Resuscitative endovascular balloon occlusion of the aorta versus resuscitative thoracotomy for noncompressible torso hemorrhage: A systematic review and meta-analysis

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BACKGROUND: Resuscitative endovascular balloon occlusion of the aorta (REBOA) has emerged as a minimally invasive alternative to resuscitative thoracotomy (RT) for noncompressible torso hemorrhage. Comparative effectiveness remains uncertain. This is a systematic review and meta-analysis evaluating the effectiveness and safety of REBOA versus RT in adult trauma patients with exsanguinating hemorrhagic shock or traumatic cardiac arrest.

METHODS: A systematic search of MEDLINE, PubMed, Embase, Scopus, and ClinicalTrials.gov was performed through August 2025 for comparative observational studies assessing REBOA versus RT with supraceliac aortic cross-clamping in adults (≥18 y). The primary outcome was in-hospital mortality, with stratified analyses by physiological state (shock vs. cardiac arrest) and early versus late mortality. Secondary outcomes included overall complications, neurological status, and aortic occlusion metrics.

RESULTS: Fourteen studies comprising 9,028 patients (2,477 REBOA; 6,551 RT) were included; six studies (2,912 patients) contributed to the primary pooled analysis. REBOA was associated with significantly lower in-hospital mortality (OR: 0.17, 95% CI: 0.10–0.28; $I^2 = 53.2\%$; moderate-certainty evidence). The benefit was greater in hemorrhagic shock (OR: 0.18, 95% CI: 0.12–0.28) than in cardiac arrest (OR: 0.32, 95% CI: 0.15–0.69). Early mortality showed the most substantial effect (OR: 0.12, 95% CI: 0.07–0.23). REBOA improved neurological outcomes but increased complication rates (OR: 7.81, 95% CI: 3.88–15.72) and prolonged aortic occlusion duration.

CONCLUSIONS: REBOA demonstrates superior survival compared with RT in carefully selected patients with trauma, particularly those in hemorrhagic shock. Despite increased complications, current evidence supports REBOA as the preferred aortic occlusion strategy when performed by experienced teams within structured trauma systems. Further research should refine selection criteria and methods to mitigate complication risk. (*J Trauma Acute Care Surg.* 2026;00: 00–00.

LEVEL OF EVIDENCE: Systematic Review and Meta-Analysis, Level III.
KEYWORDS: REBOA, resuscitative thoracotomy, noncompressible torso hemorrhage, hemorrhagic shock, traumatic cardiac arrest.

Severe trauma remains a leading cause of death globally, with noncompressible torso hemorrhage (NCTH) driving potentially preventable mortality.[1] Delays to hemostatic control correlate directly with increased mortality,[2,3] motivating the evolution of resuscitative strategies delivering immediate vascular control in critically injured patients.

Resuscitative thoracotomy (RT) with supraceliac aortic cross-clamping has been the salvage standard, though highly invasive with significant physiological stress.[4] Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) emerged as a minimally invasive alternative, allowing proximal control through femoral access while maintaining cerebral and coronary perfusion, though hindered by risks of distal ischemia and reperfusion injury.[5]

RATIONALE

Uncertainty persists regarding REBOA versus RT due to heterogeneous evidence. While some studies report survival advantages with REBOA, others show inconsistent benefits, particularly after stratification by injury mechanism or physiological status. Prior reviews were limited by small samples, heterogeneous cohorts, and in-

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sufficient power for robust subgroup analyses.[6]

Outcomes with REBOA are strongly influenced by institutional experience, training, and system-level resources. The steep endovascular learning curve and interinstitutional protocol variation likely contribute to inconsistent results.[7,8] Patient selection remains critical yet poorly defined, with outcomes varying by injury pattern, hemodynamics, and intervention timing. This systematic review addresses these gaps by synthesizing comprehensive comparative evidence.

OBJECTIVES

This systematic review and meta-analysis evaluates the effectiveness and safety of REBOA compared with RT with supraceliac aortic cross-clamping in adults with exsanguinating hemorrhagic shock or traumatic cardiac arrest. The primary objective is to compare overall mortality. Secondary objectives include mortality analyses stratified by clinical presentation (hemorrhagic shock vs. traumatic cardiac arrest) and timing (early < 24 h vs. late/in-hospital > 24 h), complication rates, aortic occlusion metrics, and favorable neurological outcomes.

METHODS

Eligibility Criteria

We include adult trauma patients (≥ 18 y) with exsanguinating hemorrhagic shock or traumatic cardiac arrest from torso injuries, while we exclude those with primary pericardial tamponade or tension pneumothorax. No randomized trials were identified; included studies were comparative observational studies (prospective/retrospective cohorts, registries, and comparative effectiveness designs). Excluded case reports, series with < 10 patients, editorials, narrative reviews, animal/cadaveric studies, or studies without at least one outcome. No date/language restrictions; peer-reviewed articles and conference abstracts were eligible if extractable outcome data were available.

Information Sources and Search Strategy

MEDLINE, PubMed, Embase, Scopus, and ClinicalTrials.gov were searched from January 2000 to September 2025, without language limits, supplemented by reference list screening. PICO-based strategy targeting trauma with shock/cardiac arrest, REBOA versus RT, mortality/complications, using database-specific controlled vocabulary/syntax. Full strategies are in the Supplementary Materials.

Selection Process

Records were deduplicated and screened independently by two reviewers per PRISMA guidelines, Supplemental Digital Content 4, http://links.lww.com/TA/F234, with disagreements resolved by consensus or a third reviewer. Zotero managed references, while Excel documented the process.

Data Collection Process

Two reviewers independently extracted data on study/patient characteristics, interventions, comparators, and outcomes using a standardized template. Discrepancies were resolved by consensus or a third reviewer. Authors were contacted for missing critical data.

Handling of Potential Patient Duplication

To avoid double-counting across overlapping registries (AAST AORTA Registry,[9,10] R Adams Cowley Shock Trauma Center,[4,11] Japan Trauma Data Bank),[7] we mapped publications to data source and calendar period, selecting one primary comparative report per data set per analysis (favoring larger cohorts with granular outcomes). Overlapping secondary reports were excluded from quantitative synthesis. Mutually exclusive subgroups were included only in corresponding stratified analyses, ensuring no patient contributed twice to pooled estimates.

