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INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Volume preservation of a shattered kidney after blunt trauma by superselective renal artery embolization

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PURPOSE
We examined whether superselective embolization of the renal artery could be effectively employed to preserve traumatic kidneys and assessed its clinical outcomes.

METHODS
Between December 2015 and November 2019, 26 patients who had American Association for the Surgery of Trauma grade V traumatic shattered kidneys were identified. Among them, a retrospective review was conducted of 16 patients who underwent superselective renal artery embolization for shattered kidney. The mean age was 41.2 ± 15.7 years, and the mean follow-up duration was 138.2 ± 140.1 days. Patient data including procedure details and clinical outcomes were reviewed, and the preserved volume of kidney parenchyma was calculated.

RESULTS
Bleeding control was achieved in 13 (81%) patients and kidney preservation was achieved in 11 (79%). There was no mortality, and the median intensive care unit stay was 1.5 days. The mean volume of remnant kidney was 122.3 ± 66.0 cm^3 (70%) on the last follow-up computed tomography. The estimated glomerular filtration rate was not significantly changed after superselective renal artery embolization.

CONCLUSION
Superselective renal artery embolization using a microcatheter for the shattered kidney effectively controlled hemorrhage in acute stage trauma and enabled kidney preservation.

The kidney is the most frequently traumatized organ in the genitourinary system;[1] moreover, relatively young patients (31–38 years old) experience traumatic kidney injury more commonly.[2,3] Injuries classified as the American Association for the Surgery of Trauma (AAST) grade IV or less are usually managed by nonsurgical interventions.[4-6] Although several factors affect the choice of management, the development of a minimally invasive treatment modality, along with an understanding of the progress and feasible outcomes of nonoperative management (NOM), play an important role.[6] A minimally invasive treatment with significantly improved outcomes involves embolization of blood vessels that are causing active bleeding[7-9] and endourologic stenting of urine leakage.[10,11]

Recently, there have been several reports regarding successful NOM using embolization even in AAST grade V kidney injury,[7,8,12-14] and a few review articles suggested that NOM should be attempted if possible.[3-5] The previous reports regarding NOM in AAST grade V injury focused mainly on effective bleeding control and survival.[8-11,15-21] However, recent advances in embolization techniques using microcatheters also allow preservation of part of the damaged organ.[22,23]

A shattered kidney refers to the extreme of multiple renal lacerations, often with devitalized areas due to infarction macrohematuria and urinary extravasation resulting from injuries to the collecting system.[8,19] In this study, we proposed that if the renal bleeding due to trauma was resolved using superselective embolization, the remaining viable parts of the kidney could be spared. Volume preservation is an essential condition for preserving function. Therefore, superselective renal artery embolization (RAE) was used to treat patients with a shattered kidney (AAST grade V kidney injury), and the ensuing degree of kidney vol-

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umetric preservation and clinical outcomes were assessed.

Methods

This study has obtained IRB approval from Pusan National University Hospital (IRB No. H-2004-023-090). The study was conducted according to the tenets of the Declaration of Helsinki. The requirement to obtain informed consent was waived.

Patient selection and data collection

In this retrospective study, all patients with blunt trauma and evidence of kidney injury transferred to a level I regional trauma center of a tertiary referral hospital from December 2015 to November 2019 were considered for study. There were 157 patients diagnosed with renal injury on CT angiography, and 26 patients were determined as having AAST grade V renal injury. Ten patients were excluded from the study since five patients had main renal arterial injury and five underwent initial surgical nephrectomies in combination with surgery for other organ injury. Sixteen patients who underwent superselective RAE were included in this study (Figure 1). Superselective RAE is defined as embolization via a microcatheter at the branch below the main renal artery level.

Table 1 shows the injury mechanisms, initial vital signs at the time of visit, and injury severity scores (ISS). The ISS was extracted from the Korean Trauma Data Bank.

Findings of CT angiography and conventional angiography are summarized in Table 2. All CT findings included shattered kidney and perirenal hematoma. There were no cases with injury in both kidneys. One patient with right renal injury had left renal agenesis.

