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Super-selective renal artery embolization (SRAE) for iatrogenic and traumatic renal hemorrhage

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Abstract

Purpose To present the radiological and clinical outcomes of super-selective transcatheter renal artery embolization in patients with renal injury hemorrhage, and share our experience.

Methods 43 patients with renal injury hemorrhage who underwent 46 SRAEs were enrolled in this retrospective review study. Records, images, and outcomes were reviewed. The individual embolic method and its observed effects were investigated.

Results Angiography showed free extravasation in 25 angiograms, pseudoaneurysm in 15 angiograms, and arterio-venous fistulas in 1 angiogram. Most patients achieved initial clinical success (38/43, 88.4%), and 41 patients achieved final clinical success (41/43, 95.3%). 9/11 patients who adopted empirical embolization achieved initial clinical success (81.8%). In our study, the combination of PVA particles and micro-coils has emerged as the most commonly utilized material combination (24/46, 52.2%). Significant differences in hemoglobin levels were observed before and after the embolization procedure ($p = 0.026$, 95%CI: 1.03–15.54). Post-embolization clinical follow-up showed no evidence of recurrent hematuria, progression of hematoma, hypertension, and no reflux of the embolic agent.

Conclusion Though SRAE showed satisfactory results across a broad range of renal injury hemorrhage, there are still some aspects that need attention: (1) Surgical procedure should be understood, including the surgical site, access routes, and placement of implants, such as double-J stents. (2) In cases where identifying the bleeding point proves challenging, consider the possibility of an accessory renal artery.

Trial registration Chinese Clinical Trial Registry ChiCTR2400085050, Registration Date: 30 May 2024, retrospectively, non-randomized.

Keywords Super-selective embolization, Interventional radiology, Iatrogenic renal hemorrhage, Angiography, Renal trauma, Embolic agent

Introduction

Renal injury hemorrhage is a frequently encountered organ injury in clinical practice, often caused by trauma or iatrogenic incidents. Traumatic factors encompass incidents such as traffic accidents, falls from height, and stab wounds [1]. Iatrogenic renovascular injuries have increased due to the increasing number of percutaneous procedures, such as percutaneous nephrolithotomy (PCNL), partial nephrectomy (PN), or renal biopsy [2–4].

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PCNL-related renal injury hemorrhage now constitutes a significant portion of the indications for SRAE [5, 6]. PN is considered the standard reference treatment for small, isolated tumors, and renal hemorrhage, although uncommon, is a severe complication that can occur following PN [7]. Furthermore, renal trauma occurs in 1–3% of trauma patients, with 80–90% attributed to blunt mechanisms of injury [8, 9].

CT findings are crucial criteria for grading renal injuries according to the American Association for the Surgery of Trauma (AAST) classification. Traditionally, low-grade renal injuries can be conservatively managed without the need for surgical or angiographic intervention, while high-grade renal injuries often necessitate surgical exploration or nephrectomy [10].

However, in recent years, the ability to stop bleeding rapidly causes SRAE has emerged as a significant treatment option for high-grade renal injuries. Also, SRAE is one of the most effective treatments for these situations when conservative treatment fails [11]. Compared to traditional catheter techniques, super-selective coaxial catheters can accurately access the distal injured vessels, resulting in less damage to non-target tissues and greater functional renal parenchyma preservation [12].

Generally, the following conditions are considered for angiography and SRAE, including persistent gross hematuria and rapid decrease in hematocrit; continuous bleeding from the renal artery; unstable condition with grade II-IV injuries; arteriovenous fistula (AVF) or pseudoaneurysm (PSA).

This study aimed to report the success and failure of SRAE for iatrogenic and non-iatrogenic renal hemorrhage.

Patients and methods

This study retrospectively analyzed 43 patients with renal injury hemorrhage admitted to Shanghai General Hospital, School of Medicine, Shanghai Jiao Tong University between August 2015 and August 2023.

All embolization procedures were performed in the DSA room. After successful local anesthesia (lidocaine 2%), the common femoral artery (CFA) was punctured, a standard 5-French (Fr) vascular introducer sheath was inserted, and a 5-Fr Yashiro catheter (Terumo, Tokyo, Japan) was introduced to preliminarily evaluate the location and type of bleeding. Super-selective renal arterial embolization was to be undertaken mainly in cases presenting with active free extravasation, renal arterial pseudoaneurysm, and AVF. If there were no definite positive signs, empirical embolization can be considered, such as localized intensification; contrast agent retention; arterial kinking, and some seemingly visible signs.

