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Original Article

A new method for traumatic renal injury in a canine model

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Abstract

Background: Selective transcatheter angiographic embolization (TAE) is an important method for efficient and accurate hemostasis in organ injuries during emergency settings. Sometimes, TAE cannot be performed on patients because of the limitations imposed by their condition.
Methods: A total of 32 canines with traumatic right renal wounds were prepared by stab injuries. The canines were randomly divided into four groups according to different treatments. Group A was the renal neoplasty group ($n = 8$). Group B was the TAE group ($n = 8$). Group C was the group with temporary transcatheter bung associated with the renal neoplasty (TTBR) ($n = 8$), and Group D was the sham surgery control group ($n = 8$). Clinical trauma database, outcomes, and complications were analyzed to determine the feasibility and efficacy of different methods.
Results: All canines were rescued in a timely manner. There was gross hematuria in six canines (18.8%). Only one (3.1%) animal died during follow-up because of uremia. The complication rate was not statistically different according to management type (Groups A, B, and C vs. Group D; $p = 0.332$, $p = 0.372$, and $p = 0.345$, respectively). Groups B and C did better in protecting the damaged renal function with respect to creatinine than Groups A and D ($p = 0.013$ and $p = 0.032$, respectively). However, Group C did a better job in protecting the damaged renal function than Group B ($p = 0.015$).
Conclusion: Use of TTBR can protect the damaged organ's functions more efficiently. Combined with the hybrid operating shelter, the method is a good damage control method for treating similar trauma in emergencies.

Keywords: damage control; hybrid operating shelter; organ function protection; renal trauma; selective transcatheter angiographic embolization

1. Introduction

Worldwide, trauma is currently the sixth leading cause of death, accounting for 10% of mortalities.[1] The urogenital system has consistently been shown to be involved in 10% of patients presenting after trauma and is a significant factor in trauma-induced morbidity and mortality.[2] Renal injuries have been reportedly encountered by trauma surgeons, accounting for 1–3% of all traumatic injuries.[3,4] There are many mechanisms for injury. Usually, when associated with unstable hemodynamics or other organ injuries, patients require surgical exploration. The most common management of renal injury is nephrectomy.[5] Renal function insufficiency after renal injuries or after treatments occur frequently; they often correlate with increased mortality. Thus, the ability to rescue the extent of nephron function loss is an important factor when assessing outcomes after renal injuries. The treatment of renal trauma has changed from surgical exploration to an approach that conserves nephrons.[6,7] Currently, many methods are used to prevent nephron loss, including partial nephrectomy, renal neoplasty, selective transcatheter angiographic embolization (TAE), and nonoperative management.[3,8,9]

Although there is an increasing number of patients undergoing nonoperative management of penetrating renal trauma in clinical practice,[10] TAE has been widely used to manage

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renal trauma, and it has been confirmed as an effective tool. However, owing to circumstances of skill or situation, such as in disaster assistance or field relief environment, use of TAE may be rendered nearly impossible.

To date, there has been no study using temporary transcatheter bung associated with renal neoplasty (TTBR) to treat renal trauma. This study evaluated our experiences with this method in canines in the hybrid operating shelter. We made comparisons of outcomes and complications between different management types. We think that TTBR has the potential to treat some specified patients with renal trauma. The immediate and short-term results of TTBR are presented and discussed.

2. Methods

2.1. Ethics statement

This study was performed with the approval of the institutional animal research committee of the hospital (Approval No. 2012-396). All experimental procedures were conducted according to guidelines on the ethical use of animals and the National Institutes of Health "Guide for the Care and Use of Laboratory Animals" (NIH publication No. 80−23, revised 1996).

2.2. Experimental animals

A total of 32 adult beagle dogs (weight, 10.5−15.0 kg) were randomly divided into four groups according to hemostasis method: Group A, the exploratory and renal neoplasty group ($n = 8$); Group B, the TAE group ($n = 8$); Group C, the TTBR group ($n = 8$); and Group D, the sham surgery control group ($n = 8$).

