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Resuscitative endovascular balloon occlusion of the aorta in abdominal trauma: zone-specific outcomes and predictors of mortality

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Abstract

Background Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is increasingly utilized for hemorrhage control in trauma; however, zone-specific outcomes in abdominal trauma remain inadequately characterized.

Methods We retrospectively analyzed 404 patients with abdominal trauma who underwent REBOA between 2019 and 2022. Patients were stratified by aortic occlusion zone (zones 1, 2, or 3), and their demographic characteristics, injury patterns, resuscitation requirements, and clinical outcomes were compared.

Results The cohort was predominantly male (83.8%), with a median age of 35.0 years. The distribution of the zones was as follows: Zone 1 (33.7%); Zone 2 (4.7%); and Zone 3 (61.6%). Patients in Zone 1 presented with more severe hemodynamic compromise (median SBP 77.0 mmHg vs. 107.0 mmHg in Zone 2 and 103.0 mmHg in Zone 3, $P < 0.001$) and lower GCS scores (median 6.0 vs. 15.0 in both Zones 2 and 3, $P < 0.001$). Mortality was significantly higher in Zone 1 (73.6%) than in Zones 2 (27.8%) and 3 (37.7%) ($P < 0.001$). Multivariate analysis identified GCS score (OR 0.80 per point increase, 95% CI 0.73–0.87, $P < 0.001$) and Zone 3 placement (OR 0.20 vs. Zone 1, 95% CI 0.08–0.47, $P < 0.001$) as independent predictors of survival. Overall mortality decreased from 58% in 2019 to 36% in 2022, despite the increased utilization of REBOA.

Conclusion REBOA zone placement and neurological status are powerful independent predictors of mortality in patients with abdominal trauma. These findings support a zone-specific approach to REBOA deployment in patients with abdominal trauma.

Keywords REBOA, Abdominal trauma, Hemorrhage control, Aortic occlusion, Trauma resuscitation, Endovascular techniques

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Introduction

Trauma is a leading cause of mortality worldwide, with hemorrhage accounting for approximately 40% of trauma-related deaths [1]. Abdominal trauma presents particular challenges in hemorrhage control because of its anatomical complexity and difficulty in achieving rapid access to bleeding sources [2]. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) has emerged as a promising adjunct in the management of non-compressible torso hemorrhage, offering a minimally invasive alternative to resuscitative thoracotomy for temporary hemorrhage control [3].

REBOA is a minimally invasive endovascular technique involving the percutaneous insertion of a balloon catheter into the femoral artery, which is then advanced into the aorta [4–6]. Upon inflation, the balloon creates a temporary occlusion to control bleeding and maintain perfusion to vital organs, serving as an alternative to emergency thoracotomy and aortic clamping for temporary hemodynamic stabilization [7, 8]. The aorta is conceptually divided into three zones for REBOA placement: Zone 1 (descending thoracic aorta to celiac artery), Zone 2 (celiac artery to renal arteries, generally considered a no-occlusion zone), and Zone 3 (infrarenal aorta to aortic bifurcation) [9]. Zone selection is typically determined by the suspected location of the hemorrhage, with Zone 1 targeting intra-abdominal bleeding and Zone 3 targeting pelvic hemorrhage [10].

Despite the increasing adoption of REBOA in trauma centers worldwide, evidence regarding its efficacy and optimal application remains limited and conflicting [11–13]. A nationwide analysis by Joseph et al. reported higher mortality rates in trauma patients who underwent REBOA than in matched controls without REBOA (35.7% vs. 18.9%), raising concerns regarding patient selection and potential complications [14]. Conversely, Bini et al. demonstrated a survival benefit of REBOA compared with open aortic occlusion in patients with pelvic trauma [15].

International multicenter studies have provided additional insights into the outcomes of REBOA across diverse healthcare settings. The ABO Trauma Registry, an international collaboration spanning multiple countries, reported a 30-day mortality of 48–64% depending on the occlusion strategy, with better outcomes observed with non-continuous occlusion [16, 17], demonstrating that REBOA can be safely performed in both blunt and penetrating trauma with lower complication rates using smaller-caliber (7 Fr) devices. The DIRECT-IABO registry reported that partial occlusion was employed in 70% of patients, with shorter occlusion times (< 30 min in Zone 1) associated with improved survival, emphasizing the importance of undelayed deployment before an impending cardiac arrest. Data from both the ABO Trauma Registry and the AORTA database identified delta systolic blood pressure as a stronger predictor of mortality than pre-occlusion blood pressure alone [18, 19].

The heterogeneity in the reported outcomes likely reflects variations in institutional protocols, provider experience, patient selection criteria, and timing of the intervention. Furthermore, the specific impact of REBOA zone placement on clinical outcomes remains inadequately characterized, with limited data comparing outcomes across different zones in patients with abdominal trauma [20–23].

This study aimed to address this knowledge gap by analyzing zone-specific outcomes in a large cohort of patients with abdominal trauma who underwent REBOA [23–25]. By examining demographic characteristics, injury patterns, resuscitation requirements, and mortality across different REBOA zones, we sought to identify independent predictors of mortality and inform evidence-based approaches to REBOA utilization. Additionally, by analyzing the temporal trends in REBOA use and associated outcomes from 2019 to 2022, we aimed to provide insights into the evolution of this technique and its integration into contemporary trauma care algorithms.

