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Contemporary Role of Open Surgery in the Management of High-Grade Renal Injury

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Abstract
Purpose of Review This review focuses on latest developments in kidney trauma management and the role of open surgical intervention.
Recent Findings In the last decade, there had been an obvious drift towards conservative, non-operative, management of kidney trauma, undoubtedly when it is secondary to blunt trauma. Improved imaging, minimally invasive interventions, advancements including stent and nephrostomy insertions for urine extravasation, and angiography with angioembolization for acute or impending arterial bleeding have narrowed the necessity for open surgery, even when dealing with high-grade kidney injury. Still, open surgical intervention has its essential role, predominantly in the severely bleeding-unstable patient, high-grade penetrating kidney trauma, patients with concomitant intra-abdominal injuries, and the cases of non-operative surgical approach failure.
Summary Open surgical management has a contracted but still critical share in kidney trauma management. Being alert to the indications for open intervention and mastering the different surgical techniques could impact kidney salvageability and long-term clinical outcome.

Keywords Kidney · Renal · Trauma · Penetrating injury · Non-operative management · Open surgery

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Abbreviations

AAST	American Association for the Surgery of Trauma
NOM	Non-operative management
BRT	Blunt renal trauma
PRT	Penetrating renal trauma
HGRI	High-grade renal injury
ISS	Injury severity score

Introduction

Trauma is the leading cause of death in the USA in persons between the ages of 1 and 45 and is the fourth leading cause of death in all age groups [1]. Overall, 10% of trauma patients have genitourinary system injuries [2], and 1.4–3.25% have renal injury [3••]. Most studies report blunt renal trauma (BRT) as the primary (80–90%) mechanism of renal trauma compared to penetrating renal trauma (PRT) [4]. Renal trauma predominantly affects young males [5] and frequently occurs concomitantly with other intra-abdominal organ injuries [6]. Severity on the AAST Kidney Injury Scale is associated with greater morbidity and mortality [7]. Most renal injuries are low grade (1–3), and only 36% of all injuries are high grade (4–5) using the AAST-OIS grading system [5]. Of patients presenting to urban trauma centers, 25% sustain penetrating versus 9% in rural areas [8].

Recently, the trend is towards non-operative management (NOM), even in patients who present with high-grade renal injury (HGRI) [9•]. While outcomes are comparable, the ever-growing rate of obesity, hypertension, and resulting chronic kidney disease argue for nephron-sparing management in the setting of renal trauma [10]. We will review the evidence for this approach and the still essential role of open surgery in the management of HGRI. From a pragmatic standpoint, a clear-cut algorithm for determining optimal treatment pathways will

be muddied in real-world situations based on clinical scenario, clinical assessment, mechanism of injury, etc. Other clinical variables to consider are the severity of parenchymal injury, associated collecting system injury, vascular injury, and concomitant organ injury. One overriding concern with acute open surgical management is the potential need for nephrectomy [11]. Patients who sustain renal loss in the setting of trauma are at risk for hypertension and potential renal function deterioration. On the other hand, NOM risks urinoma or extravasation of urine, possible development of hypertension (secondary to Page or Goldblatt kidney), and arteriovenous fistulas or pseudoaneurysms which carry the risk of delayed and potentially life-threatening renal hemorrhage [11].