2.3. Pre- and postoperative preparation and protocol

Traumatic renal injury in Groups A, B, and C was induced using a sharp-pointed knife from the right costospinal angle. The double-edged knife was 15 cm long and 2 cm wide, and the size of the stab wound was about 2 cm in width and 10 cm in depth. Ultrasound confirmed renal hemorrhage. Group A canines underwent surgical exploration to find the injured part and then they were safely sutured. In general, we used the surgical technique described by Master and McAninch.[11] The Master and McAninch method involves dissecting skin and peritoneum from a midline incision, finding the right renal region and injured part, and then suturing the wound with absorbable stylolites. Group B underwent superselective TAE with gelatin sponge. Group C underwent TTBR (described next). The sham injury group underwent exploratory surgery only, but had not developed any traumatic renal injury. In order to observe the level of right renal function injury, the left kidney vessels of all groups were ligatured under exploratory surgery.

All efforts were made to minimize suffering. All dogs were anesthesized with 2.5% pentobarbital sodium, and recovered in an intensive care unit in a timely manner. They were provided opioid analgesia, and supportive oxygenation (95%). The wounds were disinfected every day. All dogs were intramuscularly injected with penicillin (240 w u/d) for infection prevention.

Animal data points collected include pulse, systolic blood pressure, hemoglobin, transfusion requirement, renal outcomes (serum creatinine and Puncture Biopsy Histology Score),[12] time of hemostasis, and mortality.

2.4. Field hybrid operating shelter

The Mobile Field Intervention and Surgery Shelter, as described in previous literature, was used in the angiography and operating suite[13,14]; it consists of a high-quality angiographic C-arm installed in the shelter used for combined surgical and endovascular procedures for trauma cases. It has been developed to enable clinicians to perform angiographic and surgical procedures simultaneously. It has the characteristics of mobility and flexibility in a complicated environment.

2.5. Arteriography, TAE, and TTBR techniques

In Groups A and B, arteriography was performed with the standard percutaneous technique using a common femoral artery approach. All angiography or TAE procedures were performed by two experienced interventional radiologists in the field hybrid operating shelter. A 5.5F arterial sheath was placed in the common femoral artery with the tip positioned at the level of the external iliac artery. This afforded rapid and safe exchange of angiographic catheters for aortography and selective catheterization of the main artery. The procedure started with intra-arterial digital subtraction angiography of the aorta, followed by selective renal arteriography, which was directed to the injured right kidney (available in all 32 animals). Then, hemostasis management was performed. In Group B, superselective catheterization with a coaxial microcatheter (Tracker; Boston Scientific, Watertown, MA, USA) was used to embolize the identified lesion. The gel-foam particles (Surgifoam or Gelfoam; Ethicon, Somerville, NJ, USA) were slowly injected by hand at 0.1−0.2 mL/s. In Group C, a balloon was inflated in the initial segment of selective branch for temporary bunging hemostasis. After the kidney was adequately exposed, the injury was debrided and definitive repair was performed. Five minutes later, the balloon was deflated. The catheter was slowly withdrawn. All canines were provided with antibiotics prior to the embolization procedure.

2.6. Statistical analysis

SPSS (version 11.0) (IBM SPSS, Chicago, America) was used for statistical analysis. All values are expressed as mean ± standard deviation. Differences were calculated with Kruskal−Wallis test, followed by Mann−Whitney U analysis. The Bonferroni correction of the analysis of variance was used to correct for multiple comparisons. The correlations (r) between hemostasis time and renal function in different groups were calculated using the Spearman correlation test.

3. Results

3.1. General data

A total of 32 canines were included in the final statistical analysis. There was no significant statistical difference in the clinical data ($n = 32$) (Fig. 1). All processes were performed in our self-made shelter (Fig. 2). Twenty-four animals served as renal traumatic models. The evaluation was based primarily on the similarity of parenchymal laceration depth and the absence of vascular injury. According to the American Association for the Surgery of Trauma standard,[15] the injury models were in stages 2−3. There were 21 animals (87.5%) with significant hematuria owing to traumatic renal bleeding. Finally, most animals with renal neoplasty (Group A, $n = 8$), TAE (Group B, $n = 8$), and TTBR (Group C, $n = 8$) resulted in the successful hemostasis (87.5%), except for three dogs in Group A. Hemorrhage volume was highest in Group A, in which three animals received transfusions. Time of hemostasis was shortest in Group C (Fig. 3). Creatinine level was abnormal in 24 animals after the intervention. We found some differences in renal function among the groups. The renal function abnormality in Group C was less than those observed in Groups A and B ($p < 0.016$).

