Resuscitative endovascular balloon occlusion of the aorta and resuscitative thoracotomy are associated with similar outcomes in traumatic cardiac arrest

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BACKGROUND: Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a minimally invasive alternative to resuscitative thoracotomy (RT) for patients with hemorrhagic shock. However, the potential benefits of this approach remain subject of debate. The aim of this study was to compare the outcomes of REBOA and RT for traumatic cardiac arrest.

METHODS: A planned secondary analysis of the United States Department of Defense-funded Emergent Truncal Hemorrhage Control study was performed. Between 2017 and 2018, a prospective observational study of noncompressible torso hemorrhage was conducted at six Level I trauma centers. Patients were dichotomized by REBOA or RT, and baseline characteristics and outcomes were compared between groups.

RESULTS: A total of 454 patients were enrolled in the primary study, of which 72 patients were included in the secondary analysis (26 underwent REBOA and 46 underwent resuscitative thoracotomy). Resuscitative endovascular balloon occlusion of the aorta patients were older, had a greater body mass index, and were less likely to be the victims of penetrating trauma. Resuscitative endovascular balloon occlusion of the aorta patients also had less severe abdominal injuries and more severe extremity injuries, although the overall injury severity scores were similar. There was no difference in mortality between groups (88% vs. 93%, $p = 0.767$). However, time to aortic occlusion was longer in REBOA patients (7 vs. 4 minutes, $p = 0.001$) and they required more transfusions of red blood cells (4.5 vs. 2.5 units, $p = 0.007$) and plasma (3 vs. 1 unit, $p = 0.032$) in the emergency department. After adjusted analysis, mortality remained similar between groups (RR, 0.89; 95% confidence interval, 0.71–1.12, $p = 0.304$).

CONCLUSION: Resuscitative endovascular balloon occlusion of the aorta and RT were associated with similar survival after traumatic cardiac arrest, although time to successful aortic occlusion was longer in the REBOA group. Further research is needed to better define the role of REBOA in trauma. (*J Trauma Acute Care Surg.* 2023;95: 912–917. Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.)

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KEY WORDS: Traumatic cardiac arrest; resuscitative endovascular balloon occlusion of the aorta; REBOA; resuscitative thoracotomy.

Emergency resuscitative thoracotomy (RT) is a well-described procedure that has been used for decades as an emergency truncal hemorrhage control procedure in select patients with cardiac arrest secondary to traumatic hemorrhage. Current guidelines advocate for RT in appropriately selected patients under limited circumstances.[1,2] When successful, RT can be a life-saving intervention. However, overall success rates remain low despite improvements in prehospital care and attempts to refine patient selection. The overall survival to discharge after RT in the Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) registry was 5%, but it has been reported to be as high as 19.9% based on Trauma Quality Improvement Program Data (TQIP), and outcomes are significantly better for younger patients with penetrating injuries.[3,4] Because of low survival rates and high procedure-related morbidity, there have been efforts to develop less invasive methods of managing traumatic cardiac arrest.

Recently, resuscitative endovascular balloon occlusion of the aorta (REBOA) has regained popularity as a minimally invasive alternative to RT. Although first described during the Korean War, the use of this technique has increased significantly over the past decade due to the development of a low-profile device that can be delivered through a 7-French sheath.[5] Proponents of REBOA suggest that equivalent aortic occlusion can be achieved to temporize truncal hemorrhage while avoiding the morbidity of a thoracotomy.[6,7] Resuscitative endovascular balloon occlusion of

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the aorta has also been reported to improve the quality of chest compressions.[8] Observational studies of REBOA have shown associations with improved survival in patients with traumatic hemorrhage, particularly those with pelvic hemorrhage, although these benefits are not demonstrated consistently, and there are no randomized controlled trials to inform its use.[4,9] Catheter-based aortic occlusion has also been successfully applied to nontraumatic hemorrhage.[10–12] Although these results are encouraging, the exact role of REBOA within a trauma algorithm remains undefined, and current guidelines only recommend its use in hemodynamically unstable patients with pelvic injuries.[13]

Likewise, the role of REBOA in traumatic cardiac arrest remains undefined. For this reason, we conducted a secondary analysis of the recent Emergency Truncal Hemorrhage Control (ETHC) observational study to compare outcomes between REBOA and RT in traumatic cardiac arrest. We hypothesized that in-hospital mortality was similar in the two emergency hemorrhage control procedures.