Data Items

Primary outcome: in-hospital mortality. Secondary mortality analyses stratified by clinical presentation (hemorrhagic shock vs. traumatic cardiac arrest) and timing (early < 24 h vs. late/in-hospital > 24 h). Secondary outcomes: favorable neurological outcome, major postprocedure complications, and aortic occlusion duration.

Extracted patient variables: age, sex, mechanism, presenting systolic blood pressure and GCS, prehospital CPR, and arrest timing. Intervention variables: REBOA zone, access site, procedure-related complications; RT variables: surgical approach, associated procedures. Study-level variables: design, geography, study period, sample size, trauma center level. Median/IQR were treated as approximately normal for conversion when mean/SD were unavailable.

Study Risk of Bias Assessment

Observational studies assessed with the Newcastle-Ottawa Scale (NOS): 7 to 9 stars (high), 4 to 6 (moderate), and 0 to 3 (low). Two reviewers assessed independently with consensus/third-reviewer adjudication.

Effect Measures

Dichotomous outcomes used Mantel-Haenszel odds ratios (ORs) with 95% CIs; continuous outcomes used mean differences (MDs) with 95% CIs. For interpretation, ORs < 0.2 were considered very large, 0.2 to 0.5 large, 0.5 to 0.8 and 1.25 to 2.0 moderate, and 0.8 to 1.25 minor. Absolute minute differences were retained for continuous outcomes to preserve clinical interpretability without arbitrary cutoffs, given no validated threshold for aortic occlusion duration. Effect measures were not re-expressed.

Synthesis Methods

Study Eligibility

Of 14 studies, 6 informed the primary mortality meta-analysis (2,912 patients). Stratified analyses included hemorrhagic shock (seven studies; 1,700 patients), traumatic cardiac arrest (four studies; 1,835 patients), early mortality < 24 hours (four studies; 280 patients), and late/in-hospital mortality > 24 hours (six studies; 890 patients). Studies were pooled when effect estimates could be derived (dichotomous: extractable numerators/denominators; continuous: mean/SD or convertible data).

Data Preparation

Event counts were converted to odds ratios using the Mantel-Haenszel method; medians and interquartile ranges were converted to means and standard deviations when appropriate; outcome definitions were harmonized.

Statistical Synthesis

Random-effects models (REML with Hartung-Knapp-Sidik-Jonkman correction) were the primary; fixed-effects models were used as sensitivity analyses. Heterogeneity was summarized with I^2, τ^2, and Cochran's Q, with prediction intervals. Analyses were conducted using R 4.3.0 (metafor).

Visual Display

Forest plots were generated for all outcomes; Baujat and leave-one-out analyses were performed when feasible. Funnel plots not constructed (≤ 7 studies/outcome).

Heterogeneity Exploration

Subgroup analyses compared hemorrhagic shock versus traumatic cardiac arrest when data allowed; meta-regression/interaction tests not performed (few studies). No stratification by study design (each outcome included ≤ 7 studies; design confounded with data source/calendar period; design incorporated into NOS and GRADE and considered in interpretation).

When crude and adjusted/propensity score-matched (PSM) estimates were both reported, crude odds ratios from raw counts were pooled for consistency; adjusted/PSM estimates were not pooled (noncomparable modeling) but were reviewed descriptively and in selected subgroup/sensitivity analyses (PSM effects were similar to crude when both were available). Pooling crude rather than adjusted estimates may result in residual confounding due to unadjusted baseline imbalances between groups. In addition, because each outcome included ≤ 7 studies and study design was often confounded with data source and calendar period, we did not stratify by study design; instead, design was incorporated into NOS quality assessment and GRADE certainty ratings and considered in interpretation.

Sensitivity Analyses

Leave-one-out and fixed-effects models supported robustness; further sensitivity analyses were limited by study numbers.

Reporting Bias Assessment

With ≤ 7 studies per outcome, formal publication-bias testing (funnel plots, Egger test, and trim-and-fill) was not performed. Reporting bias assessed qualitatively (study characteristics, funding, selective reporting) by two independent reviewers with consensus/third-reviewer adjudication; no automation tools used; investigators not contacted for unpublished data.

Certainty Assessment

Certainty rated using GRADE (baseline low for observational evidence), considering risk of bias, inconsistency (I^2/τ^2), indirectness, imprecision, and publication bias (no formal testing, < 10 studies/outcome), with upgrading considered for large effects. Two reviewers assessed each outcome by consensus; the Summary of Findings tables used standard wording ("probably," "may," "very uncertain") (Table S5, Supplemental Digital Content 2, http://links.lww.com/TA/F232).

RESULTS

Study Selection

The search identified 1,603 records; 579 duplicates were removed, leaving 1,024 unique records. After excluding 933 records based on PICO criteria, 91 full-text reports were assessed, resulting in 64 exclusions. Primary exclusion reasons were duplicate patient populations (18), noncomparative studies (15), insufficient outcome data (12), case series without comparison (6), and overlapping cohorts with larger studies (16). Ultimately, 14 unique studies met eligibility for quantitative synthesis (Fig. 1).

Study Characteristics

Fourteen comparative studies (2015–2025) evaluated REBOA versus RT in trauma centers, totaling 9,028 patients (2,477 REBOA; 6,551 RT). Cohorts were predominantly male (> 70–80%), with mean ages of 30–53 years. REBOA cohorts were mainly blunt trauma (62–94%); RT cohorts were more often penetrating (47–94%).