Once the specific bleeding site and responsible blood vessel were identified, a 2.7-Fr Progreat microcatheter (Terumo, Tokyo, Japan) was advanced to the target vessel through the existing 5-Fr Yashiro catheter. Embolic materials, including micro-coils, PVA particles, and gelatin sponge particles, were positioned as distally as possible to minimize renal parenchymal infarction. Post-embolization renal arteriography was obtained by injecting the existing 5-Fr catheter to confirm the embolization results. This ensured the absence of free extravasation and the disappearance of the PSA, AVF, and other positive signs.

Technical success of the procedure was defined as complete occlusion of all renovascular bleeding with arterial embolization through documented arterial angiography at the end of the procedure. Clinical success was defined as the cessation of gross hematuria within 3 days, absence of need for blood transfusion, absence of a further decrease in hemoglobin by > 15 g/L, and absence of need for repeat embolization or subsequent surgery [12].

All p values were 2-sided with significance considered at $p < 0.05$. Statistical analysis was done with SPSS Statistics 25.

Results

Forty-six transcatheter embolization procedures in 43 patients (31 men, 12 women; mean age, 53 years; age range, 23–80 years) with renal injury hemorrhage. 3 patients required SRAE twice and two of them underwent empirical embolization. All patients presented with unilateral renal hemorrhage.

Renal injuries were caused by iatrogenic injury in 34 out of 43 patients (79.1%), and by trauma in 9 out of 43 patients (20.9%). Among iatrogenic injury patients, 17/34 underwent PCNL (50.0%), 13/34 underwent PN (38.2%), 3/34 (8.8%) for ureteroscope, and 1/34 case (2.9%) underwent renal biopsy. In trauma patients, 8/9 experienced blunt trauma (88.9%) and 1/9 sustained a stab wound (11.1%) (Table 1).

Iatrogenic renal hemorrhage patients ($n = 34$) commonly presented with nephrostomy or drainage tubes draining hemorrhagic fluids (22/34, 64.7%) and persistent/intermittent gross hematuria (17/34, 50.0%). Non-iatrogenic cases may exhibit poor mental status, pain, and progressive hypotension. 93.0% (40/43) showed hemoglobin reduction, and 55.8% (24/43) received erythrocyte suspension transfusion due to excessive bleeding (Table 1).

Diagnostic angiographic findings (Table 2) revealed 54.3% (25/46, Fig. 1a) with free extravasation, 32.6% (15/46, Fig. 1b) with PSA, and 2.2% (1/46, Fig. 1c) with AVF. Additionally, 4.3% (2/46) showed localized intensification, 4.3% (2/46) had contrast retention, and 4.3%

Table 1 Characteristics of 43 patients with bleeding after a percutaneous renal procedure

Characteristics	Value
Patients	43
Average Age	53
Gender	
Male	31
Female	12
Injury Causes	
Percutaneous nephrolithotomy	17
Partial nephrectomy	13
External trauma	9
Ureteroscope	3
Biopsy	1
Clinical Presentations	
Drainage of hemorrhagic fluid	22
Gross hematuria	17
Pain	12
Diagnostic Tests	
Decrease in hemoglobin levels	40
Blood transfusion	24

Table 2 Angiographic findings in 43 patients with 46 SARE cases

Imaging Findings	Cases (%)
Direct signs	
Free extravasation	25 (54.3%)
Pseudoaneurysm	15 (32.6%)
Arteriovenous fistula	1 (2.2%)
Indirect signs	
Localized intensification	2 (4.3%)
Contrast agent retention	2 (4.3%)
Arterial kinking	2 (4.3%)
Seemingly visible signs	5 (10.9%)
No apparent abnormalities	1 (2.2%)

(2/46) had arterial kinking. Seemingly visible signs were present in 10.9% (5/46), while 2.2% (1/46) had no apparent abnormalities. Empirical embolization was performed in 23.9% (11/46) cases, with 81.8% (9/11) achieving initial clinical success, and all achieving final clinical success.

