The American Journal of Surgery xxx (xxxx) xxx

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.elsevier.com/locate/amjsurg

Original Research Article

Worse outcomes with resuscitative endovascular balloon occlusion of the aorta in severe pelvic fracture: A matched cohort study

Chih-Ying Chien [a,b], Meghan R. Lewis [a], Joshua Dilday [a], Subarna Biswas [a], Yong Luo [a,c], Demetrios Demetriades [a,*]

[a] Division of Trauma and Surgical Critical Care, LAC+USC Medical Center, University of Southern California, Los Angeles, CA, United States
[b] Department of General Surgery, Chang Gung Memorial Hospital, Keelung, Taiwan
[c] Trauma Center & Critical Care Medicine, The Second Affiliated Hospital, Hengyang Medical School, University of South China, Hengyang, Hunan, China

ARTICLE INFO

Keywords:
REBOA
Pelvic fractures
Worse outcomes

ABSTRACT

Background: Severe pelvic fracture is the most common indication for resuscitative endovascular balloon occlusion of the aorta (REBOA). This matched cohort study investigated outcomes with or without REBOA use in isolated severe pelvic fractures.

Methods: Trauma Quality Improvement Program database study, included patients with isolated severe pelvic fracture (AIS≥3), excluded associated injuries with AIS >3 for any region other than lower extremity. REBOA patients were propensity score matched to similar patients without REBOA. Outcomes were mortality and complications.

Results: 93 REBOA patients were matched with 279 without. REBOA patients had higher rates of in-hospital mortality (32.3% vs 19%, p = 0.008), higher rates of venous thromboembolism (14% vs 6.5%, p = 0.023) and DVT (11.8% vs 5.4%, p = 0.035). In multivariate analysis, REBOA use was independently associated with increased mortality and venous thromboembolism.

Conclusions: REBOA in severe pelvic fractures is associated with higher rates of mortality, venous thromboembolism.

1. Introduction

Despite the advancements of modern medical care, hemorrhage remains the most common cause of preventable death in the trauma population.[1–7] Many of these deaths result from the inability to control pelvic hemorrhage quickly enough.[8] Non-compressible torso hemorrhage (NCTH), including that due to pelvic fractures, poses a difficult treatment challenge,[9,10] and is a proposed indication for resuscitative endovascular balloon occlusion of the aorta(REBOA).

Strategies for controlling bleeding associated with pelvic fractures include pelvic binders, external pelvic fixation, angioembolization, preperitoneal packing, laparotomy with bilateral internal iliac artery occlusion, and resuscitative endovascular balloon occlusion of the aorta (REBOA).[11–15] As the popularity of REBOA has increased, multiple trauma guidelines have promoted its use.[16–19] REBOA use in traumatic situations varies greatly across trauma centers with no universally accepted standard of care.

There is relatively sparce literature on REBOA in pelvic fractures and the results are often contradictory. Almost all published studies have included multitrauma patients, with severe associated injuries to many body areas. Adverse outcomes in these patients are often the result of injuries not related to pelvic fracture bleeding. In order to eliminate these complicating factors, we designed a matched cohort study which compared outcomes of REBOA and non-REBOA in isolated severe pelvic fractures.

2. Patients and methods

This retrospective, cohort-matched study was performed using the 2016–2018 Trauma Quality Improvement Program (TQIP) database. The TQIP database includes a subset of patients from the National Trauma Data Bank (NTDB), who are admitted to level I or II trauma centers, with age ≥16 years and abbreviated injury scale (AIS) score >2 in at least one body region. Due to the use of a deidentified database, this

* Corresponding author. USC School of Medicine Director of Trauma, Emergency Surgery, and Surgical Critical Care, LAC+USC Medical Center 2051 Marengo St, Los Angeles, CA, 90033, United States.
E-mail address: demetrios.demetriades@med.usc.edu (D. Demetriades).

https://doi.org/10.1016/j.amjsurg.2022.09.057
Received 20 August 2022; Received in revised form 25 September 2022; Accepted 28 September 2022
Available online 10 October 2022
0002-9610/

study was deemed exempt from full approval by our local Institutional Review Board (IRB).

All patients presenting with isolated blunt pelvic fracture (pelvis AIS ≥3) were included. Patients were excluded if they were transferred from another hospital, lacked signs of life on arrival, died in the emergency department (ED), or presented with significant injuries (AIS >3) other than lower extremity. We also excluded the patients with missing ED vital signs and age. Patients receiving REBOA were identified using the *International Statistical Classification of Diseases and Related Health Problems –tenth revision* (ICD 10) procedure codes. Patients with REBOA placement in zone III were identified by "04L03DJ", "04L03DZ", "04L04DZ", and "04L04ZZ" ICD 10 codes. Patients receiving zone 1 REBOA were identified by the "02LW3DJ" ICD 10 code. Preperitoneal packing was identified by ICD10 procedure code: "2W43X5Z "and "2W13X6Z".