The numbering of embolized arterial sequences was performed based on the branching order of the renal artery on angiography; therefore, the main renal artery was numbered "1", and subsequent branches were numbered consecutively. In addition, the total number of embolized vessels was counted.

Interventional procedures

The digital subtraction angiography covering the abdominal aorta was performed using a 5 F pigtail catheter with the tip positioned at the suprarenal abdominal aorta in the anteroposterior view to outline the renal arterial anatomy and identify bleeding sites. Selective cannulation of the renal arteries was subsequently performed to identify the bleeding sites on a uniplanar angiographic suite (Infinix-i, Canon Medical Systems Corporation) using 5 F Cobra (n=15) or Rosch hepatic (n=1) catheters (Cook Medical). All pathologic renal arterial branches (Table 2) were

Main points

- Superselective embolization of the renal artery could be a useful method of nonoperative management to preserve traumatic kidneys.
- This method could provide high rates of bleeding control and kidney preservation without mortality and with a short intensive care unit stay.
- Superselective renal artery embolization using a microcatheter for shattered kidneys may be recommended in acute hemodynamically stable trauma.

Table 1. Patient characteristics

Parameter	Total (n=16)
Age (years), mean ± SD	41.19 ± 15.66
Men: Women, n	12:4
Follow-up (days), median (range)	140.0 (4-496)
Injury mechanism, n (%)	
Fall	6 (37.5)
Motorcycle traffic accident	3 (18.8)
Slip down	3 (18.8)
Blunt force injury	2 (12.5)
In-car traffic accident	2 (12.5)
Initial vital sign	
SBP (mmHg), mean ± SD	90.31 ± 20.53
DBP (mmHg), mean ± SD	57.06 ± 15.60
HR (bpm), mean ± SD	94.25 ± 21.50
Hemoglobin (g/dL), mean ± SD	11.3 ± 2.02
Transfusion (mL), median (range)	1200 (0-4000)
Injury severity score, mean ± SD	27.19 ± 8.13
ICU stay (days), median (range)	1.5 (1-13)
Hospital stay (days), median (range)	23.0 (13-41)

The volume of RBCs used for transfusion was 250-300 mL per bag.
SD, standard deviation; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; ICU, intensive care unit.

Table 2. CT and conventional angiography finding of patients with AAST grade V shattered kidney

	Total (n=16)
CT angiography findings	
Contrast extravasation	8
Contrast extravasation + pseudoaneurysm	6
Contrast extravasation + parenchymal devascularization	1
Pseudoaneurysm	1
Conventional angiography findings	
Contrast extravasation	6
Pseudoaneurysm	3
Contrast extravasation + pseudoaneurysm	3
Pseudoaneurysm + arteriopelvic fistula	2
Truncation of arteries	2

CT, computed tomography; AAST, American Association for the Surgery of Trauma.