Understanding the relationship between REBOA zone placement and clinical outcomes is critical for optimizing patient selection, refining technical approaches, and improving survival rates in patients with severe abdominal trauma.

Methods

Study design and data source

This retrospective cohort study analyzed National Trauma Data Bank (NTDB) data from 2019 to 2022 to identify trauma patients with documented abdominal injuries who underwent resuscitative endovascular balloon occlusion of the aorta (REBOA).

Study population

Patients were included if they met all the following criteria: underwent REBOA placement during the study period (2019–2022), had complete trauma registry data, and presented with at least one documented abdominal injury (AIS Region 4). We employed a deterministic linkage approach using unique patient identifiers across all the datasets. The integration process involved the initial merging of REBOA procedure data with trauma registry data, subsequent merging with AIS Region 4 abdominal injury data, and retention of only complete cases with data from all three sources (inner join methodology). To ensure data integrity, duplicate records were identified and removed, retaining only the first occurrence of each patient. Records with missing identifiers were excluded from the analysis.

Variables and outcomes

The final dataset included demographic characteristics (age, sex, race, and ethnicity), injury patterns, severity metrics (Injury Severity Score [ISS] and AIS scores), REBOA procedure details and timing, physiological parameters (vital signs and laboratory values), hospital course variables (intensive care unit length of stay and ventilator days), clinical outcomes (mortality and complications), and hospital characteristics. The primary outcome was in-hospital mortality. Secondary outcomes included massive transfusion requirements, length of hospital stay, and complications.

Statistical analysis

Data processing and statistical analyses were performed using R version 4.3.0 (R Foundation for Statistical Computing). Descriptive statistics were calculated for all the variables of interest. Continuous variables are presented as median (interquartile range [IQR]) and categorical variables as numbers (percentages). Statistical comparisons between groups were performed using appropriate tests based on data distribution: t-test or analysis of variance for normally distributed continuous variables, Mann-Whitney U or Kruskal-Wallis test for non-normally distributed continuous variables, and Fisher's exact test or χ^2 test for categorical variables.

Outliers were managed using winsorization (capping at 1.5 × IQR from the first and third quartiles). Winsorization was employed rather than simple outlier exclusion because it preserves the sample size while reducing the influence of potentially spurious extreme values, which is particularly relevant in trauma research, where physiological parameters can vary dramatically due to measurement artifacts, data entry errors, or extreme clinical presentations [26]. Missing values were excluded from the analysis. Patients with missing data for any variable included in the multivariable model were excluded from the regression analysis, resulting in a complete-case analysis.

Multivariable logistic regression was performed to identify the independent predictors of mortality while controlling for potential confounders. A forced-entry approach was used for the regression model, with all candidate variables entered simultaneously based on clinical relevance and the prior literature. This approach was chosen to preserve the integrity of important predictors, regardless of their individual statistical significance, and to avoid issues associated with stepwise selection, including inflated type I error rates, biased parameter estimates, and model instability. The regression model included demographic factors (sex and age), injury characteristics (ISS category and abdominal injury severity), physiological parameters (systolic blood pressure and GCS score), and REBOA-specific variables (zone placement). The results are presented as adjusted odds ratios (aORs) with 95% confidence intervals (CIs). The model fit was evaluated using the likelihood ratio chi-square test. Statistical significance was set at $P < 0.05$ for all analyses.

Results

Patient characteristics

A total of 404 patients who underwent REBOA for abdominal trauma were included in the final analysis. The cohort was predominantly male (339 patients [83.9%]) with a median age of 35.0 (25.0–50.0) years. Regarding REBOA placement, 249 patients (61.6%) underwent zone 3 placement, 136 (33.7%) underwent zone 1 placement, and 19 (4.7%) underwent zone 2 placement.

Patient characteristics by REBOA zone

Significant demographic differences were observed between the REBOA zones (Table 1). Zone 2 patients were notably older (median age, 58.0 [35.0–68.0] years) than Zone 1 (30.0 [23.0–44.0] years) and Zone 3 patients (36.0 [25.0–50.0] years) ($P < 0.001$). Sex distribution was similar across zones, with males comprising 83–85% of each group ($P = 0.95$). As illustrated in Fig. 1, Zone 1 patients presented with the most severe hemodynamic compromise, with a median systolic blood pressure of 77.0 (0.0-108.0) mm Hg compared with 107.0 (82.0-136.0) mm Hg for Zone 2 and 103.0 (78.0-134.0) mm Hg for Zone 3 patients ($P < 0.001$). Neurological status also differed significantly, with Zone 1 patients demonstrating the lowest median Glasgow Coma Scale (GCS) score of 6.0 (3.0–14.0), while Zone 2 and Zone 3 patients had median GCS scores of 15.0 (14.0–15.0) and 15.0 (7.0–15.0), respectively ($P < 0.001$). Injury severity varied across groups, with Zone 1 patients having the highest median Injury Severity Score of 20.0 (16.0–26.0) compared with 17.0 (13.0-22.5) for Zone 2 and 16.0 (9.0–24.0) for Zone 3 patients ($P = 0.01$).