METHODS

Study Design

A planned secondary analysis of the United States Department of Defense-funded ETHC study was performed. Between May 31, 2017, and June 15, 2018, a prospective observational study of noncompressible torso hemorrhage was conducted at six US Level I trauma centers. Inclusion criteria for the primary study included: (1) 15 years or older (or ≥50 kg body weight if age unknown); (2) evidence of truncal hemorrhage arising below the diaphragm in which the decision for emergent truncal hemorrhage control intervention (operative or endovascular) was made within 60 minutes of emergency department (ED) arrival; and (3) presentation to one of the participating Level I trauma centers at highest activation level. The ETHC study was approved by each trauma center's institutional review board. Although the study was not designed to compare the effectiveness of various temporary or definitive hemorrhage control procedures or the outcomes of patients undergoing hemorrhage control interventions, data on patients receiving both endovascular (REBOA) and open (RT) hemorrhage control procedures were collected. For patients undergoing REBOA, all received the Prytime ER-REBOA catheter (Prytime Medical, Boerne, TX). The primary publication from this study was a descriptive analysis including only patients who underwent REBOA. The goal of this planned secondary analysis was to compare outcomes after REBOA or RT in patients experiencing traumatic cardiac arrest prior to initiation of the hemorrhage control procedure. All data elements were collected prospectively by direct observation. Only ETHC study patients who experienced traumatic cardiac arrest (defined as receiving cardiopulmonary resuscitation) in the ED immediately prior to or during the initiation of the emergency hemorrhage control procedure were enrolled in the secondary analysis.

Statistical Analysis

Traumatic cardiac arrest patients were dichotomized by their emergency truncal hemorrhage control procedure (REBOA or RT), and baseline characteristics were compared using Student's *t* test for continuous data, Wilcoxon rank-sum test for nonparametric data, and Fisher's exact test and χ^2 test for categorical data. Unadjusted in-hospital outcomes were also compared. Kaplan Meier time-to-event curves (where successful aortic occlusion was the event of interest) were created to compare differences by treatment group, and a log rank test was performed. To account for imbalances in the baseline characteristics between groups, an inverse probability of treatment weighted (IPTW) analysis was performed. Baseline characteristics of the patients were used to estimate the probability of treatment using multivariable logistic regression. The estimated probabilities were used to assign weights to each patient. Average treatment effects were then calculated on the weighted observations using multivariable logistic regression with the same covariates. All statistical analyses were performed using commercially available statistical software (Stata 15.1; StataCorp LLC, College Station, TX and R 4.0.5, R Foundation for Statistical Computing, https://www.R-project.org/).

Article Preparation

To enhance the quality, readability, and value of the prepared article, the STROBE checklist for cohort studies published by the Equator network (https://www.equator-network.org/reporting-guidelines/strobe/) was utilized.[14] The completed checklist is available as Supplemental Digital Content, http://links.lww.com/TA/D155.

RESULTS

Between May 31, 2017, and June 15, 2018, 454 patients with evidence of noncompressible torso hemorrhage arising below the diaphragm and a decision for emergency hemorrhage control intervention (REBOA or RT) were enrolled in the primary ETHC study. Of these, 74 (16%) experienced traumatic cardiac arrest with CPR performed immediately prior to or during the emergency hemorrhage control procedure. Two patients had return of spontaneous circulation before an emergency hemorrhage control procedure could be performed and were excluded from the analysis. The remaining 72 patients underwent an emergency truncal hemorrhage control procedure and were enrolled in the secondary analysis. Of these, 26 underwent REBOA and 46 underwent resuscitative thoracotomy. Baseline characteristics are summarized in Table 1. Resuscitative endovascular balloon occlusion of the aorta patients were older, had a greater body mass index, and were less likely to be the victims of penetrating trauma. Resuscitative endovascular balloon occlusion of the aorta patients also had less severe abdominal injuries (as measured by Abbreviated Injury Score [AIS] Abdomen) and more severe extremity injuries (as measured by AIS Extremity), although the overall injury severity scores were similar between groups. Prior to arriving at the hospital, patients who later underwent REBOA had a lower mean systolic blood pressure. However, at the time of presentation to the ED, vital signs and markers of physiologic derangement were similar between groups. In six of the REBOA patients, the descending thoracic aorta could not be successfully occluded. The reasons for this include the following: inability to obtain femoral artery access (n = 4), REBOA balloon rupture (n = 1), and patient death prior to successful balloon inflation (n = 1). Three of the unsuccessful