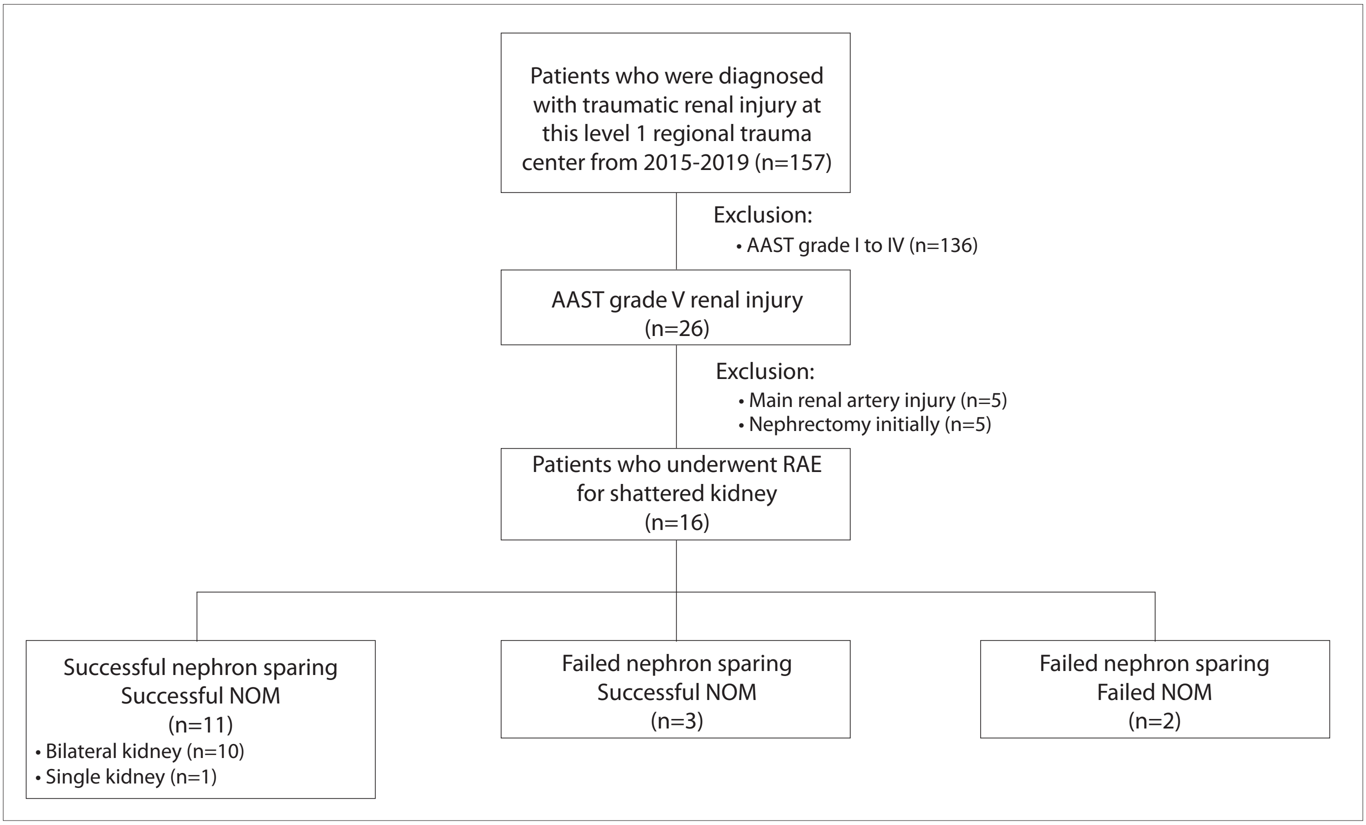


Figure 1. Flow chart depicting patient selection process. AAST, Association for the Surgery of Trauma; RAE, renal artery embolization; NOM, nonoperative management.

embolized whenever possible. To preserve kidney parenchyma as much as possible, superselective embolization was performed by introducing a coaxial microcatheter such as 1.7 F (Veloute; Asahi Intecc), 1.68 F (Radiostar; TaeWoong Medical Co.), or 2.0 F (Progreat; Terumo) as closely as possible to the pathologic arterial site. The choice of embolic materials was determined at the discretion of the 3 attending interventional radiologists (with 21, 7, and 5 years of experience). For n-butyl-2-cyanoacrylate (NBCA) (Histoacryl, B. Braun) embolization, NBCA was mixed with iodized oil (Lipiodol Ultra Fluide; Guerbet) at ratios of 1:2 to 1:4 (the ratio was at the discretion of the attending interventional radiologist). The microcatheter was flushed with 5% dextrose solution to avoid gluing and occlusion of the lumen during the NBCA injection, and 0.5-2 mL of the mixture was carefully injected under fluoroscopic monitoring. The ratio, volume, and injection rate were based on the size and flow of the targeted vessel.

Technical and clinical success assessment and follow-up

Technical success was defined as controlled bleeding upon completion of angiography. Clinical success was defined as successful kidney preservation through superselective embolization. This included cases receiving other procedures, including percutaneous drainage (PCD), percutaneous nephrostomy (PCN), or double J stent insertion due to perirenal hematoma/urinoma. Clinical failure was defined as a kidney preservation failure where either 1) surgical nephrectomy was performed after superselective embolization or 2) NOM was initially successful but progressed to a non-perfused kidney and failed preservation of the damaged kidney.