Clinical interventions and outcomes by REBOA zone

As shown in Fig. 2, the resuscitation requirements reflected the differences in injury severity. Zone 1 patients received the highest volume of blood products in the first 4 h (median, 2100.0 [15.0-6207.5] mL) compared to Zone 2 (median, 1.0 [0.0-1000.0] mL) and Zone 3 patients (median, 1400.0 [5.0-4900.0] mL) ($P = 0.002$). Similarly, total blood product administration was highest in Zone 1 patients (median, 6323.0 [1500.0–13 400.0] mL), followed by Zone 3 patients (median, 3900.0 [820.0–10 600.0] mL), and lowest in Zone 2 patients (median, 310.0 [0.0-3525.0] mL) ($P = 0.007$).

Table 1 Comparison of clinical characteristics by REBOA zone

Variable	Overall *N* = 404	REBOA Zone			*p*-value
		Zone 1 *N* = 136	Zone 2 *N* = 19	Zone 3 *N* = 249	
Age (years)					< 0.001
Median [Q1-Q3]	35.0 [25.0–50.0]	30.0 [23.0–44.0]	58.0 [35.0–68.0]	36.0 [25.0–50.0]	
Unknown	6	2	0	4	
Sex					0.949
Female	65 (16.2%)	20 (15.0%)	3 (15.8%)	42 (16.9%)	
Male	336 (83.8%)	113 (85.0%)	16 (84.2%)	207 (83.1%)	
Unknown	3	3	0	0	
Systolic Blood Pressure (mmHg)					< 0.001
Median [Q1-Q3]	95.0 [69.0-127.0]	77.0 [0.0-108.0]	107.0 [82.0-136.0]	103.0 [78.0-134.0]	
Unknown	31	15	1	15	
Pulse Rate (bpm)					0.059
Median [Q1-Q3]	103.0 [75.0-125.0]	94.5 [0.8-129.5]	100.0 [83.0-113.0]	105.0 [79.0-122.5]	
Unknown	21	12	0	9	
Respiratory Rate (breaths/min)					0.018
Median [Q1-Q3]	20.0 [16.0–24.0]	18.0 [11.0–23.0]	19.5 [16.0–25.0]	20.0 [16.0–25.0]	
Unknown	43	26	1	16	
Total GCS Score					< 0.001
Median [Q1-Q3]	14.0 [3.0–15.0]	6.0 [3.0–14.0]	15.0 [14.0–15.0]	15.0 [7.0–15.0]	
Unknown	14	5	0	9	
Injury Severity Score					0.012
Median [Q1-Q3]	17.0 [10.0–25.0]	20.0 [16.0–26.0]	17.0 [13.0-22.5]	16.0 [9.0–24.0]	
Unknown	186	61	11	114	
Blood Units (first 4 h)					0.002
Median [Q1-Q3]	1,400.0 [7.0–4,900.0]	2,100.0 [15.0–6,207.5]	1.0 [0.0–1,000.0]	1,400.0 [5.0–4,900.0]	
Unknown	10	4	0	6	
Plasma Units (first 4 h)					0.127
Median [Q1-Q3]	800.0 [0.0–3,250.0]	1,200.0 [5.0–3,603.0]	10.0 [0.0–1,225.0]	775.0 [0.0–3,132.0]	
Unknown	24	7	4	13	
Platelets Units (first 4 h)					0.179
Median [Q1-Q3]	5.5 [0.0-500.0]	6.0 [0.0-550.0]	0.0 [0.0-100.0]	7.0 [0.0-500.0]	
Unknown	24	7	4	13	
Total Blood Products					0.007
Median [Q1-Q3]	4,400.0 [825.0–11,650.0]	6,323.0 [1,500.0–13,400.0]	310.0 [0.0–3,525.0]	3,900.0 [820.0–10,600.0]	
Unknown	93	35	6	52	
Massive Transfusion					0.002
No	55 (17.7%)	8 (7.9%)	5 (38.5%)	42 (21.3%)	
Yes	256 (82.3%)	93 (92.1%)	8 (61.5%)	155 (78.7%)	
Unknown	93	35	6	52	
Ventilator Days					0.005
Median [Q1-Q3]	2.0 [1.0–5.0]	1.0 [1.0–4.0]	2.0 [1.0–4.0]	2.0 [1.0–6.0]	
Unknown	167	56	9	102	
ICU Length of Stay (days)					0.392
Median [Q1-Q3]	4.0 [2.0–10.0]	4.0 [1.0–12.0]	3.0 [1.5–10.0]	5.0 [2.0–10.0]	
Unknown	164	81	3	80	
Mortality					< 0.001
Died	175 (48.1%)	81 (73.6%)	5 (27.8%)	89 (37.7%)	
Survived	189 (51.9%)	29 (26.4%)	13 (72.2%)	147 (62.3%)	
Unknown	40	26	1	13	

Values are presented as medians [IQR] for continuous variables and n (%) for categorical variables. P-values were calculated using the Kruskal-Wallis test for continuous variables and Fisher's exact test for categorical variables. Outliers were handled using winsorization (capping at 1.5 × IQR from Q1/Q3). Missing values were reported separately