Patient demographics (age, gender, comorbid conditions), initial vital signs on ED admission (systolic blood pressure [SBP], heart rate [HR], Glasgow Coma Scale [GCS], and injury characteristics (injury severity score [ISS], body region-specific AIS) were obtained. Blood product utilization was collected, as well as the use of venous thromboprophylaxis (subcutaneous heparin [SQH], low-molecular weight heparin [LMWH]). For those undergoing interventions (laparotomy or angioembolization), the timing from hospital presentation to surgery was included. The primary outcome was in-hospital mortality. Secondary outcomes included in-hospital complications, and intensive care unit length of stay (ICULOS), and hospital length of stay (HLOS).

Propensity score matching was utilized to compare patients receiving REBOA to similar patients without REBOA. The patients were matched for age, ED vital signs, ISS score, AIS 3 for head, face, neck, chest, abdomen, extremity and spine, AIS 3 for specific abdominal organ injuries (liver, spleen, kidney, mesentery), pelvis AIS (3, 4, and 5), hollow viscus injuries, laparotomy, preperitoneal packing, angioembolization, and comorbidities. Multivariate logistic regression was used to assess outcome differences between matched subjects.

3. Statistical analysis

Missing value of SBP, HR, GCS, and age ranged from 1.2% to 3.1% were deleted.

Patients in the REBOA group were matched to the no-REBOA group using 1:3 nearest-neighbor propensity score matching without replacement. The analysis of propensity score matching was performed using R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria).[20]

Non-normal distributed continuous variables were recorded by medians with interquartile range (IQR) and Mann-Whitney U-tests were used to test for differences. Categorical variables were compared using chi-square test or Fisher's exact test. Statistically significant was defined by p value less than 0.05($P < 0.05$). Multivariate regression analysis was used to evaluate post-match differences in outcomes. Covariates with potential clinical relevance were included, interaction terms between covariates were checked, and models were optimized using Hosmer and Lemeshow goodness-of-fit test. All statistical analyses were performed using IBM SPSS Statistics 28 software (IBM Corporation, Armonk, NY).

4. Results

4.1. Demographic, clinical and therapeutic interventions

Of 966,430 database patients, 15,638 were identified as having isolated severe pelvic fractures. 93 patients (0.6%) were treated with REBOA. The pre-match demographic data are shown in supplemental table 1. Propensity score matching produced 372 patients, 93 in the REBOA group and 279 patients in the No-REBOA group. The matching displayed homogeneous demographic, comorbidity, and injury-related variables (Table 1). Overall, 143 patients (36.6%) were hypotensive on admission (40.9% in REBOA and 35.1% in the No REBOA, p = 0.32) and the median ISS was 29 (29.0 in REBOA vs 29.0 in the No REBOA, p = 0.987).The incidence of moderate severity (AIS = 3) associated injuries in the head, neck, face, chest, abdomen, solid abdominal organ injuries, and extremity, was similar in the two groups (Table 1). The overall rate of associated hollow viscus injury was 19.4%, with no difference seen between the study groups. In the REBOA group, 5 patients (5.4%) had Zone 1 placement and 88 patients (94.6%) had REBOA placed in Zone 3.

The incidence, type and severity of associated abdominal injuries were the same in the two groups. The two study groups (REBOA Vs No REBOA) had similar rates of laparotomy (62.4% vs. 63.4%; p = 0.852), preperitoneal packing (17.2% vs 15.4%; p = 0.682), and

Table 1
Post-match demographic data.

