

Feasibility and Outcomes of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for Non-Compressible Torso Hemorrhage in a Resource-Limited Setting

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Introduction: We evaluated feasibility and outcomes of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage in a resource-limited setting.

Methods: This retrospective–prospective cohort study included 23 trauma patients undergoing REBOA at a tertiary center in Thailand (2012–2024). Primary endpoints were 24-hour and 28-day survival.

Results: Patients presented with profound shock (median systolic blood pressure 60 mmHg) and severe neurological impairment (median Glasgow Coma Scale 7); 43.5% received prehospital cardiopulmonary resuscitation. REBOA increased systolic blood pressure by 39.8 ± 20.7 mmHg, achieving 82.6% return of spontaneous circulation. The 24-hour and 28-day survival rates were 26.1% and 21.7%, respectively—superior to historical resuscitative thoracotomy outcomes (2–8.5%). Univariate analysis identified Glasgow Coma Scale 9–12 as the strongest survival predictor versus 3–8 (crude odds ratio 23.33, 95% confidence interval 1.95–279.43, $P = 0.013$). No limb ischemia occurred, and acute kidney injury developed in 21.7% of the patients.

Conclusions: In this small observational cohort from a resource-limited setting, REBOA was feasible and was associated with an immediate systolic blood pressure increase, with 26.1% 24-hour survival and 21.7% 28-day survival. Higher Glasgow Coma Scale on arrival was associated with survival. REBOA represents a feasible option in resource-limited trauma centers.

Keywords: REBOA; Hemorrhagic Shock; Non-Compressible Torso Hemorrhage; Endovascular Procedures

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INTRODUCTION

Exsanguinating hemorrhage constitutes the leading cause of preventable mortality in trauma patients, accounting for 30–40% of trauma-related deaths worldwide [1,2]. Among hemorrhagic deaths, non-compressible torso hemorrhage (NCTH) presents unique therapeutic challenges. In contrast to extremity hemorrhage, which responds to tourniquet application or direct pressure,

NCTH arising from thoracic, abdominal, or pelvic injuries necessitates urgent surgical or endovascular intervention [3].

For several decades, resuscitative thoracotomy (RT) with aortic cross-clamping has served as the definitive intervention for patients with non-responding hemorrhagic shock from NCTH. Nevertheless, survival following RT remains poor, ranging from 2% in blunt trauma to 8.5% overall [4,5]. The procedure is highly invasive, demands considerable surgical expertise, and is associated with substantial morbidity among survivors.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) was initially described by Hughes in 1954 during the Korean War to be used in saving the lives of soldiers suffering from intra-abdominal hemorrhage [6]. The procedure has gained renewed interest in contemporary trauma care [7]. The technique employs percutaneous or open femoral arterial access with endovascular balloon catheter placement to achieve temporary aortic occlusion, thereby maintaining cerebral and

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coronary perfusion while controlling subdiaphragmatic hemorrhage [8].

Recent investigations from Western trauma centers report survival rates of 50–65% in selected REBOA patients, suggesting potential advantages over RT [9,10]. However, these outcomes might not be generalizable to diverse healthcare environments. Data from Southeast Asian trauma centers remain limited, and critical questions persist regarding optimal patient selection, deployment timing, and complication rates in resource-constrained settings.

Our institution, a tertiary referral trauma center located in northeastern Thailand, has been performing REBOA since 2012. This study evaluates clinical outcomes of REBOA in patients with NCTH, identifies factors associated with survival, and characterizes the complication profile in our population. These findings contribute to the expanding evidence base supporting REBOA utilization and could inform protocol development in similar healthcare settings.

METHODS

Study Design and Setting

We conducted a combined retrospective–prospective observational cohort study in a 1,000-bed tertiary referral trauma center serving northeastern Thailand. The study population comprised all trauma patients undergoing REBOA for NCTH between January 2012 and December 2024. The retrospective phase encompassed January 2012 to December 2022; the prospective phase extended from January 2023 to December 2024. The Ethics Committee approved this study; informed consent requirements were waived for retrospectively collected data.

Patient Selection

This was a complete enumeration study including all consecutive patients meeting the inclusion criteria during the 12-year study period.

Inclusion criteria: adult trauma patients (age > 18 years); clinical diagnosis of NCTH (abdominal, pelvic, or thoracic hemorrhage); REBOA performed as a component of resuscitation in non-responder hemorrhagic shock patients.

Exclusion criteria: age < 18 years; REBOA performed for non-traumatic indications; incomplete medical records (retrospective cohort only).

No formal sample size calculation was performed a priori. With 23 patients (18 from the retrospective phase and five from the prospective phase) and an observed survival rate of 21.7%, the 95% confidence interval for survival ranges from 7.5% to 43.7%, providing reasonable precision for this rare intervention in a resource-limited setting.