REBOA attempts were successfully converted to RT. Unadjusted hospital outcomes are presented in Table 2. Resuscitative endovascular balloon occlusion of the aorta patients received more units of red blood cells and plasma in the ED, although 24-hour blood products were similar to RT patients. Unadjusted mortality rates were also similar, as were primary causes of death. By univariate logistic regression, the risk of mortality was the same across trauma centers. Regarding the emergency hemorrhage control procedure (RT or REBOA), the time from hospital presentation to aortic occlusion (AO) was greater in the REBOA group. The time from making the decision to perform an emergency hemorrhage control procedure to successful aortic occlusion (placement of the aortic cross-clamp in RT or balloon inflation in REBOA) was also longer in the REBOA group (Table 2). Differences in time to successful AO by group are illustrated in the Kaplan-Meier time-to-event curves shown in the Figure 1. By log-rank test, time to AO was significantly longer in the REBOA group ($p = 0.001$).

IPWT Analysis

Imbalances in the baseline characteristics (age, body mass index, AIS abdomen, AIS extremity, and penetrating mechanism) were used as covariates in a multivariable logistic regression where the emergency hemorrhage control procedure was the dependent variable. The study site was also included as a covariate. From this logistic regression, the inverse probability of treatment was used to assign weights to each patient. After multivariable logistic regression on the weighted observations using the same covariates, the risk of mortality remained similar between groups (RR, 0.89; 95% confidence interval, 0.71–1.12; $p = 0.304$).

DISCUSSION

The aim of this study was to compare the outcomes of REBOA and RT for traumatic cardiac arrest as a secondary analysis of the prospectively obtained ETHC study. Our results showed that using REBOA did not result in a mortality or transfusion benefit compared with RT in traumatic cardiac arrest. In addition, REBOA was associated with longer time to AO. As the role of REBOA in trauma continues to be explored, there are several issues regarding REBOA and RT that warrant further discussion.

One of the many potential benefits of REBOA is that it provides a method to temporize truncal hemorrhage while also serving as an adjunct to cardiopulmonary resuscitation. This potential benefit has been most widely described in nontraumatic cardiac arrest. As there is no need for hemorrhage control in nontraumatic or nonhemorrhagic cardiac arrest, the implementation of REBOA in these circumstances is to improve coronary and cerebral perfusion during cardiopulmonary resuscitation. This is postulated to provide maximum neuroprotection and increase the likelihood of return of spontaneous circulation (ROSC).[15] In addition, several other proposed physiologic benefits of REBOA have been described. First, AO in aorta zone 1 (the descending thoracic aorta between the takeoff of the left subclavian and the diaphragm) may reduce ventricular fibrillation in these patients by stimulating the aortic baroreceptors and activating the parasympathetic nervous system.[15] Aortic occlusion may also decrease the drug distribution volume of vasoactive medications needed during resuscitation and thereby potentially increasing their efficacy.[15] Although these potential benefits appear promising, current evidence supporting REBOA in nontraumatic cardiac arrest remains limited. Some observational studies report the use of REBOA in the ED for nontraumatic out of hospital cardiac arrest.[16] The REBOARREST trial is an upcoming randomized trial which will hopefully further delineate the role of REBOA in this scenario.[17]