Most of the patients were followed up for 6 months after discharge. Among these, patients with noticeable changes of serum blood urea nitrogen (BUN), creatinine, and glomerular filtration rate (GFR) were referred to a nephrologist, and dimercaptosuccinic acid (DMSA) and diethylenetriamine pentaacetic acid (DTPA) tests for kidney function were performed.

The preserved kidney volume was calculated from the CT images taken at the last follow-up. Kidney volume was measured according to a standardized volumetric method based on the axial CT images, by sum of all the preserved kidney areas of the axial image.[24] The volumes obtained by CT volumetry performed by interventional radiologist and specialized abdominal radiologist using CT image analysis software linked to an Aquarius iNtuition workstation (TeraRecon). Because the initial non-injured-state volume of the injured kidney was not calculated exactly, it was necessary to estimate it based on previous literature. Based on Korean data, the kidney on the left side is 1.02 times larger than that on the right.[25] The percentage volume of the preserved kidney was calculated as:

$$\frac{\text{Preserved volume of injured kidney}}{\text{Contralateral kidney volume} \times (\text{Right: 1.02 or Left: 0.98})} \times 100$$

Major complications were classified as those requiring extended hospitalization, advanced level of care, or resulting in permanent adverse sequelae or death; other complications were considered minor.[26,27]

Statistical analysis

The normal distribution of values was assessed with the Kolmogorov-Smirnov test,

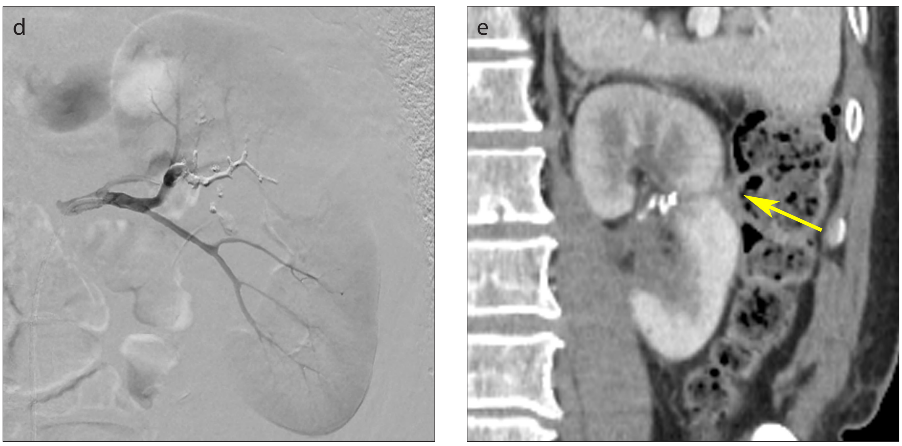


Figure 2. a–e. Image scans of a 57-year-old man who presented with abrupt abdominal pain after falling. Contrast-enhanced CT scan coronal image **(a)** shows contrast leakage *(arrow)* at the left kidney mid-pole with adjacent perirenal hematoma and shattered left kidney upper pole. Contrast-enhanced CT scan coronal image **(b)** shows another shattered left kidney lower pole. Right renal arteriography **(c)** shows active contrast leakage via upper subsegmental artery *(arrow)* and pseudoaneurysm. Post-embolization (NBCA/lipiodol mixture) arteriography **(d)** shows no active bleeding focus and segmental perfusion defect. It also shows patent perfusion of the residual left kidney. The 57-day follow-up CT scan coronal image **(e)** reveals partial ischemic renal parenchyma with focal cortical effacement *(arrow)* of the remnant left kidney without any residual complications, and a 137.0 cm^3 of remnant kidney volume was confirmed.