Primary Survey

All patients underwent the primary survey with simultaneous resuscitation following the ATLS®-protocol. Extended Focused Assessment Sonography in Trauma (eFAST) and portable chest X-ray were performed as the adjunct to the primary survey to exclude significant intrathoracic injuries. All of the results were reviewed immediately by the trauma surgeon staff on duty before deciding to undergo the REBOA procedure. However, owing to limitations in capabilities (such as hybrid emergency room, emergency computed tomography (CT) scan, or availability of interventional radiology), most decisions regarding the procedure are the responsibility of the trauma surgeon staff on duty (Figure 1).

The procedure can be performed in the emergency department (ED), operating room, or the intensive care unit (ICU). This decision depends on the hemodynamics of the patient and the availability of the operating room. In other words, if the patient's condition is stable enough and the operating room is available, the patient should undergo the procedure in the operating room. However, if the operating room is unavailable at that time, the procedure can buy some time for resource management.

REBOA Technique

All REBOA procedures adhered to our standardized institutional protocol:

- (1) *Vascular access:* Common femoral artery cannulation via open cutdown or percutaneous Seldinger technique.
- (2) *Sheath insertion:* 7-French introducer sheath was inserted to ensure intraluminal placement, then exchanged to 10–12-French Aortic sheath.
- (3) *Catheter deployment:* An aortic stent graft balloon was advanced under fluoroscopic guidance when available, or by utilizing external anatomical landmarks without fluoroscopy.
- (4) *Balloon positioning:*
 - Zone 1 (descending thoracic aorta): Abdominal or pelvic hemorrhage
 - Zone 3 (infrarenal aorta): Isolated pelvic hemorrhage
- (5) *Balloon inflation:* Gradual inflation with contrast medium until distal pulse cessation
- (6) *Occlusion management:*
 - Maximum continuous occlusion duration: 60 minutes
 - Partial deflation or intermittent occlusion is employed if prolonged hemorrhage control is required
- (7) *Definitive hemorrhage control:* Emergency surgery or interventional radiology

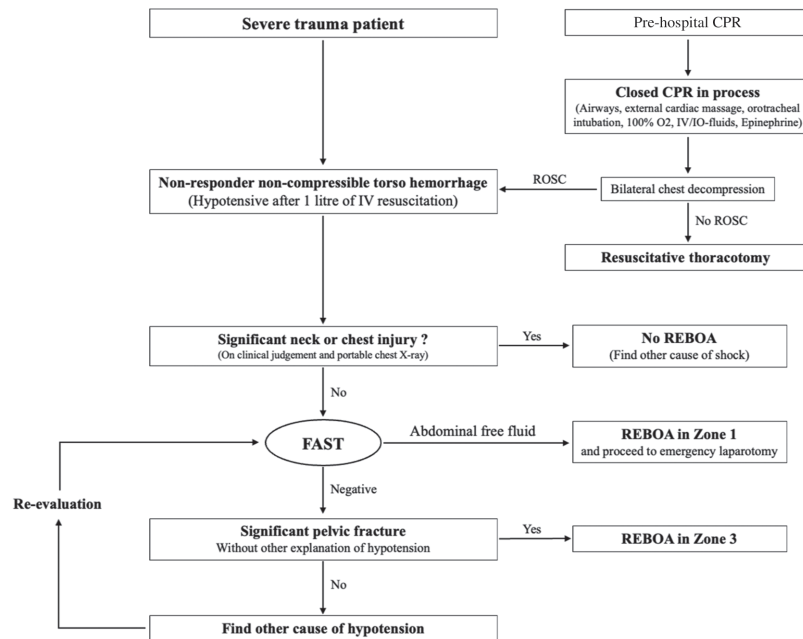


Figure 1 Flowchart showing algorithm for severe non-compressible torso hemorrhage management. CPR: cardiopulmonary resuscitation; ROSC: return of spontaneous circulation; FAST: Focused Assessment Sonography in Trauma; REBOA: Resuscitative Endovascular Balloon Occlusion of the Aorta; IV: intravenous; IO: intraosseous

(8) *Balloon removal*: Gradual deflation following hemorrhage control. After sheath removal, the common femoral artery was sutured using polypropylene material in the open cut down group, and using percutaneous vascular closure device in the percutaneous puncture group. The distal pulses were evaluated when the operation was finished.

All of the patients received the treatment in the same protocol and same devices.

The attending trauma surgeon determined REBOA deployment based on clinical presentation, hemodynamic instability despite resuscitation, and suspected NCTH.

Data Collection and Definitions

All data, such as electronic medical records, trauma registry databases, and operative documentation, were extracted from the internal hospital database. Variables collected encompassed:

Demographic characteristics: Age, sex, weight, height, body mass index; mechanism of injury; prehospital cardiopulmonary resuscitation.

Presentation variables: Vital signs on arrival (systolic blood pressure measured by cuff in the upper extremity; heart rate); Glasgow Coma Scale (GCS) score on arrival (prior sedation); injury severity scores.

Procedural variables: REBOA deployment location (ED, operating room, ICU); vascular access method (open versus percutaneous); balloon Zone (1 or 3); time metrics (door-to-procedure, door-to-occlusion, pre-hospital-balloon-inflation, emergency department-to-operating room transfer, aortic occlusion duration, total operative time).

