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Review

Iatrogenic Trauma During Percutaneous Nephrolithotripsy: Current Approaches to Diagnosis, Treatment, and Prevention

Kuandyk Beisenov [1], Yuriy Pak [2], Roman Kim [3], Yerzhan Sharapatov [4*]

[1] Associate Professor of the Department of Urology and Andrology, Sharmanov National Medical University, Astana, Kazakhstan. E-mail: Alisher.turlygul@gmail.com
[2] Head of the City Urology Center at City Multidisciplinary Hospital No. 2, Astana, Kazakhstan. E-mail: Uropak78@mail.ru
[3] Head of the Department of Urology, National Coordination Center for Emergency Medicine, Astana, Kazakhstan. E-mail: kvroman0999@gmail.com
[4] Professor of the Department of Urology and Andrology, Sharmanov National Medical University, Astana, Kazakhstan. E-mail: erzhan.uro@gmail.com

*** Corresponding author:** : erzhan.uro@gmail.com

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Abstract

Percutaneous nephrolithotripsy is the leading surgical treatment for large, multiple, and complex kidney stones; however, establishing percutaneous access and performing intrarenal manipulations carry a risk of iatrogenic injury.

This review aims to systematize current data on the mechanisms, risk factors, diagnosis, treatment, and prevention of traumatic complications associated with percutaneous nephrolithotripsy.

A targeted search of clinical guidelines, systematic reviews, meta-analyses, multicenter studies, and representative clinical series was conducted using the PubMed, Scopus, and Web of Science databases.

The review covers injuries to the renal parenchyma and pelvicalyceal system, arterial and venous bleeding, pseudoaneurysm, arteriovenous fistula, and damage to the pleura, lung, colon, liver, spleen, and other adjacent structures. The most significant predictors of complications include incorrect puncture trajectory, upper-pole supracostal access, multiple puncture tracts, high stone burden, active urinary tract infection, abnormal renal anatomy, comorbidities, and insufficient surgeon experience. Early diagnosis relies on a comprehensive assessment of intraoperative signs, hemodynamic parameters, hemoglobin trends, and findings from ultrasound and contrast-enhanced computed tomography.

Most limited injuries are successfully managed through adequate drainage, hemostatic therapy, antibiotic treatment, and close monitoring. Persistent or delayed arterial bleeding requires selective angiography and superselective embolization of the injured vessel. Open surgery is rarely performed, primarily in cases of hemodynamic instability or when minimally invasive methods prove ineffective. Preventive measures include meticulous preoperative imaging, individualized planning of a safe access route, the use of ultrasound and combined navigation systems, monitoring of intrarenal pressure, limiting the number of access tracts, and standardizing surgical technique. Teamwork, readiness to immediately switch treatment strategies, the availability of interventional radiology services, and clear protocols for the postoperative monitoring of patients at high risk of hemorrhage or injury to adjacent organs during the early postoperative period are of particular importance.

This comprehensive approach enables the timely detection of injury, the selection of organ-sparing strategies, and a reduction in the incidence of severe complications.

Keywords: percutaneous nephrolithotripsy, iatrogenic injury, bleeding, injury to adjacent organs, angioembolization, prevention of complications.

1. Introduction

Urolithiasis is one of the most common diseases of the urinary system and is characterized by high rates of recurrence, repeat interventions, and loss of ability to work [1].

Percutaneous nephrolithotripsy remains the treatment of choice for large stones, staghorn calculi, and complex intrarenal anatomy, as it achieves higher stone-free rates compared to extracorporeal shock wave lithotripsy and retrograde intrarenal surgery in cases of high stone burden [2]. Current European Association of Urology guidelines regard the percutaneous approach as the first-line standard for kidney stones larger than 20 mm, as well as for certain lower-pole stones and staghorn calculi [3].

Despite the development of miniaturized instruments, improved visualization, and the widespread adoption of ultrasound guidance, the procedure carries a specific risk of injury to the renal parenchyma, the pelvicalyceal system, segmental vessels, and adjacent organs. According to a global study by the Clinical Research Office of the Endourological Society, which covered more than 5,800 interventions, the complication rate following percutaneous nephrolithotomy was approximately 20%, although the majority of these complications were of low severity [4,5]. According to a global study by the Clinical Research Office of the Endourological Society involving over 5,800 procedures, the complication rate following percutaneous nephrolithotomy was approximately 20%, although the majority of complications were of low severity [5, 6]. In large series, the rates are typically 2–7% for blood transfusion, <1–2% for embolization, approximately 1–3% for pleural complications, and <1% for colonic injury. The variation in these figures reflects differences in complication definitions, stone complexity, tract diameter, patient positioning, and center experience [5–10].

