

Efficacy and safety of endovascular treatment for iatrogenic renal injuries following percutaneous interventions

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KEY WORDS

embolization, percutaneous intervention, renal injury

ABSTRACT

INTRODUCTION Renal artery embolization (RAE) is a minimally-invasive therapeutic option for iatrogenic renal vascular injuries (IRVIs).

AIM We aimed to assess the efficacy and safety of RAE in treating IRVIs resulting from percutaneous interventions.

MATERIALS AND METHODS The study included 34 patients (25 men, 9 women; mean [SD] age, 49.1 [18.9] years) who were treated with RAE for IRVIs at our center between February 2019 and May 2025. The etiology and type of IRVIs, hemoglobin levels, accompanying radiological findings, and parameters related to the RAE procedure were retrospectively analyzed.

RESULTS Among the 34 patients, the etiology of IRVI was percutaneous biopsy in 17 individuals and percutaneous nephrolithotomy in the remaining 17 cases. A total of 35 RAE procedures were performed (1 reintervention). The IRVIs were classified as active extravasation (n = 24), pseudoaneurysm (n = 9), and arteriovenous fistula (n = 2). Parenchymal laceration was observed in 10 patients, and a collecting system injury was noted in 1 individual. The embolic agents used were coils (49%), N-butyl cyanoacrylate mixed with lipiodol (28%), polyvinyl alcohol (PVA) particles (14%), a combination of coils, glue, and lipiodol (6%), and a combination of PVA particles and coils (3%). The technical success rate was 100%, while the clinical success rate was 97%. Only 1 patient required reintervention due to persistent hemorrhage. Minor complications occurred in 3 patients, and no major complications were observed.

CONCLUSIONS RAE is a safe, highly effective, and minimally-invasive treatment for IRVIs. The procedure offers additional advantages, including nephron preservation and the potential for repeat intervention, if necessary.

INTRODUCTION Percutaneous interventional techniques are widely utilized for the diagnosis and treatment of renal pathologies. These minimally-invasive procedures cause less parenchymal and functional damage, and are therefore considered nephron-sparing. The most common procedures are percutaneous biopsy (PB), percutaneous nephrostomy, and percutaneous nephrolithotomy (PNL). With the increasing use of these interventions, the incidence of procedure-related complications has also risen.¹

Iatrogenic renal vascular injury (IRVI) may occur as a result of renal artery or branch vessel

damage, manifesting as active extravasation, pseudoaneurysm, or arteriovenous fistula (AVF) formation. According to the 2018 revision of the American Association for the Surgery of Trauma renal injury classification, these findings correspond to grade 3 or higher renal injuries, for which active treatment is recommended due to a potential risk of massive and life-threatening hemorrhage.² Therefore, careful laboratory and clinical monitoring as well as prompt recognition and management of suspected IRVIs are essential after minimally-invasive renal procedures.

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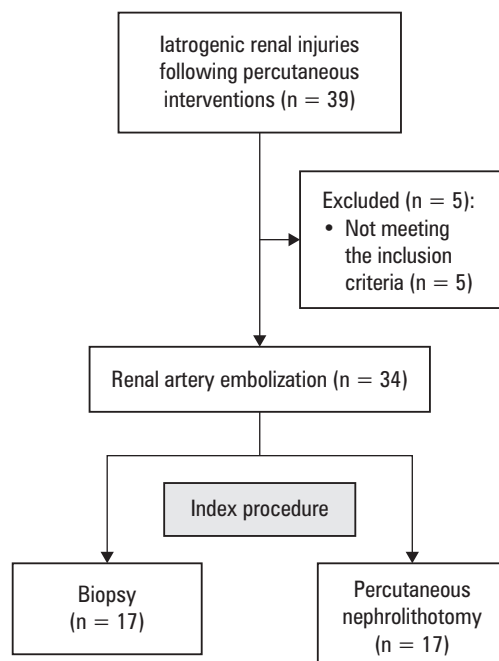
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FIGURE 1 Study flow chart



Renal artery embolization (RAE) is a minimally-invasive and nephron-sparing therapeutic option for IRVIs, and serves as a valuable alternative to surgery, particularly in hemodynamically stable patients. RAE involves angiographic identification and subsequent occlusion of the culprit vessel using temporary or permanent embolic agents. The choice of embolic material is not standardized and depends on the characteristics of the injury, patient clinical condition, and operator preference. RAE achieves high technical and clinical success rates with a low complication profile, and offers additional advantages, such as shorter hospitalization, faster recovery, and earlier return to normal activity, as compared with surgical repair.³

AIM This study aimed to evaluate the efficacy and safety of RAE performed with various embolic agents for the treatment of IRVI secondary to percutaneous renal procedures.