Non-operative Management of High-Grade Renal Injuries

NOM or expectant management is an appropriate first-line approach for most blunt renal injuries, as well as selected stab injuries and gunshot wounds [12]. Patients, who are hemodynamically unstable due to bleeding, have renal pelvis or ureter injury, and select renal vascular injuries will likely require intervention [11]. Injury severity, in a stable patient, is assessed with cross-sectional imaging, typically computed tomography (CT) with intravenous contrast. The identified injuries are graded according to the AAST-OIS Kidney Injury Scale (Table 1). Typical indications for imaging in renal trauma include a penetrating injury, blunt trauma with gross hematuria, a patient with an episode of hypotension and microscopic hematuria, significant injuries to nearby organs, large cutaneous contusion or hematoma, and bony fracture near the expected location of the kidney [6]. The contrast-enhanced cross-sectional imaging with CT of the abdomen and pelvis including arterial or venous phase and urographic delayed phase is considered the gold standard for imaging in renal trauma [13] (Fig. 1). Subsequent management includes repeated physical exams, monitoring for change in clinical symptoms, and serial measurements of hemoglobin and hematocrit. Repeat imaging is recommended in cases of fever, flank pain, or falling hematocrit and 2–4 days following AAST high-grade kidney trauma.

Conservative NOM is more commonly employed in Level I trauma centers [14]. While these patients present on admission with lower Glasgow coma score, increased ISS, and have increased overall and ICU length of stay, their nephrectomy and mortality rates were comparable to less severely injured patients at Level II trauma centers. Level I trauma center patients are 30% less likely to require multiple procedures to address their renal injury [14]. In a recent study of 151 patients who presented with Grade 4 or 5 renal injuries following blunt trauma, NOM was successful in 89% of the Grade 4 injuries and 52% of the Grade 5 injuries. The primary reasons for failure of non-operative management included persistent hemorrhage or sepsis [15]. In another study examining NOM of severe BRT, the authors examined 206 patients with Grade 4 and Grade 5 renal injuries. Approximately 75% of the patients were managed non-operatively with only 12 patients failing the non-operative approach. Major risk factors for prediction of failure of NOM in this cohort were age (55+) and mechanism of injury (motor vehicle accidents). Those patients managed non-operatively had a 90% renal salvage rate while the renal salvage rate for the entire population was 76% [16].

Patients with penetrating renal injury, isolated to the flank or retroperitoneum without peritoneal involvement are also candidates for NOM. A recent study of 92 patients who presented with penetrating abdominal trauma and hematuria found that 70 patients had documented renal injury. Of those, 47 (67%) were managed non-operatively with no conversions to open surgical exploration. Of the 25 injured kidneys which were surgically explored, 9 kidneys were initially treated with renorrhaphy and overall 18 (72%) kidneys underwent nephrectomy [17]. A second study evaluated the role of NOM in renal stab wound. Armenakas described successful NOM in

Table 1 AAST Kidney Injury Scale

Grade	Type of injury	Description of injury
1	Contusion	Microscopic or gross hematuria, urologic studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
2	Hematoma	Nonexpanding perirenal hematoma confined to renal retroperitoneum
	Laceration	< 1.0-cm parenchymal depth of the renal cortex without urinary extravasation
3	Laceration	> 1.0-cm parenchymal depth of the renal cortex without collecting system rupture or urinary extravasation
4	Laceration	Parenchymal laceration extending through the renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
5	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularizes the kidney