Physiologic response: Change in systolic blood pressure post-REBOA; return of spontaneous circulation; cardiopulmonary resuscitation requirement during REBOA. If the patient survived the first operation, the invasive monitoring is performed in the ICU to measure the physiologic response.

Resource utilization: Total blood products transfused (first 24 hours); ICU length of stay; hospital length of stay.

Outcomes

- Primary: 24-hour survival and 28-day survival.
- Secondary: Complications (lower limb ischemia, acute kidney injury, continued bleeding requiring intervention, mesenteric ischemia, access site complications); amputation requirement; cause of death.

NCTH was defined as suspected or confirmed hemorrhage from thoracic, abdominal, or pelvic sources not amenable to external compression. *Non-responder hemorrhagic shock* was defined as systolic blood pressure

< 90 mmHg with clinical signs of hypoperfusion after 1-L of intravenous (IV) crystalloid resuscitation. *Acute kidney injury* was defined according to Kidney Disease: Improving Global Outcomes (KDIGO) criteria (a serum creatinine increase of >0.3 mg/dL within 48 hours, or serum creatinine increase 1.5–1.9 times baseline within 7 days, or urine output < 0.5 mL/kg/h for 6–12 hours). *Lower limb ischemia* was defined by clinical manifestations: pain, pallor, pulselessness, paresthesia, and paralysis, which is assessed by the trauma team physicians using clinical assessment and Doppler ultrasonography immediately post-operative and every 6–8 hours until the hemodynamic is stable.

Statistical Analysis

Continuous variables were expressed as mean $\pm$ standard deviation (SD) for normally distributed data or median with interquartile range (IQR) for non-normally distributed data. The Shapiro–Wilk test assessed normality. Categorical variables were presented as frequencies and percentages.

Univariate comparisons between survivors and non-survivors used Student's *t*-test or the Mann–Whitney *U*-test for continuous variables, and chi-square or Fisher's exact test for categorical variables. Crude odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Statistical significance was defined as $P < 0.05$ (two-tailed). Given the small sample size ($N = 23$) and limited number of outcome events, multivariable regression models were restricted to avoid overfitting. All analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

Missing Data

Complete case analysis was performed for all variables. The retrospective cohort ($N = 18$, 2012–2022) had complete data for all primary and secondary outcomes. Missing data occurred for the following variables: door-to-procedure time, door-to-aortic-occlusion time, ED-to-operating room time, operative time, and aortic occlusion time. Patients with missing data for specific variables were excluded only from analyses involving those variables. No imputation methods were employed, given the small sample size.

Ethics Approval and Informed Consent

The study protocol was approved by the Khon Kaen University Ethics Committee in Human Research (HE641418). The study was conducted according to the Declaration of Helsinki. For the retrospective component, informed consent was waived by the ethics committee. For the prospective component, written informed consent was obtained from all participants or their

legal representatives. Patient data were de-identified prior to analysis.

RESULTS

Patient Selection and Flow

During the 12-year study period, from a total of 659 patients with torso hemorrhage (492 abdominal hemorrhages, 60 pelvic hemorrhages, and 107 thoracic hemorrhages), 28 trauma patients underwent REBOA at our institution. Five patients were excluded: three were < 18 years of age, and two had incomplete medical records (retrospective cohort). The final study cohort comprised 23 patients (Figure 2).

Patient Characteristics

During the study period, 23 patients underwent REBOA for NCTH. Baseline characteristics are summarized in Table 1. Mean age was 38.4 ± 19.2 years; 20 patients (87%) were male. Mean body mass index was 23.1 ± 3.7 kg/m². Ten patients (43.5%) received prehospital cardiopulmonary resuscitation.

On arrival, patients demonstrated non-responsive hemorrhagic shock after 1-L of IV crystalloid resuscitation: median systolic blood pressure 60 mmHg (IQR 40–68). Five patients (21.7%) presented with unmeasurable blood pressure; only three patients (13.0%) had systolic blood pressure ≥ 81 mmHg. Median GCS was 7 (IQR 3–11); 15 patients (65.2%) exhibited severe neurological impairment (GCS 3–8).

Procedural Details

The REBOA was decided upon and initiated by a trauma surgeon staff on duty at the emergency room based on the clinical judgement of non-responsive hemorrhagic shock from NCTH after 1-L of IV resuscitation without significant neck or chest injury. The procedure was performed in the operating room (13 patients, 56.5%), ED (nine patients, 39.1%), or ICU (one patient, 4.3%). The principle of the procedures in the operating room is to slow down bleeding and increase blood flow to vital areas. The procedures performed in the emergency room serve as a bridge to the operating room. Percutaneous access was achieved in 13 cases (56.5%), and open cutdown was required in 10 cases (43.5%). Zone 1 occlusion was employed in 22 patients (95.7%), and one patient received Zone 3 occlusion. However, the REBOA procedure did not influence the principle of damage control resuscitation.

Seven patients (30.4%) required cardiopulmonary resuscitation during REBOA deployment. Following balloon inflation, 19 patients (82.6%) achieved return of spontaneous circulation.