	Total N = 372	No REBOA n = 279 (75%)	REBOA n = 93 (25%)	p value
Age	47.0 (31.0–60)	46.0 (31–59.5)	48.0 (32.0–61.0)	0.558
≥ 65 years	54 (14.5%)	43 (15.4%)	11 (11.8%)	0.395
Male	258 (69.4%)	193 (69.2%)	65 (69.9%)	0.897
Comorbidities				
Hypertension	57 (15.3%)	44 (15.8%)	13 (14%)	0.678
Smoking	89 (23.9%)	69 (24.7%)	20 (21.5%)	0.528
Diabetes mellitus	26 (7%)	20 (7.2%)	6(6.5%)	0.814
COPD	4(1.1%)	3 (1.1%)	1(1.1%)	1
Congestive heart failure	0	0	0	NA
Chronic renal failure	5(1.3%)	3(1.1%)	2(2.2%)	0.602
Cirrhosis	8(2.2%)	6(2.2%)	2(2.2%)	1
Stroke	3(0.8%)	2(0.7%)	1(1.1%)	1
ED vital signs				
SBP	98 (78.5–121)	99(80–120)	98(76–125)	0.917
HR	107 (87–128)	106(87–127)	110(88–130)	0.751
GCS	14(3–15)	14(3–15)	13(3–15)	0.465
ISS	29.0 (24.0–34.5)	29.0 (24.0–35)	29.0 (24.0–34.0)	0.987
Head AIS score	0(0–2)	0(0–2)	1(0–2)	0.64
SBP <90 mm Hg	136 (36.6%)	98 (35.1%)	38 (40.9%)	0.32
SBP <70 mm Hg	51(13.7%)	38(13.6%)	13(14%)	0.931
HR > 120 bpm	125 (33.6%)	92 (33%)	33 (35.5%)	0.657
GCS ≤8	135 (36.3%)	104 (37.3%)	31 (33.3%)	0.493
ISS	29.0 (24.0–34.5)	29.0 (24.0–35)	29.0 (24.0–34.0)	0.987
≥ 16	358(96.2%)	268 (96.1%)	90 (96.8%)	1
Injury severity				0.882
Pelvis, AIS 3	120(32.3%)	91(32.6%)	29(31.2%)	
Pelvis, AIS 4	120(32.3%)	91(32.6%)	29(31.2%)	
Pelvis, AIS 5	132(35.5%)	97(34.8%)	35(37.6%)	
AIS each region				
Head AIS 3	60 (16.1%)	46 (16.5%)	14 (15.1%)	0.745
Face AIS 3	3 (0.8%)	2 (0.7%)	1 (1.1%)	1
Neck AIS 3	11(3%)	9 (3.2%)	2 (2.2%)	0.738
Chest AIS 3	182 (48.9%)	136 (48.7%)	46 (49.5%)	0.905
Abdomen AIS 3	191(51.3%)	147(52.7%)	44(47.3%)	0.369
Liver AIS 3	40(10.8%)	31(11.1%)	9(9.7%)	0.699
Spleen AIS 3	23(6.2%)	17(6.1%)	6(6.5%)	0.901
Kidney AIS 3	22(5.9%)	17(6.1%)	5(5.4%)	0.8
Spine AIS 3	24(6.5%)	19(6.8%)	5(5.4%)	0.626
Upper Extremity AIS 3	15(4%)	13(4.7%)	2(2.2%)	0.374
Lower extremity except pelvis AIS ≥3	166(44.6%)	120(43%)	46(49.5%)	0.278
Hollow viscus injury	72(19.4%)	55(19.7%)	17(18.3%)	0.762
Mesentery AIS 3	7(1.9%)	4(1.4%)	3(3.2%)	0.373

AIS, abbreviated injury scale; COPD, chronic obstructive pulmonary disease; ED, emergency department; GCS, Glasgow Coma Scale; HR, heart rate; ISS, injury severity score; REBOA, resuscitative endovascular balloon occlusion of the aorta; SBP, systolic blood pressure.

angioembolization (46.2% vs 49.8%; p = 0.549) (Table 2). The time to laparotomy and embolization was similar in the two groups. REBOA patients received significantly more blood products at 4 h and 24 h (Table 2). The type of pharmacological venous thromboembolism(VTE) prophylaxis (Heparin, LMWH) was identical in the two study groups (Table 2). The timing of VTE prophylaxis was also similar between two groups (Table 2).

4.2. Outcomes

The 24-h and in-hospital mortality was significantly higher in the REBOA group (25.8% vs 10.8% p < 0.001 and 32.3% vs 19% p = 0.008 respectively). The VTE and deep vein thrombosis(DVT) complication rate was significantly higher in the REBOA group (VTE:14% vs 6.5%, p = 0.023; DVT:11.8% vs 5.4%; p = 0.035). Other complications, such as acute kidney injury(AKI), acute respiratory distress syndrome(ARDS), surgical site infections, severe sepsis, ventilator associated pneumonia (VAP) and enteric fistulas were similar in the two groups (Table 3). There were no significant differences in HLOS and ICU LOS between the two groups.

Multivariate analysis identified risk factors for death after isolated pelvic fracture. REBOA use was independently associated with increased odds of mortality (OR: 2.017, 95% CI: 1.065–3.819, p = 0.031). Other independent factors associated with mortality included age≥65 years, GCS≤8, 4hr pack red blood cell (PRBC) transfusion, and cirrhosis (Table 4). REBOA use was also found to be an independent risk factor for VTE (OR:2.798, 95% CI: 1.21–6.473, p = 0.016) (Table 5).

Table 2
Post-match interventions.