Study populations varied: mixed hemorrhagic shock/cardiac arrest cohorts in AAST AORTA studies[2,9,10,13] and multicenter analyses;[14,15] Japanese databases focused on hemorrhagic shock;[6,8] others emphasized traumatic cardiac arrest.[4,16,17] Most studies reported improved survival with REBOA (Table 1; Table S1, Supplemental Digital Content 2, http://links.lww.com/TA/F232), particularly in propensity-adjusted analyses, though interpretation is limited by heterogeneity and confounding. Baseline physiological severity often differed between groups, reinforcing selection bias as an important consideration. Reporting of key modifiers (mechanism, SBP category, occlusion zone) was inconsistent; therefore, these variables were used primarily to contextualize between-study heterogeneity rather than enable robust stratified meta-analyses (Tables S3–S4,

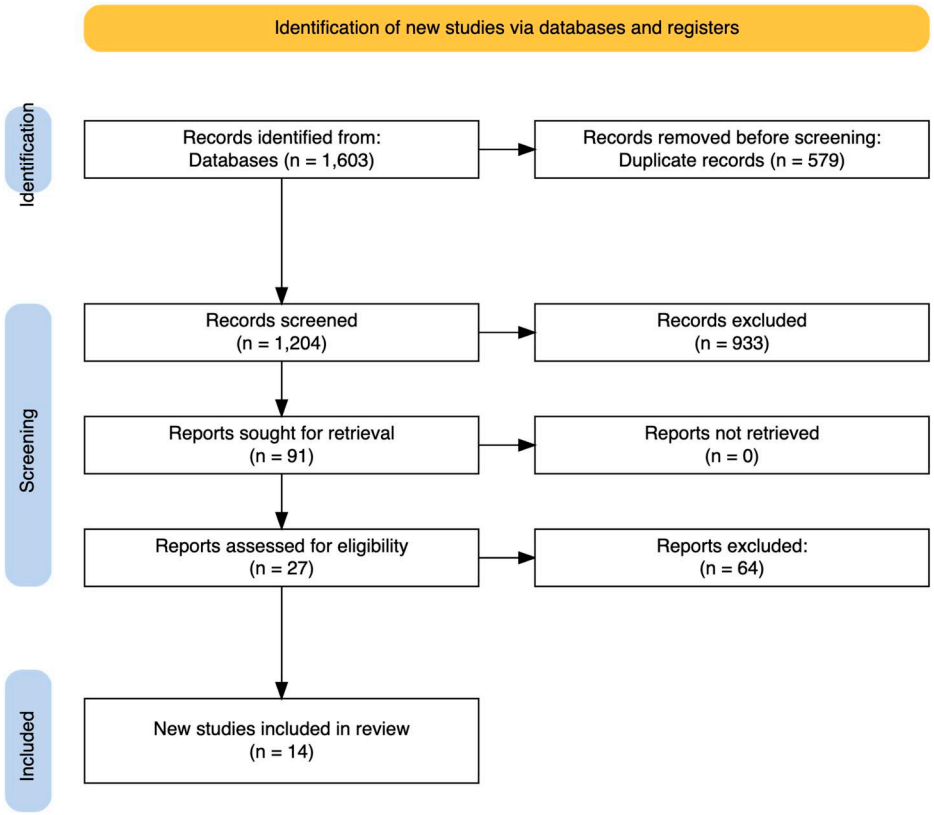

Figure 1. PRISMA flow diagram.[12]

Supplemental Digital Content 2, http://links.lww.com/TA/F232).

RT was typically used in more physiologically compromised patients (lower SBP, worse GCS, more arrests), suggesting selection bias. Ordoñez et al[18] reported mortality >50% with SBP <60 mm Hg, supporting earlier aortic occlusion in profound shock.

Risk of Bias in Studies

All included studies were evaluated using the Newcastle-Ottawa Scale for observational studies, which assesses three domains: selection, comparability, and outcome/exposure. Scores ranged from 7 to 9 out of a maximum of 9 points (see Table S2, Supplemental Digital Content 2, http://links.lww.com/TA/F232).

Results of Individual Studies

Study-level results for the primary outcomes, namely in-hospital mortality and survival to hospital discharge, and for secondary outcomes related to the early clinical course, including early mortality, the need for cardiopulmonary resuscitation (CPR) in the emergency department, and favorable neurological outcome, are presented in detail in Tables S3–S4, Supplemental Digital Content 2, http://links.lww.com/TA/F232. These supplementary tables provide a granular, study-by-study comparison of REBOA and RT cohorts, summarizing baseline characteristics, event counts, and outcome rates across all included studies, thereby allowing a rigorous assessment of consistency and heterogeneity of effects between trials.

Results of Syntheses

General Mortality

Of 14 included studies, 6 (2017–2025) met criteria for the primary mortality meta-analysis, totaling 2,912 critically injured patients (930 REBOA; 1,982 resuscitative thoracotomy) with sample sizes of 26 to 2,134; most cohorts were mixed hemorrhagic shock and traumatic cardiopulmonary arrest (n = 4, 67%).

Random-effects meta-analysis showed significantly lower mortality with REBOA versus supraceliac aortic cross-clamping (OR: 0.17, 95% CI: 0.10–0.28; $P < 0.0001$), corresponding to an 83% mortality reduction (Fig. 2). Fixed-effect estimates were similar (OR: 0.15, 95% CI: 0.12–0.19; $P < 0.0001$), and the prediction interval (OR: 0.05–0.59) supported benefit across diverse populations and settings.

Heterogeneity was moderate ($I^2 = 53.2\%$, $\tau^2 = 0.17$, $P = 0.058$). Leave-one-out analyses were stable (OR: 0.16–0.19). Aso et al[8] contributed most to between-study variance, whereas Brenner et al[15] most influenced the pooled estimate due to sample size; excluding either did

TABLE 1. Characteristics of Included Studies (Author, Year, Study Design, Country, Sample Sizes, Demographics, and Primary Outcomes)