3.2. Transcatheter angiography and embolotherapy

After injury models were created, angiography was performed. Renal angiography demonstrated contrast medium extravasation in 24 (100%) animals (Figs. 4C and 4E), pseudoaneurysm in four (3 in Group A, 1 in Group B; 16.7%), and arteriovenous fistula in one (in Group C; 4.2%). The post-treatment renal angiography was observed. Hemostasis was considered successful if immediate cessation of contrast medium extravasation and/or the abnormal arterial branch was present. In Group C, after the balloon was inflated in the initial segment of the selective branch, we rechecked angiography, and hemostasis was successful—that is, temporal bunging hemostasis was successful (Figs. 4F and 4G). Hemostasis was successful in all 24 animals (100%), with the absence of contrast medium extravasation on the post-treated angiography (Fig. 4H).

3.3. Follow-up data

Complication directly related to the angiography was not found. The overall survival rate was 96.9% ($n = 31$). One animal in Group A was sacrificed by euthanasia during follow-up, owing to irreversible renal damage. One month later, ultrasonographic detection showed complete resolution of all perinephric collections. The renal function and morphological outcomes are summarized in Fig. 5. The mean creatinine levels improved significantly in Groups B and C at the last follow-up ($p < 0.016$). During 1-month follow-up, creatinine levels were elevated in Groups A, B, and C (Fig. 5). However, there was no statistical significance among Groups B, C, and D ($p > 0.016$). There was significant deterioration in renal function ($p < 0.016$) in Group A, compared with that in Groups B and C.

It was obvious that the hemostasis times in the experimental groups were all greater than those observed in the sham group ($p < 0.016$). Moreover, the hemostasis time in Group C was less than those seen in Group A and Group B ($p < 0.016$). Statistical correlations between hemostasis time and renal function were evident for all injury groups. We found that the hemostasis time correlated with the renal function in the model groups—Group A ($n = 7$): $r = 0.694$,

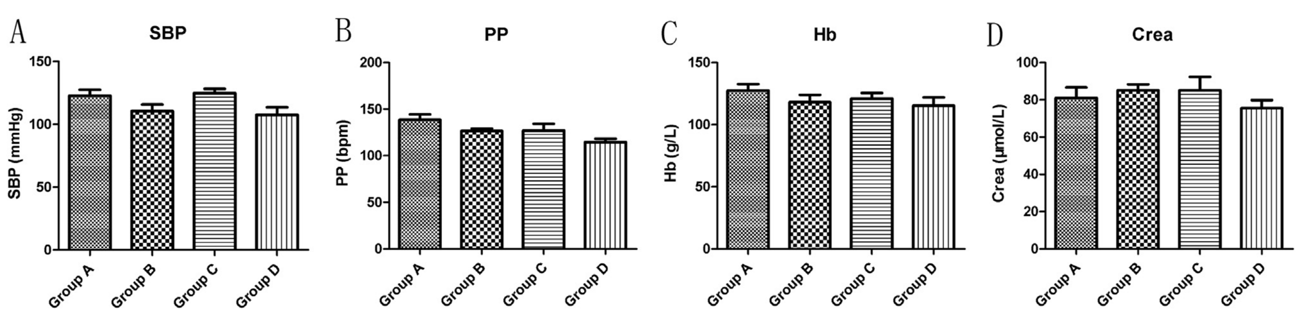

Fig. 1. Laboratory data prior to the operation. No statistically significant difference in SBP, PP, Hb, and creatinine levels among different groups. * $p > 0.05$. bpm = beat per minute; Crea = creatinine; Hb = hemoglobin; PP = peripheral pulse; SBP = systolic blood pressure.

Fig. 2. The field hybrid operating shelter. (A) The shelter in transit. (B) The shelter when seen from outside. (C) The shelter when unfolded from inside.