Table 3. Characteristics of embolization

Parameter	Total (n=16)
Order of embolized artery, mean ± SD (range)	2.9 ± 1.0 (1-4)
Number of embolized arteries, mean ± SD (range)	1.9 ± 0.8 (1-3)
Embolic materials, n*	
Fiber-coated microcoil	6
NBCA/iodized oil	3
Microcoil + NBCA/iodized oil	4
Gelatin sponge + microcoil	2
PVA particle	1

SD, standard deviation; Fiber-coated microcoil (Tornado, Cook Medical; VortX, Boston Scientific); NBCA, n-butyl-2-cyanoacrylate (Histoacryl, B. Braun); iodized oil (Lipiodol, Laboratoire Andre Guerbet); gelatin sponge (Cutanplast, Mascia Brunelli; EG-gel, Engain); PVA, polyvinyl alcohol (Contour SE, Boston Scientific).
*Number of patients.

and descriptive statistics were performed, including mean, median, standard deviation, and percentages. The comparison of the preprocedural factors between the clinical success and the failed groups was performed with an independent t-test. The results were calculated using MedCalc Statistical Software version 18 (MedCalc Software).

Results

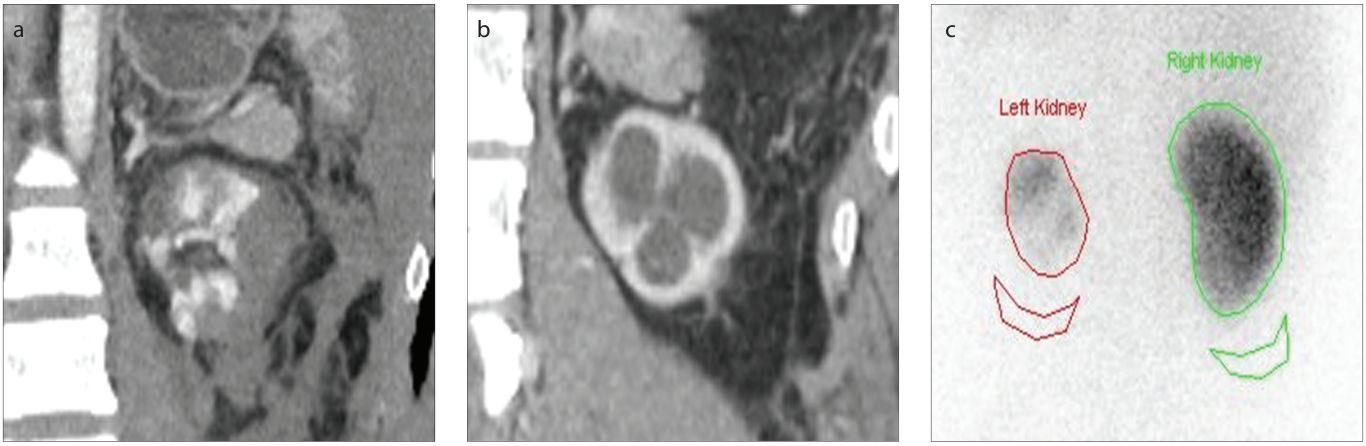
The mean time from arrival at the emergency department to the procedure was 97.5 ± 36.4 minutes. The mean largest order of embolized vessels was 2.9 ± 1.0, and the mean number of embolized vessels was 1.9 ± 0.8. The frequency of embolization materials used during the procedure is reported in Table 3.

Technical successes were achieved in 13 of 16 patients (81%), which were confirmed by renal angiography and abdominal aortography. Delayed bleeding occurred in three patients, and additional embolizations were performed.

Kidney preservation was successful in 11 of 16 patients (clinical success rate of 69%; Figure 2), including a single kidney patient. NOM was achieved in 14 of 16 patients (88%), the mortality rate was 0%, and the duration of intensive care unit stay was 1.5 days (1–13 days).

The mean volume of preserved injured kidney was 122.3 ± 66.0 cm^3. The mean volume of the contralateral non-injured kidney was 167.8 ± 60.7 cm^3. A mean of 70% ± 26% of kidney parenchyma was spared through superselective RAE. Notably, the volume of kidney preserved in the patient with a single kidney was approximately 205.3 cm^3, but the volume ratio could not be calculated. The mean follow-up duration was 148.0 ± 193.6 days.