Author	Year	Study design	Country	No patients (REBOA/TR)	Mean age (y)	Sex (% men)	Primary outcome
Abe at al[7]	2016	Retrospective cohort	Japan	607/233	54	68	In-hospital mortality
Aso et al[8]	2017	Retrospective cohort	Japan	191/68	NA*	60	In-hospital mortality
Balch et al[10]	2023	Retrospective cohort	US	13/13	40	77	Survival to discharge
Brenner et al[18]	2018	Prospective Cohort	US	83/202	40	82	Survival to discharge
Brennee et al[15]	2024	Retrospective cohort	US	531/1603	39	82	In-hospital mortality
Cralley et al[19]	2022	Comparative effectiveness	US	306/685	32	82	Survival
Dubose et al[8]	2016	Prospective Cohort	US	46/68	41	81	Mortality
Koh et al[15]	2023	Prospective Cohort	US	26/46	39	72	In-hospital mortality
Liao et al[20]	2025	Retrospective cohort	US	138/208	47	73	Mortality
Moore et al[2]	2015	Retrospective cohort	US	24/72	31	88	Overall survival
Ordoñez et al[17]	2020	Prospective Cohort	Colombia	50/57	31	88	Mortality at 24 h
Teeter et al[4]	2018	Retrospective	US	33/18	36	86	Resuscitation quality
Teeter et al[10]	2018	Prospective Cohort	US	22/28	30	86	Interruptions in compressions
Yamamoto et al[16]	2020	Retrospective cohort	Japan	144/1339	55	69	Survival to discharge

*Age was reported only in categories in the original study; no single summary value (mean or median) was provided for the overall cohort or study groups.

not materially change the survival advantage (Figures S1–S2, Supplemental Digital Content 3, http://links.lww.com/TA/F233).

Mortality in Shock Patients

Seven of 14 studies (1,700 patients: 1,032 REBOA; 668 RT) reported hemorrhagic shock mortality. Random-effects meta-analysis showed lower mortality with REBOA (OR: 0.18, 95% CI: 0.12–0.28; $P < 0.0001$), an 82% reduction in odds of death versus supraceliac aortic cross-clamping; GRADE certainty was moderate. Aso et al[8] reported unadjusted and propensity score-matched (PSM) estimates; the PSM analysis was used to reduce baseline imbalance. Fixed-effects results were similar (OR: 0.19, 95% CI: 0.15–0.25; $P < 0.0001$), and the prediction interval (OR: 0.07–0.51) supported clinically meaningful benefit across settings (Fig. 3). Heterogeneity was low-to-moderate ($I^2 = 41.5\%$, $\tau^2 = 0.13$; $P = 0.114$). Leave-one-out estimates were stable (OR: 0.16–0.21). Baujat diagnostics showed Abe et al[7] contributed most to model weight (large sample), while Aso et al (PSM) and Brenner et al[8,20] explained most between-study variance; excluding either did not materially change the effect (Figures S3–S8, Supplemental Digital Content 3, http://links.lww.com/TA/F233). Overall, among patients in hemorrhagic shock, REBOA was associated with a significant, consistent survival advantage versus RT (Fig. 3).

Mortality in Cardiac Arrest Patients

Four of 14 studies (1,835 patients: 259 REBOA; 1,576 RT) informed the cardiac arrest subgroup. Random-

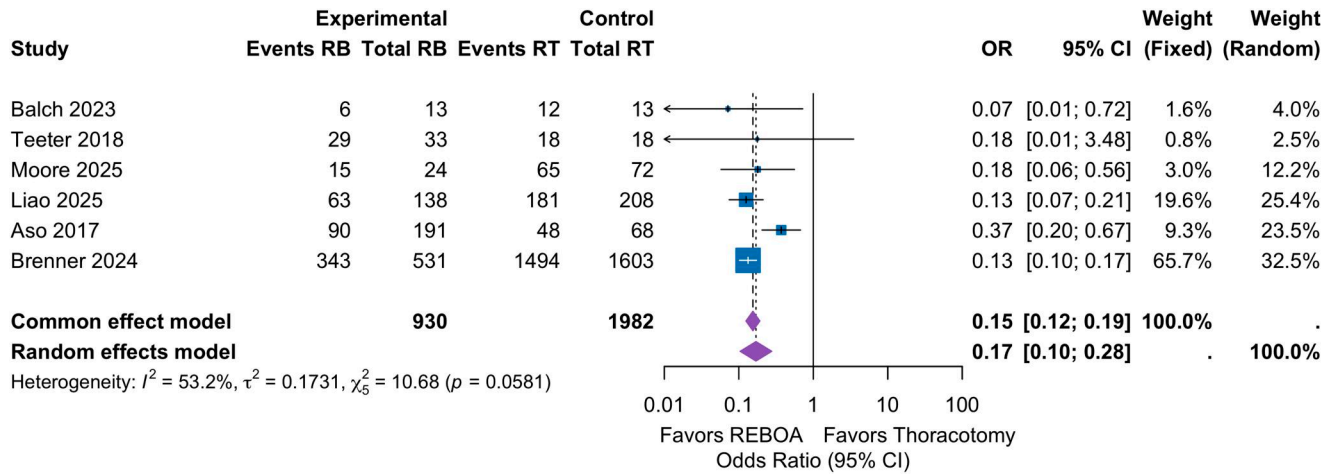

Figure 2. Forest plot: general mortality—REBOA versus resuscitative thoracotomy.

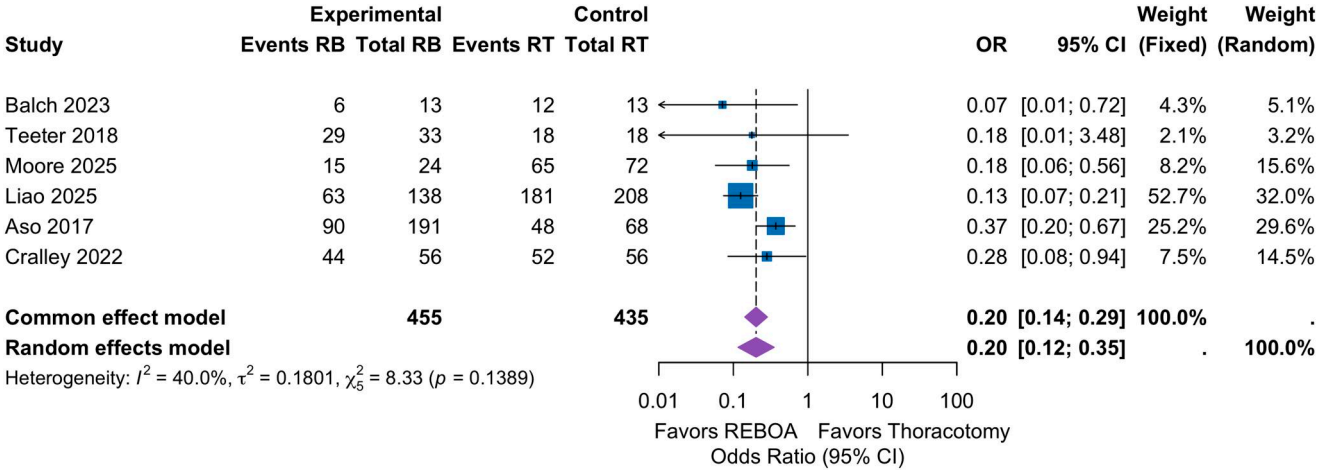

Figure 3. Forest plot: mortality in shock patients—REBOA versus resuscitative thoracotomy.

