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Current Status of Diagnosis of Postoperative Hemorrhage Following Percutaneous Nephrolithotomy (PCNL)

Qi Fan, Wuxiong Yuan

Hunan Provincial People's Hospital, The First Affiliated Hospital of Hunan Normal University, Changsha, Hunan, 410005, China

ABSTRACT
Percutaneous nephrolithotomy (PCNL) is one of the primary minimally invasive approaches for treating complex renal stones. However, postoperative hemorrhage, as a common and potentially life-threatening complication, severely impacts patient prognosis and hospital resource utilization. In recent years, various imaging modalities have gradually played an important role in diagnosing postoperative bleeding. This paper comprehensively analyzes the clinical classification of postoperative bleeding, and focuses on comparing the characteristics and applicable scenarios of digital subtraction angiography (DSA), computed tomography angiography (CTA), and contrast-enhanced ultrasound (CEUS) in bleeding diagnosis, providing more accurate decision-making support for clinical practice.

KEYWORDS
Percutaneous nephrolithotomy (PCNL); Hemorrhage; DSA; CEUS

1 Indroduction

Urinary calculi are common and increasingly prevalent worldwide, with a 6.4% prevalence in China [1-3]. PCNL is the preferred treatment for complex kidney stones due to its high clearance rate, low recurrence, and manageable complications [4-6].Compared to ESWL and URS, PCNL is less affected by stone characteristics, making it widely applicable [7]. Despite its maturity, PCNL is not risk-free, with potential complications like urinary tract infection, obstruction, hematuria, and renal impairment. Postoperative bleeding is the most common and critical complication, if treatment is delayed, mild cases may require blood transfusion and prolonged hospitalization, while severe case can develops into hemorrhagic shock, resulting in the loss of kidneys and even life-threatening patients [8].Hemorrhage occur either during or after the procedure, with a prevalence of 14-24% [9]，The incidence of blood transfusion following PCNL ranges from 4.5-18.3% [10]. Although most bleeding can be controlled through conservative treatment, severe intraoperative and postoperative bleeding remains an undeniable obstacle to the development of percutaneous nephrolithotomy, with 0.3% to 1.2% of cases still requiring treatment through methods such as renal arteriography and selective embolization [10]. Meanwhile, for patients experiencing postoperative bleeding, the significant increase in their hospital stay and average hospitalization costs imposes a substantial financial burden on both the patients and the hospital [11-12].

Facing this clinical challenge, accurately identifying the type of bleeding and promptly selecting appropriate imaging diagnostic methods postoperatively have become crucial for ensuring surgical safety and efficacy. This article will analyze the clinical classification of postoperative bleeding and focus on evaluating the application value and limitations of several current main diagnostic methods (DSA, CTA, CEUS).

2 Clinical classification of postoperative hemorrhage after PCNL

Nearly all patients experiencing varying degrees of gross hematuria in the early postoperative period.Most bleeding is self-limiting and resolves with conservative treatment. However, a hemoglobin drop of more than 2 g/dL may indicate a higher risk of more severe bleeding [13].While there is no unified classification for major postoperative bleeding after PCNL, some clinicians have drawn from classifications used in hepatobiliary and pancreatic surgery, dividing it into three types: acute bleeding, intermittent bleeding, and slow, persistent bleeding [14].This distinction not only helps in assessing the progression of the condition but also provides guidance for the timing of subsequent imaging examinations and interventions.

2.1 Acute bleeding

This type of bleeding occurs shortly after surgery, with bright red urine, often mixed with clots, and a rapid drop in hemoglobin. In some cases, acute hemodynamic instability or hemorrhagic shock may even occur. DSA is often performed immediately to identify the bleeding source and perform hemostasis. Due to its rapid bleeding and obvious signs, it is the easiest to recognize and manage clinically.

2.2 Intermittent bleeding

Typical signs of Intermittent Bleeding include intermittent hemoglobin decreases and bright red hematuria in the nephrostomy tube or bladder irrigation, but overall hemodynamics remain stable.This type of bleeding is often mistaken for normal postoperative fluctuations. Without careful monitoring, it can lead to excessive blood loss, anemia, or even hemorrhagic shock. Regular re-examination of blood routine tests are crucial to avoid serious complications from delayed intervention.

2.3 Slow and persistent bleeding

This type of bleeding typically manifests as the continuous passage of reddish or brownish urine postoperatively with a slow decline in hemoglobin and stable vital signs. The cause may be small vessel tears or intermittent vessel spasms. Early imaging may not show typical findings, but without follow-up, it could evolve into a pseudoaneurysm or arteriovenous fistula. Therefore, a multi-stage assessment plan should be made, and DSA and embolization should be considered if necessary [14].