MATERIALS AND METHODS Patients Clinical, radiological, and procedural data of all patients who experienced IRVI following a percutaneous renal intervention between February 2019 and May 2025 were retrospectively retrieved from institutional records. We included adult patients (aged >18 y) with IRVI confirmed on contrast-enhanced computed tomography angiography (CTA) and/or digital subtraction angiography (DSA), who underwent RAE.

Exclusion criteria comprised: 1) age under 18 years, 2) renal vascular injuries of noniatrogenic origin (eg, trauma, tumor invasion, or spontaneous rupture), 3) cases primarily managed by surgery or conservative treatment instead of RAE, and 4) incomplete clinical, radiological, or procedural data. Flow chart of the study is presented in **FIGURE 1**.

Preinterventional imaging Following the percutaneous procedures, a diagnosis of IRVI was established based on CTA or DSA findings in patients with

a clinical and laboratory suspicion of hemorrhage. These patients were subsequently referred to our department for RAE. All CTA examinations were performed in the emergency radiology unit, using a 64-slice CT scanner (Aquilion 64, Toshiba, Japan). The patient management pathway, from the completion of imaging to transfer to the angiography suite for RAE, was coordinated through a multidisciplinary collaboration between the emergency, radiology, and urology departments.

Embolization procedure All interventions were performed by an experienced interventional radiologist with 12 years of practice in the field.

All procedures were conducted under local anesthesia (Priloc, Vem, Türkiye). Vascular access was obtained via retrograde puncture of the right common femoral artery, and a 5 Fr vascular sheath (Shunmei, Shenzhen, China) was placed. Diagnostic renal angiography was performed using a Simmons-2 catheter (Imager 2, Boston Scientific, Marlborough, Massachusetts, United States).

Preprocedural CTA and angiography findings were jointly reviewed to determine the nature and location of the vascular injury. The target artery was selectively or superselectively catheterized using a coaxial microcatheter system (Direxion, Boston Scientific).

The choice of the embolic agent was individualized based on angiography findings and operator preference. The materials available for the procedure included coils (Interlock, Boston Scientific), N-butyl cyanoacrylate (NBCA; Histoacryl, Braun, Germany) with ethiodized oil (Lipiodol, Guerbet, France), and polyvinyl alcohol (PVA) particles (Contour, Boston Scientific).

Upon procedure completion, control angiography was performed to confirm technical success and evaluate for complications. Successful embolization was defined as complete cessation of contrast extravasation, total occlusion of the pseudoaneurysm sac and its feeding artery, or elimination of early venous filling in the cases of AVF (**FIGURE 2**).

Hemostasis at the puncture site was achieved by manual compression in all cases.

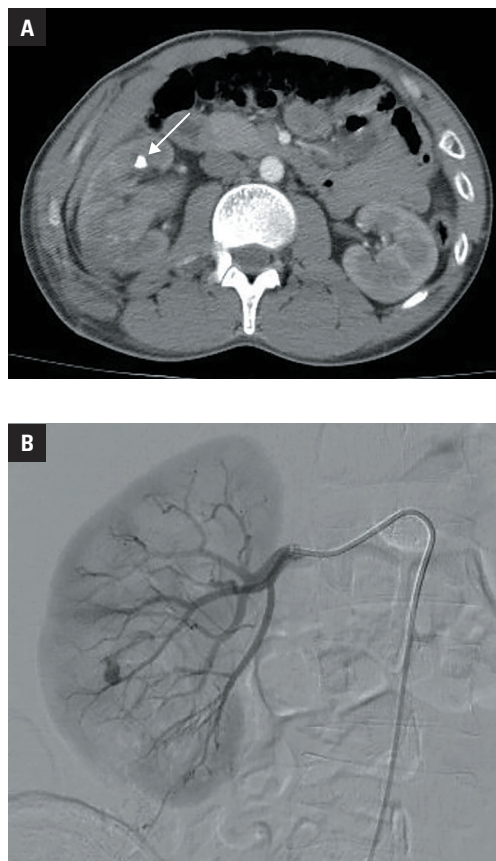
Postprocedural follow-up Following RAE, the patients were monitored in the interventional radiology suite for at least 3 hours before transfer to the emergency or urology department. Postprocedural management involved multidisciplinary cooperation.