Three patients underwent SRAE twice. One patient, who underwent embolization twice, also had empirical embolization (Fig. 2). The initial angiogram showed a double-J stent with a negative result (Fig. 2a). Gelatin sponge particles were injected into a branch of the mid-segment of the renal artery with seemingly contrast retention (Fig. 2b). Five hours later, hemoglobin progressively decreased to 47.7 g/L and the emergency second angiogram revealed bleeding from the lower branch of the right kidney, with a noticeable overflow of contrast (Fig. 2c). Subsequent embolization with a 3*3.3 mm micro-coil and PVA-560 particles (Fig. 2d) ultimately achieved clinical success.

Another patient, undergoing embolization twice, exhibited contrast extravasation near the distal flat tube during the first angiography (Fig. 3a). After successful embolization using a small quantity of PVA-350 particles (Fig. 3b), the hemoglobin level decreased to 66 g/L. A pseudoaneurysm was detected at the original site during the second angiography (Fig. 3c), leading to successful embolization with two 3*3.3 micro-coils and PVA-350 particles (Fig. 3d), achieving technical and clinical success.

40/43 patients presented with a decrease in hemoglobin levels (93.0%). In 3/43 patients without a significant decrease in hemoglobin (7.0%), two of them were classified as traumatic renal hemorrhage and the other one as iatrogenic renal hemorrhage. In patients who achieved clinical success through SRAE finally ($n=41$), 34/41 patients exhibited elevated hemoglobin levels following SRAE (82.9%). 7/41 patients experienced a transient decrease in hemoglobin levels (17.1%), followed by a gradual increase. The hemoglobin levels show significant differences before and after embolization treatment ($p=0.026$, 95%CI: 1.03–15.54).

Regarding embolization materials, PVA particles were the most common embolization material used in our study (40/46, 87.0%), and the combination of PVA particles and micro-coils was the most frequently utilized material combination in our study (24/46, 52.2%). In situations where only a single material was used ($n=19$), PVA particles also accounted for the majority (15/19, 78.9%). Among cases using micro-coils ($n=27$), only eight of them were treated with a single micro-coil (8/27, 29.6%), while two or more micro-coils were more frequently utilized (19/27, 70.4%). Even in a case where rupture and bleeding of renal angiomyolipoma were treated with PN, nine micro-coils were used for embolization. Table 3 shows the usage status of embolization materials.

The average interval between iatrogenic injuries and embolization surgery is 5.7 days, significantly longer than injuries caused by trauma (<1 day). This could be due to the broader and more severe range of renal injuries caused by trauma. Also, iatrogenic injuries may receive timely conservative treatment that could contribute to managing renal bleeding to a certain extent.

11/13 patients underwent PN caused by kidney tumors (84.6%) and 2/13 caused by cysts (15.3%). The pathological results indicated that nine of the tumors were malignant (9/11, 81.8%), and two were benign (2/11,

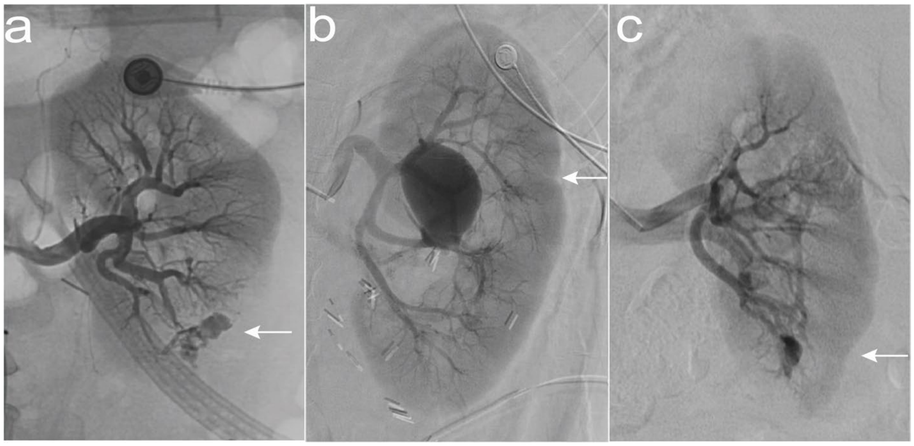

Fig. 1 **a** free extravasation; **b** pseudoaneurysm; **c** arteriovenous fistula