3 Diagnosis of postoperative bleeding after PCNL

Bloody drainage from the nephrostomy tube is the primary indicator of bleeding, often mixed with clots and accompanied by symptoms like increased heart rate, decreased blood pressure, or even heart failure. Persistent hemoglobin decrease is a key lab indicator for evaluating active bleeding. Timely identification of the bleeding site and nature is crucial for treatment planning. Diagnostic methods like DSA, CTA, and CEUS each have specific advantages for different bleeding types. Rational selection and combination of these methods enhance diagnostic efficiency and safety.

3.1 DSA

DSA has long been considered the gold standard for diagnosing renal vascular injury. Its advantage lies in its ability to accurately display renal artery pathways and identify arterial bleeding. It can also perform TAE(transcatheter arterial embolization) simultaneously, significantly reducing treatment time and maximizing kidney tissue protection [15].However, the DSA positive results depend on active bleeding, so for chronic or intermittent bleeding, false-negative results may occur [14].Additionally, DSA is an invasive procedure with high operational costs, which may cause additional trauma and radiation risks to patients, making it difficult to repeat multiple times. Therefore, DSA is primarily used for cases of acute bleeding with hemodynamic instability or when other imaging methods fail to clearly identify the lesion.

The main types of vascular lesions observed in PCNL postoperative kidney DSA include: pseudoaneurysms , arteriovenous fistulas , and arterial tears [16].

3.1.1 Pseudoaneurysm

Pseudoaneurysms are the most common manifestation on DSA, with an incidence ranging from 31.3% to 48.4% [14,16-18]. They forms cystic arterial dilation in the renal parenchyma after vascular injury, with blood flowing into the parenchyma. If ruptured, they can cause acute, life-threatening bleeding.

3.1.2 Arteriovenous fistula

The high pressure in the renal artery is a key factor in the formation of arteriovenous fistulas.The incidence of these fistulas ranges from 12.5% to 32.3% [14,16-18]. They occur when blood flows from the damaged artery into an adjacent damaged vein. On DSA, abnormal connections between them can be seen. In larger arteriovenous fistulas, blood from the renal artery can shunt heavily into the vein, leading to venous dilatation resembling an aneurysm. This can result in partial renal ischemia, potentially causing rapid renal function deterioration in patients. Furthermore, during or after embolization, ectopic embolism can occur. Pulmonary embolism is a common and severe complication of ectopic embolism, requiring careful attention [17].

3.1.3 Arterial tear

The insertion of a dilator sheath can easily lead to renal artery tears. This type of injury primarily manifests as blood flowing from the damaged artery into the renal pelvis or perirenal space，with an incidence of 16.0% to 43.7% [15,17-18] . On imaging, contrast extravasation can be observed into the renal parenchyma or perirenal tissues.

3.1.4 Complex lesions

Complex lesions refer to cases where more than one DSA finding is present. These are most commonly seen in patients who undergo multiple punctures during PCNL, with an incidence of 11.8% to 12.5% [14,17].

3.2 CTA

CTA, a highly effective diagnostic tool for lower gastrointestinal bleeding, has a sensitivity and specificity of around 90% [19-20].Urologists have also used CTA to detect some cases of post-PCNL bleeding. However, unlike the gastrointestinal system, the kidneys are solid organs, and blood can be compressed by renal parenchyma or hydronephrosis. Some researchers have combined CTA with 3D printing has shown superiority over conventional angiography for detecting renal bleeding [18]. Additionally, CTA is contraindicated in patients with renal insufficiency, asthma, and hyperthyroidism due to its use of an iodine contrast agent.

3.3 CEUS

CEUS utilizes intravenous microbubble contrast agents named sulfur hexafluoride to enhance the visualization of solid organ perfusion and improve the ability to observe blood flow [21]. After being injected into the elbow vein, 80% of the contrast agent is cleared through the lungs within 2 minutes, and the rest is cleared from the body after 15 minutes, without causing cardiac or renal toxicity [22].Contrast agent microbubbles generate strong echoes at resonance frequency, with second harmonic signals 1000 times stronger than tissue, enhancing color Doppler signals for blood flow assessment [23].Due to its simplicity, safety, and ability to be repeated multiple times, CEUS can be performed at the bedside, making it convenient for dynamic monitoring and follow-up, especially for intermittent or slow bleeding. It has already been used for diagnosing active bleeding in various abdominal solid organs[24]. However, CEUS also has certain limitations: it is operator-dependent and cannot provide structural 3D images so can not clearly display the complete structure of large vessels. Therefore, CEUS is primarily used as a screening or post-operative monitoring tool. Some urologists have started to apply CEUS in diagnosing percutaneous nephrostomy or post-PCNL bleeding, particularly for intermittent and slow, persistent bleeding types, showing promising potential.