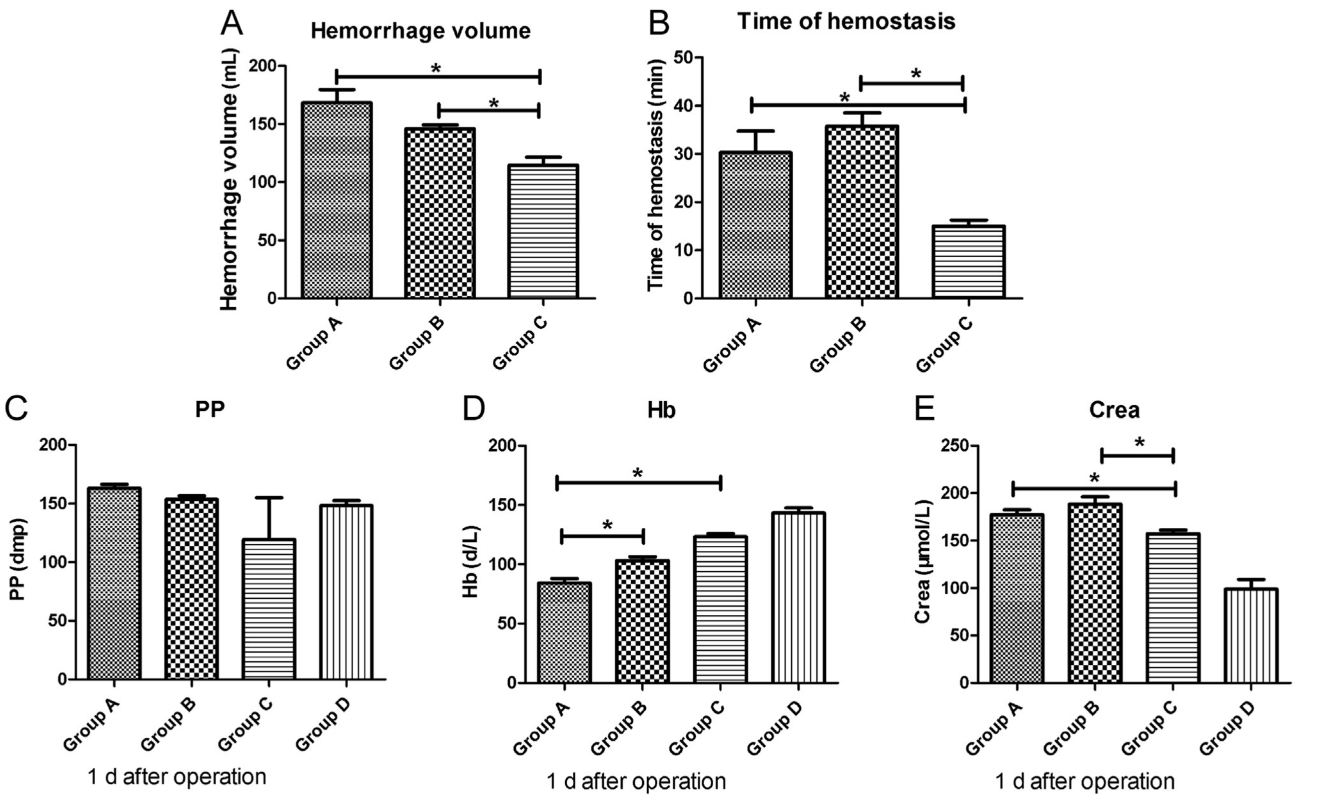

Fig. 3. Data of traumatic renal injury model. (A) Hemorrhage was greatest in Group A (control to Group C). (B) Hemostasis time in Group C was shortest in Groups A, B, and C. (C, D, E) Laboratory data after the operation (control to Group C). * $p < 0.05$. Crea = creatinine; Hb = hemoglobin; PP = peripheral pulse.