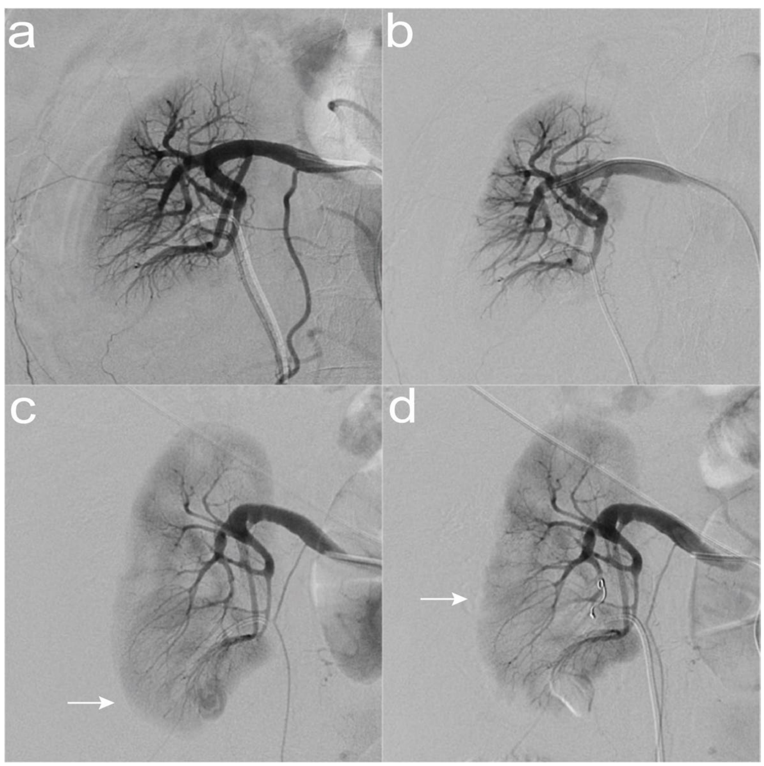

Fig. 2 **a** initial angiogram; **b** re-angiogram after embolization; **c** second angiogram; **d** second re-angiogram after embolization

18.2%). For the two cases with benign tumors, pathological results indicated renal angiomyolipoma (AML). One underwent PN due to ruptured bleeding, and the other due to the rapid growth of the tumor recently. In malignant tumors, 7/9 renal clear cell carcinoma (KIRC, 77.8%), 1/9 renal papillary cell carcinoma (11.1%), and 1/9 renal cell carcinoma, unclassified (11.1%). For the two patients with cysts, one experienced cyst rupture due to external impact, while the other had discovered cyst enlargement during a recent ultrasound examination (maximum diameter increased from 53 mm a year ago to 55 mm). Moreover, the patient-caused biopsy had a pathological diagnosis of IgA nephropathy.

All patients achieved technical success. 38/43 patients achieved initial clinical success (88.4%), and 41/43 patients achieved clinical success finally (95.3%) through