Perirenal fluid collection was observed in all patients, and hematoma and urinoma were combined due to the natural course



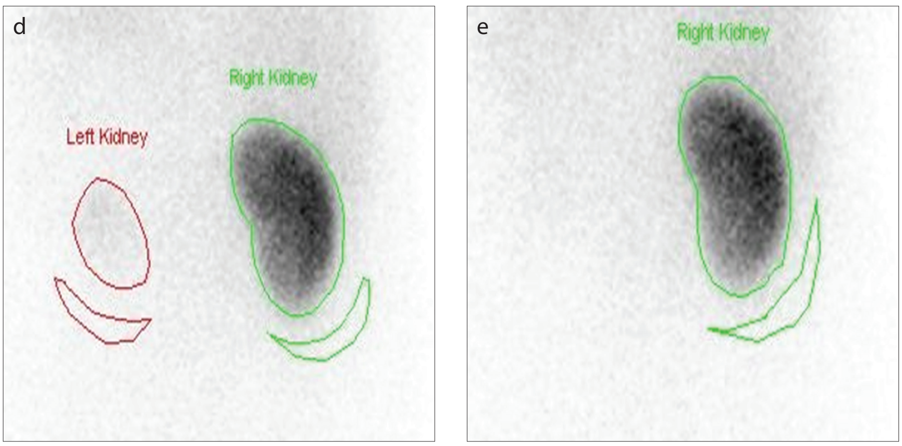


Figure 3. a–e. Images of a 23-year-old man who presented with abdominal pain after motorcycle traffic accident. Contrast-enhanced CT scan coronal image **(a)** shows contrast leakage in a severely macerated, shattered left kidney. The 485-day follow-up CT scan **(b)** shows atrophic change of the left renal parenchyma with caliectasis. Panels **(c–e)** show Tc-99m dimercaptosuccinic acid at 29 days **(c)**, 124 days **(d)**, and 478 days **(e)** after embolization (with fiber-coated microcoils); the total relative uptake ratio (right:left) are 85.3:14.7, 96.5:3.5, and 100:0, respectively. On Tc-99m diethylenetriamine pentaacetic acid at 484 days after embolization, the glomerular filtration rate is 8.5 mL/min for the left kidney (not shown).

Table 4. Comparison of clinical success (kidney preservation) and failure groups

	Success (n=11)	Failure (n=5)	*P*
ISS	25.81 ± 6.87	30.20 ± 10.66	.34
Hemoglobin - ER (g/dL)	11.14 ± 2.17	11.64 ± 1.81	.66
Hemoglobin - postprocedural (g/dL)	10.42 ± 2.22	10.46 ± 1.47	.97
Heart rate (bpm)	91.09 ± 17.58	101.20 ± 59.56	.40
Systolic blood pressure (mmHg)	92.73 ± 21.95	85.00 ± 18.03	.50
Transfusion (mL)	2.91 ± 3.01	4.40 ± 3.36	.39
Age (years)	43.27 ± 15.31	36.60 ± 17.18	.45

Data are presented as mean ± standard deviation.
ISS, injury severity score; ER, emergency room.

of the shattered kidney. In seven patients (44%), uncontrolled pain was observed, resulting in PCD insertion for fluid drainage. Among them, one patient had painful massive perirenal fluid collection that occurred immediately after superselective RAE, and PCN and PCD were performed. After 6 days, a retrograde double J stent was inserted; however, the large amount of urine drainage via PCD was not controlled. The urine generated from the surviving small shattered portion of the lower pole of the kidney with severe pelvicalyceal injury was judged to be the main cause of this fluid collection. Embolization was performed to sacrifice the problematic shattered renal remnant. After embolization, urine leakage gradually resolved, and the patient was discharged on day 21 after the second embolization.

Kidney preservation failed in five patients (31%). In three patients, the kidney preservation failed despite successful NOM (Figure 3). The injured kidney showed a gradual atrophic change and lost perfusion on follow-up CT scan. In two patients, surgical nephrectomy was performed after embolization due to uncontrolled infected urinoma, as NOM had also failed.

The mean values of estimated GFR at admission and follow up after superselective renal artery embolization were 86.8 ± 19.1 mL/min/1.73 m^2 and 96.2 ± 21.0 mL/min/1.73 m^2, respectively (P = .31); there was no significant decrease in the estimated GFR value, suggestive of renal function impairment in any patient (P = .19).