effects meta-analysis favored REBOA (OR: 0.32, 95% CI: 0.15–0.69; $P = 0.004$), a 68% reduction in odds of death; fixed-effects estimates were identical (OR: 0.32, 95% CI: 0.15–0.69; $P = 0.004$). The prediction interval (OR: 0.09–1.13) suggested likely benefit in most settings but possible variability with prehospital arrest duration, system expertise, and patient selection (Fig. 4). Heterogeneity was absent ($I^2 = 0\%$, $\tau^2 = 0.00$; $P = 0.63$). Leave-one-out ORs ranged from 0.27 to 0.49 (Supplementary Figure S7, Supplemental Digital Content 3, http://links.lww.com/TA/F233). Baujat diagnostics identified Yamamoto et al and Brenner et al[17,20] as most influential, without altering conclusions when excluded (Figures S9–S10, Supplemental Digital Content 3, http://links.lww.com/TA/F233). Overall, REBOA was associated with a clinically meaningful survival advantage in traumatic cardiopulmonary arrest.

Early Mortality (< 24 h)

Four of 14 studies (280 patients: 120 REBOA; 160 RT) reported early mortality. Random-effects meta-analysis favored REBOA (OR: 0.12, 95% CI: 0.07–0.23; $P < 0.0001$), an 88% reduction in early mortality odds; fixed-effects estimates were identical (OR: 0.12, 95% CI: 0.07–0.23; $P < 0.0001$) (Fig. 5). Heterogeneity was absent ($I^2 = 0\%$, $\tau^2 = 0.00$; $P = 0.54$). Leave-one-out ORs ranged from 0.10 to 0.15 (Figures S11–S13, Supplemental Digital Content 3, http://links.lww.com/TA/F233). Baujat diagnostics indicated Moore et al and Teeter et al[2,4] modestly contributed to influence/heterogeneity, without changing the protective effect when excluded. Overall, REBOA conferred a substantial, consistent first-24-hour survival benefit in shock or cardiac arrest (Fig. 5).

Late or In-Hospital Mortality (> 24 h)

Six of 14 studies (890 patients: 455 REBOA; 435 RT) reported mortality beyond 24 hours. Random-effects meta-analysis favored REBOA (OR: 0.20, 95% CI: 0.12–0.35; $P < 0.0001$), an 80% reduction in odds of death versus supraceliac aortic cross-clamping. Fixed-effects estimates were similar (OR: 0.20, 95% CI: 0.14–0.28;

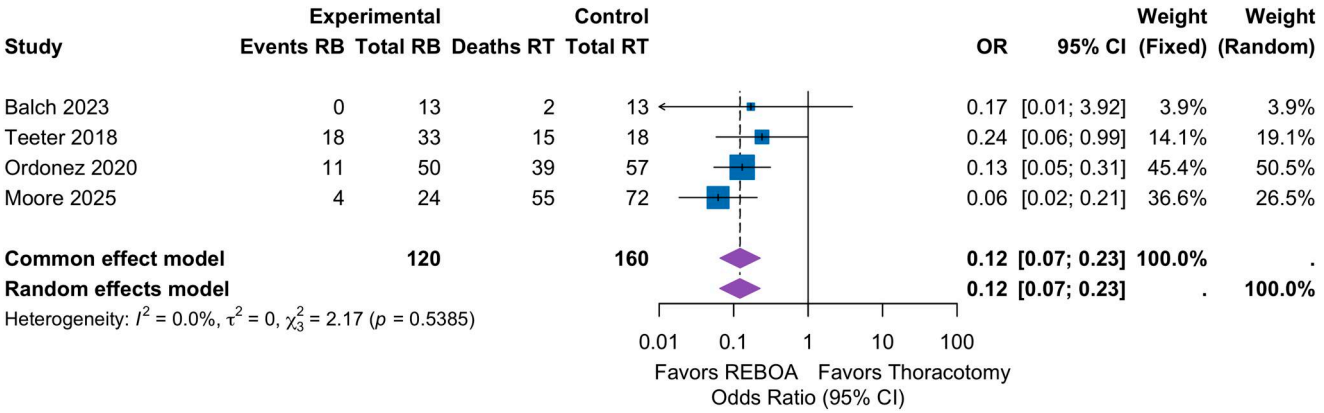

Figure 4. Forest plot: mortality in cardiac arrest patients—REBOA versus resuscitative thoracotomy.