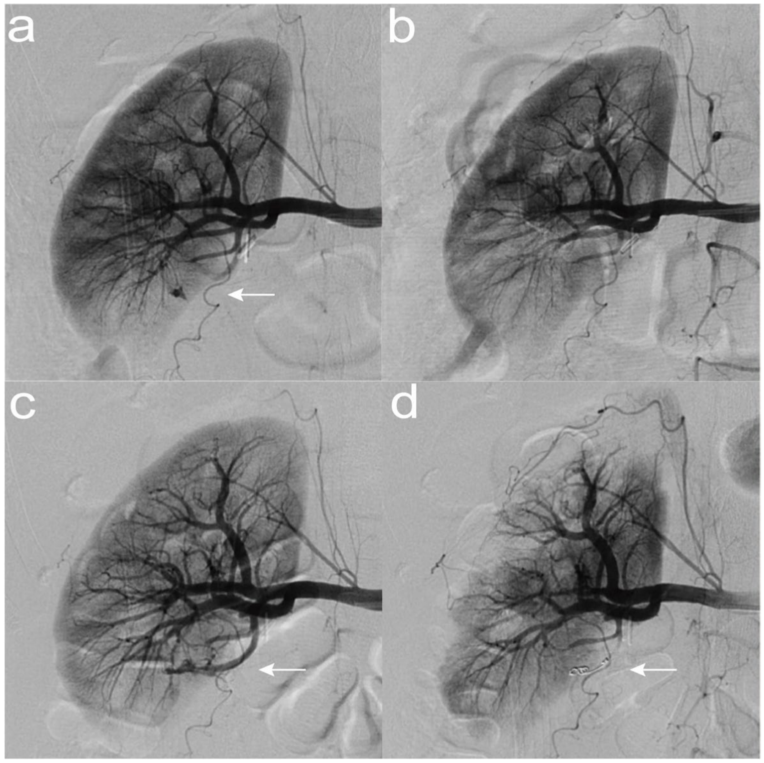

Fig. 3 **a** initial angiogram; **b** re-angiogram after embolization; **c** second angiogram; **d** second re-angiogram after embolization

Table 3 Embolic material used in 43 patients with 46 arteries embolization

Embolic materials	Number of procedures (%)
micro-coil alone	1 (2.2%)
gelatin sponge alone	3 (6.5%)
PVA alone	15 (32.6%)
micro-coil/PVA	24 (52.2%)
micro-coil/gelatin sponge	2 (4.3%)
PVA/gelatin sponge	1 (2.2%)

SRAE. In iatrogenic renal hemorrhage, 30/34 patients achieved clinical success in single-session SRAE (88.2%), 3/34 patients achieved final clinical success and experienced a second embolization, while 1/34 patients underwent left nephrectomy after initial embolization failure (2.9%). In non-iatrogenic renal hemorrhage, 8/9 patients with blunt trauma (88.9%) achieved clinical success, and 1/9 patients with penetrating trauma (11.1%) received abdominal exploratory surgery due to lack of improvement following embolization.

One patient failed to achieve clinical success which was caused by a stab wound (Fig. 4). The angiogram revealed a distal arteriovenous fistula in the lower segment branch of the left kidney artery, with contrast agent gush from this site beyond the outline of the kidney, presenting significant retention signs (Fig. 4a). Two 3 mm micro-coils and PVA-350 particles were positioned on the target artery branch (Fig. 4b). This patient achieved only technical success.

Discussion

In this 8-year retrospective study, we obtained 100% technical success and 88.4% initial clinical success in SRAE related to iatrogenic renal hemorrhage, these are similar to currently published studies [3, 6, 13]. Among the 9 cases of non-iatrogenic renal injury, 8 cases achieved favorable clinical outcomes through SRAE.

All patients in the PN group achieved technical success (13/13, 100%), with 92.3% (12/13) attaining final clinical success. Compared to a study involving 24 patients, both technical and clinical success rates were 96% [14]. In nine patients we encompassed, blunt injuries occupied the majority reached AAST grade III, and achieved clinical success.

The patient who was injured by stabbing underwent exploratory laparotomy three days after SRAE (Fig. 4). The result of the exploratory laparotomy indicated that the continued decline in hemoglobin following SRAE was

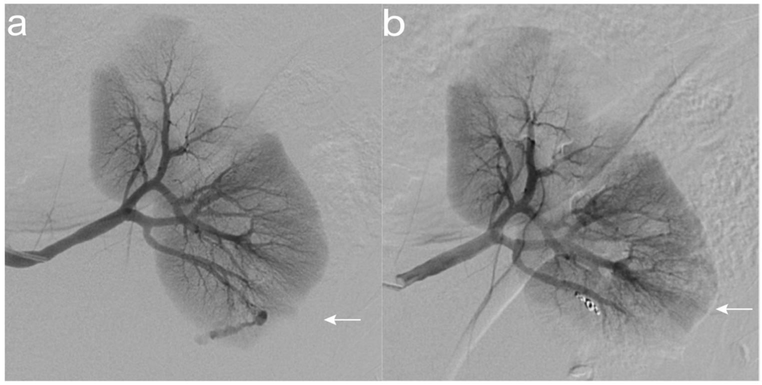

Fig. 4 **a** angiogram; **b** re-angiogram after embolization

due to injury involving other organs. Although SRAE did not achieve clinical success, the procedure successfully prevented the need for kidney removal, preserving renal function.

