year post-injury, finding that renal function remained stable over this time period [105]. These results are supported by another study of 67 renal injuries (36% blunt trauma) that underwent post-injury dimercapto-succinic acid renal scan and found that the mean decrease in renal function corresponded to injury grade ($p < 0.005$ in multivariate analysis), with a mean decrease in renal function of 15% for grade III, 30% for grade IV, and 65% for grade V injuries [106]. In multivariate analysis, there was no difference in the decrease in renal function between blunt and penetrating renal injury or in those injuries that were managed operatively versus conservatively.

A study evaluating 52 patients who underwent renal reconstruction after renal trauma found that renal function on the reconstructed side had a mean 39.3% preservation of function, with 81% of patients having more than one-third function of the injured kidney based on radionucleotide scintigraphy [107].

Two studies evaluated the rates of chronic kidney disease after renal trauma. One compared trauma patients with and without renal injuries, finding that 230 patients without renal injury had an incidence of acute kidney injury of 17.4% compared to 11.4% in the patients with renal injury [108]. Another multi-institutional study evaluating grade IV and V renal injuries (49% blunt trauma) found that 6/89 patients developed chronic kidney disease (CKD) (serum creatinine range 2.0–15.6 mg/dl), and of these 6 patients, 3/5 with long-term follow-up developed progressive and permanent renal failure requiring dialysis [80].

Hypertension

Patients who sustain renal injuries have an increased risk of renovascular hypertension, with the incidence of renal trauma-related hypertension estimated between less than 1 and 5% [80, 109–113]. As a result, the European Association of Urology (EAU) Guidelines on Urologic Trauma, the AUA Urotrauma Guidelines, and the Societé Internationale d'Urologie (SIU)/World Health Organization (WHO) consensus statement on renal trauma all recommend periodic monitoring of blood pressure for the first year after injury, at least for a subset patients who have sustained high-grade injuries [30, 37, 82].

Renovascular hypertension after trauma may develop through several mechanisms: renal arterial stenosis or occlusion, parenchymal compression caused by perinephric hematoma (Page kidney), or chronic scar formation [109, 111, 112]. All of these result in a reduction in renal blood flow, which can then cause a unilateral hypersecretion of renin and resultant hypertension [25]. Diagnosis can be made with selective angiography and renal vein renin levels. Older studies of renal trauma patients show rates of new-onset hypertension of 4–5%, with onset between two weeks and eight months of injury [80, 112]. A more recent study contradicts these data, showing that patients who develop hypertension after renal trauma typically manifest it during their initial hospitalization and do not develop delayed hypertension during long-term follow-up [114].

Management with medications, renal artery bypass surgery, or partial or total nephrectomy has been shown to be effective [109, 111]. In studies evaluating conservative treatment, treatment rates range from 28 to 50% [111, 112, 114, 115]. In terms of surgical management, elevated renin levels from the affected kidney have been shown to predict a good response to surgical treatment [111, 116]. Similarly, one study showed that in cases of arterial stenosis or occlusion, early nephrectomy within the first year after injury had better response rates compared to delayed nephrectomy [108].

Other Complications

Other rare complications may include chronic pyelonephritis, post-trauma hydronephrosis, stone formation, fistulae, or flank pain [82].

Mortality

Mortality following renal trauma is nearly always related to associated injuries, with estimates of renal trauma driven mortality at less than 0.1% of all deaths [25].

Conclusions

The majority of renal trauma is caused by blunt mechanisms, making it vital for emergency providers and surgeons to have an understanding of renal trauma. Evaluation and management of blunt renal trauma has evolved significantly over the past decade. Guidelines from urologic societies have helped to disseminate indications for imaging and managing high-grade kidney injuries. Over time, there has been an evolution toward non-operative management, as data have shown good success with conservative approaches. The goal of diagnosing and managing renal trauma should be to preserve renal function, and this includes appropriate treatment of complications and failed conservative management. Long-term follow-up and assessment of renal function in these patients is lacking and requires updating.

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