	Total N = 372	No REBOA n = 279 (75%)	REBOA n = 93 (25%)	p value
Laparotomy	235(63.2%)	177(63.4%)	58(62.4%)	0.852
Time to laparotomy hrs*	1.97 (1.03–5.58)	2.04 (1.06–6.13)	1.77 (0.9–5.2)	0.469
Angioembolization	182(48.9%)	139(49.8%)	43(46.2%)	0.549
Time to angioembolization hrs*	3.37 (2.18–4.78)	3.38 (2.3–5.02)	3(1.95–4.3)	0.132
Preperitoneal packing	59(15.9%)	43(15.4%)	16(17.2%)	0.682
Time to packing hrs*	1.65(1.04 -2.99)	1.66 (1.04–3.07)	1.4 (1.1–2.95)	0.684
4hr blood transfusion				
PRBCs * u	6(2–11.9)	5(2–10)	9(5.5–16.5)	**<0.001**
Plasma * u	4(0–8)	2.2(0–6.1)	6(2–12)	**<0.001**
24hr blood transfusion				
PRBCs * u	8(4–15.1)	7(3–13)	12(6.2–20)	**<0.001**
Plasma * u	5.2(1–10.9)	4(0–9.2)	8(4–14)	**<0.001**
VTE prophylaxis method *				0.778
None	22(7.5%)	19(8.2%)	3(4.8%)	
Heparin	67(22.7%)	54(23.2%)	13(21%)	
LMWH	204(69.2%)	158(67.8%)	46(74.2%)	
Other	2(0.7%)	2(0.9%)	0	
VTE prophylaxis time ≤72 h *	161(55.5%)	124(54.1%)	37(60.7%)	**0.363**

LMWH, low molecular weight heparin; PRBC, pack red blood cell; REBOA, resuscitative endovascular balloon occlusion of the aorta; VTE, venous thromboembolism.
* Hours to laparotomy missing 5.1%.
* Hours to angioembolization missing 3.8%.
* Hours to abdominal wall packing missing 6.8%.
* PRBC 4hr missing 1.9%.
* PRBC 24hr missing 1.9%.
* Plasma 4hr missing 2.2%.
* Plasma 24hr missing 2.2%.
* VTE prophylaxis method only recorded those who survived at least 72 h and missing 1.7%.
* VTE prophylaxis time only recorded those who survived at least 72 h and missing 3.3%.

Table 3
Outcomes in the REBOA and No REBOA groups.

	Total N = 372	No REBOA n = 279 (75%)	REBOA n = 93 (25%)	p value
HLOS, days	17.0 (7.5–28.0)	17.0 (10.0–28.5)	18.0 (2.0–28.0)	0.433
ICU LOS, days[a]	7.5 (4.0–16.0)	8.0 (4.0–16.0)	7.0 (3.0–14.0)	0.344
Complications				
AKI	39 (10.5%)	29 (10.4%)	10 (10.8%)	0.922
ARDS	11 (3%)	9 (3.2%)	2 (2.2%)	0.738
VTE	31 (8.3%)	18 (6.5%)	13 (14%)	**0.023**
DVT	26 (7%)	15(5.4%)	11 (11.8%)	**0.035**
PE	10 (2.7%)	6 (2.2%)	4 (4.3%)	0.276
Deep incisional surgical site infection	6(1.6%)	4(1.4%)	2(2.2%)	0.642
Organ space surgical site infection	2(0.5%)	1(0.4%)	1(1.1%)	0.438
Severe sepsis	16(4.3%)	13(4.7%)	3(3.2%)	0.77
VAP	14(3.8%)	10(3.6%)	4(4.3%)	0.756
Enterocutaneous fistula	0	0	0	NA
Extremity compartment syndrome	8(2.2%)	4(1.4%)	4(4.3%)	0.111
Abdominal compartment syndrome	0	0	0	NA
Abdominal fascia left open	4 (1.1%)	4 (1.4%)	0	0.576
24hr mortality	54(14.5%)	30(10.8%)	24(25.8%)	**<0.001**
In hospital mortality	83 (22.3%)	53 (19%)	30 (32.3%)	**0.008**

AKI, acute kidney injury; ARDS, acute respiratory distress syndrome; DVT, deep vein thrombosis; HLOS, hospital length of stay, ICULOS, intensive care unit length of stay; PE, pulmonary embolism; VAP, ventilator associated pneumonia.
[a] ICU LOS: only calculate with ICU days patients.

Table 4
Multivariable analysis for risk factors associated with in-hospital mortality.

factor	Odds ratio	95% CI	P value
Age ≥65 years	3.05	1.386–6.711	**0.006**
Male	0.91	0.487–1.701	0.768
SBP <90 mm Hg	1.157	0.636–2.103	0.633
HR > 120 bpm	0.771	0.417–1.427	0.407
GCS ≤8	3.943	2.108–7.378	**<0.001**
HTN	0.748	0.292–1.917	0.545
DM	2.133	0.691–6.585	0.188
CRF	1.144	0.096–13.636	0.915
cirrhosis	8.303	1.831–37.648	**0.006**
4hr PRBC transfusion	1.08	1.041–1.12	**<0.001**
Pelvis AIS 3	ref	Ref	ref
Pelvis AIS 4	0.903	0.427–1.908	0.789
Pelvis AIS 5	1.191	0.585–2.426	0.63
REBOA	2.017	1.065–3.819	**0.031**
Laparotomy	1.07	0.556–2.059	0.84

AIS, abbreviated injury scale; CRF, chronic renal failure; DM, diabetes mellitus; GCS, Glasgow Coma Scale; HR, heart rate; HTN, hypertension; PRBC, pack red blood cell; REBOA, resuscitative endovascular balloon occlusion of the aorta; SBP, systolic blood pressure.