Table 1 Comparison of the imaging modalities for postoperative hemorrhage following PCNL

Imaging Modali - ties	Advantages	Disadvantages	Applicable Scenarios
DSA	1.As the gold standard for diagnosis, it can accurately display blood vessels and small lesions. 2. TAE can be performed simultaneously .	1.Invasive procedure with relatively unavoidable risks. 2.May produce false negatives for chronic or intermittent bleeding types. 3.High economic cost and relatively low reproducibility.	1.Patients with acute massive bleeding, especially in hemodynamically unstable situations. 2. When other examinations (such as CTA, CEUS) cannot provide a clear diagnosis.
CTA	1.Fast examination, suitable for emergency situations. 2.High spatial resolution, capable of displaying the integrity of large blood vessels.	1.Use is restricted in patients with renal insufficiency, asthma, or hyperthyroidism. 2.Poor sensitivity in diagnosing small vessel bleeding.	1. Emergency bleeding cases, especially when the patient cannot tolerate or refuses DSA. 2.When there is concurrent bleeding from other organs.
CEUS	1.Non-invasive and radiation-free, suitable for multiple dynamic observations, and applicable to intermittent bleeding. 2.It can be done at the bedside.	1.Dependent on the operator's experience. 2.Cannot be used for treatment.	1.Multiple monitoring of hemodynamically stable patients with intermittent or slow bleeding. 2.Auxiliary screening when there are no obvious imaging abnormalities but clinical suspicion of bleeding persists.

4 Outlook and future research directions

Although the current imaging evaluation system has established, there is still a lack of consistent evidence-based standards for developing a standardized, stratified diagnostic pathway based on the dynamic characteristics of bleeding. While DSA remains the gold standard for bleeding diagnosis, it heavily depends on the "visibility" of the bleeding, and the timing of intervention requires careful consideration, with no unified standards in place. CTA has contraindications in some patients with renal insufficiency, limiting its applicability. CEUS, with its real-time capabilities and high sensitivity to microblood flow, offers a new approach for non-invasive monitoring. However, its sensitivity and specificity still need to be quantified in comparison with DSA, and the decision-making relationship between CEUS and TAE interventions requires further in-depth research and clarification for broader application.

In summary,PCNL has been widely and successfully applied. However, post-operative bleeding remains unpredictable and variable. There is still a need to better address the challenges in diagnostic processes, risk assessment, and intervention timing. In particular, intermittent and slow bleeding, with its irregular bleeding rhythm and often subtle manifestations, can lead to delayed recognition or even misdiagnosis, resulting in misaligned or delayed interventions, thereby increasing patient risk.

References

[1] RAHEEM O A, KHANDWALA Y S, SUR R L, et al. Burden of Urolithiasis: Trends in Prevalence, Treatments, and Costs[J/OL]. European Urology Focus, 2017, 3(1): 18-26.

[2] WANG Q, WANG Y, YANG C, et al. Trends of Urolithiasis in China: A National Study Based on Hospitalized Patients from 2013 to 2018[J/OL] . Kidney Diseases, 2023, 9(1): 49-57.

[3] LI Y, XIE L, LIU C. Prediction of systemic inflammatory response syndrome and urosepsis after percutaneous nephrolithotomy by urine culture, stone culture, and renal pelvis urine culture: systematic review and meta-analysis[J/OL]. Heliyon, 2024, 10(13): e33155.

[4] ZHANG Y, WU Y, LI J, et al. Comparison of Percutaneous Nephrolithotomy and Retrograde Intrarenal Surgery for the Treatment of Lower Calyceal Calculi of 2-3 cm in Patients With Solitary Kidney[J/OL]. Urology, 2018, 115: 65-70.

[5] BOZKURT I H, YONGUC T, ARSLAN B, et al. Minimally invasive surgical treatment for large impacted upper ureteral stones: ureteroscopic lithotripsy or percutaneous nephrolithotomy?[J/OL]. Canadian Urological Association Journal, 2015, 9(3-4): 122.

[6] MACLENNAN S, WISEMAN O, SMITH D, et al. Updated systematic review and meta-analysis of extracorporeal shock wave lithotripsy, flexible ureterorenoscopy, and percutaneous nephrolithotomy for lower pole renal stones[J/OL]. European Urology, 2025: S0302283825000612.