The clinical significance of the problem is determined not only by the immediate risk of severe bleeding or damage to an adjacent organ. Even limited trauma can lead to urinoma, prolonged urinary fistula, clot obstruction, readmission, additional imaging, and interventions. Delayed vascular complications, primarily pseudoaneurysm and arteriovenous fistula, often present after discharge with sudden macrohematuria and a drop in hemoglobin. Therefore, safety is determined by the entire chain of care: preoperative planning, technical access, recognition of intraoperative danger signals, and organized postoperative monitoring [11-13].

Literature regarding complications of percutaneous surgery is heterogeneous. Most data on rare injuries are derived from retrospective series and case reports, whereas randomized trials are generally focused on comparisons of tract size, patient positioning, drainage methods, or navigation techniques and are insufficiently powered to evaluate uncommon adverse events [14]. Furthermore, complications may be classified according to the Clavien–Dindo system or its modifications, or reported without standardized definitions and information about their management. Even among studies applying established classification systems, reported complication rates remain markedly heterogeneous [15]. This necessitates a critical synthesis of the available evidence, clearly distinguishing reproducible clinical patterns from conclusions based on small series and isolated observations.

The relevance of this review stems from the expanding indications for mini-percutaneous techniques, the increasing number of procedures performed on patients with obesity, comorbidities, and renal anomalies, and the shift of some interventions toward shorter hospital stays. In this context, preventing injury requires not only reducing instrument diameter but also personalizing the access trajectory and accounting for the retrorenal position of the bowel, the level of the pleural recess, vascular architecture, and intrarenal anatomy [16,17].

The purpose of the review is to systematize and critically evaluate current data on the causes, mechanisms, clinical manifestations, diagnosis, treatment, and prevention of iatrogenic injuries occurring during percutaneous nephrolithotripsy.

2. Materials and methods

To prepare this review, a thematic search for publications was conducted in the PubMed, Scopus, and Web of Science databases. The search utilized English-language terms—such as “percutaneous nephrolithotomy,” “percutaneous nephrolithotripsy,” “complication,” “iatrogenic injury,” “bleeding,” “vascular injury,” “pseudoaneurysm,” “arteriovenous fistula,” “collecting system perforation,” “colon injury,”

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"pleural injury," "hydrothorax," "liver injury," "splenic injury," and "supracostal access"—along with their corresponding equivalents. Additionally, the reference lists of relevant reviews and guidelines were analyzed (Table 1).

Table 1 – Expanded publication selection flowchart based on PRISMA 2020 principles

PRISMA stage	Description	Number
Identification	Records identified in databases and additional sources	1110
Duplicate removal	Duplicate records identified after merging results	286
Pre-screening	Records with no available bibliographic data, irrelevant publication types, and technical duplicates	31
Screening	Titles and abstracts screened for relevance to the review topic	793
Excluded during screening	Publications unrelated to traumatic complications of percutaneous surgery	621
Full text requested	Publications selected for full-text assessment	172
Full text not received	Publications for which full-text assessment was not possible	9
Eligibility assessment	Full-text publications screened against inclusion criteria	163
Excluded after assessment	Full-text publications that did not meet criteria for analytical synthesis	93
Inclusion	Unique sources included in the qualitative analytical synthesis	70

The final analytical array included 70 sources. The highest level of evidence was available for overall complication rates, comparative safety of standard and miniature tracts, factors of blood loss, and results of selective angioembolization. Data on damage to the colon, liver, spleen, duodenum and pleurorenal fistulas are represented mainly by case series and clinical cases. Therefore, frequency estimates for rare injuries should be interpreted as indicative, and clinical management should be adapted to the patient's stability, location of injury, presence of infection, and availability of interventional radiology.

3. Results

Classification and General Mechanisms of Iatrogenic Trauma

It is appropriate to classify iatrogenic injuries based on the operative stage, anatomical location, and time of onset. During the puncture phase, potential complications include injury to an interlobar or segmental artery, trans-parenchymal passage outside the safe zone, and perforation of the pleura, lung, colon, liver, or spleen. During tract dilation, injury may be exacerbated by the dilator deviating from the guidewire, excessive advancement of the sheath, or the creation of a tract that is not aligned with the axis of the selected calyx. During the nephroscopy phase, injury is associated with leverage movements of the instrument, perforation of the calyceal neck or renal pelvis, fragment migration, and thermal energy effects [18,19].

Based on location, injuries are classified as involving the renal parenchyma and vessels, the collecting system, the ureter, thoracic organs, and intra-abdominal or retroperitoneal structures. Based on the timing of clinical manifestation, injuries are categorized as intraoperative, early postoperative, or delayed. This classification is of practical importance: venous bleeding usually becomes apparent during the procedure and often ceases following tamponade, whereas a pseudoaneurysm may manifest days or weeks later. Bowel injury is sometimes detected not at the time of puncture, but rather following the onset of fever, the appearance of intestinal contents via the nephrostomy tube, or the development of retropneumoperitoneum [20,21].