5. Discussion

This matched retrospective cohort study showed that patients with isolated severe pelvic fractures treated with REBOA had higher mortality compared to those not receiving REBOA. In addition, patients treated with REBOA had higher rates of VTE.

Severe pelvic fracture is one of the most common indications for

Table 5
Multivariable analysis for risk factors associated with VTE[a].

factor	Odds ratio	95% CI	P value
Male	0.943	0.385–2.308	0.898
SBP <90 mm Hg	0.822	0.348–1.943	0.655
HR > 120 bpm	1.715	0.743–3.958	0.206
GCS ≤8	1.245	0.52–2.981	0.622
CRF	12.31	1.412–107.298	**0.023**
4hr PRBC transfusion	1.04	0.992–1.091	0.101
VTE prophylaxis time ≤72 h	1.752	0.757–4.058	0.191
Pelvis AIS 3	ref	ref	ref
Pelvis AIS 4	1.134	0.421–3.056	0.803
Pelvis AIS 5	1.161	0.406–3.321	0.781
REBOA	2.798	1.21–6.473	**0.016**
Laparotomy	1.121	0.465–2.705	0.799
Angioembolization	1.499	0.644–3.487	0.347

AIS, abbreviated injury scale; CRF, chronic renal failure; GCS, Glasgow Coma Scale; HR, heart rate; PRBC, pack red blood cell; REBOA, resuscitative endovascular balloon occlusion of the aorta; SBP, systolic blood pressure; VTE, venous thromboembolism.

[a] Only include patients who survived at least 72 h.

REBOA use.[16,21,22] However, previous studies have reported contradictory results. In a joint statement from the American College of Surgeons Committee on Trauma, the American College of Emergency Physicians, the National Association of Emergency Medical Services Physicians and the National Association of Emergency Medical Technicians regarding the clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in civilian trauma systems in the USA, it is stated that the quality of clinical evidence to support REBOA use in trauma patients is poor with no Class I or II data and thus the existing data must be interpreted with caution.[23]

Matusmoto et al. performed a retrospective study from the Japanese Trauma Data Bank examining 3149 severe pelvic trauma patients, 256 of whom underwent REBOA. The study population included patients with severe associated injuries. The authors reported that the REBOA group had worse mortality despite adjusting for major comorbidities.[24] In another retrospective study, Mikdad et al. compared preperitoneal packing (PPP) to REBOA use in pelvic trauma using propensity score matching. They found that mortality was higher in patients treated with REBOA compared to PPP.[25] Several other studies have also reported worse outcomes with REBOA use in severe multitrauma patients. In a TQIP study by Joseph et al., trauma patients who underwent REBOA placement in the ED were matched with a similar cohort of patients with no-REBOA. There was no significant difference between groups in 4-h blood transfusion. The mortality rate was higher in the REBOA group as compared with the no-REBOA group (35.7% vs 18.9%, P = 0.01). Patients in the REBOA group also had significantly higher rates of acute kidney injury.[26] Two other matched cohort studies using the Japanese Trauma Data Bank reported significantly higher mortality rates after REBOA use in severe torso trauma.[27,28]

Some studies have reported no difference in outcomes between REBOA and Non REBOA groups. In a systematic review and meta-analysis, Castellani et al.[29] included 11 studies with 5866 participants, and reported no difference in overall mortality between REBOA and Non-REBOA groups.

However, other studies have reported improved outcomes after REBOA use in pelvic trauma patients.[12,30,31] Harfouche et al. suggested that REBOA is effective in controlling pelvic hemorrhage.[31] Another study by Pieper et al. focused on improved hemodynamics after REBOA deployment in blunt pelvic trauma.[12] However, these two studies did not compare their results to patients treated without REBOA. Asmar et al. analyzed 156 patients from TQIP with pelvic trauma undergoing PPP or REBOA before further endovascular or operative intervention.[30] In this specific subpopulation, they found REBOA to be associated with improved outcomes compared to PPP. However, they did not include patients who did not receive REBOA or PPP as a temporary strategy before definitive intervention.

A major problem with most prior studies is the inclusion of multi-trauma patients, with associated severe head, chest or abdominal injuries, because many of the deaths and complications are not related to pelvic bleeding. In order to eliminate these complicating variables, the present study excluded patients with severe associated injuries (AIS>3) to the torso or the head. In addition, there was meticulous matching for chronic comorbidities, associated moderate injuries with body area AIS = 3, severity of pelvic fracture (AIS 3,4,5), associated hollow viscus injuries, laparotomy, preperitoneal packing and angioembolization.