Fig. 1 REBOA utilization and mortality trends (2019–2022). Annual REBOA cases (blue bars) peaked in 2021 (122 cases), whereas mortality rates (red line) showed an overall decline from 58% in 2019 to 36% in 2022. Despite fluctuations in case volume, mortality demonstrated a significant reduction over the four-year period, suggesting improved outcomes with REBOA implementation

Massive transfusion requirements differed significantly across zones: 125 of 136 Zone 1 patients (91.9%) required massive transfusion compared to 12 of 19 Zone 2 patients (63.2%) and 196 of 249 Zone 3 patients (78.7%) ($P = 0.002$). The median number of ventilator days also showed significant differences ($P = 0.005$), with Zone 3 patients requiring the longest duration of mechanical ventilation (2.0 [1.0–6.0] days) compared with Zone 1 (1.0 [1.0–4.0] days) and Zone 2 patients (2.0 [1.0–4.0] days). The length of stay in the intensive care unit did not differ significantly among the groups ($P = 0.39$).

Mortality outcomes

In-hospital mortality rates differed significantly based on REBOA zone placement. Zone 1 patients experienced the highest mortality (100 of 136 patients [73.5%]), while Zone 2 and Zone 3 patients had mortality rates of 5 of 19 patients (26.3%) and 94 of 249 patients (37.8%), respectively ($P < 0.001$).

Outcomes by survival status

Several significant differences were observed between the survivors and non-survivors (Table 2). Systolic blood pressure was significantly lower in non-survivors (median, 88.0 [60.0-121.0] mmHg) than in survivors (105.0 [83.0-135.0] mm Hg) ($P < 0.001$). Neurological status was markedly worse in non-survivors, with a median GCS score of 8.0 (3.0–14.0) compared to 15.0 (14.0–15.0) in survivors ($P < 0.001$). Injury severity was also higher in non-survivors (median ISS, 20.0 [13.0–26.0]) than in survivors (16.0 [10.0–21.0]) ($P = 0.003$). Resuscitation requirements were substantially higher in non-survivors, who received more blood products in the first 4 h (median, 3875.0 [41.0-8086.0] vs. 660.0 [0.0-3300.0] mL; $P < 0.001$) and required massive transfusions more frequently (189 of 200 patients [94.5%] vs. 144 of 199 patients [72.4%]; $P < 0.001$).

Multivariable analysis

Logistic regression analysis was performed on 176 patients with complete data for all the model variables. The model demonstrated a good overall fit (likelihood ratio χ^2 = 66.86, $P < 0.001$) and identified independent predictors of mortality (Table 3). Compared with Zone 1 placement, Zone 3 placement was associated with an 80% reduction in mortality risk (aOR, 0.20; 95% CI, 0.08–0.47; $P < 0.001$). Zone 2 placement showed a trend toward lower mortality than Zone 1 (aOR, 0.28; 95% CI, 0.03–2.19; $P = 0.22$), but this did not reach statistical significance.

Temporal trends

Figure 3 illustrates the temporal trends in REBOA utilization and associated mortality rates between 2019 and 2022. REBOA utilization increased from 83 cases in 2019 to a peak of 122 cases in 2021, followed by a decrease to 96 cases in 2022. Concurrently, mortality rates decreased from 48 of 83 patients (57.8%) in 2019 to 35 of 96 patients (36.5%) in 2022, suggesting potential improvements in patient selection, procedural techniques and post-procedure management.