Hemoglobin, hematocrit, and serum creatinine levels were routinely monitored to evaluate for recurrent bleeding and contrast-induced nephropathy.

Follow-up CTA was routinely performed on the first postprocedural day, regardless of the final angiographic outcome, due to the dynamic nature of the vascular injury and potential rebleeding associated with fluctuations in blood pressure or coagulation status.

Subsequent CTA examinations were performed at 3 and 6 months postprocedure, provided that

FIGURE 2 Imaging findings in a 26-year-old man who underwent renal artery embolization for iatrogenic renal vascular injury following percutaneous nephrolithotomy. The patient was referred to our interventional radiology department due to hemoglobin level decrease following the index procedure. On arterial-phase computed tomography angiography, active bleeding with a perirenal hematoma was observed (**A**; arrow). Renal angiography was performed using a Simmons-2 diagnostic catheter (Imager2 Boston Scientific, Marlborough, Massachusetts, United States) and visualized a pseudoaneurysm (**B**). The lesion was navigated with a microcatheter (Renegade, Boston Scientific), and coil embolization (Interlock, Boston Scientific) was successfully performed (**C**).



no new clinical or laboratory abnormalities were detected in the meantime.

Definitions Technical success was defined as complete angiographic occlusion of the vascular lesion (eg, pseudoaneurysm, active extravasation, or AVF) or complete cessation of hemorrhage.

Clinical success referred to sustained hemodynamic and laboratory stability without evidence of recurrent bleeding and without a need for repeat embolization or surgery.

IRVIs were categorized as active extravasation, pseudoaneurysm, or AVF, based on combined CTA and DSA findings. Associated imaging findings, such as hematoma, parenchymal laceration, or collecting system injury, were also recorded.

Complications were classified as major or minor according to the Cardiovascular and Interventional Radiology reporting standards.⁴ Minor complications were defined as those not requiring additional treatment or prolonged hospitalization, while major complications included those resulting in extended hospital stay, unplanned escalation of care, permanent adverse outcome, or death.

Data collection Comprehensive review of clinical notes, procedural reports, and pre- and postprocedural imaging findings was conducted for all patients. Collected data included demographics (age, sex), laboratory values (pre- and postprocedural hemoglobin and hematocrit levels), imaging findings (type of IRVI, associated injuries), etiology of the iatrogenic injury (eg, PB, PNL), embolic materials used, technical and clinical outcomes, and procedure-related complications.



Statistical analysis Descriptive statistics were used to summarize all variables. Categorical variables were expressed as counts and percentages, whereas continuous variables were presented as means with SD and medians with interquartile ranges (IQRs). Intergroup comparisons were performed using the Fisher exact test for categorical variables and the Kruskal–Wallis test for continuous variables. A *P* value below 0.05 was considered significant. For *P* values between 0.05 and 0.1, a tendency toward a difference was noted, while *P* values greater than 0.1 were interpreted as indicating no difference. Statistical analyses were conducted using StataSE software, version 14.2 (StataCorp LLC, College Station, Texas, United States).

Ethics Ethical approval for this retrospective study was obtained from the Sakarya University Non-Interventional Research Ethics Committee (E-43012747–050.04-489673–393). Owing to its retrospective design, the requirement for written informed consent was waived.

RESULTS Demographic data Between February 2019 and May 2025, a total of 35 RAE procedures were performed in 34 patients who presented with a clinical suspicion of hemorrhage and were subsequently diagnosed with IRVI on CTA.