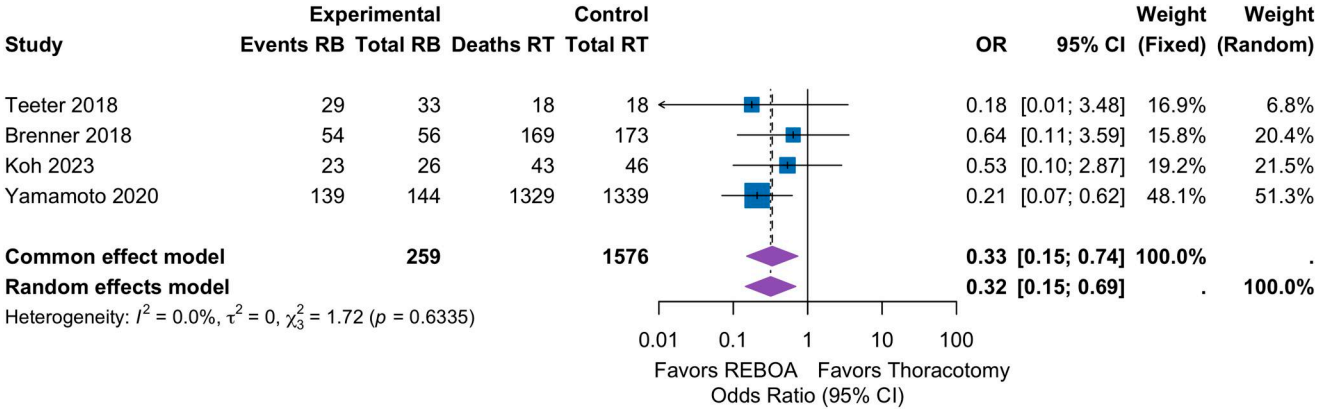

Figure 5. Forest plot: early mortality (< 24 h)—REBOA versus resuscitative thoracotomy.

$P < 0.0001$), with a prediction interval of 0.05 to 0.75 supporting benefit across settings. Heterogeneity was low-to-moderate ($I^2 = 40.0\%$, $\tau^2 = 0.18$; $P = 0.139$). Leave-one-out ORs ranged from 0.14 to 0.29 (Fig. 6). Baujat diagnostics identified Aso et al and Liao et al[8,19] as main variance contributors, without materially changing the effect when excluded.

For hospital mortality restricted to patients presenting exclusively in cardiac arrest, Koh et al and Yamamoto et al[16,17] provided stratified data: Koh et al[16] reported 88.5% mortality with REBOA (23 of 26) versus 93.5% with thoracotomy (43 of 46), and Yamamoto et al[17] reported 96.5% (139 of 144) versus 99.3% (1,329 of 1,339), respectively. Combined, mortality was 95.3% with REBOA versus 99.1% with thoracotomy, an absolute survival benefit of 3.8% (~5 additional lives) across 1,555 patients, suggesting a modest but consistent benefit despite a very poor prognosis. Abe et al[7] was the only study analyzing shock-only in-hospital mortality (excluding arrest): crude cohort (n = 903) showed 90.1% mortality with thoracotomy (210 of 233) versus 66.8% with REBOA (405 of 607), and PSM analysis (n = 304) remained lower with REBOA (72.6%, 106 of 146) versus thoracotomy (91.0%, 122 of 134), indicating a larger apparent benefit in shock-only patients (Figures S14–S20, Supplemental Digital Content 3, http://links.lww.com/TA/F233).

Overall Complications

Three of 14 studies (468 patients: 175 REBOA; 293 RT) reported overall complications. Random-effects pooling showed higher complications with REBOA (OR: 7.81, 95% CI: 3.88–15.72; $P < 0.0001$); fixed- and random-effects estimates were identical, with no heterogeneity ($I^2 = 0\%$, $\tau^2 = 0$). Leave-one-out ORs ranged from 7.60 to 10.99. Influence diagnostics showed Liao et al[19] contributed ~90% of model weight, without reversing directionality or significance when excluded. These findings suggest that, despite survival benefit in shock and arrest,

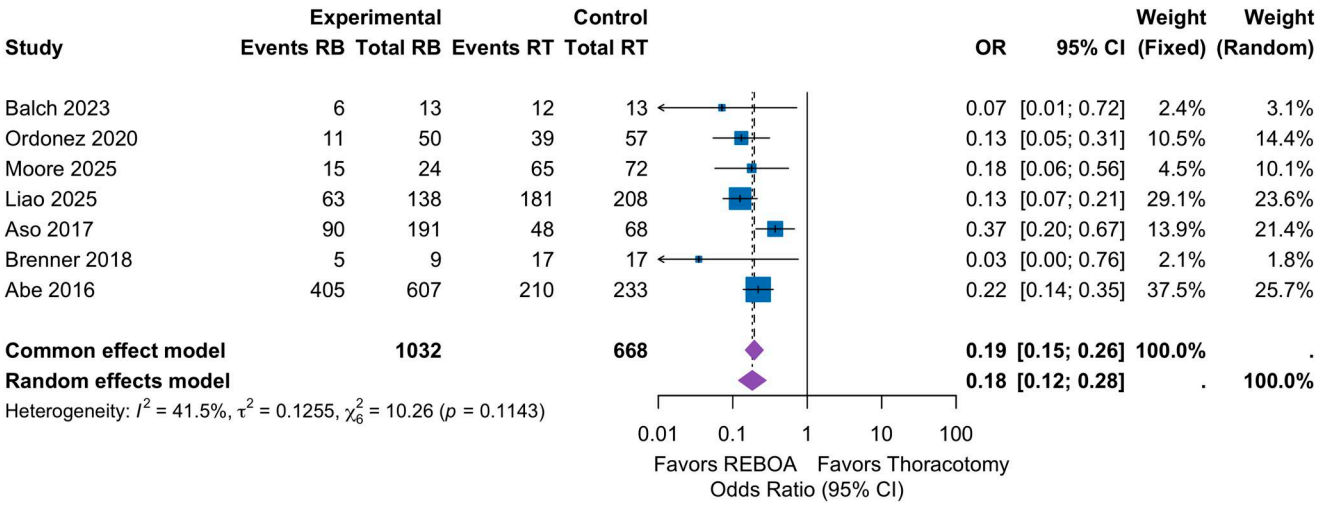

Figure 6. Forest plot: Late or in-hospital mortality (> 24 h)—REBOA versus resuscitative thoracotomy.

REBOA carries a substantially higher complication burden. Brenner et al[15] reported access-related complications in 30 of 278 REBOA patients (10.8%) versus 2 of 246 thoracotomy patients (0.8%), without further disaggregation by complication type (Figures S21–S22, Supplemental Digital Content 3, http://links.lww.com/TA/F233).