Advance one grade for bilateral injuries up to Grade 3

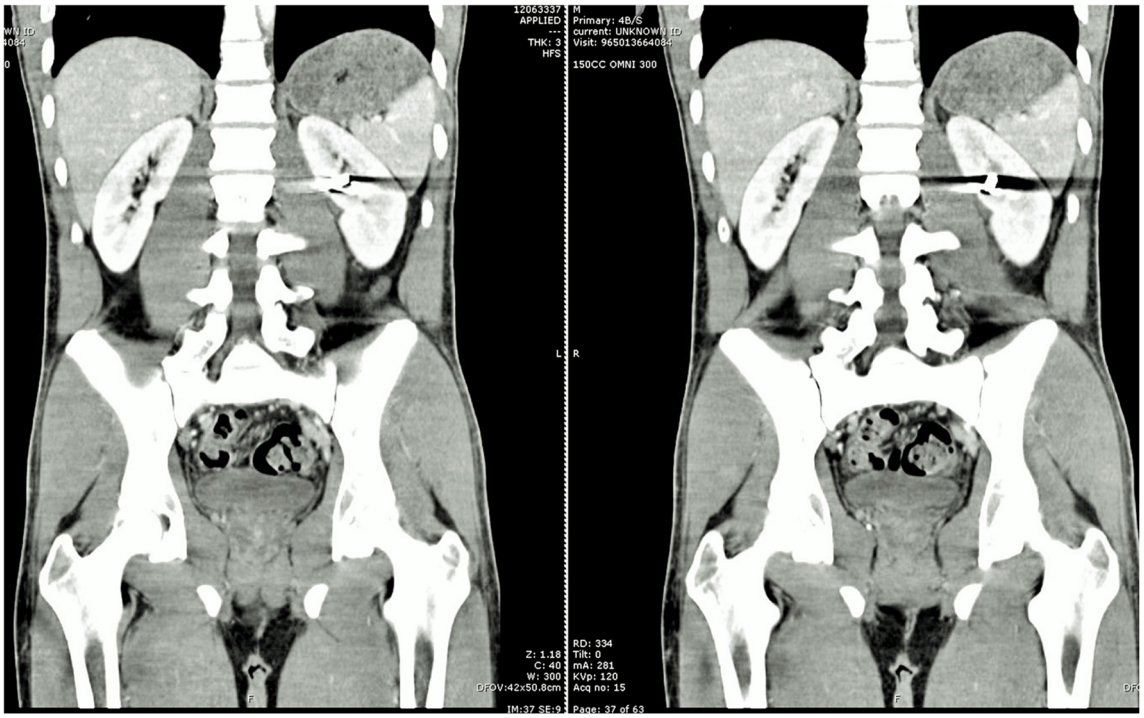

Fig. 1 Preoperative coronal CT scan showing bullet in the left kidney

54% of 200 injuries. Three of the patients initially treated with NOM did require surgical intervention; however, 80% of the kidneys were reconstructed successfully with only a 12% nephrectomy rate [18].

NOM for blunt renal injuries in children is also an accepted option for HGRI [19]. In a meta-analysis of published studies on pediatric patients with Grade 4 renal injuries, 73% of the patients were managed non-operatively without the need for any subsequent interventions [20]. Another study explored failure of conservative management in pediatric renal trauma and found that the patients who required intervention had a higher transfusion rate, larger perinephric hematomas, a laceration located in the antero-medial portion of the kidney, and active intravascular contrast extravasation [21].

While NOM may be appropriate for both blunt and penetrating renal injury, there are circumstances in which open surgical management is necessary. A recent retrospective review examined a national trauma database of more than 19,000 renal injuries. The factors that predicted failure of NOM included PRT (e.g., gunshot wounds and stab wounds), higher grade injuries of associated intra-abdominal organs, and higher renal injury grade [22].

Minimally Invasive Intervention

In patients who fail NOM or it is deemed inappropriate, possible treatment options include either operative management or minimally invasive interventions. Multiple variables must be taken into consideration prior to making this decision including hemodynamic stability of the patient, accompanying other organ injuries, extensiveness of the injury, and the salvageability of the kidney.

A minimally invasive option for failed NOM due to active kidney bleeding is angiography with embolization. As the trend for expectant management has risen in renal trauma patients, super-selective embolization of the specific injured artery has increased. A recent study of more than 9000 renal injuries from a national trauma database found that 165 patients underwent diagnostic angiography with 47% undergoing angioembolization as well. However, 68 of these patients did require a second procedure, with repeat angioembolization being the most common. Despite the need for multiple procedures, the overall renal salvage rate was 92%, including 88% for Grade 4 and Grade 5 injuries [23]. Breyer et al. introduced their experience with 26 patients undergoing angiography and angioembolization treatment due to renal bleeding. This study included not only renal trauma patients but patients with iatrogenic renal injury and spontaneous hemorrhage from renal masses. Most patients were successfully managed with embolization, including most of the Grade 4 renal injuries. However, embolization did fail in all Grade 5 traumatic injuries [24]. Another study demonstrated a higher success managing Grade 5 BRT with angiography and embolization. Ten hemodynamically unstable patients underwent successful treatment, with resolution of active arterial contrast extravasation and only one complication, a new diagnosis of hypertension [24, 25].