Patient demographic characteristics and distribution of index procedures are summarized in **TABLE 1**. The study population was evenly divided into the PNL and PB groups (*n* = 17 each) according to the index procedure. A significant difference in age was observed: the PNL patients

TABLE 1 Demographic characteristics of the study population and distribution of index procedures

Parameter		All patients (n = 34)	PNL (n = 17)	PB (n = 17)	P value
Index procedure		34 (100)	17 (50)	17 (50)	–
Age, y	Mean (SD)	49.1 (18.9)	41.9 (17.8)	56.6 (16.9)	0.02
	Median (IQR)	50 (31–67)	36 (29–50)	64 (50–71)	–
	Range	20–81	20–81	22–76	–
Sex	Men	25 (74)	14 (83)	11 (65)	0.26
	Women	9 (26)	3 (17)	6 (35)	
Procedure side ^a	Right	15 (43)	11 (61)	4 (24)	0.06
	Left	19 (54)	7 (39)	12 (71)	
	Allograft	1 (3)	0	1 (6)	
Discharge before RAE ^a	Yes	23 (66)	16 (89)	7 (41)	0.005
	No	12 (34)	2 (11)	10 (59)	

Data are presented as number (percentage) unless indicated otherwise.

a Assessed for the number of RAE procedures (n = 35)

Abbreviations: IQR, interquartile range; PB, percutaneous biopsy; PNL, percutaneous nephrolithotomy; RAE, renal artery embolization

TABLE 2 Pre- and postprocedural laboratory values

Parameter		All patients	PNL	PB	P value
Hemoglobin before RAE, g/dl	Mean (SD)	8.42 (2.11)	9.26 (2.39)	7.53 (1.27)	0.02
	Median (IQR)	8.2 (7.25–9.3)	8.85 (7.67–10.07)	7.7 (6.6–8.2)	–
Hemoglobin after RAE, g/dl	Mean (SD)	9.39 (1.68)	9.88 (1.95)	8.88 (1.04)	0.09
	Median (IQR)	9.2 (8.25–10.05)	10 (8.4–10.35)	8.7 (8.2–9.6)	–
Hematocrit before RAE, %	Mean (SD)	25.41 (6.17)	27.93 (6.86)	22.75 (3.84)	0.01
	Median (IQR)	24.9 (21.95–27.9)	27.4 (23.78–29.88)	23.3 (19.8–25.2)	–
Hematocrit after RAE, %	Mean (SD)	27.52 (7.03)	29.88 (6.07)	25.02 (6.91)	0.04
	Median (IQR)	27 (24.2–30.55)	29.9 (25.8–31.1)	25.8 (23.8–28.6)	–
Creatinine before RAE, mg/dl	Mean (SD)	3.07 (4.69)	1.17 (0.76)	5.07 (6.06)	0.02
	Median (IQR)	1.5 (0.83–4.04)	0.91 (0.76–1.43)	4.24 (2.85–5.23)	–
Creatinine after RAE, mg/dl	Mean (SD)	2.2 (1.92)	1.17 (0.7)	3.29 (2.14)	0.008
	Median (IQR)	1.12 (0.87–3.45)	1.02 (0.85–1.15)	3.31 (1.1–4.49)	–

SI conversion factors: to convert hemoglobin to g/l, multiply by 10; hematocrit to proportion of 1, by 0.01; creatinine to $\mu\text{mol/l}$, by 88.4

Abbreviations: see TABLE 1

were younger than those undergoing PB (mean [SD], 41.9 [17.8] vs 56.6 [16.9] y, respectively; $P = 0.02$), indicating that PB was generally performed in older patients. Of the total cohort, 25 patients were men and 9 were women, with no significant difference in sex distribution between the groups ($P = 0.26$).

Details of the index procedure Regarding laterality, PNL procedures were more frequently performed on the right kidney (61%), whereas PB procedures predominantly involved the left kidney (71%). One patient in the PB group underwent biopsy of a renal allograft. A trend toward a difference in laterality was observed between the groups ($P = 0.06$).

A significantly higher proportion of patients in the PNL group (n = 16; 89%) had been discharged prior to the diagnosis of IRVI, as compared with the PB group (n = 7; 41%; $P = 0.005$), suggesting that the PB patients either required longer inpatient monitoring or developed more acute post-procedural complications.

Pre- and postprocedural laboratory values Pre- and postprocedural laboratory findings are presented in TABLE 2. Across the entire cohort, mean (SD) hemoglobin level increased markedly from 8.42 (2.11) g/dl pre-RAE to 9.39 (1.68) g/dl post-RAE ($P < 0.001$). Similarly, mean (SD) hematocrit level increased from 25.41% (6.17%) to 27.52% (7.03%), a change approaching statistical significance ($P = 0.054$).