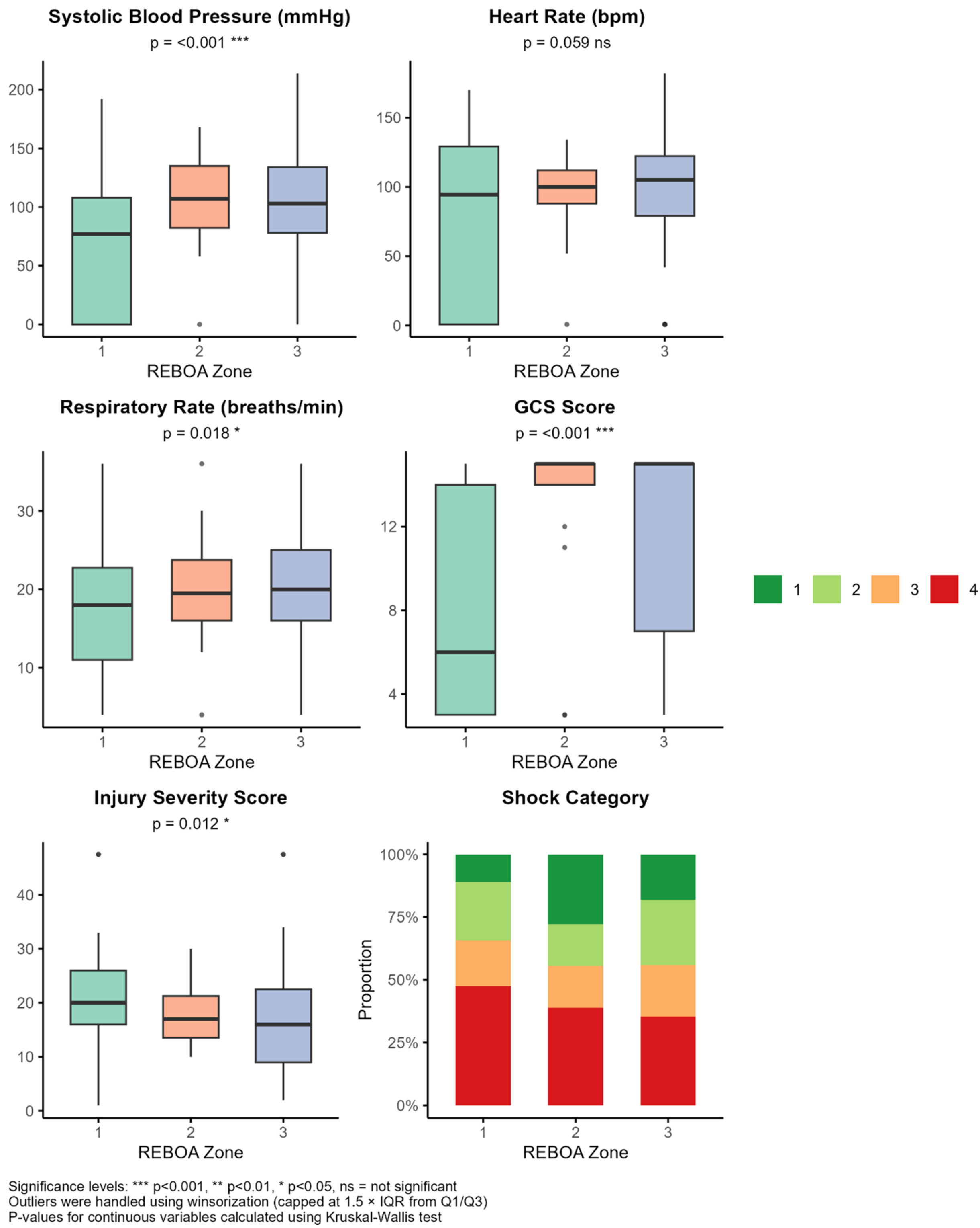

Fig. 2 Physiological parameters by REBOA Zone. The figure presents a comprehensive comparison of the key physiological parameters across the three REBOA zones (1, 2, and 3). Statistically significant differences were observed in systolic blood pressure ($P<0.001$), GCS score ($P<0.001$), respiratory rate ($P=0.018$), and injury severity score ($P=0.012$), whereas the heart rate showed no significant difference between zones ($P=0.059$). Zone 1 patients demonstrated greater physiological derangement with wider parameter variability, particularly in systolic blood pressure and GCS scores. The shock category distribution (bottom right) reveals progressively decreasing proportions of severe shock (red) from Zone 1 to Zone 3, with Zone 1 showing the highest percentage of critical cases. Statistical analysis was performed using the Kruskal-Wallis test with outliers managed through winsorization (capped at 1.5 × IQR from to Q1/Q3)

Table 2 Comparison of clinical characteristics by mortality

Variable	Overall $N=364$	Survived $N=189$	Died $N=175$	p-value
Age (years)	36.0 [25.0–50.0]	36.0 [25.0–50.0]	36.0 [26.0–50.0]	0.834
Sex				0.777
Male	303 (83.7%)	157 (83.1%)	146 (84.4%)	
Female	59 (16.3%)	32 (16.9%)	27 (15.6%)	
Systolic Blood Pressure (mmHg)	100.0 [72.0-129.0]	105.0 [83.0-135.0]	88.0 [60.0-121.0]	< 0.001
Pulse Rate (bpm)	105.0 [78.0-126.0]	105.0 [81.0-121.0]	106.0 [72.5-128.5]	0.514
Respiratory Rate (breaths/min)	20.0 [16.0–24.0]	20.0 [18.0–25.0]	19.5 [14.0-23.5]	0.008
Total GCS Score	14.0 [5.0–15.0]	15.0 [14.0–15.0]	8.0 [3.0–14.0]	< 0.001
Injury Severity Score	17.0 [10.0–25.0]	16.0 [10.0–21.0]	20.0 [13.0–26.0]	0.003
Blood Units (first 4 h)	1,750.0 [11.0–5,250.0]	660.0 [0.0–3,300.0]	3,875.0 [41.0–8,086.0]	< 0.001
Plasma Units (first 4 h)	1,200.0 [5.0–3,500.0]	250.0 [0.0–2,037.0]	2,100.0 [24.0–5,400.0]	< 0.001
Platelets Units (first 4 h)	125.0 [0.0-550.0]	0.0 [0.0-400.0]	300.0 [2.0-847.0]	< 0.001
Total Blood Products	5,686.0 [987.5–12,107.0]	2,100.0 [0.0–7,423.0]	10,250.0 [5,200.0–16,175.0]	< 0.001
Massive Transfusion	231 (82.5%)	109 (72.2%)	122 (94.6%)	< 0.001
Ventilator Days	2.0 [1.0–5.0]	4.0 [2.0-7.5]	1.0 [1.0–2.0]	< 0.001
ICU Length of Stay (days)	4.0 [2.0–10.0]	6.0 [3.0–11.0]	1.0 [1.0–3.0]	< 0.001