Failure of NOM due to complications other than bleeding could also be managed with minimally invasive interventions, namely ureteral stent or percutaneous nephrostomy insertions to deal with urine leakage and percutaneous drainage for urinomas and nephric or perinephric abscesses.

Open Operative Management

The indications for open surgical management and renal exploration in patients with renal trauma include hemodynamic instability unresponsive to fluid resuscitation and/or angiographic intervention, penetrating abdominal or retroperitoneal trauma, an expanding or pulsatile retroperitoneal hematoma identified during trauma laparotomy, the inability to accurately assess the injury radiographically, and failure of NOM and/or minimally invasive treatments. High AAST grade kidney injury by itself is not an absolute indication for open exploration. Although stable hematomas detected during exploration for associated injuries should not be opened, central or expanding hematomas indicate injuries of the renal pedicle, aorta, or vena cava and mandate exploration.

Efforts have been made to delineate which Grade 4 injuries require urgent intervention. In an analysis of 102 patients with Grade 4 injuries at a Level I trauma center, a large perirenal hematoma, intravascular extravasation, and medial laceration were all strong predictors for urgent intervention [26]. These findings have been reinforced by other studies which found that these factors were also prognostic indicators of intervention for renal hemorrhage in their trauma patients [27, 28].

The preferred surgical approach is through midline laparotomy in the setting of trauma (Fig. 2). Often, the trauma surgical team had performed a rapid assessment of the intraoperative contents and the kidneys are explored after life-threatening injuries are evaluated or managed. In patients taken directly to the operating room without imaging, a single shot intravenous urogram can be used to assess for presence of a functioning contralateral kidney.

Our preference is to obtain early, rapid vascular control of the affected renal unit. Access to the vascular pedicle could be obtained either through the posterior parietal peritoneum and incising over the aorta medial to the inferior mesenteric vein, or by dissecting along the plane of the psoas muscle fascia lateral to the great vessels and directly clamping the hilum [26].

Few studies have evaluated the need for vascular control prior to renal surgery in the setting of trauma. One randomized prospective trial examined 56 patients with PRT who were randomized to undergo upfront vascular control versus no vascular control. They did not find any significant differences in blood loss or nephrectomy rates between the two groups but did see an increased operative time in the vascular control group. However, of the 17 patients with Grade 4 or 5 injuries, only 1 patient underwent partial nephrectomy; the remaining required complete nephrectomy, and the randomization of groups was inconsistent [29].

In patients found to have renal injury, the entire kidney should be exposed, taking care not to injure the renal capsule, to reveal any lacerations, evacuate hematoma, and facilitate full mobility for repair (Fig. 3).

Suture ligation of bleeding vessels and closure of the collecting system with absorbable suture, 3-0 or 4-0 polyglactin, followed by parenchyma and capsular approximation with absorbable suture is necessary for renal salvage and reconstruction (Fig. 4). At our institution, we use 2-0 polyglactin, placed in a horizontal mattress fashion to reapproximate the capsule. While there is no literature noting the best hemostatic agent, using hemostatic agents and tissue sealants may aid in the post-operative hemostasis following acute reconstruction. Additionally, surgical bolsters, for example rolled Surgicel©, can assist with closure of the dead space