In contrast to a previous study, which suggested that almost all low-grade (I-III) injuries identified on CT scans could be managed without surgical or angiographic intervention [10], our experience favors renal angiography and embolization for grade III, especially with active bleeding. This approach aligns with findings from several other reports [9, 15]. In cases where the hematoma is close to the renal capsule, Grade II injuries also necessitate SRAE implementation. Renal artery embolization is widely accepted for stable grade IV injuries, while there is still debate regarding its role in unstable patients and grade V injuries [5]. Undeniably, the application of SRAE is increasing for higher-grade renal injuries, potentially preventing nephrectomy in up to 88% of grade IV and V injuries [16].

The absence of obvious signs during the initial angiography was the main reason leading to the second embolization. Iatrogenic vascular damage or transient vasospasm during the initial intervention may also be contributing factors. Arterial spasm, which may cause a decrease in arterial diameter during angiography, can lead to inaccurate detection of positive signs or even result in negative findings during the procedure. Since spasms are reversible, removing the stimulus can allow spasming blood vessels to return to their normal diameter, potentially leading to clinical failure.

A total of three patients underwent SRAE twice. Of these, two cases (2/17, 11.8%) were associated with PCNL, compared to 17.8% reported in another study [17]. The remaining case, which was associated with PN, may be related to arterial spasm (Fig. 3). During the first embolization, a vascular spasm may have developed, resulting in a technically successful angiographic appearance post-embolization. However, during the second angiography, a PSA was identified at the original site. This indicates that after the spasm resolved, the initially small amount of PVA particles was insufficient to completely embolize the target vessel, allowing the damaged artery to continue bleeding.

In the diagnostic and therapeutic process of renal injury hemorrhage, identifying the responsible vessels for the bleeding is particularly crucial. It serves as a prerequisite for subsequent embolization therapy, especially in cases where the hemorrhagic focus is relatively small, vessels overlap and there is interference from intestinal gas. Also, vasospasm may cause vascular constriction, resulting in unclear vascular delineation or artifacts. Implants such as double-J stents may produce shadows in the image or interfere with the visualization of surrounding tissues, making diagnosis difficult. Positional factors may lead to changes in the position of structures, making certain abnormalities or lesions difficult to observe in certain positions, which may also result in negative angiographic findings.

Not all angiography procedures are capable of identifying the bleeding focus with certainty. In such cases, empirical embolization may be considered as an alternative approach, particularly when indicators such as localized intensification, contrast agent retention, arterial kinking, and other seemingly visible signs are present (Fig. 2). But before using it, the following situations must be evaluated: the surgical techniques previously employed by the patient, including details about the surgical site, and entry and exit pathways; the positioning of implants such as double-J stents, as well as changes in patient positioning; the patient experiences severe pain, accompanied by a rapid or sustained decrease in hemoglobin after surgery; postoperative CT reveals positive signs or continuous follow-up shows an increase in hematoma size.

The presence of accessory renal arteries (ARA) can also make it difficult to identify the bleeding site. A study indicated that the prevalence of ARA in Asia is ranging 4% to 18.4% [18]. Since ARA typically originates from the abdominal aorta, bypassing the renal hilum and entering the kidney directly from its upper or lower poles, DSA renal angiography may not visualize them adequately. Therefore, even if there is damage to accessory renal arteries, positive findings may be difficult to detect on angiography. Generally, preoperative CT scans can help us determine the presence of accessory renal arteries.

The choice of embolic agents is typically guided by the clinical situation. Micro-coils, being the primary embolic material, are commonly used to occlude larger vessels. Micro-coils can lead to complete occlusion equivalent to that seen with surgical ligation [19]. Generally, micro-coil embolization depends on the ability of thrombosis. Coagulopathic states such as thrombocytopenia, platelet dysfunction, and abnormal clotting factors may hinder complete vessel occlusion. Furthermore, the time to occlusion also depends on the type of micro-coils used and the rate of flow of the target vessel embolized [20].

Choosing the proper type and size of micro-coils can be challenging, as can precisely deploying them. In the majority of instances, a single micro-coil proves insufficient for resolution, and in our study, 27/46 cases (58.7%) used micro-coils for embolization, and 19/27 cases (70.4%) requiring more than a single micro-coil, aligning with previous studies [21, 22]. Micro-coils demonstrate excellent performance in small arteries where reflux control is challenging. Potential complications of micro-coil embolization include occlusion of nontarget vessels and coil migration, which was not observed in our study.