The most important finding in the present study is the significantly higher mortality in patients treated with REBOA. The explanation for this worse outcome is not clear. REBOA controls pelvic bleeding by temporary occlusion of the abdominal aorta and reduction of the pelvic arterial inflow. However, over 85% of hemorrhage from pelvic fractures results from venous injury or the fractured bony surfaces.[32,33] It is possible that reduction of the arterial flow below the aortic occlusion decreases blood flow to both lower extremities and the correlating systemic venous return, however, venous collaterals from the portal system may backflow to the pelvis, resulting in no appreciable difference in pelvic bleeding. A major risk with REBOA is the resulting ischemia below the occlusion and the subsequent reperfusion injury after release of the occlusion. Reperfusion injury with severe inflammatory response can result in hemodynamic instability, deterioration of the coagulopathy, organ dysfunction, and worse outcomes. Li et al., in a randomized experimental study of massive hemorrhage in swine, reported that 60-minute occlusion of the aorta with REBOA was associated with distal organ inflammation and injury, hemodynamic deterioration and coagulopathy.[34]

In the present study, the REBOA group received more blood products than the Non-REBOA group. There are various possible explanations for this observation: one is that in patients with a REBOA, the surgeon might be more aggressive with blood product administration because of the perceived critical condition of the patient. A second explanation is more frequent coagulopathy in patients with REBOA, due to ischemia/reperfusion effect, as shown by Li et al. A third explanation is that patients managed with REBOA may have been in more critical condition than Non-REBOA patients, despite the meticulous matching for injury severity, physiological condition on admission, and comorbid conditions. Lastly, it might be a combination of all of the above hypotheses.

An interesting observation in the present study was the finding that 60% of the REBOA patients were not hypotensive on admission and the average time to laparotomy was 2 h. It is possible, that in environments with short prehospital times, the initial blood pressure may be normal, only to deteriorate a few minutes later! Regarding the observation that the median time to laparotomy was 2 h, a possible explanation for this prolonged time is that many of the patients had no major intra-abdominal injuries, which could lead to efforts to resuscitate with transfusions and angiointervention. Another possible explanation, is the variability of indications and individual experience of the surgical team.

The present study did not show any difference to laparotomy or angioembolization between the REBOA and no-REBOA groups, as shown in previous studies (26,30). However, these studies excluded patients with placement of REBOA >1 h of admission, while in the present study this was not an exclusion criterion.

Another interesting finding in the present study is the significantly higher incidence of VTE complications in the REBOA group. This was demonstrated in both the matched groups and in a multivariate analysis which identified REBOA as an independent risk factor for VTE. This is the first study to evaluate venous thromboembolic complications following REBOA application and this finding has great clinical importance. It is possible that a major reduction of the arterial flow to the iliac and lower extremity veins, especially in association with reperfusion injury, may lead to thrombotic events.

The literature regarding REBOA and AKI is not consistent. One swine

model study found acute tubular necrosis in 80% of cases in complete-REBOA group.[35] Joseph B et al. found there were higher rates of AKI in a REBOA group compared to no-REBOA.[26] However, other database studies which focused on patients with pelvic fractures have not shown higher AKI rate in REBOA groups.[25,30] We also did not find a significant increase in AKI with REBOA use. The most likely explanation for this is the zone 3 deployment in 95% of the REBOA patients.

Our study is the largest national study to compare the outcomes of REBOA and no-REBOA intervention in severe isolated pelvic fracture patients. By excluding patients with severe associated injuries, we eliminated a major complicating factor which could make the interpretation of the results difficult. In addition, the matching of the two groups was very specific to ensure similar physiological conditions. Finally, a multivariate analysis was performed to identify independent risk factors for mortality and VTE complications.

There are, however, significant limitations inherent to the TQIP database which should be acknowledged. Firstly, the database does not provide important REBOA specific variables, such as the duration of aortic occlusion, duration of partial occlusion, and arterial sheath size. Secondly, despite the tight epidemiological, anatomical, and physiological injury severity matching of the two groups, it is possible that patients in the REBOA group were physiologically more compromised, but this was not reflected in the captured data. Although the study excluded patients with associated severe injuries and also matched for moderate injuries (AIS = 3) for each anatomical body area, there is still the possibility of selection bias for REBOA intervention. Thirdly, the cause of mortality is not part of the data collected in the TQIP database.

6. Conclusion

REBOA usage in isolated severe pelvic fractures is associated with higher rates of mortality and VTE complications. Its role is questionable and there is not high-quality evidence to support its routine clinical use. Further prospective studies are needed to determine the outcomes impact of this increasingly popular intervention in trauma.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2022.09.057.