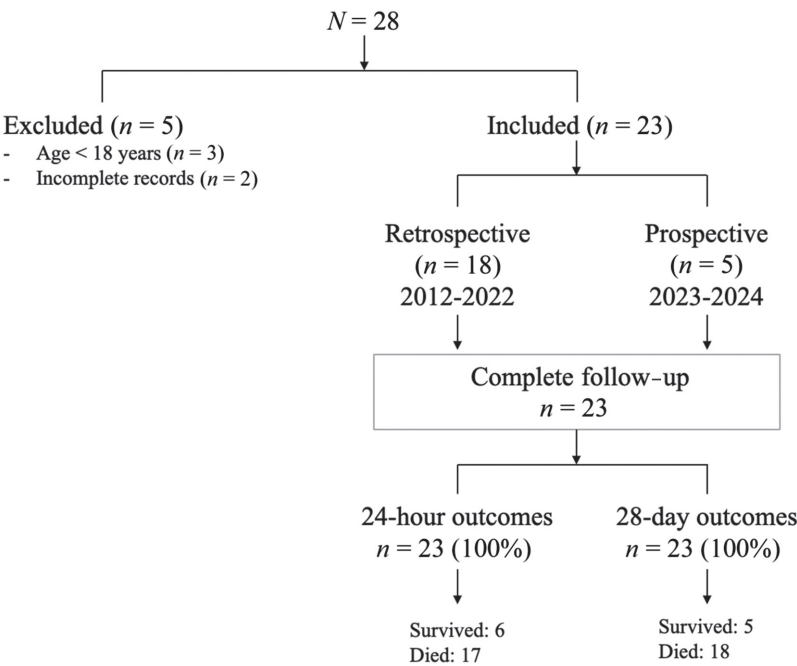


Figure 2 Total number of trauma patients treated with Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage between 2012 and 2024. Out of the 23 patients included, 17 died within the first 24 hours and, out of the remaining six patients, only five were alive after 28 days.

Only one type of balloon, the Stent graft aortic balloon, was used throughout the study period.

Time Metrics and Hemodynamic Response

Median door-to-procedure time was 33 minutes (IQR 18–54), and median door-to-occlusion time was 39 minutes (IQR 22–62). Mean time to balloon inflation was 6.7 ± 3.4 minutes. For patients undergoing ED REBOA, the median operating room transfer time was 40 minutes (IQR 15–73). Median aortic occlusion time was 53 minutes (IQR 30–93), and mean operative time was 215.4 ± 99.8 minutes.

REBOA produced a mean systolic blood pressure increase of 39.8 ± 20.7 mmHg. Patients required massive transfusion: mean 38.7 ± 25.6 units of blood products within the first 24 hours.

Clinical Outcomes

Survival

The 24-hour survival rate was 26.1% (6/23). One additional patient died between 24 hours and 28 days, yielding a 28-day survival rate of 21.7% (5/23). All five 28-day survivors were discharged alive (Table 2).

Complications

Continued bleeding necessitating additional intervention occurred in 15 patients (65.2%) while en-route for damage

Table 1 Baseline characteristics and procedural details for patients who underwent Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage (N = 23).

Variable	Value
Demographic Data	
Age, years	38.4 ± 19.2
Male sex	20 (87.0)
Weight, kg	68.5 ± 7.0
Height, cm	171.8 ± 6.7
Body mass index, kg/m²	23.1 ± 3.7
Mechanism of injury	
Blunt	22 (95.65)
Penetrating	1 (4.35)
Prehospital	
Cardiopulmonary resuscitation	10 (43.5)
Presentation	
Systolic blood pressure, mmHg*	60 (40–68)
Systolic blood pressure category	
0 mmHg	5 (21.7)
1–59 mmHg	6 (26.1)
60–80 mmHg	9 (39.1)
>81 mmHg	3 (13.0)
Glasgow Coma Scale	7 (3–11)
Glasgow Coma Scale category	
3–8	15 (65.2)
9–12	8 (34.8)
Trauma score	
AIS – Head > 2	14 (60.87)
AIS – Chest > 2	10 (43.47)
AIS – Abdomen > 2	23 (100)

(Continued)

Variable	Value
AIS – Extremities > 2	12 (52.17)
ISS*	41 (29, 51)
RTS*	4.50 (2.63, 6.38)
Major bleeding sources	
Liver	12 (52.17)
Pelvic bones	7 (30.43)
Spleen	4 (17.39)
Mesenteric vessels	4 (17.39)
Portal vein	1 (4.35)
Pancreas	1 (4.35)
Vena cava	1 (4.35)
Common iliac artery	1 (4.35)
Hepatic artery	1 (4.35)
REBOA procedure	
Location	
Operating room	13 (56.5)
Emergency department	9 (39.1)
Intensive care unit	1 (4.3)
Access method	
Percutaneous	13 (56.5)
Open cutdown	10 (43.5)
Balloon occlusion zone	
Zone 1	22 (95.7)
Zone 3	1 (4.3)
CPR during REBOA	7 (30.4)
Return of spontaneous circulation	19 (82.6)
Time metrics	
Door-to-procedure, minutes*	33 (18–54)
Door-to-aortic occlusion, minutes*	39 (22–62)
Time to balloon inflation, minutes	6.7 ± 3.4
Emergency department-to-operating room, minutes [†]	40 (15–73)
Aortic occlusion time, minutes*	53 (30–93)
Operative time, minutes	215.4 ± 99.8
Hemodynamic response	
Change in systolic blood pressure, mmHg	39.8 ± 20.7
Transfusion	
Total blood products, units	38.7 ± 25.6