Values are presented as medians [IQR] for continuous variables and n (%) for categorical variables. P-values were calculated using appropriate tests based on data distribution: t-test/ANOVA for normally distributed continuous variables, Mann-Whitney U/Kruskal-Wallis test for non-normally distributed continuous variables, and Fisher's exact test/Chi-square test for categorical variables. Outliers were handled using winsorization (capping at 1.5 × IQR from Q1/Q3). Missing values were excluded from the analysis

Table 3 Logistic regression analysis: mortality predictors

Variable	Odds Ratio	95% Confidence Interval	P-value
Sex	0.7062	0.2351–2.1214	0.535
Age (years)	1.0203	0.9967–1.0445	0.092
Systolic Blood Pressure	1.0052	0.9960–1.0145	0.265
Total Glasgow Coma Scale	0.7983	0.7307–0.8722	< 0.001***
Injury Severity Score Category			
Moderate (9–15)	3.3055	0.4611–23.6971	0.234
Severe (16–24)	0.4613	0.0079–27.0040	0.709
Very Severe (25+)	6.0685	0.2779–132.5085	0.252
Abdominal Injury Severity			
Serious	0.3774	0.0683–2.0842	0.264
Severe	3.1666	0.0636–157.7564	0.563
Critical	0.3516	0.0189–6.5528	0.484
Maximal	1 (omitted)		
REBOA Placement Zone			
Zone 2	0.2760	0.0347–2.1919	0.223
Zone 3	0.1959	0.0815–0.4708	< 0.001***

Note. OR = odds ratio; CI = confidence interval; REBOA = resuscitative endovascular balloon occlusion of the aorta. Model based on $n=176$ patients with complete data. Reference categories: male sex, ISS mild (< 9), abdominal injury severity moderate, REBOA Zone 1. Maximal abdominal injury severity omitted due to collinearity

Discussion

REBOA has emerged as an important damage-control intervention for patients with severe abdominal trauma and hemorrhagic shock. This study presents one of the largest analyses of REBOA use, specifically in patients with abdominal trauma, providing critical insights into zone-specific outcomes and independent predictors of mortality in these patients. Our findings have significant implications for the application and refinement of the REBOA protocol in trauma care.

Our analysis demonstrated striking differences in mortality based on REBOA zone placement, with Zone 1 patients experiencing a 73.6% mortality rate compared to 27.8% and 37.7% for Zones 2 and 3 patients, respectively. This substantial disparity persisted in the multivariate analysis, where Zone 3 placement was associated with an 80% reduction in mortality risk compared that with of Zone 1. These findings align with, but also expand upon, previous research by Joseph et al., who reported a 35.7% overall mortality rate in patients with REBOA compared to 18.9% in matched controls without REBOA [14]. The higher mortality in our Zone 1 cohort likely reflects greater injury severity and hemodynamic compromise in these patients, as evidenced by their lower systolic blood pressure and GCS scores and higher transfusion requirements.

It is important to note that the association between zone placement and mortality cannot be interpreted causally because of the observational nature of this study. Zone selection is inherently linked to injury location and severity; patients with pelvic hemorrhage receive Zone 3 placement, while those with intra-abdominal bleeding receive Zone 1 placement. The lower mortality observed with Zone 3 placement likely reflects both differences in underlying injury patterns and the generally less severe hemodynamic compromise in this patient population, as evidenced by their higher presenting blood pressure and GCS scores.