The Clavien–Dindo system allows for the grading of injury consequences based on the extent of treatment required. An injury managed by prolonged drainage or pharmacological therapy is classified as low-grade; the need for endoscopic, endovascular, or surgical intervention corresponds to grade III; organ failure to grade IV; and death to grade V. However, the same anatomical injury may be assigned a different grade depending on the timeliness of its detection [22].

Injury to the renal parenchyma and collecting system

The creation of a percutaneous tract is inevitably accompanied by limited damage to the parenchyma, however, a properly selected puncture through the posterior calyx papilla passes in a relatively low-vascular plane and minimizes the risk of significant

bleeding. The danger increases with medial puncture, passing through the neck of the cup at an acute angle, inserting the needle or dilator too deeply, and repeated attempts at access. The tangential canal increases the length of the intrarenal tract and forces the surgeon to use the nephroscope as a lever, widening the parenchymal rupture [23,24].

Perforation of the calyx or renal pelvis manifests as a sudden loss of image clarity, reduced irrigation fluid return, contrast extravasation, and the appearance of a perirenal collection. Minor injury occurring under low irrigation pressure typically does not lead to severe consequences. Continuing the procedure in the presence of poor visualization, high pressure, and active infection increases the risk of urinoma, fragment extravasation, electrolyte imbalances, and sepsis. In cases of significant perforation, it is recommended to halt active lithotripsy, establish internal or external drainage, and assess the extent of the extravasation [24,25].

The micro-percutaneous technique warrants special attention. The minimal tract diameter reduces parenchymal trauma but limits fluid outflow. During vigorous irrigation, intra-pelvic pressure can rise, leading to pyelovenous and pyelolymphatic reflux, calyceal perforation, and the migration of fragments outside the kidney. Consequently, reducing the access diameter does not automatically lower all risks; controlled irrigation, unimpeded outflow, and continuous monitoring of visibility are essential [26].

Fluid extravasation into the retroperitoneal space typically resolves following the cessation of irrigation and adequate drainage. Massive accumulation may lead to increased intra-abdominal pressure, respiratory impairment, and abdominal compartment syndrome. Clinical signs include progressive abdominal distension, hypotension, rising airway pressure, hypothermia, and a discrepancy between the volume of fluid infused and the volume recovered. Such a situation necessitates immediate termination of the procedure, assessment via ultrasound or computed tomography, and drainage of any significant fluid collection [27,28].

Vascular Injuries and Bleeding

Bleeding is the most common traumatic complication of percutaneous nephrolithotripsy. Its source may be parenchymal veins, interlobar and segmental arteries, or vessels within the wall of the pelvicalyceal system. Venous bleeding is typically diffuse, associated with tract dilation, and subsides following temporary occlusion with a nephrostomy tube. Arterial injury is characterized by pulsatile bleeding, a rapid drop in hemoglobin levels, hemodynamic instability, or recurrent gross hematuria [29].

Factors associated with blood loss include a large stone burden, staghorn calculi, the absence of hydronephrosis, multiple access tracts, prolonged operative time, a large-diameter tract, diabetes mellitus, infection, anatomical abnormalities, and surgeon inexperience. Some studies link the risk to upper-pole access; however, this effect is partly attributable to stone complexity and the need for a longer tract [29]. Systematic reviews confirm that tract miniaturization generally reduces the drop in hemoglobin levels and the rate of blood transfusions, though it may increase the duration of lithotripsy [30].

The initial management strategy for moderate intraoperative bleeding involves halting traumatic maneuvers, maintaining the guidewire position, achieving temporary tamponade using the working sheath or a nephrostomy catheter, correcting coagulopathy, and assessing hemodynamic status. Blindly continuing lithotripsy when anatomical landmarks have been lost is unacceptable. If necessary, the procedure is concluded with drainage, as attempting complete stone removal in the presence of bleeding increases the risk of further vascular injury [31].

A pseudoaneurysm forms when a damaged artery communicates with a contained cavity, whereas an arteriovenous fistula arises from simultaneous injury to an artery and a vein. Typical clinical manifestations include delayed gross hematuria—sometimes accompanied by urinary retention due to clots, pain, tachycardia, and a drop in hemoglobin levels. In hemodynamically stable patients, the optimal imaging modality is multiphase contrast-enhanced computed tomography or CT angiography. In cases of ongoing, clinically significant bleeding, diagnostic angiography simultaneously offers the opportunity for therapeutic intervention [32,33].