The preprocedural factors such as ISS, initial blood pressure, hemoglobin, heart rate, amount of transfusion of packed red blood cells, and age were not significantly different between patients in whom kidney preservation was successful and those in whom it failed (Table 4).

There were no procedure-related deaths. The infected urinomas with fever, pain, and elevation of C-reactive protein resulted in nephrectomy, as early major complications were observed in 13% (2/16) of the patients. The following early minor complications were observed in 38% (6/16) of patients:

nausea and/or vomiting in 25% (4/16) and flank pain in 13% (2/16). Delayed complications (>30 days after trauma) included two cases of persistent microscopic hematuria (13%), one of newly developed hypertension (6%), and one of acute pyelonephritis (6%) on post-procedural day 67.

Discussion

In trauma, the use of interventional radiology may increase the number of patients who are successfully managed nonoperatively or act as a bridge to definitive surgery in initially unstable patients.[28,29]

The purpose of this study was to evaluate the efficacy of treatment via superselective RAE instead of nephrectomy for shattered kidney. Superselective embolization using a microcatheter was performed in all patients for whom kidney preservation was considered. In all patients, embolization was performed on arteries distal to the main renal artery, and embolization was performed as selectively as possible to maximize the preservation of viable, perfused renal tissue.[29] It was possible to achieve kidney preservation as well as bleeding control through this procedure.

In this study, the mean largest order of embolized vessel was 2.9 ± 1.0. It should be noted that because the numerical classification of the renal artery branches is not based on the functional unit that supplies the anatomical section of the kidney, correlation with the volume of the preserved kidney cannot be confirmed. However, our results suggest that the more distal and precise the target vessel control, the greater the possibility of kidney preservation because the kidney is a definite end-artery organ.

Whether the remnant kidney parenchyma's calculated volume is associated with renal functional preservation cannot be determined based on the design of this study. Routine renal function tests such as DMSA or DTPA were not performed on patients who visited the center for trauma unless there was any noticeable change in serum BUN, creatinine, and estimated GFR after returning to their daily routine. However, it is certain that preserved kidneys will surely help in relatively young patients. In particular, superselective RAE will be even more important in treating the same situation in renal cell carcinoma as in indications where nephron-sparing surgery is being considered, for example, when a mass lesion in the opposite kidney is suspected of malignancy, or when anephric patients need renal replacement therapy immediately after nephrectomy, instances of unilateral renal agenesis, previous contralateral nephrectomy, or irreversible impairment of contralateral renal function due to a benign disorder.

After successful hemostasis through superselective RAE, perirenal urinoma may occur when the functional remnant kidney is accompanied by severe pelvicalyceal injury. In persistent urinoma, spontaneous resolution can be expected by performing conservative management (draining with PCD, diversion of urine with PCN, and double J stent insertion). However, if the urine leakage is caused by functional remnants and is not solved by these treatments, embolization may be attempted to sacrifice the problematic kidney instead of surgical nephrectomy.

There were no statistically significant differences between the successful and failed kidney preservation groups in terms of pre-procedural factors. Moreover, even if superselective RAE fails to preserve the kidney, NOM can succeed; if complications occur, elective nephrectomy can be performed later.

Several limitations should be acknowledged in this study. First, this was a retrospective study with the accompanying inherent limitations. We only included patients who were transferred to our institution for the management of trauma, which can be a potential selection bias. Second, the study population (n=16) was not sufficiently large to confirm our results statistically; this was associated with the relative rarity of using an embolization procedure for shattered kidney. Moreover, further studies are needed to correlate the remaining kidney volume on follow-up CT and functional preservation through serial DMSA and DTPA test.

In conclusion, this report documents our experience in performing superselective RAE in patients with a shattered kidney. After the procedure, initial hemostasis was achieved in 81% of the patients, and a mean of 70% of the kidney volume was preserved in 69% of the patients. Superselective RAE using a microcatheter for the shattered kidney effectively controlled hemorrhage in acute stage trauma and enabled kidney volume preservation.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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