Data are mean ± SD, n (%), or *median (interquartile range). [†]Among patients who underwent REBOA in the emergency department (n = 9). CPR: cardiopulmonary resuscitation; SD: standard deviation; AIS: Abbreviated Injury Scale; RTS: Revised Trauma Score; ISS: Injury Severity Score. All variables had complete data for all 23 patients. No imputation was performed.

control surgery. Acute kidney injury developed in five patients (21.7%), all of whom were survivors. Notably, no cases of lower limb ischemia were observed (0%).

Factors Associated with Survival

Univariate analysis

Table 3 presents univariate analysis comparing 24-hour survivors and non-survivors. Higher systolic blood pressure on arrival demonstrated a trend toward improved survival (median 69 versus 58 mmHg, $P = 0.103$). Higher GCS was significantly associated with survival (median 11 versus 3, $P = 0.024$). There were three

Table 2 Clinical outcomes and complications for patients who underwent Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage ($N = 23$).

Outcome	n (%)
Survival	
24-hour survival	6 (26.1)
28-day survival	5 (21.7)
In-hospital survival	5 (21.7)
Mortality cause	
Exsanguination	15 (65.2)
Severe acidosis (multiorgan failure)	2 (8.7)
Brain herniation	1 (4.3)
Complications	
Continued bleeding requiring intervention	15 (65.2)
Acute kidney injury	5 (21.7)
Lower limb ischemia	0 (0)

intracerebral hemorrhages and one diffuse axonal injury from the six surviving patients reported from the CT scan after stabilization. No survivor had received prehospital cardiopulmonary resuscitation, compared with 58.8% of non-survivors. A shorter aortic occlusion time showed a trend toward improved survival (median 31.5 versus 65 minutes; $P = 0.147$).

28-day mortality

Similar patterns emerged for 28-day mortality (Table 4). Patients with GCS 9–12 had 14-fold higher odds of survival than those with GCS 3–8 (crude OR 14.0, 95% CI 1.20–163.37, $P = 0.035$). Other variables demonstrating trends included arrival systolic blood pressure (crude OR 1.13 per mmHg, 95% CI 0.97–1.31, $P = 0.112$), ED-to-operating room time (crude OR 1.02 per minute, 95% CI 1.00–1.04, $P = 0.078$), and total blood products (crude OR 0.96 per unit, 95% CI 0.90–1.01, $P = 0.121$).

DISCUSSION

This study presents our 12-year institutional experience with REBOA for non-compressible torso hemorrhage at a tertiary trauma center in Thailand. Our findings demonstrate that REBOA achieved 21.7% survival in a critically ill patient population presenting with profound hemorrhagic shock. While this survival rate is lower than that reported in some recent Western series (50–65%) [9,10], it must be interpreted in the context of our patient population's extreme physiologic derangement.

Patient Severity and Outcomes

Our cohort represented exceptionally critically ill patients. Median systolic blood pressure on arrival was 60 mmHg; 21.7% presented with unmeasurable blood pressure. Nearly half (43.5%) required prehospital cardiopulmonary resuscitation, and two-thirds

Table 3 Factors associated with 24-hour survival in patients who underwent Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage.