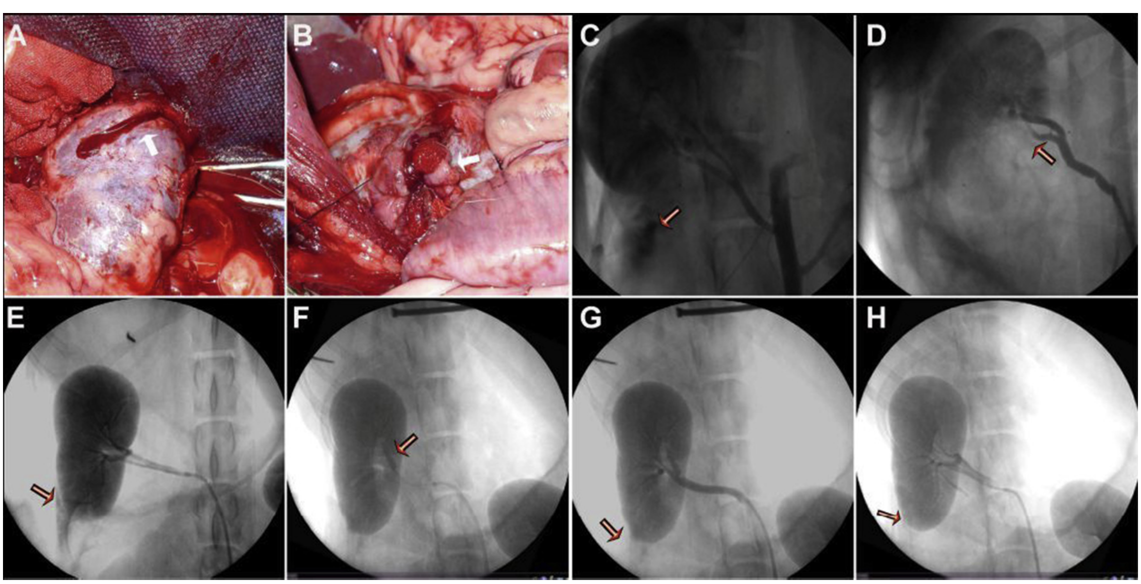

Fig. 4. Traumatic renal injury model. (A, B) Group A. After obstructing the renal pedicle with Satinsky's clamp, we found the bleeding part and sewed it up; no active bleeding could be seen (white arrow). (C, D) Group B. Renal angiography shows contrast medium extravasation (red arrow). After TAE with gelatin sponge particulate embolization, the extravasation stopped. There was a comparatively large ischemic zone (red arrow). (E, F, G) Group C. Renal angiography showed contrast medium extravasation (red arrow). After finding the bleeding part, the saccule was injected with contrast media to block the blood supply (red arrow), and angiography was rechecked. After sewing up the injured part, we removed the blocked sacculus, and rechecked angiography again. (H) The hemorrhage had stopped (red arrow). TAE = transcatheter angiographic embolization.

$p = 0.021$; Group B ($n = 8$): $r = 0.715$, $p = 0.039$; and Group C ($n = 8$): $r = 0.796$, $p = 0.019$. Therefore, hemostasis time clearly indicated the extent of renal protection of the different groups.

4. Discussion

The kidney is the most commonly injured organ in all abdominal trauma cases.[16,17] There are many prognostic