Superselective angioembolization has become the treatment of choice for arterial bleeding following percutaneous intervention [29]. The use of a microcatheter allows for the occlusion of a pseudoaneurysm or fistula with minimal loss of functioning parenchyma. Technical success rates in specialized series exceed 85–90%; repeat embolization is required in cases of multiple bleeding sources, vasospasm, or incomplete occlusion. Open surgical exploration or nephrectomy is rarely necessary and is considered in cases of hemodynamic instability, failure to achieve endovascular control, or concomitant renal disruption [34].

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Pleural and pulmonary complications

A supra-costal approach provides a direct trajectory to the upper calyx and the ureteropelvic junction but increases the likelihood of injury to the diaphragm, pleura, and lung. The risk rises with puncture above the eleventh rib, a high-lying kidney, inspiration during needle advancement, and a lateral trajectory. The pleural recess extends below the twelfth rib along the posterior axillary line; therefore, the anatomically safe zone varies depending on the respiratory phase and patient position [35].

Potential complications include hydrothorax, hemothorax, pneumothorax, nephropleural fistula, and injury to the lung parenchyma. Intraoperative signs may include decreased oxygen saturation, increased airway pressure, and the appearance of fluid in the pleural cavity on ultrasound. Postoperatively, dyspnea, chest pain, tachypnea, diminished breath sounds, and unexplained hypoxemia raise concern. Small, asymptomatic effusions can be monitored expectantly, whereas significant hydrothorax, hemothorax, or pneumothorax requires pleural drainage [36].

Prevention relies on careful analysis of preoperative CT scans, performing the puncture closer to the superior border of the rib below, coordination with the anesthesiologist, and advancing the needle through the diaphragm during controlled expiration. Once the calyx is entered, the guidewire and dilators are advanced during breath-holding without altering the trajectory. When using an approach above the eleventh rib, there should be a low threshold for postoperative ultrasound or radiographic assessment [37].

Colon injury

Colon injury is rare, but delayed diagnosis can lead to fecal peritonitis, retroperitoneal abscess, and sepsis. Predisposing factors include a retrorenal position of the colon, significant weight loss, advanced age, prior abdominal surgery, spinal deformities, horseshoe or ectopic kidney, megacolon, and puncture lateral to the posterior axillary line. The prevalence of a retrorenal colon on CT scans varies depending on body position and the level of the slice; this anomalous position is detected more frequently on the left side [38,39].

Injury may be recognized by the appearance of gas or bowel contents via the nephrostomy tube, visualization of the colonic mucosa, an unusual guidewire course, or contrast extravasation into the bowel lumen. Delayed symptoms include fever, pain, leukocytosis, diarrhea, fecal fistula, and retropneumoperitoneum. If injury is suspected, contrast-enhanced CT is performed; antegrade nephrostomography is helpful in selected cases [40,41].

In cases of extraperitoneal injury in a stable patient without diffuse peritonitis, conservative management is often feasible: the nephrocolic tract is isolated from the urinary system, the nephrostomy tube is gradually withdrawn from the kidney into the colon to serve as a colostomy drain, urine is diverted via an internal stent, broad-spectrum antibiotics are administered, and enteral nutrition is temporarily restricted. The drain is removed after confirmation of fistula closure. Intraperitoneal perforation, septic instability, bowel wall necrosis, or the failure of conservative management necessitate surgical intervention [42].

The most reliable preventive measure is the identification of a retrorenal bowel loop on preoperative computed tomography. In cases of anatomical anomaly, ultrasound-guided puncture with visualization of the inter-organ space or CT-guided puncture is preferred. Needle trajectories that are excessively lateral or horizontal should be avoided. In patients with a horseshoe kidney, the approach is typically made more medially and posteriorly, taking into account the anterior position of the renal pelvis and vascular anatomical variations [40,43].

Injury to the liver, spleen and other organs

Injuries to the liver and spleen are extremely rare and are primarily associated with an upper-pole approach. Liver puncture is more likely on the right side in cases of hepatomegaly, a low-lying liver, or a high-positioned kidney; splenic injury is more likely on the left in cases of splenomegaly and a supra-costal trajectory. A small trans-parenchymal tract may remain asymptomatic and close spontaneously following controlled removal of the nephrostomy tube. Persistent bleeding, an expanding hemoperitoneum, hemodynamic instability, or injury to the organ hilum require the involvement of an interventional radiologist and an abdominal surgeon [35,41].

Contrast-enhanced computed tomography (CT) allows for the assessment of the tract's course and the detection of active extravasation, subcapsular hematoma, and free fluid. In hemodynamically stable patients, an organ-sparing approach is preferred: observation, serial hemoglobin monitoring, temporary retention of the drainage catheter to act as a tamponade, and selective embolization if the bleeding source is arterial. Immediate removal of a catheter traversing a parenchymal organ may eliminate the tamponade effect and exacerbate bleeding [44].