Variable	Died (N = 17)	Survived (N = 6)	Crude OR (95% CI)	P
Age, years*	27 (24–48)	47 (20–62)	1.01 (0.97–1.06)	0.566
Weight, kg	67.6 ± 6.9	71.2 ± 7.4	1.08 (0.94–1.24)	0.282
Body mass index, kg/m ² *	21.8 (20.1–25.5)	22.9 (21.5–25.1)	1.15 (0.89–1.49)	0.279
Prehospital CPR				
No	7 (41.2)	6 (100)	Reference	—
Yes	10 (58.8)	0 (0)	—	—
Systolic blood pressure, mmHg*	58 (0–64)	69 (67–81)	1.13 (0.98–1.31)	0.103
Glasgow Coma Scale*	3 (3–8)	11 (9–12)	1.76 (1.08–2.89)	0.024
Glasgow Coma Scale category				
3–8	14 (82.4)	1 (16.7)	Reference	—
9–12	3 (17.6)	5 (83.3)	23.33 (1.95–279.43)	0.013
Trauma scores				
ISS	39.9 ± 16.5)	49.7 ± 17.2	1.228 (–6.74–26.19)	0.233
REBOA location				
Operating room	9 (52.9)	4 (66.7)	Reference	—
Emergency department	7 (41.2)	2 (33.3)	0.64 (0.09–4.58)	0.659
Intensive care unit	1 (5.9)	0 (0)	—	—
Access method				
Open	8 (47.1)	2 (33.3)	Reference	—
Percutaneous	9 (52.9)	4 (66.7)	1.78 (0.25–12.45)	0.562
CPR during REBOA				
No	11 (64.7)	5 (83.3)	Reference	—
Yes	6 (35.3)	1 (16.7)	0.37 (0.03–3.91)	0.406
Change in SBP, mmHg	36.9 ± 18.4	47.8 ± 26.3	1.03 (0.98–1.08)	0.268
Door-to-procedure, minutes*	28 (15–40)	34.5 (30–126)	1.01 (0.99–1.02)	0.428
Door-to-occlusion, minutes*	35 (20–51)	42 (38–131)	1.01 (0.99–1.02)	0.438
Occlusion time, minutes*	65 (35–103)	31.5 (25–55)	0.97 (0.93–1.01)	0.147
Operative time, minutes	231.1 ± 107.3	176.0 ± 70.7	0.99 (0.98–1.01)	0.261
Total blood products, units*	41.7 ± 26.5	30.3 ± 23.2	0.98 (0.94–1.02)	0.349

Data are mean ± SD, n (%) or *median (interquartile range). Bold indicates $P < 0.05$. CI: confidence interval; CPR: cardiopulmonary resuscitation; OR: odds ratio; SBP: systolic blood pressure; SD: standard deviation; ISS: Injury Severity Score. Total blood products included red blood cells, plasma, platelet concentration, and cryoprecipitated.

Table 4 Factors associated with 28-day mortality in patients who underwent Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for non-compressible torso hemorrhage.

Variable	Died (n = 18)	Survived (n = 5)	Crude OR (95% CI)	P
Age, years*	27 (22–48)	53 (41–62)	1.03 (0.98–1.09)	0.215
Weight, kg	68.3 ± 7.3	69.4 ± 6.7	1.02 (0.89–1.18)	0.746
Body mass index, kg/m ²	23.2 ± 4.1	22.7 ± 1.5	0.97 (0.73–1.28)	0.818
Prehospital CPR				
No	8 (44.4)	5 (100)	Reference	—
Yes	10 (55.6)	0 (0)	—	—
Systolic blood pressure, mmHg*	58.5 (0–65)	70 (68–81)	1.13 (0.97–1.31)	0.112
Glasgow Coma Scale*	4.5 (3–8)	11 (9–11)	1.52 (1.00–2.31)	0.051
Glasgow Coma Scale category				
3–8	14 (77.8)	1 (20.0)	Reference	—
9–12	4 (22.2)	4 (80.0)	14.00 (1.20–163.37)	0.035
Door-to-occlusion, minutes*	37 (20–51)	45 (38–131)	1.01 (0.99–1.02)	0.317
Emergency department-to-operating room, minutes*	35 (15–59)	63 (60–121)	1.02 (1.00–1.04)	0.078
Occlusion time, minutes*	59 (30–103)	33 (25–55)	0.98 (0.94–1.01)	0.219
Operative time, minutes	232.6 ± 103.9	160.2 ± 66.2	0.99 (0.97–1.00)	0.174
Total blood products, units	43.3 ± 26.6	22.2 ± 13.3	0.96 (0.90–1.01)	0.121

Data are mean ± SD, n (%), or *median (interquartile range). Bold indicates $P < 0.05$. CI: confidence interval; CPR: cardiopulmonary resuscitation; OR: odds ratio; SD: standard deviation. Total blood products included red blood cells, plasma, platelet concentration, and cryoprecipitated.

demonstrated severe neurological impairment (GCS 3–8). These characteristics indicate that our patients were moribund, representing a population that would traditionally undergo resuscitative thoracotomy with anticipated survival rates of only 2–8.5% [4,5].

Compared with these historical outcomes, REBOA appears to confer superior survival in this critically ill population. The American Association for the Surgery of Trauma (AAST) Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) registry reported overall REBOA survival of 54.8%; however, their cohort demonstrated a median systolic blood pressure of 80 mmHg with only 23% receiving cardiopulmonary resuscitation [11]. When examining exclusively their most severely injured patients (systolic blood pressure < 70 mmHg), survival approximated 30%, which is more comparable with our results [11].

GCS as a Prognostic Indicator

The most striking finding was the robust association between presenting GCS and survival. Patients with GCS 9–12 had 23-fold higher odds of 24-hour survival than those with GCS 3–8, with important implications for patient selection.

GCS likely serves as a surrogate marker for multiple physiologic derangements. Lower GCS may reflect: prolonged hypoperfusion with cerebral injury; more severe hemorrhagic shock; concomitant traumatic brain injury; advanced acidosis and coagulopathy, which can improve after resuscitation. This finding aligns with previous investigations suggesting that REBOA achieves optimal efficacy when deployed before complete cardiovascular collapse [12,13]. The Japanese DIRECT-IABO (Diagnostic and Interventional Radiology in Emergency, Critical care and Trauma-Intra-Aortic Balloon Occlusion registry) study similarly identified consciousness level as a significant REBOA survival predictor [14].