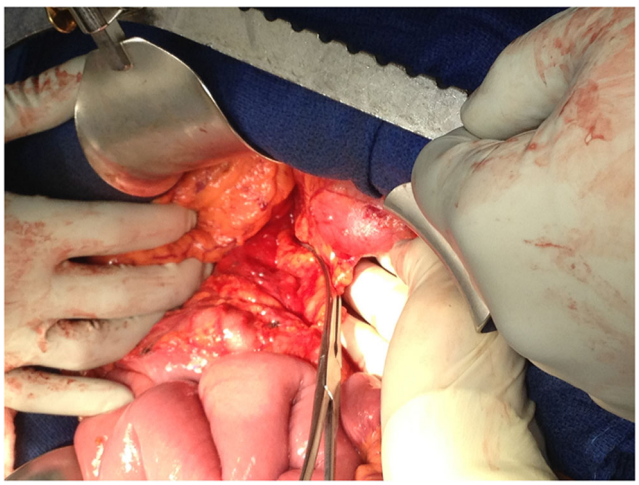

Fig. 2 Exploratory laparotomy of a patient with left kidney trauma showing primary renal pedicle control with a vascular clamp

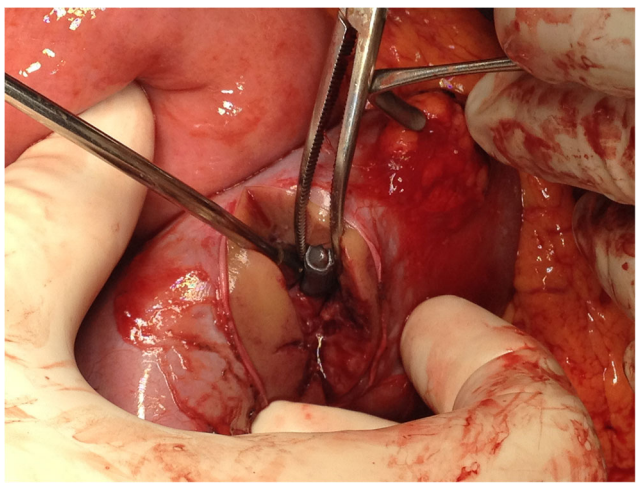

Fig. 3 Extraction of bullet from the left kidney

Fig. 4 Repaired left kidney showing the protruding bolsters of coagulating agent

and assist with hemostasis. Our preferred method is shown in Fig. 4. Other options include the use of a peritoneal or omental patch and other cellulose-derived products such as Gelfoam©. If there is a significant loss of renal capsule, the use of hemostatic products, such as Nu-Knit (layered cellulose), is helpful with reapproximation of the renal parenchyma as a backing bolster suture. Finally, a closed suction drain should be used when the collecting system is violated, to assist with drainage of any unanticipated urine leak and prevent urinoma formation.

A review of national trauma data of over 6200 renal injuries representing 62% of the US population showed an 11% rate of surgery and a 7% nephrectomy rate. Of the patients undergoing exploration, the nephrectomy rate was 64% which was greater than previously reported rates of 11–47% [3••]. Voelzke and colleagues specifically evaluated management of penetrating renal injury secondary to gunshot wounds. They reviewed over 200 patients who presented with renal gunshot wounds, and approximately 50% of these patients required open surgery with reconstruction or repair of the kidney. Of patients who underwent surgery, 15% had nephrectomy, and the majority of nephrectomies were in patients with Grade 5 injuries [30]. Others have shown that predictors of nephrectomy include overall injury severity, renal AAST, ISS, hemodynamic instability, and need for blood transfusions in both PRT and BRT [31]. These findings were further supported by a study reviewing national trauma data bank that showed AAST grade of renal injury was the strongest predictor of the need for nephrectomy. Other predictors included the need for laparotomy for other injuries and the need for repair of bowel injury [32•].