Isolated injuries to the duodenum, gallbladder, pancreas, and major vessels have been reported. Due to their rarity, no standardized management algorithms exist. General principles include terminating the procedure, retaining the guidewire or drainage catheter until the anatomy is clarified, performing contrast-enhanced CT, obtaining early multidisciplinary consultation, and controlling the source of

contamination or hemorrhage. If injury to the aorta or inferior vena cava is suspected, any manipulation of an instrument within the vessel must be performed only when there is readiness for endovascular or open vascular control [45].

Ureteral injury and drainage complications

Injury to the ureteropelvic junction and proximal ureter can occur during forceful advancement of a guidewire, dilator, forceps, or nephroscope. The risk is increased in cases of impacted stones, inflammatory stenosis, or attempts to extract a large fragment through a narrow infundibulum. Perforation is typically managed with internal stenting and adequate drainage; continuing aggressive manipulation increases the likelihood of extravasation and subsequent stricture formation [46].

Nephrostomy catheters and internal stents can also cause iatrogenic injury if malpositioned. A balloon inflated within the renal parenchyma or a blood vessel causes pain and hemorrhage, while advancing the catheter too deeply can injure the ureteropelvic junction. Rarely, the proximal end of an internal stent may embed itself into a perforation in the renal pelvic wall. Before securing the drainage device, its position must be confirmed via nephroscopy or contrast imaging; imaging studies should also be performed in the event of atypical pain, lack of drainage, or progressive hematuria [47].

Influence of patient position, navigation method, and tract size

Percutaneous nephrolithotripsy is performed with the patient in the prone or supine position, or in various modified positions. The prone position offers a large surface area for selecting the puncture site and provides familiar anatomical landmarks. The supine position facilitates anesthetic access, allows for simultaneous retrograde procedures, and may reduce the risk of colonic injury due to bowel displacement; however, the available puncture zone is more limited. Meta-analyses show no consistent superiority of one position over the other regarding the overall rate of severe complications; outcomes depend largely on the team's experience [48].

Fluoroscopy clearly visualizes the pelvicalyceal system following contrast administration and the position of the instruments, but it does not directly visualize the pleura, bowel, or blood vessels. Ultrasound guidance allows for visualization of the kidney, puncture depth, and intervening organs; it reduces or eliminates radiation exposure and is particularly useful in cases of a non-dilated system, pregnancy, or atypical anatomy. Combined use of ultrasound and fluoroscopy integrates the advantages of both methods. In complex cases, CT guidance, endoscopically controlled puncture, or electromagnetic systems are employed [49].

Diagnosis and initial management algorithm

Recognition of an injury occurs during the procedure. A sudden loss of visibility, a mismatch in irrigation volume, an unusual guidewire position, contrast extravasation, hemodynamic instability, a drop in oxygen saturation, or the appearance of material atypical for the urinary tract necessitates an immediate halt to the procedure. The primary question is not whether the stone removal can be completed, but rather the nature of the injury and the safety of proceeding with the intervention [50].

If an injury is suspected, controlled access should be maintained, irrigation pressure reduced, limited contrast imaging performed, and vital signs assessed. If visibility is not restored or the anatomy remains unclear, the procedure is concluded by placing a drain. Postoperative monitoring includes assessment of pulse rate, blood pressure, urine output, urine color, hemoglobin and creatinine levels, and signs of systemic inflammation. The choice of imaging modality depends on the suspected complication: ultrasound detects hydrothorax and large fluid collections, whereas contrast-enhanced computed tomography (CT) provides better characterization of vascular injury and damage to adjacent organs [51].

In the event of bleeding, hemodynamic stability is assessed first. For a stable patient without ongoing significant blood loss, observation, nephrostomy tube tamponade, coagulation correction, and serial monitoring are acceptable approaches. Recurrent gross hematuria, the need for repeat transfusion, a drop in hemoglobin levels, or active extravasation are indications for angiography and selective embolization. In cases of shock, resuscitation measures are initiated concurrently with efforts to immediately control the source of bleeding. When injury to a hollow viscus is suspected, the intraperitoneal or extraperitoneal nature of the injury and the presence of sepsis must be determined. An isolated retroperitoneal bowel injury in a stable patient may be managed by separating the urinary and intestinal tracts, whereas peritonitis necessitates surgery. In cases of pleural injury, the extent of intervention depends on the degree of respiratory failure and the size of the collection. Regardless of the injury site, clinical deterioration during conservative management warrants early escalation of care rather than prolonged observation [52,53].

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Prevention of iatrogenic trauma

Prevention begins with an analysis of thin-slice computed tomography (CT) scans. The surgeon must assess the spatial arrangement of the calyces, parenchymal thickness, intercostal spaces, the kidney's relationship to the pleura, liver, spleen, and colon, as well as vascular variants. An access plan is formulated prior to patient positioning but is confirmed via ultrasound after positioning, as organ locations shift. In cases of complex staghorn calculi, it is essential to determine beforehand whether the target calyces can be reached via a single tract without excessive levering of the instrument [54].