Aortic Occlusion Metrics

Two of 14 comparative studies assessed time to aortic occlusion (AO) in patients with trauma requiring REBOA or resuscitative thoracotomy for cardiac arrest or exsanguinating shock. Teeter et al[4] reported longer times with REBOA (median: 577 s, IQR: 377–815) than thoracotomy (451 s, IQR: 275–648), a +2.1-min delay, whereas DuBose et al[9] found shorter times with REBOA (6.6 ± 5.6 min) versus thoracotomy (7.2 ± 15.1 min), a 0.6-min difference. Pooled estimates, therefore, showed substantial variability without consistent superiority, suggesting time to AO is strongly influenced by operator experience, procedural standardization, and institutional protocols; even modest delays may be clinically relevant in exsanguinating trauma, underscoring the need for efficiency and standardized training. In the only traumatic cardiac arrest–specific analysis, Koh et al[16] reported longer decision-to-occlusion times with REBOA than thoracotomy [median: 7 min (IQR: 4.5–10) vs. 4 min (IQR: 3–6); $P = 0.001$], highlighting a key limitation in arrest where minutes may affect resuscitation success. Brenner et al[15] reported longer AO duration with REBOA (48.5 ± 59.5 min) than RT (27.5 ± 29.4 min), and AO durations ≥60 to 90 minutes were strongly associated with higher mortality across mechanisms, reinforcing recommendations to limit complete occlusion to < 30 min when feasible and highlighting the trade-off between prolonged endovascular control and ischemic burden (Figures S23–S26, Supplemental Digital Content 3, http://links.lww.com/TA/F233).

Favorable Neurological Outcomes at Discharge

Two of 14 studies reported consistently better neurological recovery with REBOA versus RT. In Balch et al,[11] 46% of REBOA patients achieved complete recovery (GCS 15 at discharge, 6/13) versus 0% with RT (0/13). In Brenner et al,[15] mean discharge GCS was higher with REBOA (8 ± 6) than RT (4 ± 3), a medium-to-large effect (Cohen $d \approx 0.84$). Collectively, these data suggest REBOA may improve neurological preservation among survivors in addition to survival (Figures S27–S31, Supplemental Digital Content 3, http://links.lww.com/TA/F233).

The certainty of evidence was graded using GRADE. Overall mortality and hemorrhagic shock mortality were of moderate certainty. Cardiac arrest mortality and late/in-hospital mortality were of low to moderate certainty. Early mortality was of low certainty despite large effects due to small samples and observational designs. Complications, time to AO, and neurological outcomes were of very low certainty, driven by survivorship bias, conflicting findings, and methodological limitations. Aortic occlusion duration was of low certainty, reflecting concerns regarding prolonged ischemia and clinical implications.

DISCUSSION

This systematic review synthesizing comparative observational data shows REBOA is strongly associated with lower mortality than resuscitative thoracotomy in adults with exsanguinating hemorrhage or traumatic cardiac arrest. Across 14 studies (9,028 patients) and the primary meta-analysis (6 studies; 2,912 patients), REBOA was associated with an 83% reduction in death odds (OR: 0.17, 95% CI: 0.10–0.28), supported by moderate-certainty GRADE evidence, suggesting REBOA may be preferable in the studied populations.

Prior reviews highlight this work's incremental value. Manzano-Núñez et al[6] pooled only three studies (1,276 patients), limiting stratified analyses. Ko et al[21] included 25 studies but combined heterogeneous comparators without separating shock from arrest or detailing early versus late mortality. The 2025 EAST guideline found no clear REBOA benefit in unstable trauma but a survival advantage versus RT in cardiac arrest.[1] We focused exclusively on adult NCTH requiring REBOA versus RT, incorporated 14 contemporary cohorts (9,028 patients, including Brenner et al and Liao et al[15,19]), and applied prespecified rules preventing double-counting across overlapping registries.

Stratified analyses showed differential effects by population and time. In hemorrhagic shock (excluding arrest), REBOA reduced death odds by 82% (OR: 0.18, 95% CI: 0.12–0.28) across seven studies (1,700 patients; $I^2 = 41.5\%$). In traumatic cardiac arrest, REBOA reduced death odds by 68% (OR: 0.32, 95% CI: 0.15–0.69) across four studies (1,835 patients) with no heterogeneity ($I^2 = 0\%$), despite geographic and system variation.

Temporal analyses suggested benefit in both early and late phases. Early mortality (< 24 h) favored REBOA (OR: 0.12, 95% CI: 0.07–0.23; 88% reduction), consistent with rapid hemodynamic stabilization, and the effect persisted for late/in-hospital mortality (> 24 h) (OR: 0.20, 95% CI: 0.12–0.35; 80% reduction). Among survivors, neurological outcomes favored REBOA, with complete recovery (GCS 15) versus none in the RT group in one study and higher mean discharge GCS in a multicenter cohort (8 ± 6 vs. 4 ± 3).

Physiologically, these findings align with REBOA's rapid afterload augmentation and preferential redistribution of limited cardiac output to coronary and cerebral circulations,[22] potentially avoiding the global disruption of emergency thoracotomy and providing a coherent pathway from early stabilization to sustained survival and neurological preservation across time horizons. However, this survival signal was accompanied by higher complications with REBOA (OR: 7.81, 95% CI: 3.88–15.72), largely access-related (distal embolism/ex-

tremity ischemia ~10.8% vs. 0.8% with RT), representing a key clinical trade-off.

Procedural metrics underscored operational constraints. Time to aortic occlusion was highly variable, including delays in arrest (median: 7 vs. 4 min), and occlusion duration was longer with REBOA (48.5 ± 59.5 vs. 27.5 ± 29.4 min), with prolonged occlusion strongly associated with higher mortality. This heterogeneity likely reflects system factors, protocols, team proficiency, and anatomy rather than intrinsic device effects; in this context, variability is itself a signal that outcomes depend on a trained, well-resourced trauma system.

Interpreting complications requires attention to practice evolution. Early series with 11- to 12-Fr sheaths reported higher access morbidity; AORTA data showed dedicated 7-Fr devices reduced distal embolism fourfold (20.0% vs. 5.6%; $P = 0.014$).[9] Contemporary reviews cite distal embolization/limb ischemia as the most frequent complications (pooled ~16%, range: 4–52.6%).[22] Recent work suggests a shift toward systemic ischemia-reperfusion complications in survivors (higher AKI: 10.7% vs. 3.2%; amputation: 3.6% vs. 0.7%). Prolonged occlusion > 90 minutes was associated with markedly higher mortality.[15] Earlier cohorts may overestimate contemporary access risk with 7-Fr platforms; occlusion strategy/duration may be the principal modifiable harm driver today.