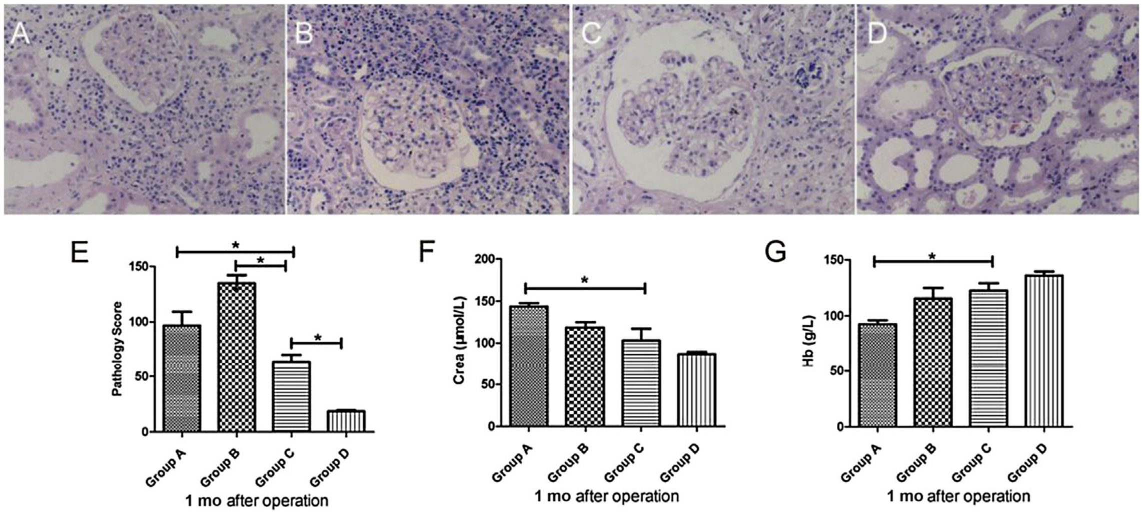

Fig. 5. Data from follow-up. (A, B, C, D) Different degrees of injuries in biopsy (HE, 200×) in Groups A, B, and C. (E) Pathology score showing that the injuries in Group B were the most serious (control to Group C). (F, G) Laboratory data, 1 month later; animals in Group C had recovered better (control to Group A). * $p < 0.05$. Crea = creatinine; Hb = hemoglobin; HE = hematoxylin and eosin.

factors for patients, including the stage of injury, the mechanism of injury, and surgical exploration or nephrectomy.[18–20] The key point of deeply wounded patient survival has been early hemostasis. However, the loss of renal function is often neglected. Benefits of renal salvage include decreased mortality rates and decreased risks for developing chronic kidney disease.[21] Surgical repairs must be performed within 4 hours of injury in order to preserve renal function. However, only 14–29% of kidneys are ever restored to normal function.[21–23] Thus, in this report, we describe our experience with a new damage control method to evaluate the extent of renal protection in canines with renal injuries. We found that TTBR was a safe and reliable method to treat renal injury in our field shelter. This approach would be able to protect renal function better. There was a reliable consistency between hemostasis time and the extent of residual renal injury, which indicated that rapid hemostasis is a feasible method.

The treatment of unstable renal injuries includes nonoperative management, TAE, and renal exploration, and then even nephrectomy or renal neoplasty. However, it is still under debate what the sequence of these treatment steps should be. The chosen method could be based on the Organ Injury Scaling for Kidney Trauma developed by the American Association for the Surgery of Trauma (AAST OIS).[24] Most renal injuries, especially blunt trauma, are managed nonoperatively.[10,25] Observation and resuscitation alone is sufficient treatment for most traumatic renal injuries as most are of lower grade.[26] High-risk cases are very likely to benefit from TAE, renal repair, or nephrectomy to stop fatal hemorrhage.

There are many conflicting views in grading injuries.[27] Management for renal trauma has changed dramatically since the AAST OIS publication two decades ago.[26,28,29] Many unnecessary explorations and increased nephrectomy rates have appeared. Many patients have lost organs because of misgrading; their organs should have been preserved.[3,19] Therefore, several other variables are routinely considered adjuncts.[20]

Nonoperative methods remain controversial.[22] In a recent review of the clinical management of renal injuries, the medical literature reported a nonoperation rate of 30.4–32% since 2000.[9,30] The published data support increasing conservative attempts in hemodynamically stable patients.[21] The aim of conservative management is to minimize the incidence of unnecessary repairs and decrease iatrogenic nephrectomy rates.[31–33] Patients who were managed conservatively had a higher rate of renal complications, including anemia, fever, hematuria, pseudoaneurysm formation, arteriovenous fistula, post-traumatic renovascular hypertension,[34] and delayed bleeding.[21] There are many dangers of secondary operation for the complications.[15,23,35] If the renal fascia becomes violated and renal cortical bleeding is noted, by packing the renal fossa too tightly, the kidney may atrophy.[15,36–38] Furthermore, nonoperative treatment requires infusion, braking, and observation. These could not be supported under certain environments, such as battlefields. Patients with associated injuries also may need laparotomy.[39] Gunshot injuries or other penetrating injuries often call for debridements.[35,40–42]