Safe puncture is directed through the papilla of a posterior calyx along its axis. The needle is advanced using short, controlled movements; once urine is obtained, the position is confirmed via imaging. The guidewire must pass freely into the renal pelvis or ureter. Resistance encountered during dilator advancement must not be overcome by force; instead, one must check for kinking and ensure proper alignment. The working sheath should not be inserted deeper than necessary, particularly in cases of thin parenchyma or a non-dilated collecting system [55].

During lithotripsy, irrigation pressure is kept at the minimum level required to maintain visibility. Prolonged, stationary application of the laser or ultrasonic probe against the mucosa is unacceptable. Large fragments are extracted only after sufficient fragmentation, avoiding the forced passage of forceps through narrow infundibula. Procedures are halted if visibility deteriorates. Limiting operative time and employing a staged approach for complex stones is safer than attempting to achieve complete clearance at the cost of progressive tissue injury. Organizational measures include standardized monitoring of anticoagulant therapy, urine culture and treatment of infection, a protocol for managing massive hemorrhage, round-the-clock availability of interventional radiology, and team training in complication recognition. Simulation-based training in puncture techniques, mentorship, and outcome auditing are particularly important during the learning phase. A complication registry should document not only the need for intervention but also the access type, number of punctures, tract diameter, time to diagnosis, and functional outcome [56, 57].

Special clinical situations

In patients with a horseshoe, ectopic, or rotated kidney, standard surface landmarks are unreliable. The calyces may have an atypical posterior orientation, the renal pelvis may be located anteriorly, and the vascular supply often includes multiple accessory branches. Furthermore, the bowel frequently occupies a retrorenal position. Preoperative assessment of the spatial relationship between the kidney, blood vessels, and hollow viscera is essential; in cases of uncertainty, ultrasound or CT guidance for the puncture is preferred. Attempting to use a standard posterolateral trajectory without accounting for rotation increases the risk of the needle passing outside the renal parenchyma [58,59].

Obesity increases the depth of access, needle mobility within soft tissues, and the likelihood of losing coaxial alignment during tract dilation. A long access tract requires appropriate instrumentation and secure guidewire fixation. Concurrently, obesity can hinder ultrasound visualization and the assessment of blood loss based on external signs. Conversely, in patients with low body weight, the protective layer of retroperitoneal fat is reduced, meaning the bowel and parenchymal organs may lie closer to the intended trajectory [60].

In patients with a solitary kidney, even limited trauma carries a higher functional cost. The number of access tracts should be minimized, bleeding must be controlled with particular care, and reliable drainage ensured. In the presence of chronic kidney disease and anemia, there is less reserve to compensate for blood loss and contrast medium load. A decision to perform angiography should not be unduly delayed due to concerns about nephrotoxicity if ongoing bleeding threatens organ function; the contrast volume should be reduced, and embolization performed as selectively as possible. Repeat percutaneous surgery following open intervention, prior nephrolithotomy, or radiation therapy is complicated by scarring and impaired normal tissue mobility. While dilation may require greater force, advancing the dilator forcefully is particularly hazardous in this scenario. Preoperative imaging must delineate any deformity of the pelvicalyceal system and the position of the bowel, and the team should plan in advance for alternative access or a staged treatment approach [61,62].

4. Discussion

Current data indicate that the severity of iatrogenic injury is determined by a combination of anatomical damage and the timeliness of the response. Most limited parenchymal and venous injuries can be managed with drainage and observation. In contrast, ongoing arterial bleeding, intraperitoneal bowel perforation, and major vessel injury require active source control. A blanket approach favoring conservative management is as hazardous as unjustifiably early open surgery; the choice must be

based on hemodynamic status, contrast imaging findings, and the clinical course [63-66].

Instrument miniaturization significantly reduces mean blood loss but does not eliminate injury resulting from an incorrect trajectory. Moreover, high-volume irrigation through a narrow tract creates a distinct risk profile. Similarly, a supracostal approach should not be considered inherently flawed: when indications are appropriate, it improves access to complex calculi but requires respiratory coordination and management of the pleural space. Consequently, safety is ensured by matching the technique to the specific anatomical challenge rather than by simply selecting the "least invasive" instrument [66-68].

The quality of evidence is limited by the retrospective nature of most studies, variations in bleeding definitions, and incomplete reporting of delayed complications. Publications rarely specify the number of puncture attempts, the precise trajectory, or the operator's level of training, even though these factors can significantly influence risk. Future studies require a minimum standardized dataset: preoperative anatomy, patient positioning, navigation method, access location and level, tract diameter and number, intrarenal pressure, energy type, operative time, injury morphology, Clavien–Dindo grade, and functional outcome [15,69].