Despite the potential advantages of REBOA, there are several important disadvantages. First, ensuring technical proficiency is a major concern for widespread implementation of REBOA across trauma centers. While the procedure is conceptually simple, the minimum number of procedures needed to demonstrate basic proficiency has not yet been determined. Currently, training for REBOA is done with programs such as the Basic Endovascular Skills for Trauma course.[18] While these courses provide an initial exposure, comfort with the technique decreases if REBOA is not applied frequently over time.[19] Besides overcoming the initial learning curve, maintaining comfort with the procedure is also critical, particularly since patients with indications for REBOA do not present frequently to most institutions. This is best illustrated by a recent retrospective study showing an association with improved survival after REBOA in high-volume REBOA centers.[20] Finally, the ability to rapidly place a REBOA may be limited by the absence of femoral arterial access in patients who present in or progress rapidly to cardiac arrest. In such patients, obtaining femoral access (either percutaneous or by cutdown), especially during cardiopulmonary resuscitation, may delay successful placement of the catheter. Romagnoli et al.[21] demonstrated that obtaining femoral artery access is the rate-limiting step for achieving AO with REBOA. The increased time to AO with REBOA observed in this study may reflect some of the limitations.

This difference in time to AO with REBOA seen in our results may also be the reason for greater transfusions in these patients. Increased time to AO with REBOA compared with RT was also described in a recent study of the AORTA registry.[21] In addition, 24-hour blood product transfusion was also greater with REBOA.[22] Besides time to AO, another factor which could have contributed to the difference in transfusions is the nature of the AO itself. Resuscitative thoracotomy allows for cross-clamping of the aorta for AO which provides a constant consistent level of occlusion, whereas the balloon occlusion provided by REBOA provides for a dynamic level of occlusion based of the patient's physiology. A recent porcine study has shown that changes in balloon volume are needed to maintain adequate AO with REBOA.[23] The lack of dynamic monitoring of AO related to patient physiology may have resulted in adequate AO and continued blood loss in these patients, thereby resulting in greater transfusion requirement. Newer iterations of REBOA catheters may include feedback mechanisms to ensure appropriate AO after deployment.

Another potential drawback to REBOA in patients with traumatic cardiac arrest is that it does not allow for open cardiac massage like RT. Historically, open cardiac massage has been considered to provide superior coronary and cerebral perfusion compared to closed chest compressions after cardiac arrest.[24] In addition, in the event of cardiac tamponade, RT would allow for decompression of the pericardium while REBOA does not.

TABLE 1. Baseline Characteristics Dichotomized by Emergency Hemorrhage Control Procedure

	REBOA (n = 26)	RT (n = 46)	*p*
Demographics			
Age, y	46 (20)	35 (14)	0.022
Male gender	16 (62%)	36 (78%)	0.212
White race	13 (50%)	21 (46%)	0.913
Hispanic	7 (29%)	9 (21%)	0.684
Body Mass Index, kg/m^2	23 (22, 27)	26 (24, 30)	0.020
Penetrating mechanism	5 (19%)	25 (54%)	0.008
Gunshot wound	4 (15%)	22 (48%)	0.013
Pedestrian struck by automobile	9 (35%)	5 (11%)	0.033
Injury severity			
Injury Severity Score	27 (12)	33 (17)	0.282
AIS Head	2 (0–3)	0 (0–3)	0.465
AIS Face	0 (0–0)	0 (0–0)	0.564
AIS Chest	3 (3–4)	3 (2–4)	0.825
AIS Abdomen	3 (2–3)	4 (2–4)	0.046
AIS Extremity	3 (2–4)	3 (0–3)	0.039
AIS External	1 (1–1)	1 (0–1)	0.455
Prehospital data			
Heart rate, bpm	90 (47)	71 (56)	0.185
Systolic blood pressure, mm Hg	128 (77–153)	66 (0–90)	>0.001
Glasgow Coma Scale score	3 (3–11)	3 (3–5)	0.215
Cardiopulmonary resuscitation	10 (38%)	24 (52%)	0.382
Red blood cell, units	0 (0–0)	0 (0, 0)	0.240
Plasma, units	0 (0–0)	0 (0, 0)	0.048
Platelets, units	0 (0–0)	0 (0, 0)	1.000
Crystalloid, mL	0 (0–265)	s0 (0–926)	0.143
Emergency department data at presentation			
Heart rate, bpm	0 (0–93)	0 (0–86)	0.908
Systolic blood pressure, mm Hg	0 (0–83)	0 (0–87)	0.665
Glasgow Coma Scale score	3 (3, 3)	3 (3–3)	0.455
Lactic acid, mmol/L	11.7 (4.9)	11.0 (4.3)	0.679
Base excess, mEq/L	−15 (−21 to −10)	−20 (−27 to −13)	0.551
Revised Trauma Score	0.58 (0–4.09)	0.58 (0–3.69)	0.618