In a recent study of patients with high-grade BRT (here defined as AAST Grades 3–5), 4 of the 44 required immediate nephrectomy with Grade 5 injuries, and another 3 patients underwent delayed nephrectomy due to persistent hemorrhage and blood transfusion requirements. A ureteral stent and percutaneous drain were needed for one patient who had urinary extravasation. Angioembolization was needed for a pseudoaneurysm and one renorrhaphy was performed [33]. Another prospective study examined the management of over 150 cases of Grade 4 renal injuries at an urban Level I trauma center. These authors compared 43 cases of isolated renal injury with 110 cases of renal injury associated with other intra-abdominal injuries. HGRIs with associated injuries to other intra-abdominal organs are more likely to require operative exploration, and thus renal reconstruction was more likely to be attempted. Of the cases with isolated renal injury, 58% underwent NOM. Patients with persistent bleeding, requiring multiple transfusions, were more likely to be explored surgically. Other indications for exploration included injury to the ureteropelvic junction, a large area of devitalized tissue, and incomplete radiologic evaluation. Overall, isolated kidney injuries required fewer explorations (42 versus 77%); however, the renal salvage rate was identical at 88% [34].

Of patients who undergo open surgery within the first 24 h of presentation for their renal trauma, the nephrectomy rate was found to be 64% in a study of national trauma data. Patients undergoing surgery tended towards higher grade injuries on the AAST scale, 82.9% AAST Grade 4–5 BRT and 53.8% AAST Grade 4–5 PRT [35•]. While some renal injuries necessitate nephrectomy, open surgery does not always result in complete nephrectomy. Damage control maneuvers (e.g., external drainage, packing) can be utilized in an unstable patient to allow salvage of the injured kidney once the patient has been resuscitated and stabilized [36]. Finally, in comparing NOM with open surgical intervention, a recent literature review examined 11 studies comprising 1500 patients with HGRI. Mortality and nephrectomy rates were lower in the NOM group; whereas, there was no difference in the complications rate. However, a possible selection bias exists in the open surgery patient groups as these patients had higher numbers of Grade 5 injuries, hemodynamic instability, and a higher ISS on presentation compared to the NOM patients [37].

Effect on Renal Function/Future Directions

Both conservative management and open surgery carry risk of complications. A recent review of the literature found conflicting data on complication rates between the two strategies. This review also examined overall mortality rates between the two strategies and found higher rates in the operative group, although this was likely due to selection bias as the more severely injured patients were more likely to undergo exploration. Additionally, nephrectomy rates were higher in the exploration groups [37]. In Grade 4 injuries due to BRT, studies have reported preserved function of 35–40% in the injured

kidney [15]. Long-term follow-up is generally poor for trauma patients, but extrapolating from the partial versus radical nephrectomy data for renal cancer; radical nephrectomy is associated with an increased risk of developing chronic kidney disease as well as a decrease in overall survival when compared to partial nephrectomy [37].

More recently, laparoscopic management of renal trauma has been described. In a case report of a Grade 4 renal injury with extensive devitalized parenchyma and urinary extravasation, a laparoscopic nephrectomy was performed during the acute hospitalization [38]. A second study described successful retroperitoneal laparoscopic nephrectomy for 3 patients with Grade 4 BRT who had failed angioembolization and were hemodynamically unstable [39]. Nonetheless, it should be emphasized that this should only be performed by highly experienced laparoscopic surgeons in select circumstances. Open surgical repair or nephrectomy remains the standard approach for management of the injured kidney in acute trauma patients.

Future directions include hybrid operating rooms which have immediate imaging capabilities such as angiography, CT, or even magnetic resonance imaging and are equipped for minimally invasive procedures as well. These may play a greater role in the future management of renal trauma allowing simultaneous advanced diagnosis and immediate management of identified intra-abdominal and renal vascular injuries. One recent case report describes a patient who suffered blunt abdominal trauma and underwent open splenectomy and endovascular management of an injury to the renal artery [40].

Conclusion

Currently, most renal traumas are managed non-operatively. However, there still remains an important role for open surgery. Hemodynamically unstable patients with high-grade PRT and those with concomitant intra-abdominal injuries are more likely to require open surgery. When performing open surgery for renal trauma, every effort should be made to perform reconstruction with renal preservation unless the severity of injury or clinical scenario dictates otherwise. Successful management of renal trauma with renal sparing techniques can help lessen or prevent long-term sequelae of chronic renal insufficiency.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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