We did not perform formal sensitivity analyses given the small sample size ($N = 23$). However, the consistency of GCS as a predictor across both 24-hour and 28-day mortality on univariate analysis, and the magnitude of effect (crude OR 23.33 for 24-hour, crude OR 14.00 for 28-day) strengthens confidence in this finding. The finding remained robust when analyzed as both a continuous variable (OR 1.76 per point) and a categorical variable (9–12 vs 3–8). Nevertheless, GCS alone cannot be the sole deciding factor in initiating or terminating a procedure. We recommend using it as part of a decision-making process, along with other factors.

Procedural Metrics and Timing

Our median door-to-occlusion time of 39 minutes exceeds that reported by many Western centers (20–30 minutes) [15,16]. However, this must be contextualized

by our deployment locations. Only 39.1% of REBOA procedures were performed in the ED; the majority (56.5%) occurred in the operating room, necessitating patient transport. For patients undergoing emergency department REBOA, the median door-to-occlusion time was 37 minutes, which is more comparable to the published literature. Upon reviewing their medical history, we found that some patients reported a transient response to resuscitation for a short period, which might have been the reason for the delay in deciding to proceed with the procedure. But once the decision was made to proceed with the procedure, it only took about 6 minutes to the aortic occlusion time.

Interestingly, shorter prehospital-occlusion showed a trend toward improved survival, but this did not reach statistical significance ($P = 0.438$). This might reflect competing priorities in trauma resuscitation. Some patients might benefit from rapid ED REBOA deployment, whereas others might be better served by immediate operative intervention with REBOA performed in the operating room concurrent with definitive hemorrhage control.

Hemodynamic Response

REBOA achieved a mean systolic blood pressure increase of 39.8 mmHg, consistent with the physiologic objective: temporarily augmenting afterload and maintaining vital organ perfusion proximal to the balloon. The 82.6% return-of-spontaneous-circulation rate demonstrates REBOA's effectiveness in reversing cardiovascular collapse.

Nevertheless, hemodynamic improvement must be weighted against the risk of prolonged aortic occlusion. Our median occlusion time of 53 minutes falls within recommended limits; however, 25% of patients experienced occlusion times exceeding 93 minutes. Prolonged occlusion is associated with reperfusion injury, metabolic acidosis, and spontaneous-circulation dysfunction [17].

Complications

Our complication profile was favorable compared with some published series. Most notably, no cases of lower limb ischemia requiring intervention were observed, in contrast to some studies reporting limb ischemia rates of 10–20% [18,19]. Several factors could explain this finding: short occlusion times (median 53 minutes), potentially preventing severe distal ischemia; Zone 1 occlusion predominance (95.7%), possibly providing superior collateral flow versus Zone 3 occlusion; percutaneous access (56.5%), potentially reducing vascular injury compared with open cutdown; and early mortality before limb ischemia manifestation.

Acute kidney injury occurred in 21.7% of patients, exclusively among survivors, representing an acceptable

complication rate for a life-saving intervention and lower than the 30–40% acute kidney injury rate reported in some REBOA series [17]. The true rate might be higher, as many patients died before kidney injury.

Comparison with Resuscitative Thoracotomy

Although our study lacked a direct comparison with a resuscitative thoracotomy group, our 21.7% survival rate compares favorably with historical resuscitative thoracotomy survival rates of 2–8.5% in similar patient populations [4,5]. REBOA offers several theoretical advantages: less invasive (percutaneous capability); faster deployment (thoracotomy not required); maintainability during operating room transport; reversibility (controlled reperfusion via gradual balloon deflation) and lower technical skill threshold than resuscitative thoracotomy.

However, the REBOA cannot replace the resuscitative thoracotomy in the event of witnessed cardiac arrest, or the need of intrathoracic intervention. The procedure serves only if it is certain that the patient has abdominopelvic bleeding and no significant neck or chest injury.

The resuscitative thoracotomy retains advantages in specific clinical scenarios: cardiac tamponade requiring pericardial window; cardiac injury requiring direct repair; massive air embolism requiring cardiac venting; and inability to obtain femoral access. The optimal algorithm likely incorporates both techniques, with REBOA serving as the initial approach for most NCTH patients without significant neck or chest injury, and resuscitative thoracotomy reserved for specific thoracic injuries or failed REBOA [20].

Resource-Limited Settings

Our experience demonstrates the feasibility of REBOA in resource-limited settings. Thailand is classified as an upper-middle-income country; while our center maintains adequate basic equipment and blood supply, we lack certain resources available at Western trauma centers, such as hybrid operating rooms, hybrid emergency room, 24/7 interventional radiology, or a fluoroscopic machine in the emergency room. Despite these limitations, reasonable outcomes were achieved.