When stratified by index procedure, pre-RAE hemoglobin levels were significantly lower in the PB group than the PNL group (64.7% vs 33.3%; $P = 0.02$). Pre-RAE hematocrit levels were also lower in the PB group, as compared with the PNL patients ($P = 0.02$). Although post-RAE hemoglobin levels remained lower in the PB than the PNL group (mean [SD], 8.88 [1.04] vs 9.88 [1.95] g/dl, respectively), this difference was not significant ($P = 0.09$; trend observed).

Mean (SD) serum creatinine levels decreased from 3.07 (4.69) mg/dl pre-RAE to 2.2 (1.92) mg/dl post-RAE ($P = 0.28$). While creatinine levels remained nearly identical in the PNL group (mean [SD], 1.17 [0.76] vs 1.17 [0.7] mg/dl, pre- vs post-RAE, respectively; $P = 0.97$), a non-significant decrease was observed in the PB group (median [IQR], 4.24 (2.85–5.23) mg/dl vs 3.31 (1.1–4.49) mg/dl, respectively; $P = 0.29$). Creatinine levels were consistently higher in the PB group, both before and after RAE, reflecting the frequent presence of underlying chronic renal parenchymal disease in this population (pre-RAE, $P = 0.02$; post-RAE, $P = 0.008$).

Iatrogenic renal vascular injury type and associated radiological findings

The distribution of IRVI types and associated radiological findings is summarized in TABLE 3. The overall prevalence of active extravasation, pseudoaneurysm, and AVF was 68%, 22%, and 6%, respectively. The rate of individual IRVI types was similar in the PB and PNL groups ($P = 0.52$). Hematoma formation was observed in 91% of the patients, with no difference between the groups ($P = 0.55$). However, parenchymal laceration was significantly more common in the PNL than the PB group (66.7% vs 29.4%; $P = 0.01$). A collecting system injury occurred in 1 patient from the PNL group.

TABLE 3 Type of iatrogenic renal vascular injury and associated radiological findings for all renal artery embolization procedures (n = 35)

Parameter		Total (n = 35)	PNL (n = 18)	PB (n = 17)	P value
IRVI type	Extravasation	24 (68)	13 (72)	11 (64)	0.52
	PSA	9 (26)	5 (28)	4 (24)	
	AVF	2 (6)	0	2 (12)	
Hematoma	Present	31 (89)	17 (94)	14 (82)	0.55
	Absent	4 (11)	1 (6)	3 (18)	
Hematoma type (n = 31)	Subcapsular	13 (42)	7 (41)	6 (43)	0.33
	Perirenal	10 (32)	4 (24)	6 (43)	
	Retroperitoneal	8 (26)	6 (35)	2 (14)	
Laceration	Present	10 (29)	9 (50)	1 (6)	0.01
	Absent	25 (71)	9 (50)	16 (94)	
Laceration grade ^a (n = 10)	Grade 2	5 (50)	4 (44)	1 (100)	0.77
	Grade 3	2 (20)	2 (22)	0	
	Grade 4	2 (20)	2 (22)	0	
	Grade 5	1 (10)	1 (11)	0	
Collecting system injury	Present	1 (3)	1 (6)	0	>0.99
	Absent	34 (97)	17 (94)	17 (100)	

Data are presented as number (percentage).

a According to the 2018 American Association for the Surgery of Trauma renal injury classification

Abbreviations: AVF, arteriovenous fistula; IRVI, iatrogenic renal vascular injury; PSA, pseudoaneurysm

TABLE 4 Details of the renal artery embolization procedure

Parameter		Total (n = 35)	PNL (n = 18)	PB (n = 17)	P value
Time interval between the index procedure and RAE, d	Median (IQR)	3 (1–9)	6 (3–31)	1 (1–3.5)	0.006
	Range	0–113	1–113	0–23	–
Embolization material	Coil	17 (49)	11 (61)	6 (35)	0.28
	Glue + lipiodol	10 (28)	4 (22)	6 (35)	
	Glue + lipiodol + coil	2 (6)	0	2 (12)	
	PVA particle	5 (14)	2 (11)	3 (18)	
	PVA particle + coil	1 (3)	1 (6)	0	
Minor complication during RAE	Present	4 (11)	3 (17)	1 (6)	0.64
	Absent	31 (89)	15 (83)	16 (94)	
Major complication during RAE	Present	0	0	0	>0.99
	Absent	35 (100)	18 (100)	17 (100)	

Data are presented as number (percentage) unless indicated otherwise.