References

1. Sauaia A, Moore FA, Moore EE, et al. Epidemiology of trauma deaths: a reassessment. *J Trauma*. Feb 1995;38(2):185–193. https://doi.org/10.1097/00005373-199502000-00006.
2. Harvin JA, Maxim T, Inaba K, et al. Mortality after emergent trauma laparotomy: a multicenter, retrospective study. *J Trauma Acute Care Surg*. Sep 2017;83(3):464–468. https://doi.org/10.1097/TA.0000000000001619.
3. Kotwal RS, Montgomery HR, Kotwal BM, et al. Eliminating preventable death on the battlefield. *Arch Surg*. Dec 2011;146(12):1350–1358. https://doi.org/10.1001/archsurg.2011.213.
4. Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. *J Trauma*. Jun 2006;60(6 Suppl):S3–S11. https://doi.org/10.1097/01.ta.0000199961.02677.19.
5. Drake SA, Holcomb JB, Yang Y, et al. Establishing a regional trauma preventable/potentially preventable death rate. *Ann Surg*. Feb 2020;271(2):375–382. https://doi.org/10.1097/SLA.0000000000002999.
6. Drake SA, Wolf DA, Meininger JC, et al. Methodology to reliably measure preventable trauma death rate. *Trauma Surg Acute Care Open*. 2017;2(1), e000106. https://doi.org/10.1136/tsaco-2017-000106.
7. Qasim Z, Butler FK, Holcomb JB, et al. Selective prehospital advanced resuscitative care - developing a strategy to prevent prehospital deaths from noncompressible torso hemorrhage. *Shock*. Jan 1 2022;57(1):7–14. https://doi.org/10.1097/SHK.0000000000001816.
8. Russo RM, Neff LP, Johnson MA, Williams TK. Emerging endovascular therapies for non-compressible torso hemorrhage. *Shock*. Sep 2016;46(3 Suppl 1):12–19. https://doi.org/10.1097/SHK.0000000000000641.
9. Kisat M, Morrison JJ, Hashmi ZG, Efron DT, Rasmussen TE, Haider AH. Epidemiology and outcomes of non-compressible torso hemorrhage. *J Surg Res*. Sep 2013;184(1):414–421. https://doi.org/10.1016/j.jss.2013.05.099.
10. Morrison JJ, Rasmussen TE. Noncompressible torso hemorrhage: a review with contemporary definitions and management strategies. *Surg Clin North Am*. Aug 2012;92(4):843–858. https://doi.org/10.1016/j.suc.2012.05.002. vii.
11. Burlew CC, Moore EE, Smith WR, et al. Preperitoneal pelvic packing/external fixation with secondary angioembolization: optimal care for life-threatening hemorrhage from unstable pelvic fractures. *J Am Coll Surg*. Apr 2011;212(4):628–635. https://doi.org/10.1016/j.jamcollsurg.2010.12.020. ; discussion 635-7.
12. Pieper A, Thony F, Brun J, et al. Resuscitative endovascular balloon occlusion of the aorta for pelvic blunt trauma and life-threatening hemorrhage: a 20-year experience in a Level I trauma center. *J Trauma Acute Care Surg*. Mar 2018;84(3):449–453. https://doi.org/10.1097/TA.0000000000001794.
13. DuBose J, Inaba K, Barmparas G, et al. Bilateral internal iliac artery ligation as a damage control approach in massive retroperitoneal bleeding after pelvic fracture. *J Trauma*. Dec 2010;69(6):1507–1514. https://doi.org/10.1097/TA.0b013e3181d74c2f.
14. DuBose JJ, Burlew CC, Joseph B, et al. Pelvic fracture-related hypotension: a review of contemporary adjuncts for hemorrhage control. *J Trauma Acute Care Surg*. Oct 1 2021;91(4):e93–e103. https://doi.org/10.1097/TA.0000000000003331.
15. Moore LJ, Martin CD, Harvin JA, Wade CE, Holcomb JB. Resuscitative endovascular balloon occlusion of the aorta for control of noncompressible truncal hemorrhage in the abdomen and pelvis. *Am J Surg*. Dec 2016;212(6):1222–1230. https://doi.org/10.1016/j.amjsurg.2016.09.027.
16. Tran TL, Brasel KJ, Karmy-Jones R, et al. Western trauma association critical decisions in trauma: management of pelvic fracture with hemodynamic instability-2016 updates. *J Trauma Acute Care Surg*. Dec 2016;81(6):1171–1174. https://doi.org/10.1097/TA.0000000000001230.
17. Biffl WL, Fox CJ, Moore EE. The role of REBOA in the control of exsanguinating torso hemorrhage. *J Trauma Acute Care Surg*. May 2015;78(5):1054–1058. https://doi.org/10.1097/TA.0000000000000609.
18. Butler Jr FK, Holcomb JB, Shackelford S, et al. Advanced resuscitative care in tactical combat casualty care: TCCC guidelines change 18-01:14 October 2018. *J Spec Oper Med*. 2018;18(4):37–55.
19. Cannon J, Morrison J, Lauer C, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) for hemorrhagic shock. *Mil Med*. Sep 1 2018;183(suppl_2):55–59. https://doi.org/10.1093/milmed/usy143.
20. R Core Team. R. *A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2021.
21. Lendrum R, Perkins Z, Chana M, et al. Pre-hospital resuscitative endovascular balloon occlusion of the aorta (REBOA) for exsanguinating pelvic haemorrhage. *Resuscitation. Feb*. 2019;135:6–13. https://doi.org/10.1016/j.resuscitation.2018.12.018.
22. Coccolini F, Stahel PF, Montori G, et al. Pelvic trauma: WSES classification and guidelines. *World J Emerg Surg*. 2017;12:5. https://doi.org/10.1186/s13017-017-0117-6.
23. Bulger EM, Perina DG, Qasim Z, et al. Clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in civilian trauma systems in the USA, 2019: a joint statement from the American College of surgeons committee on trauma, the American College of emergency Physicians, the national association of emergency medical Services Physicians and the national association of emergency medical Technicians. *Trauma Surg Acute Care Open*. 2019;4(1), e000376. https://doi.org/10.1136/tsaco-2019-000376.
24. Matsumoto S, Funabiki T, Hayashida K, Yamazaki M, Ebihara T, Moriya T. Effectiveness and usage trends of hemorrhage control interventions in patients with pelvic fracture in shock. *World J Surg*. Jul 2020;44(7):2229–2236. https://doi.org/10.1007/s00268-020-05441-1.
25. Mikdad S, van Erp IAM, Moheb ME, et al. Pre-peritoneal pelvic packing for early hemorrhage control reduces mortality compared to resuscitative endovascular balloon occlusion of the aorta in severe blunt pelvic trauma patients: a nationwide analysis. *Injury*. Aug 2020;51(8):1834–1839. https://doi.org/10.1016/j.injury.2020.06.003.
26. Joseph B, Zeeshan M, Sakran JV, et al. Nationwide analysis of resuscitative endovascular balloon occlusion of the aorta in civilian trauma. *JAMA Surg*. Jun 1 2019;154(6):500–508. https://doi.org/10.1001/jamasurg.2019.0096.
27. Inoue J, Shiraishi A, Yoshiyuki A, Haruta K, Matsui H, Otomo Y. Resuscitative endovascular balloon occlusion of the aorta might be dangerous in patients with severe torso trauma: a propensity score analysis. *J Trauma Acute Care Surg*. Apr 2016;80(4):559–566. https://doi.org/10.1097/TA.0000000000000968. ; discussion 566-7.
28. Norii T, Crandall C, Terasaka Y. Survival of severe blunt trauma patients treated with resuscitative endovascular balloon occlusion of the aorta compared with propensity score-adjusted untreated patients. *J Trauma Acute Care Surg*. Apr 2015;78(4):721–728. https://doi.org/10.1097/TA.0000000000000578.
29. Castellini G, Gianola S, Biffi A, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in patients with major trauma and uncontrolled haemorrhagic shock: a systematic review with meta-analysis. *World J Emerg Surg*. Aug 12 2021;16(1):41. https://doi.org/10.1186/s13017-021-00386-9.
30. Asmar S, Bible L, Chehab M, et al. Resuscitative endovascular balloon occlusion of the aorta vs pre-peritoneal packing in patients with pelvic fracture. *J Am Coll Surg. Jan*. 2021;232(1):17–26 e2. https://doi.org/10.1016/j.jamcollsurg.2020.08.763.