Polyvinyl alcohol (PVA) particles were used more frequently in our study (40/46, 87%). PVA particles can lodge in the smallest vessels, and provide permanent occlusion by adhering to the vascular wall rather than secondary thrombosis to direct plugging vessels [23]. They were often used as supplements to micro-coils (24/40, 60%) or alone (15/40, 37.5%). Compared to micro-coils, PVA particles are commonly applied in peripheral vessels. Their characteristics led to the most frequent utilization of this combination (24/46, 52.2%) in our study. However, the risk of reflux should be mindful, which leads to permanent embolization of non-target vessels, subsequently aggravating renal damage.

Tris-acryl microspheres could be a safer and more effective alternative material to PVA particles [24]. Due to its regular spherical shape, tris-acryl microspheres can more easily enter peripheral blood vessels, leading to tighter embolization. However, more clinical studies are needed to demonstrate the feasibility of using this material in renal artery embolization. Liquid embolic materials were not involved in the study, like N-butyl 2-Cyanoacrylate (NBCA) [25], NBCA-MS [26], Onyx [27], and so on.

Our study has several limitations. Firstly, as a retrospective study, it restricts our ability to establish causal relationships between observations and outcomes. The time elapsed and the fact that some researchers did not participate in all surgeries may introduce errors in classification and recall bias, despite access to medical records, operative notes, and imaging data. Additionally, due to data availability constraints, we did not establish a control group for comparison.

Secondly, our research primarily focuses on angiographic judgments and decision-making during super-selective arterial embolization, and lacks long-term patient outcomes such as survival rates and quality of life post-procedure. Some patients lack extended follow-up, which is crucial for assessing post-embolization renal morphology and function.

Moreover, our study is a single-center investigation conducted at a tertiary care center specializing in urology. This specialization results in a higher proportion of PCNL cases in renal injury hemorrhage, and our physicians gain extensive experience in transitioning from conservative management to more aggressive treatment options and choosing interventional methods for iatrogenic renal hemorrhage caused by PCNL and other factors.

Conclusions

Though super-selective arterial renal embolization (SARE) has wide applications in renal injury hemorrhage, suitable for various blunt injuries, penetrating, and iatrogenic injuries, there are still some aspects worth special attention: (1) Active monitoring of hemoglobin levels is essential for both before and after surgery. (2) It is important to comprehend the surgical procedure, which encompasses knowledge of the surgical site, access routes, and the positioning of implants such as double-J stents. (3) If the bleeding point is difficult to identify, do not forget the possibility of the accessory renal artery. (4) Empirical embolization can be considered if encounter indirect signs, such as localized intensification of contrast, contrast retention, arterial kinking, and seemingly visible signs. (5) In cases where empirical embolization fails to achieve clinical success, additional assessments with cystoscopy, CT scans, or other examinations should be performed to evaluate the situation, and a second SRAE may be considered.

Abbreviations

SRAE	Super-selective renal artery embolization
CT	Computed tomography
PVA	Polyvinyl alcohol

PCNL	Percutaneous nephrolithotomy
PN	Partial nephrectomy
CFA	Common femoral artery
PSA	Pseudoaneurysm
AVF	Arteriovenous fistula.
AML	Angiomyolipoma
KIRC	Kidney renal clear cell carcinoma
AAST	American Association for the Surgery of Trauma
NBCA	N-butyl 2-Cyanoacrylate
NBCA-MS	N-butyl 2-Cyanoacrylate metacryloxysulfolane

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Authors' contributions
Xiao An designed the study; Xiao An, Ruyi Zhao, and Xiang Zhang performed surgical operations; Yicheng Feng and Xiang Zhang collected data; Yicheng Feng analyzed the data and wrote the manuscript; Xiao An proofread and revised the manuscript. All authors approved the final manuscript.

Data availability
No datasets were generated or analysed during the current study.

Availability of data and materials
Access to the database can be obtained from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study accorded with the Helsinki Declaration and was approved by the Ethics Committee of Shanghai General Hospital (Ethical approval number: 2024KS082, approve date: 22 February 2024). Given the retrospective nature of this study, this ethical committee granted an exemption from requiring the informed consent of patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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