Abbreviations: PVA, polyvinyl alcohol; others, see TABLE 1

Periprocedural details Procedural characteristics are detailed in TABLE 4. The interval between the index procedure and RAE was significantly longer in the PNL than the PB group (median [IQR], 6 [3–31] vs 1 [1–3.5] d; $P = 0.006$). This suggests that post-PNL complications may present in a delayed fashion or require a longer time for diagnosis. This is supported by the fact that a majority of patients who developed IRVIs after PNL presented as outpatients after their initial discharge.

There were no significant differences between the PB and PNL groups regarding embolic materials used ($P = 0.28$). Coils were the most frequently utilized embolic agents (49%), followed by NBCA glue with lipiodol (28%), PVA particles (14%), a combination of glue, lipiodol, and coils (6%), and a combination of PVA particles and coils (3%).

No significant relationship was identified between the embolic material used and the type of IRVI ($P = 0.75$). Coils were most commonly employed for the cases of active extravasation and pseudoaneurysm, while coils and PVA particles, as individual embolic materials, were used equally often in AVFs.

No major complications occurred during RAE in any patient. The rate of minor complications was comparable between the groups ($P = 0.64$).

DISCUSSION The primary finding of our study is the high technical and clinical success rate of RAE for IRVI treatment. The excellent safety profile of the procedure was reflected by an absence of major complications and a low rate of minor ones. Laboratory analyses revealed a significant post-procedural increase in hemoglobin and hematocrit levels. Moreover, the nonsignificant trend toward lower creatinine levels following RAE suggests that the procedure does not impair renal function, supporting its safety, particularly in the patients undergoing PB for an underlying renal parenchymal disease. In line with our findings, 2 recent papers indicated that transarterial embolization demonstrated high technical and clinical success rates in patients with iatrogenic renal injury and did not adversely impact renal function,

regardless of the embolic material used.^{5,6} A distinctive aspect of our study is its exclusive focus on IRVIs secondary to percutaneous interventions, which are becoming increasingly popular.

With the increasing use of minimally-invasive diagnostic and therapeutic methods, such as PB and PNL, a corresponding rise in the number of procedure-related bleeding complications is likely. In these procedures, the risk for renal artery injury has been associated with damage caused by equipment, such as needles, dilators, or catheters traversing the renal artery.⁷ It has been reported that the types of IRVI identified on arteriograms do not vary based on the etiology of the injury; a finding that is consistent with our study, where no association was found between the IRVI type and etiology.^{8,9} Baboudjian et al⁹ reported a mean (SD) time interval of 8 (7) days between the causative intervention and RAE, noting its similarity to previous research. Matsumoto et al⁸ demonstrated a longer interval for partial nephrectomy (mean, 15 d) and a shorter one for PB (mean, 5 d). In our study, the median (IQR) time between the index procedure and RAE was 3 (1–9) days. We found this interval to be significantly longer in the PNL group than the PB group (6 vs 1 d, respectively; $P = 0.006$).

Previous literature has demonstrated that hematoma size tends to be smaller following laparoscopic partial nephrectomy, as compared with percutaneous interventions, likely due to the direct visualization and immediate control of bleeding during surgery.¹ Our cohort did not include cases of surgically-induced IRVIs. No significant difference in hematoma size was observed between PNL- and PB-related injuries; however, parenchymal laceration was significantly more frequent in the PNL group, reflecting more extensive mechanical disruption associated with this technique. Our study demonstrated a technical success rate of 100% and a clinical success rate of 97%. Only 1 patient required reintervention for persistent hemorrhage, which was successfully managed the following day. Coils were the most frequently used embolic agent (in 17 of 35 procedures) and were utilized either alone ($n = 20$) or in combination with other materials ($n = 3$). This preference aligns with a previously published case series on RAE.¹

Our success and safety outcomes are comparable with those reported in contemporary literature. Contegiacomo et al¹ achieved technical and clinical success rates of 100% and 90.6%, respectively, in 28 patients, where glue was used as a primary embolic agent.¹ In a larger series of 50 patients, Sam et al¹⁰ reported technical and a clinical success rates of 98% each in short-term follow-up, with coils being the dominant embolic material. Wang et al¹¹ reported identical technical and clinical success rates of 89.1% using mainly coils and coil-particle combinations, with no complications recorded. Similarly, Ierardi et al³ achieved technical and clinical success rates of 100% and 95%, respectively, in 20 patients treated

predominantly with coils. Our minor complication rate of 8% was comparable to the 6% reported by Contegiacomo et al¹ and Sam et al,¹⁰ and no major complications were noted.