Continuous data are presented as mean (±SD). Discrete data are presented as median (IQR). Categorical data are presented as n (%).
AIS, Abbreviated Injury Scale; IQR, interquartile range.

However, it is important to note that the reported benefits of open cardiac massage have primarily been described by studies evaluating nontraumatic cardiac arrest. In these patients, the physiology of cardiac arrest is very different compared with the profound hypovolemia which occurs from hemorrhage. Many of these studies are also old and predate modern trauma resuscitation. More recent studies suggest that closed cardiac compressions may be equivalent to open cardiac massage.[8,25] Teeter el al. reported that end-tidal CO_2 is higher in patients with REBOA and closed cardiac compressions compared with RT with open cardiac massage.[25] Resuscitative endovascular balloon occlusion of the aorta with closed cardiac compressions also resulted in fewer interruptions of compressions during resuscitation.[8]

Multiple observational studies have been performed comparing REBOA and RT. Most notably, the AORTA study by Brenner et al. compared these techniques in a similar prospective observational study.[4] The results showed that REBOA was associated with increased survival overall, but this effect was not seen in patients requiring CPR. These findings again imply that REBOA may be best utilized in hemorrhagic shock before cardiac arrest occurs. The upcoming UK-REBOA randomized trial may help provide further insight into the potential benefits of REBOA.[26] This multicenter trial aims to randomize 120 patients with traumatic hemorrhagic shock to standard care versus standard care with REBOA. The primary outcome will be 90-day mortality.

There are several limitations in this study to address. Most importantly, although the data for this study were obtained prospectively and by direct observation, the emergency hemorrhage control procedure was not randomized. Accordingly, selection bias may result in confounding. This could account for some of the differences seen in baseline characteristics among groups, specifically age and mechanism of injury. The authors attempted to address imbalances in the groups at baseline by using propensity scores to perform an IPWT analysis. However, the groups can only be balanced on measured confounders. The decision to perform RT or REBOA in traumatic cardiac arrest is complex,

TABLE 2. Hospital Outcomes Dichotomized by Emergency Hemorrhage Control Procedure

	REBOA (n = 26)	RT (n = 46)	*p*
Died in the ED	9 (35%)	20 (43%)	0.627
In-hospital mortality	23 (88%)	43 (93%)	0.767
Cause of death = hemorrhage	18 (78%)	35 (83%)	0.865
Cause of death = traumatic brain injury	2 (9%)	6 (14%)	0.794
Hospital Days	1 (1–1)	1 (1–1)	0.793
ED red blood cells, units	4.5 (3–7)	2.5 (2–4.75)	0.007
ED plasma, units	3 (0.5–5)	1 (0, 3)	0.032
ED platelets, units	0 (0–0)	0 (0–0)	0.372
ED crystalloid, mL	0 (0–1,750)	0 (0–2,000)	0.510
Total red blood cells at 24 h, units	15 (5.25–30.75)	9.5 (3–31.75)	0.185
Total plasma at 24 h, units	8 (5.25–25.75)	6.5 (2–24.5)	0.211
Total platelets at 24 h, units	1 (0–4.75)	0 (0–2)	0.331
Total crystalloid at 24 h, mL	4,000 (100–5,000)	2,200 (250–6,300)	0.953
Time from presentation to AO, min	20 (12.25–33)	8 (6–11)	<0.001
Time from decision to AO, min	7 (4.5–10)	4 (3–6)	0.001
Time from presentation to death, min	96 (30–305)	49 (17–173)	0.118
Favorable discharge (home or rehab)	0 (0%)	2 (4%)	0.768

Continuous data are presented as mean (±SD). Discrete data are presented as median (IQR). Categorical data are presented as n (%).