Key factors enabling REBOA success in our setting included: institutional commitment (a dedicated trauma team and standardized protocols); training (ongoing education for surgeons and staff); equipment availability (maintenance of REBOA catheter inventory); and a multidisciplinary approach (surgery, anesthesia, and nursing collaboration). Our findings suggest that REBOA can be successfully implemented in similar healthcare environments, without delaying the diagnosis and management, potentially saving lives in regions where resuscitative thoracotomy is not available.

However, this procedure only slows down bleeding in the abdominopelvic cavity but does not achieve hemostasis. Therefore, there is an ongoing hemorrhage. A hospital with an insufficient blood supply or massive transfusion protocol may be another factor contributing to the mortality, which should be further studied.

Clinical Implications

Based on our findings, we propose the following clinical recommendations:

Patient selection: REBOA should be considered for NCTH patients in hemorrhagic shock; patients with higher GCS (≥ 9) are most likely to benefit; spontaneous-circulation cardiopulmonary resuscitation associates with poor outcomes but should not constitute an absolute contraindication and patients in complete cardiovascular collapse might derive limited benefit.

Deployment strategy: ED deployment may be appropriate for patients requiring immediate intervention; operating room deployment is reasonable for patients tolerating brief transport; goal door-to-occlusion time < 40 minutes and percutaneous access should be attempted when feasible.

The decision to transfer a patient depends on several factors, such as the patient's hemodynamic status at the time and the availability of the team and equipment, as surgical procedures are usually performed in an operating room with more advanced facilities. Furthermore, moving patients with so much equipment is not easy and could lead to complications.

Occlusion management: Target occlusion time < 60 minutes; consider partial deflation or intermittent occlusion if prolonged hemorrhage control is required and coordinate with the surgical team for definitive hemorrhage control.

Complication prevention: Monitor for limb ischemia, though risk appears low with appropriate technique; anticipate acute kidney injury in survivors and optimize renal protection and employ gradual balloon deflation to minimize reperfusion injury.

Study Limitations

Several important limitations exist: small sample size (23 patients) limiting statistical power and generalizability; single-center experience with potentially limited external applicability; absence of comparison group precluding direct comparison with resuscitative thoracotomy or alternative strategies; retrospective component with potential for missing data such as the duration of CPR en-route and selection bias; heterogeneous population mixing injury mechanisms and anatomic locations; lack of long-term outcomes (functional status, quality of life); variable operator

experience as the technique evolved over the 12-year period.

The small sample size ($N = 23$) with limited outcome events (six survivors at 24 hours, five at 28 days) severely constrains our statistical analyses. With an events-per-variable ratio of 5–6:1, well below the recommended 10:1 threshold, the multivariable models are at high risk of overfitting and should be interpreted as exploratory rather than confirmatory.

Because some patients did not respond to the procedure and resuscitation, ongoing data collection, such as lactate trends and base-deficit, was incomplete. Therefore, the analysis of complications related to the procedure was lacking.

Missing Data

Of the 17 fatalities, 10 were consistent with clinical signs of severe traumatic brain injury, but only six were confirmed by CT scans or autopsies. Owing to religious and belief reasons, the patients' relatives did not consent to the examination. Some of this information is therefore missing.

Similarly, the complication data (such as acute kidney injury, lower limb ischemia, or multiorgan failure) of the early deaths cannot be collected.

Future Directions

Several areas warrant further investigation: randomized controlled trials comparing REBOA with resuscitative thoracotomy in appropriate patient populations; partial REBOA evaluating partial occlusion strategies to reduce ischemic complications; multiorgan REBOA assessing prehospital deployment feasibility and safety; predictive models developing algorithms to identify ideal REBOA candidates; long-term outcomes examining quality of life and functional status in survivors; cost-effectiveness analyses of REBOA implementation; training methodologies determining optimal education strategies for REBOA proficiency and zone selection comparing Zone 1 versus Zone 3 occlusion effectiveness.

CONCLUSIONS

In this single-center cohort of trauma patients with NCTH and profound shock, REBOA use was associated with 21.7% 28-day survival and an immediate rise in systolic blood pressure. Higher GCS on presentation was associated with better survival in both 24-hour and 28-day analyses. REBOA was feasible in our resource-limited setting with no observed limb ischemia and acute kidney injury in 21.7%, but these findings should be interpreted cautiously given the small sample size and observational design.

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Ethics Statement

- (1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
- (2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

Panu Teeratakulpisarn significantly contributed to the conception, design, review, editing, and drafting the original manuscript. Parichat Tanmit was responsible for verification, formal analysis, and serving as the corresponding author. Weeriya Jeerasuwannakul focused on data collection and interpretation. Phati Angkasith contributed to designing the methodology and analysis. Supatcha Prasertcharoensuk and Narongchai Wongkonkitsin served as scientific research advisors. All authors reviewed and approved the final version of the manuscript.

Data Availability

For restricted access due to confidentiality: The data that support the findings of this study are not publicly available due to confidentiality restrictions of the hospital but are available from the corresponding author upon reasonable request.

Declaration of the Use of Generative AI in the Writing Process

No generative AI or AI-assisted technologies were used during the writing process of this manuscript.

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