The second most commonly used embolic material in our series was the glue-lipiodol mixture, employed in 12 patients with active extravasation or pseudoaneurysm (combined with coils in 2 cases). This makes our cohort one of the largest in the literature to report on the use of the glue-lipiodol combination for IRVI treatment. We achieved technical and clinical success rates of 100% with this approach, in line with recent studies.^{12–14} A glue-to-lipiodol ratio of 1:8 was used to achieve both distal penetration and occlusion of the target vessel. This concentration differs from the 1:2 to 1:4 ratios reported by Tayal et al¹² and Li et al,¹³ respectively, whose cases were predominantly PNL-related pseudoaneurysms. Narkhede et al¹⁴ reported on 31 patients treated with a glue-lipiodol mixture for IRVI, noting only minimal renal parenchymal loss (a 7.6% deficit of renal blush) during follow-up. As a liquid embolic agent, glue-lipiodol offers several advantages, including deep distal penetration, rapid polymerization, and low cost, but also carries inherent risks, such as premature polymerization leading to microcatheter adhesion or non-target embolization due to reflux during uncontrolled injection.

The potential impact of RAE on renal function due to postprocedural ischemia is a topic frequently addressed in the literature, primarily through the evaluation of creatinine level and estimated glomerular filtration rate (eGFR). A retrospective study by Groff et al,⁵ analyzing 67 procedures in 61 patients with iatrogenic pseudoaneurysms, concluded that RAE did not adversely affect renal function, regardless of the IRVI type or the size of the postoperative ischemic area. Similarly, Morita et al¹⁵ observed no decline in eGFR in 72 patients who underwent RAE after partial nephrectomy. Baboudjian et al¹⁶ found no difference in 6-month eGFR values between 24 patients who required RAE after partial nephrectomy and controls. Matsumoto et al⁸ reported acute kidney injury in 7% of 90 RAE procedures, but all patients returned to normal renal function within a week. Our findings are consistent with the literature, as no patient in our cohort experienced a postprocedural rise in creatinine levels.

Noninvasive imaging prior to RAE plays a crucial role in the detection, classification, and localization of IRVIs, as well as in procedural planning through vascular mapping. CTA offers superior lesion localization—especially for pseudoaneurysms and AVFs—and higher sensitivity for low-rate bleeding (0.3–0.5 ml/min) than angiography (0.5–1 ml/min). Although direct referral for angiography without prior imaging remains an acceptable alternative in unstable patients, preprocedural CTA provides valuable information that can optimize procedural efficiency.¹⁷ Nevertheless, discrepancies between CTA

and angiographic findings are not uncommon. Matsumoto et al⁸ reported that 33% of patients with positive preprocedural imaging findings had negative angiograms, emphasizing that clinical presentation should remain the primary factor determining patient eligibility for RAE. In our series, all patients with hemorrhage identified on CTA had corresponding active bleeding confirmed on angiography, making them eligible for immediate targeted embolization.

This study has several limitations. First, its retrospective, single-center design and relatively small sample size may limit the generalizability of the findings. Second, embolic agent selection was nonrandomized and based on the operator's discretion, precluding a head-to-head comparison of efficacy among different materials. Additionally, the absence of a control or conservatively managed group restricts the ability to evaluate the superiority of RAE over alternative therapeutic approaches. Finally, long-term renal function was not systematically assessed beyond the early postprocedural period, which limits conclusions regarding potential delayed effects of RAE on renal parenchymal preservation.

CONCLUSIONS With continued advances in imaging technology and interventional equipment, minimally-invasive renal procedures, such as PB and PNL, are being performed with increasing frequency, which leads to a corresponding rise in procedure-related vascular complications. Our study demonstrates that IRVIs involving the renal artery and its branches can be effectively and safely treated with RAE—a minimally-invasive endovascular technique with consistently high technical and clinical success rates. These findings reinforce RAE as the first-line treatment option for such injuries. The choice of embolic material and technique should be individualized, taking into account the angiographic pattern of injury, patient-related factors, and operator experience.

ARTICLE INFORMATION

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AI STATEMENT Artificial intelligence was not used in the preparation of this manuscript.

CONFLICT OF INTEREST None declared.

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