Promising areas of development include 3D planning, fusion of ultrasound and CT imaging, robotic needle positioning, and automated irrigation pressure control. However, new technologies must be evaluated not only based on the accuracy of calyceal targeting but also on their ability to reduce clinically significant injuries. Until such data become available, fundamental measures remain key: anatomical knowledge, deliberate coaxial puncture, avoidance of blind maneuvers, and early escalation of care upon signs of injury [70].

5. Conclusions

Iatrogenic injury during percutaneous nephrolithotripsy encompasses damage resulting from various mechanisms, with differing onset times and consequences. The risk is determined by renal anatomy, stone characteristics, the access method, technical procedural parameters, and the surgical team's experience.

Prevention and early diagnosis are the cornerstones of safety. Preoperative CT enables access trajectory planning, while ultrasound guidance allows for the assessment of organ positioning following patient placement. Key factors include coaxial tract dilation, low irrigation pressure, maintaining proper orientation, and timely termination of the procedure if visualization deteriorates.

In cases of arterial bleeding, CT angiography and superselective embolization achieve hemostasis while preserving renal parenchyma. Management strategies for injury to adjacent organs depend on the injury's location, the patient's stability, and the presence of infection.

Further safety improvements require the standardized recording of injury types, access parameters, timelines for diagnosis and treatment, and long-term renal function, alongside the conduct of prospective multicenter studies.

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AI Declaration. The authors used ChatGPT (OpenAI) to improve the manuscript's language and style and to assist with its organization and structure. The authors reviewed and edited all AI-assisted text and take full responsibility for the final content of the article.

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Тері арқылы нефролитотрипсия кезіндегі ятрогендік жарақат: Диагностика, емдеу және алдын алудың қазіргі заманғы тәсілдері

Бейсенов К.Т. [1], Пак Ю.Г. [2], Ким Р.В. [3], Шарапатов Е.А. [4*]

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[1] Урология және андрология кафедрасының доценті, Төрегелді Шарманова атындағы Ұлттық медицина университеті, Астана, Қазақстан. E-mail: Alisher.turlygul@gmail.com

[2] № 2 қалалық көпсалалы ауруханаңың қалалық урология орталығының меңгерушісі, Астана, Қазақстан. E-mail: Uropak78@mail.ru

[3] Урология департаментінің басшысы, Ұлттық шұғыл медицинаны үйлестіру орталығы, Астана, Қазақстан. E-mail: kvroman0999@gmail.com

[4] Урология және андрология кафедрасының профессоры, Төрегелді Шарманова атындағы Ұлттық медицина университеті, Астана, Қазақстан. E-mail: erzhan.uro@gmail.com

Түйіндеме

Перкутанды нефролитотрипсия - ірі, бірнеше және күрделі бүйрек тастарын хирургиялық емдеудің жетекші әдіс болып табылады. Дегенмен, перкутанды кіру және бүйрекішілік манипуляциялар ятрогенді зақымдану қаупімен байланысты.

Шолудың мақсаты: перкутанды нефролитотрипсияның жарақаттық асқынуларының механизмдері, қауіп факторлары, диагностикасы, емі және алдын алуы туралы ағымдағы деректерді жүйелеу.

PubMed, Scopus және Web of Science басылымдарында клиникалық нұсқаулықтарды, жүйелі шолуларды, мета-талдауларды, көп орталықты зерттеулерді және репрезентативті клиникалық сериялларды мақсатты түрде іздеу жүргізілді.

Бүйрек паренхимасы және бүйрек жамбасы мен тостағаншаларының жарақаттары, артериялық және веналық қан кетулер, жалған аневризма, артериовенозды фистула және плевра, өкпе, тоқ ішек, бауыр, көкбауыр және басқа да іргелес құрылымдардың жарақаттары қарастырылды. Асқынулардың ең маңызды болжаушыларына дұрыс емес пункция траекториясы, жоғарғы полюс супракостальды кіру, бірнеше пункция жолдары, үлкен тас жүктемесі, белсенді зәр шығару жолдарының инфекциясы, бүйрек анатомиясының бұзылуы, қатар жүретін аурулар және хирургиялық тәжірибенің жеткіліксіздігі жатады. Ерте диагноз операция кезіндегі белгілерді, гемодинамикалық параметрлерді, гемоглобин динамикасын, ультрадыбыстық зерттеуді және контрастты КТ деректерін кешенді бағалауға негізделген.