Benefit appeared greatest when REBOA was deployed before prolonged CPR and in out-of-hospital arrest (absolute survival 22.2% vs. 3.4% without prior CPR; 3.5% vs. 0.7% in OHCA), a physiologically plausible pattern suggesting more preserved intrinsic cardiac output and coronary perfusion. Teeter et al[4] showed improved resuscitation quality with REBOA during arrest, with higher cardiac compression fraction and end-tidal CO_2 during continuous closed-chest CPR versus thoracotomy, and reviews similarly report improved hemodynamics and signals toward better ROSC/survival in selected patients.[22] These subgroup signals remain observational and subject to confounding by indication and system maturity. Practice is evolving to mitigate ischemia, with growing adoption of partial REBOA (P-REBOA) and physiology-guided staged resuscitation.[23,24]

Our findings align with major registry evidence: AAST AORTA analyses generally show REBOA benefit over RT, particularly before CPR, and Brenner et al[15] using propensity matching, found REBOA superior across injury patterns; collectively, the literature supports maximal benefit when deployed before complete collapse.[22] International coherence is notable: Japanese/East Asian data suggest benefit for blunt subdiaphragmatic hemorrhage,[7,8] whereas US series enriched with arrest/penetrating mechanisms report more modest differences and emphasize RT when there are no signs of life or catastrophic thoracic injury.[6,16] In arrest, our pooled effect was more modest yet significant, consistent with studies showing physiological advantages even when survival varies.[4]

The most significant challenge to these findings comes from the UK-REBOA trial, which reported higher 90-day mortality with REBOA (54% vs. 42%; OR: 1.58).[25] This discordance likely reflects design differences: our evidence is observational and vulnerable to indication bias, whereas UK-REBOA was pragmatic and included centers with limited experience, raising learning curve concerns. Procedural fidelity issues (many allocated patients not inflated; delays to definitive control) matter because REBOA is a temporizing bridge—inefficient deployment can negate hemodynamic gains and amplify ischemic harm. Our included cohorts largely reflect mature "REBOA-to-OR" pathways.

Rather than restricting REBOA to high-volume centers, evidence supports adoption within structured systems: clear protocols, organized training, simulation-based skill maintenance, minimum competency standards, and formal partnerships with higher-volume centers for tele-education and registry participation.

Nonetheless, several important limitations of the available evidence remain. All included studies were observational, with substantial confounding by indication; propensity matching cannot address unmeasured factors (gestalt, dynamic trajectories, transfusion response, salvage cues), and the use of crude rather than adjusted odds ratios introduces the potential for residual confounding due to unadjusted baseline differences between groups. Complication analyses are vulnerable to differential survival bias ("surviving to have a complication"), likely inflating apparent morbidity in the higher-survival REBOA group versus RT. Heterogeneity in populations, protocols, and reporting persists: many cohorts mixed shock and arrest, and stratified effects differed (82% vs. 68%). Variable definitions (early/late mortality), balloon zone, and occlusion duration limited harmonized subgrouping by mechanism, signs of life, and shock severity.[26] Publication-bias assessments showed no strong small-study effects for the primary outcome, but preferential reporting of early "successful" REBOA experiences cannot be excluded.

In the context of the full evidence base, including the UK-REBOA trial, these data do not support indiscriminate replacement of RT with REBOA. Instead, they indicate REBOA is a powerful but context-sensitive tool whose effectiveness depends on the system in which it is deployed. In trauma systems with established expertise and resources, REBOA should be considered the preferred aortic occlusion approach for appropriately selected patients—particularly subdiaphragmatic noncompressible torso hemorrhage with hemodynamic instability but without established cardiac arrest. A key unknown remains the maximum safe aortic occlusion duration: REBOA duration was longer than RT (48.5 ± 59.5 vs. 27.5 ± 29.4 min), and prolonged occlusion is associated with mortality; large, detailed registries are needed to define time thresholds where risks outweigh benefits by population.

Several knowledge gaps require priority. Long-term functional outcomes and quality of life among survivors are scarce despite the complication burden; the long-term impact of access complications, limb ischemia, and other

morbidities remains unclear. Evidence is also limited by sparse granular analyses by injury mechanism and anatomy, constraining precision selection. Generalizability across health care systems and resource settings is uncertain, and interactions between REBOA and emerging resuscitation strategies remain poorly defined despite growing use. Collectively, these gaps limit the development of personalized aortic occlusion strategies that maximize benefit while minimizing harm.

CONCLUSION

In this systematic review and meta-analysis of comparative observational studies (Level III evidence), REBOA was associated with a marked survival advantage versus resuscitative thoracotomy in adult trauma patients with exsanguinating hemorrhagic shock or traumatic cardiac arrest, but with higher procedure-related complication rates and longer aortic occlusion times. Findings must be interpreted within the limitations of observational data, including residual confounding and indication bias, and do not establish causality. The results indicate that REBOA should not be used indiscriminately; instead, it should be reserved for carefully selected, potentially salvageable patients—especially those experiencing profound hemorrhagic shock or traumatic arrest—and administered by trained teams within organized trauma systems equipped for rapid definitive hemorrhage control and structured postresuscitation care. Prospective studies and registry-based quality-improvement efforts are needed to refine selection, optimize implementation, and mitigate complications while preserving survival benefit.

AUTHORSHIP

M.L.B., D.A.G., and C.A.D.L. participated in conception and study design. M.L.B. and D.A.G. participated in the literature review and data acquisition. M.L.B., D.A.G., C.A.L.Z., D.A.M.T., and C.A.D.L. contributed to data analysis and interpretation. M.L.B., D.A.G., and C.A.D.L. participated in drafting of the manuscript. M.L.B., D.A.G., C.A.L.Z, D.A.M.T., and C.A.D.L. contributed to critical revision of the manuscript.

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