31. Harfouche M, Inaba K, Cannon J, et al. Patterns and outcomes of zone 3 REBOA use in the management of severe pelvic fractures: results from the AAST aortic occlusion for resuscitation in trauma and acute care surgery database. *J Trauma Acute Care Surg.* Apr 1 2021;90(4):659–665. https://doi.org/10.1097/TA.0000000000003053.
32. Huittinen VM, Slatis P. Postmortem angiography and dissection of the hypogastric artery in pelvic fractures. *Surgery*. Mar 1973;73(3):454–462.
33. Costantini TW, Coimbra R, Holcomb JB, et al. Pelvic fracture pattern predicts the need for hemorrhage control intervention-Results of an AAST multi-institutional study. *J Trauma Acute Care Surg.* Jun 2017;82(6):1030–1038. https://doi.org/10.1097/TA.0000000000001465.
34. Li Y, Dubick MA, Yang Z, et al. Distal organ inflammation and injury after resuscitative endovascular balloon occlusion of the aorta in a porcine model of severe hemorrhagic shock. *PLoS One.* 2020;15(11), e0242450. https://doi.org/10.1371/journal.pone.0242450.
35. Russo RM, Neff LP, Lamb CM, et al. Partial resuscitative endovascular balloon occlusion of the aorta in swine model of hemorrhagic shock. *J Am Coll Surg.* Aug 2016;223(2):359–368. https://doi.org/10.1016/j.jamcollsurg.2016.04.037.