Surgical intervention remains obligatory for hemodynamic instability, including shock secondary to renal bleeding, complex lacerations,[29] renal pelvic, or ureteral injury, plus certain renovascular conditions.[10,43] The prolonged warm ischemia that may occur when under renal neoplasty usually results in irreparable damage and loss.[38] There have been only a few functional renal outcomes of surgical repairs for such situations.[36,41,44] Renal exploration was more likely to result in the loss of the injured kidney than was nonoperative management.[3,19,41] In conclusion, avoiding unnecessary nephrectomy is of utmost importance.

At present, TAE for injured segmental renal arteries is a widely accepted therapeutic modality for most renal vascular injuries.[45,46] It is considered the first-choice treatment to control ongoing renal hemorrhage in patients with iatrogenic as well as blunt and penetrating trauma. The clinical success of TAE in controlling severe hemorrhage is 57–100%.[47–49] Intravascular contrast extravasation indicates direct radiographic evidence of ongoing bleeding.[50,51] Thus, intravascular contrast extravasation should be a valuable predictor of the need for intervention to control renal bleeding. However, TAE requires specific techniques and working conditions. It is difficult to produce a marked effect in emergencies. Prior to the advent of the coaxial catheter, it was impossible to use extremely superselective technique to catheterize subsegmental artery, which resulted in significant infarction and loss of function.[48,52] Some studies have reported the complications of embolization, including pyrexia, pain, intimal dissection, hypertension, and abscess.[48,53–55] The infarct acts as a scar that has a tendency to shrink.[48,54] It can induce renal atrophy, just as we found in our study. Patients with a solitary kidney had deleterious effects after TAE, in the form of elevated serum creatinine level.[48,56] In renal trauma patients, the choice between surgery or TAE largely depends on the condition of the patient, skill level of surgeons, and the availability of interventional services in the institution.[57]

TTBR remains a damage control method. Multiorgan trauma injuries are addressed by angiography and temporal embolism. At that time, the patient becomes hemodynamically stable. Then, a laparotomy can be performed without any delay at the time of when or after evacuation. Urogenital systemic injury constitutes a small portion of battlefield injuries, ranging from 0.7% to 8%, but with renal injuries as high as 40%.[58,59] The genitourinary organ system is well suited to this style of management.[38] Complex genitourinary reconstructive surgery should be delayed until the patient is hemodynamically and metabolically stable. In emergencies, TAE is very difficult, because of the possible skill limitations of the surgeon (i.e., immediate vascular control, arteriography ability, plus experience in renal reconstructive techniques). TTBR should be used to localize hemorrhage sites and to guide angiographic or surgical intervention.[51,60]

4.1. Limitations

Despite the importance of the present findings, there exist several limitations. The small number of animals in each group analysis may limit statistics. This may have limited detection of differences attributed to other potential variables. Larger and multi-institutional studies should be done for further investigation. The lack of long-term follow-up also limits conclusions. The lack of a standardized protocol for this new study model also presents some weaknesses, including standardized wound depth, standardized breadth, and standardized process of injury. Finally, we only used ultrasound, and did not use computed tomography, to scan the animals at multiple times, and therefore, the grades were limited. Several studies reported the sensitivity of ultrasound for the detection of renal lesions to be as low as 22%.[34,61] However, because of the severity of injuries and in some special conditions, for example, in battlefield or disaster environment, it may not be possible to perform computed tomography scan.

In conclusion, despite these limitations, we feel that our method represents an important new way to protect renal trauma patients. Optimal management of traumatic renal artery injuries is controversial. The underlying objective is patient survival and organ preservation. Typically, these patients are critically ill, a sacculus is used to rapidly control fatal bleeding, and the patients are temporarily in hemostasis and subsequently resuscitated. When these patients are transported to our special mobilizable shelter, the renal injuries are neoplastied with sutures. Furthermore, we are able to rapidly assist in finding bleeding parts and discuss expected outcomes caused by delaying treatment of the injuries. This damage control in the management of renal trauma is a well-established method in severely injured patients during emergency situations.

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