[7] AKRAM M, JAHRREISS V, SKOLARIKOS A, et al. Urological guidelines for kidney stones: overview and comprehensive update[J/OL]. Journal of Clinical Medicine, 2024, 13(4): 1114.

[8] RASSWEILER J, GUMPINGER R, MILLER K, et al. Multimodal Treatment (Extracorporeal Shock Wave Lithotripsy and Endourology) of Complicated Renal Stone Disease[J/OL]. European Urology, 1986, 12(5): 294-304.

[9] NOURALIZADEH A, DARZI M M, ADIB A, et al. An assessment of the efficacy and safety of balloon nephrostomy traction in minimizing postoperative bleeding of percutaneous nephrolithotomy: a randomized controlled clinical trial[J/OL]. Langenbeck's Archives of Surgery, 2025, 410(1): 26.

[10] ZENG G, ZHONG W, MAZZON G, et al. International alliance of urolithiasis (IAU) guideline on percutaneous nephrolithotomy[J/OL]. Minerva Urology and Nephrology, 2023, 74(6)[2025-03-26].

[11] REYNOLDS L F, KROCZAK T, PACE K T, et al. Are routine laboratory investigations necessary following percutaneous nephrolithotomy?[J/OL]. Urology, 2020, 143: 80-84.

[12] SHADPOUR P, YOUSEFZADEH KANDEVANI N, MAGHSOUDI R, et al. Introducing the POPVESL score for intrarenal vascular complications of percutaneous nephrolithotomy: experience from a single high-volume referral center[J/OL]. Urology Journal, 2020(2019: Instant): 5997.

[13] THE TRAUMABASE GROUP, FIGUEIREDO S, TACONET C, et al. How useful are hemoglobin concentration and its variations to predict significant hemorrhage in the early phase of trauma? A multicentric cohort study[J/OL]. Annals of Intensive Care, 2018, 8(1): 76.

[14] LI L, ZHANG Y, CHEN Y, et al. A multicentre retrospective study of transcatheter angiographic embolization in the treatment of delayed haemorrhage after percutaneous nephrolithotomy[J/OL]. European Radiology, 2015, 25(4): 1140-1147. DOI:10.1007/s00330-014-3491-4.

[15] HE Z, LI Y, ZHANG S, et al. Long-term effects of superselective renal artery embolization on renal function after percutaneous nephrolithotomy [J/OL]. World Journal of Urology, 2025, 43(1): 96.

[16] RICHSTONE L, REGGIO E, OST M C et al. First Prize (Tie): Hemorrhage Following Percutaneous Renal Surgery: Characterization of Angiographic Findings[J/OL]. Journal of Endourology, 2008, 22(6): 1129-1136.

[17] DU N, MA J Q, LUO J J, et al. The efficacy and safety of transcatheter arterial embolization to treat renal hemorrhage after percutaneous nephrolithotomy[J/OL]. Biomed Research International, 2019, 2019: 6265183.

[18] YANG B B, LIU W Z, YING J P, et al. Computed tomography angiography and three-dimensional reconstruction of renal arteries in diagnosing the bleedings after mini-percutaneous nephrolithotomy: a single-center experience of 7 years[J/OL]. Urology, 2022, 169: 47-51.

[19] KIM G, SOTO J A, MORRISON T. Radiologic assessment of gastrointestinal bleeding[J/OL]. Gastroenterology Clinics of North America, 2018, 47 (3): 501-514.

[20] HE B, YANG J, XIAO J , et al. Diagnosis of lower gastrointestinal bleeding by multi-slice CT angiography: a meta-analysis[J/OL]. European Journal of Radiology, 2017, 93: 40-45.

[21] XIONG L, HUANG X, YE X, et al. Microultrasonic Probe Combined with Ultrasound-Guided Minipercutaneous Nephrolithotomy in the Treatment of Upper Ureteral and Renal Stones: A Consecutive Cohort Study[J/OL]. Journal of Endourology, 2020, 34(4): 429-433.

[22] QUARATO C, FERAGALLI B, LACEDONIA D, et al. Contrast-enhanced ultrasound in distinguishing between malignant and benign peripheral pulmonary consolidations: the debated utility of the contrast enhancement arrival time[J/OL]. Diagnostics, 2023, 13(4): 666.

[23] UNNIKRISHNAN S, KLIBANOV A L. Microbubbles as ultrasound contrast agents for molecular imaging: preparation and application[J/OL]. American Journal of Roentgenology, 2012, 199(2): 292-299.

[24] MALONE C D, FETZER D T, MONSKY W L, et al. Contrast-enhanced US for the interventional radiologist: current and emerging applications [J / OL]. Radiographics, 2020, 40(2): 562-588.