Көптеген шектеулі жарақаттар тиісті дренаж, гемостатикалық терапия, бактерияға қарсы емдеу және динамикалық бақылау арқылы сәтті басқарылады. Артериялық қан кетудің жалғасуы немесе кешіктірілуі селективті ангиографияны және зақымдалған тамырдың суперселективті эмболизациясын қажет етеді. Ашық хирургия сирек қолданылады, негізінен тұрақсыз гемодинамика немесе минималды инвазивті әдістердің тиімсіздігі жағдайларында. Алдын алу ота алдындағы мұқият бейнелеуді, жеке қауіпсіз қолжетімділікті жоспарлауды, ультрадыбысты және біріктірілген навигацияны қолдануды, бүйрекішілік қысымды бақылауды, трактатты шектеуді және стандартталған хирургиялық техниканы қамтиды. Ерекше маңыздысы - командалық жұмыс, емдеуді дереу түрлендіруге дайындық, интервенциялық радиологияға қолжетімділік және операциядан кейінгі ерте кезеңде қан кету және көршілес органдардың зақымдану қаупі жоғары науқастарды операциядан кейінгі бақылаудың айқын алгоритмдері. Кешенді тәсіл жарақатты уақтылы анықтауға, мүшелерді сақтау стратегияларын таңдауға және ауыр асқынулардың пайда болу жиілігін азайтуға мүмкіндік береді.

Түйін сөздер: тері арқылы нефролитотрипсия, ятрогенді жарақат, қан кету, көршілес мүшелердің зақымдануы, ангиоэмболизация, асқынулардың алдын алу.

Ятрогенные травмы при перкутанной нефролитотрипсии и современные подходы к их диагностике, лечению и профилактике

Бейсенов К.Т. [1], Пак Ю.Г. [2], Ким Р.В. [3], Шарапатов Е.А. [4*]

[1] Доцент кафедры урологии и андрологии, Национальный медицинский университет имени Төрегелді Шарманова, Астана, Казахстан. E-mail: Alisher.turlygul@gmail.com

[2] Заведующий Городским урологическим центром Городской многопрофильной больницы № 2, Астана, Казахстан. Email: Uropak78@mail.ru

[3] Руководитель департамента урологии, Национальный координационный центр экстренной медицины, Астана, Казахстан. E-mail: kvroman0999@gmail.com

[4] Профессор кафедры урологии и андрологии, Национальный медицинский университет имени Төрегелді Шарманова, Астана, Казахстан. E-mail: erzhan.uro@gmail.com

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Резюме

Перкутанная нефролитотрипсия является ведущим методом хирургического лечения крупных, множественных и сложных камней почки, однако формирование чрескожного доступа и выполнение внутрипочечных манипуляций сопряжены с риском ятрогенной травмы.

Цель обзора: систематизировать современные данные о механизмах, факторах риска, диагностике, лечении и профилактике травматических осложнений перкутанной нефролитотрипсии.

Проведен целевой поиск клинических рекомендаций, систематических обзоров, метаанализов, многоцентровых исследований и репрезентативных клинических серий в базах PubMed, Scopus и Web of Science.

Рассмотрены травмы почечной паренхимы и чашечно-лоханочной системы, артериальное и венозное кровотечение, псевдоаневризма, артериовенозная фистула, повреждения плевры, легкого, толстой кишки, печени, селезенки и других соседних структур. Наиболее значимыми предикторами осложнений являются неправильная траектория пункции, верхнеполюсный надреберный доступ, множественные пункционные тракты, большая каменная нагрузка, активная инфекция мочевых путей, аномальная анатомия почки, сопутствующая патология и недостаточный опыт хирурга. Ранняя диагностика основывается на комплексной оценке интраоперационных признаков, гемодинамических показателей, динамики гемоглобина, данных ультразвукового исследования и контрастной компьютерной томографии.

Большинство ограниченных травм успешно устраняется адекватным дренированием, гемостатической терапией, антибактериальным лечением и динамическим наблюдением. Продолжающееся или отсроченное артериальное кровотечение требует селективной ангиографии и суперселективной эмболизации поврежденного сосуда. Открытое хирургическое вмешательство применяется редко, преимущественно при нестабильной гемодинамике или неэффективности малоинвазивных методов. Профилактика предусматривает тщательную предоперационную визуализацию, индивидуальное планирование безопасного доступа, использование ультразвуковой и комбинированной навигации, контроль внутрипочечного давления, ограничение количества трактов и стандартизацию хирургической техники. Особое значение имеют командное взаимодействие, готовность к немедленной конверсии лечебной тактики, доступность интервенционной радиологии и четкие алгоритмы послеоперационного мониторинга пациентов с повышенным риском кровотечения и повреждения смежных органов в раннем послеоперационном периоде.

Комплексный подход позволяет своевременно распознавать травму, выбирать органосохраняющую тактику и снижать частоту тяжелых осложнений.

Ключевые слова: перкутанная нефролитотрипсия, ятрогенная травма, кровотечение, повреждение.

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