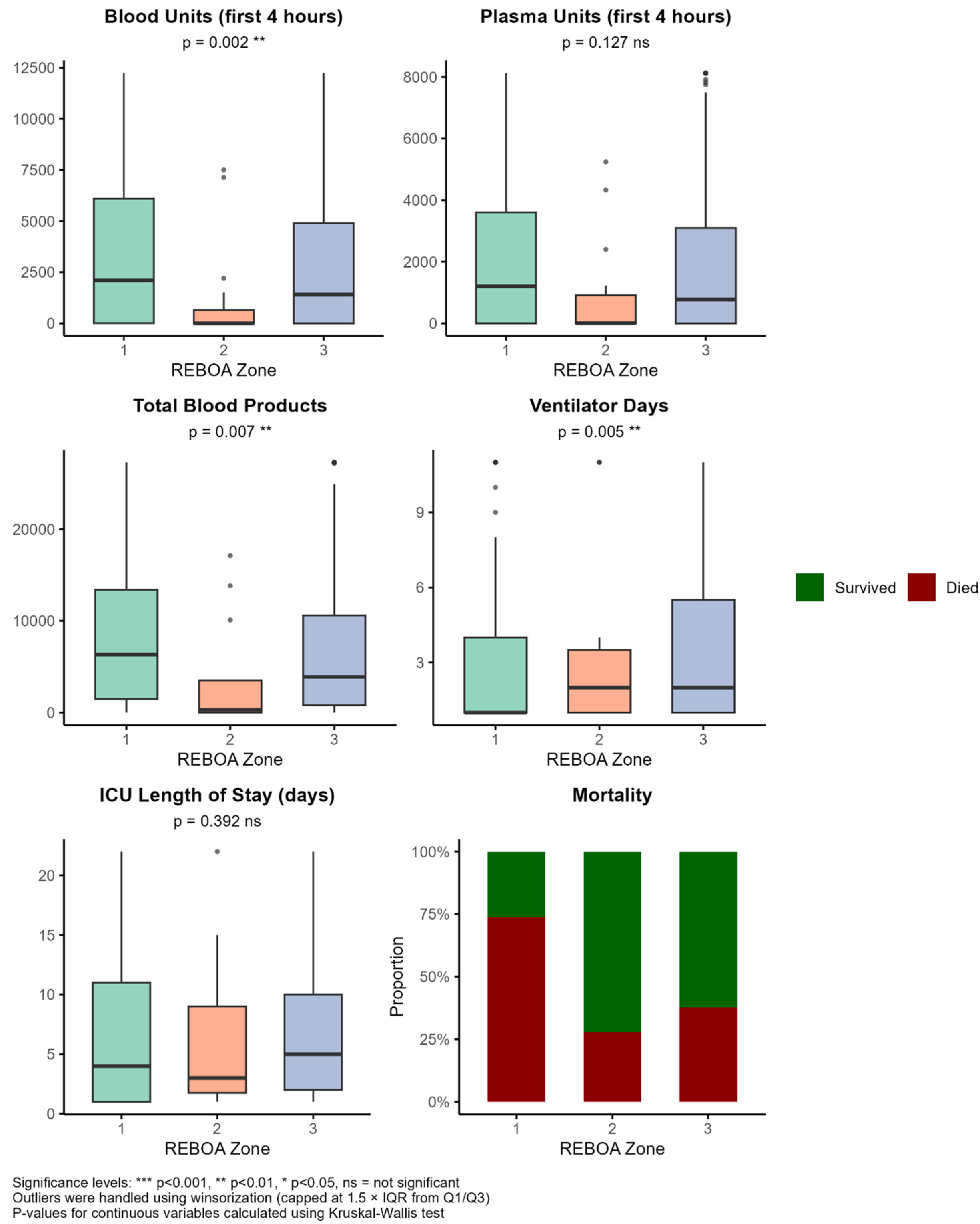

Fig. 3 Interventions and outcomes by REBOA Zone. Zone 1 REBOA demonstrated significantly higher blood utilization ($P=0.002$) and total blood products ($P=0.007$) compared to Zones 2–3. Ventilator days varied significantly across zones ($P=0.005$), whereas ICU length of stay did not ($P=0.392$). Zone 1 had markedly higher mortality (~ 70%) versus Zones 2 (~ 30%) and 3 (~ 40%). Plasma administration showed no significant difference between the zones ($P=0.127$). The analysis used the Kruskal-Wallis test with winsorization for outliers

The appropriate selection of patients for REBOA remains a challenge. Wannatoop et al. (2024) emphasized that while the prevalence of suitable bleeding sources for REBOA was high (38.6–50.2%), a significant proportion of patients also had contraindications (12.6–25.8%) [27]. Our data support the critical importance of patient selection, as those with less severe presentations (higher GCS score, higher SBP, and lower ISS) and Zone 3 placement had significantly better outcomes. This suggests that REBOA may be most beneficial when applied to carefully selected patients with anatomically appropriate injuries before the development of profound shock or coagulopathies.

Our multivariate analysis identified the GCS score as a strong, independent predictor of mortality. This finding highlights the critical importance of neurological status in determining outcomes after REBOA. Although previous studies have focused primarily on hemodynamic parameters, our results suggest that neurological assessment should be equally prioritized in decision-making algorithms for REBOA deployment. Paran et al. (2023) reported that achieving a post-balloon inflation SBP greater than 80 mmHg was associated with reduced 24-hour mortality, but our data suggest that neurological status may be an even more powerful predictor of survival [28].

The resource-intensive nature of REBOA is evident in our findings, with high transfusion requirements, particularly in patients with Zone 1 injuries. This aligns with previous research comparing REBOA to resuscitative thoracotomy, which found that REBOA required more blood transfusions despite similar survival outcomes [29]. Zone 1 occlusion, while effective for severe hemorrhage control, is associated with a higher risk of systemic inflammatory response and reperfusion injury, warranting a maximum occlusion duration of 30 minutes [9].

While our study did not specifically assess gastrointestinal complications, Matsumoto et al. (2024) reported higher rates of feeding intolerance (77% vs. 27%) and longer times to feeding goal achievement in patients with REBOA [30]. This highlights the need for comprehensive postprocedural care protocols that address not only hemodynamic stabilization but also the management of potential complications of the procedure.

Although our database limitations precluded direct assessment of REBOA-specific complications, published registry data provide important context for the risk-benefit assessment [31]. Reported that 12.1% of patients undergoing REBOA at their Level 1 Trauma Center experienced vascular injuries related to device placement, including local vessel injury (58.3%), distal embolization (16.7%) and pseudoaneurysm formation (8.3%) [32]. Documented an 8.6% rate of access-related limb ischemic complications in 48-hour survivors from the AORTA registry, with four limbs ultimately requiring amputation [33] found a 7% vascular access-site complication rate in 24-hour REBOA survivors and demonstrated that ultrasound-guided access was protective against such complications. These complication rates underscore the importance of close coordination between vascular and trauma surgeons and highlight an important area for future research.