and there may be residual confounding. This may be partially observed in the increased time from admission to the decision for AO seen in the REBOA group. Unfortunately, it is not possible to discern from these data if the delay in decision for AO was due to patient factors (*i.e.*, relatively later progression to cardiac arrest or intermittent return of spontaneous circulation during initial resuscitation efforts) or procedure factors (i.e., delaying the decision for REBOA vs. RT until after initial attempts to obtain femoral access). In addition, the number of patients enrolled in the study is small. Capturing traumatic cardiac arrest in a prospective observational study by direct observation is challenging, primarily because of the nature of the disease and its relative infrequency even at high-volume Level I trauma centers.

In conclusion, this secondary analysis showed that REBOA and RT were associated with similar survival after traumatic cardiac arrest, although time to successful AO was longer

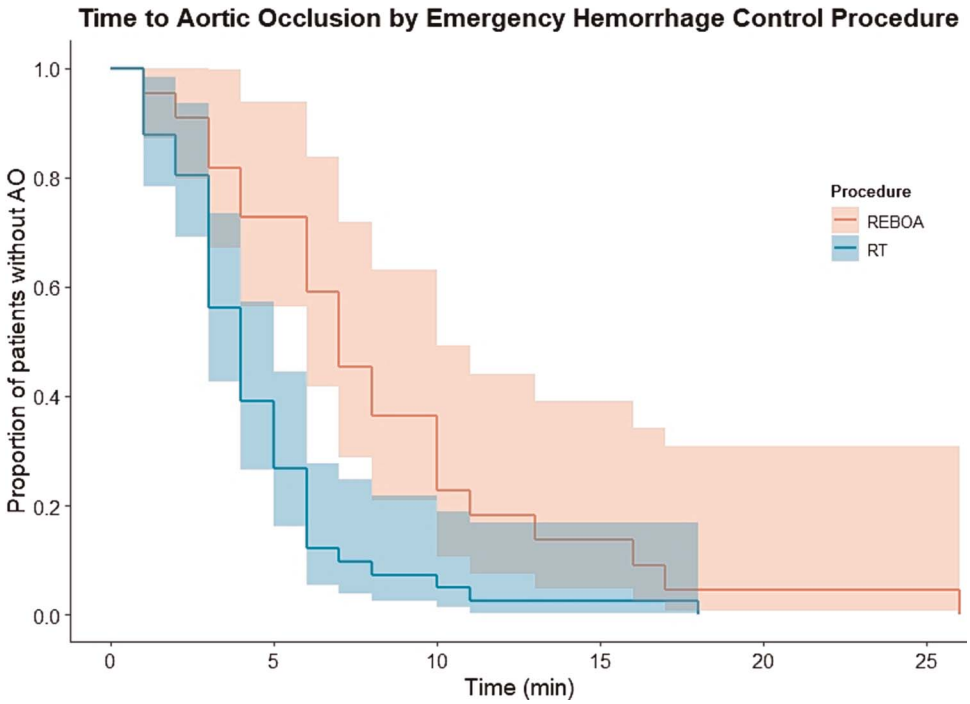

Figure 1. Kaplan-Meier analysis of time to successful AO dichotomized by emergency hemorrhage control procedure.

in the REBOA group. As mortality outcomes are similar, the decision to perform REBOA or RT in traumatic cardiac arrest will continue to depend on specific patient presentation. In the absence of femoral arterial access at the time of arrest, RT may offer decreased time to successful AO. Further research is needed to better define the role of REBOA in trauma.

AUTHORSHIP

E.Y.K. and D.E.M. contributed to study conception and design. E.Y.K., E.E.F., C.E.W., T.M.S., C.J.F., E.E.M., B.C.M., K.I., E.M.B., and D.E.M. contributed to acquisition of data, primary analysis, and interpretation of the data. E.Y.K. and D.E.M. contributed to drafting the article. E.Y.K., E.E.F., C.E.W., T.M.S., C.J.F., E.E.M., B.C.M., K.I., E.M.B., and D.E.M. contributed to critical revision.

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DISCLOSURE

The authors declare no conflicts of interest.

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