The debate between partial (pREBOA) and intermittent (iREBOA) aortic occlusion continues to evolve as a potential strategy to extend the therapeutic duration of REBOA while minimizing ischemia-reperfusion injury. Dewey et al. (2025), cited in our study, demonstrated that partial REBOA Zone 1 was associated with lower mortality compared to complete REBOA Zone 1 and emergency department thoracotomy [10, 34] compared pREBOA and iREBOA in a porcine hemorrhage model and found that pREBOA reduced time at full occlusion while delivering more distal aortic flow without increasing blood loss, though neither technique demonstrated a survival benefit in their highly lethal injury model. Japanese multicenter data from a previous study showed that partial occlusion was performed in 70% of their REBOA patients, with shorter occlusion times (< 30 min in Zone 1 with partial occlusion) associated with improved survival and successful hemodynamic stabilization [18]. Paran et al. (2023) found no significant differences in mortality or complication rates between partial and total occlusion in their international registry analysis [28]. These findings, combined with our temporal data showing declining mortality rates over time, suggest that the optimization of occlusion strategies, alongside improvements in patient selection and postprocedural management, may contribute to improved outcomes. However, prospective comparative trials are required to establish the superiority of specific occlusion protocols.

Our temporal analysis from 2019 to 2022 revealed encouraging trends, with an overall decline in mortality from 58% to 36%, despite increased utilization. These findings contrast with those of the nationwide analysis by Joseph et al. (2019), who reported higher mortality in patients undergoing REBOA than in matched controls [14]. The improved outcomes in our cohort may reflect the growing institutional experience, refinement of patient selection criteria, optimization of occlusion strategies, and development of comprehensive postprocedural management protocols. This learning curve effect has also been observed in international registries, with the ABO Trauma Registry demonstrating better outcomes with increasing center experience [16].

Although our study focused specifically on abdominal trauma, it is worth noting that REBOA has shown promising results in other trauma scenarios. Bini et al. (2022) reported a higher survival rate with REBOA compared to open aortic occlusion in pelvic trauma (35% vs. 80% mortality), with no significant difference in systemic complications among survivors [15]. These findings, combined with our zone-specific outcomes, suggest that REBOA may offer particular advantages for hemorrhage control in specific anatomical regions, especially the pelvis and lower abdomen (Zone 3). Epstein et al. confirmed that patients with Zone 1 REBOA had a higher mortality rate (71.4% vs. 48.8%, $P = 0.002$) and mortality odds ratio (OR 1.85, 95% CI 1.18–2.89, $P = 0.007$) compared to Zone 3[9].

Our study had several limitations. As this was an observational study, causality between REBOA zone placement and outcomes could not be established. Zone placement is determined by the injury location, creating inherent confounding by indication that cannot be fully addressed through statistical adjustment alone. Selection bias may have influenced zone placement decisions, with more severely injured patients receiving Zone 1 placement, which would bias the results against Zone 1, independent of any true zone-specific effect. Additionally, we did not have data on balloon inflation times or the degree of occlusion (partial vs. complete), which may have significantly affected the outcomes. Importantly, the NTDB does not comprehensively capture all post-REBOA complications, such as limb ischemia, access-site vascular injuries, or amputation rates directly attributable to the procedure. Based on published registry data, vascular complications occur in approximately 7–12% of patients undergoing REBOA, and the inability to assess these complications limits our comprehensive risk-benefit assessment. Furthermore, missing data reduced the sample available for multivariable analysis to 176 patients (43.6% of the cohort), which may limit the generalizability of the regression findings. Future research should focus on the prospective evaluation of REBOA protocols using standardized approaches for zone selection based on injury patterns and physiological parameters. The development of validated clinical decision tools that incorporate both hemodynamic and neurological parameters could improve patient selection and optimize outcomes. Additionally, the investigation of adjunctive measures to mitigate complications, such as protocols to minimize ischemia-reperfusion injury, will be valuable.

Conclusion

Our findings demonstrate that REBOA zone placement and GCS status are powerful independent predictors of mortality in patients with abdominal trauma. The significant association between Zone 3 placement and improved survival suggests that anatomically targeted occlusion may optimize outcomes while minimizing the risks. The improved temporal trends in mortality, despite increased utilization, provide encouraging evidence that outcomes can be enhanced by experience and protocol refinement.

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Author contributions
M.R. conceived the study, performed the statistical analysis, and wrote the main manuscript. N.A.N.A. and B.I. contributed to data collection and analysis. A.A.A., Y.B., and F.R. assisted with data extraction and outcome assessment. All authors have reviewed and approved the manuscript.

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Data availability
The data that support the findings of this study are available from the National Trauma Data Bank (NTDB); however, restrictions apply to the availability of these data, which were used under license for the current study and are therefore not publicly available.

Declarations

Ethics statement
This study used de-identified data from the National Trauma Data Bank (NTDB) and was conducted in accordance with the Declaration of Helsinki and federal regulations for human subject research. As this study involved the analysis of existing de-identified datasets, institutional review board approval was not required for this study.

Consent to participate
Not applicable. This study used de-identified data from the National Trauma Data Bank (NTDB). Individual patient consent was not required, as the research involved the analysis of existing de-identified datasets.

Consent to publish
Not applicable. This study used de-identified data from the National Trauma Data Bank (NTDB). Individual patient consent for publication was not required.

Competing interests
The authors declare no competing interests.

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