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Endovascular Versus Open: Emergency Department Resuscitative Endovascular Balloon Occlusion of the Aorta or Thoracotomy for Management of Post-Injury Non-compressible Torso Hemorrhage

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Non-compressible torso hemorrhage (NCTH) (i.e. bleeding from anatomical locations not amenable to control by direct pressure or tourniquet application) is a leading cause of potentially preventable death after injury. In select trauma patients with infra-diaphragmatic NCTH-related hemorrhagic shock or traumatic circulatory arrest, occlusion of the aorta proximal to the site of hemorrhage may sustain or restore spontaneous circulation. While the traditional method of achieving proximal aortic occlusion included Emergency Department thoracotomy (EDT) with descending thoracic aortic cross-clamping, resuscitative endovascular balloon occlusion of the aorta (REBOA) affords a less invasive option when thoracotomy is not required for other indications. In this article, we review the innovation, pathophysiologic effects, indications for, and technique of EDT and partial, intermittent, and complete REBOA in injured patients, including recommended methods for reversing aortic occlusion. We also discuss advantages and disadvantages of each of these methods of proximal aortic occlusion and review studies comparing their effectiveness and safety for managing post-injury NCTH. We conclude by providing recommendations as to when each of these methods may be best, when indicated, to manage injured patients with NCTH.

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INTRODUCTION

Non-compressible torso hemorrhage (NCTH) (i.e. bleeding from anatomical locations not amenable to control by direct pressure or tourniquet application) is a leading cause of potentially preventable death after injury [1–5]. In 2012, Morrison and Rasmussen defined NCTH as torso hemorrhage from one of four anatomic sites (lung, abdominal solid organ, major vascular, or the pelvis) in patients with signs of hemorrhagic shock (blood pressure (BP) <90 mmHg or lactate >4 mmol/L) and/or the need for immediate open or endovascular hemorrhage control [5,6]. In one retrospective cohort study, approximately 70% of included trauma patients with NCTH were reported to be bleeding from an anatomic site within the abdomen or pelvis and the primary cause of death was exsanguination, often occurring 2 hours following presentation [7].

In select trauma patients with infra-diaphragmatic NCTH-related hemorrhagic shock or traumatic circulatory arrest, occlusion of the aorta proximal to the site of hemorrhage may sustain or restore spontaneous circulation [8,9]. While the traditional method of achieving proximal aortic occlusion included Emergency Department thoracotomy (EDT) with descending thoracic aortic cross-clamping [8,9], resuscitative endovascular balloon occlusion of the aorta (REBOA) affords a less invasive option when thoracotomy is not required for other indications (e.g. cardiac tamponade) [10]. REBOA requires that the common femoral artery (CFA) be accessed percutaneously or via femoral cutdown. A catheter with a compliant balloon near its tip is then inserted into the aorta through a femoral sheath and partially, intermittently, or completely inflated in aortic zone 1 (located between the left subclavian and celiac artery) or zone 3 (located between the lowest renal artery and aortic bifurcation) (Figure 1) [10].

In this article, we review the innovation, pathophysiologic effects, indications for, and technique of EDT and partial, intermittent, and complete REBOA in injured patients, including recommended methods for reversing aortic occlusion. We also discuss advantages and disadvantages of these methods of proximal aortic occlusion and review studies comparing their effectiveness and safety for managing post-injury NCTH. We conclude by providing recommendations as to when each of these methods may be best, when indicated, to manage injured patients with NCTH.

Ethical Approval and Informed Consent

Ethical approval was not required. Informed consent was not required.

PATHOPHYSIOLOGIC EFFECTS OF PROXIMAL AORTIC OCCLUSION

Proximal aortic occlusion has several potentially beneficial pathophysiologic effects among hemodynamically unstable patients [11–14]. Zone 1 aortic occlusion increases preload, systematic vascular resistance, central aortic BP, and coronary (the aortic diastolic-to-right atrial pressure difference during myocardial relaxation) and cerebral perfusion [15]. In contrast, zone 3 aortic occlusion causes only a mild increase in mean arterial pressure [15]. Finally, proximal aortic occlusion reduces hemorrhage distal to the level of the occlusion, and in patients with profound hemorrhagic shock secondary to intra-abdominopelvic hemorrhage, it may prevent cardiovascular collapse during laparotomy [11–14].

Some data suggests that zone 1 aortic occlusion, particularly via REBOA, may also help in achieving return of spontaneous circulation (ROSC) after circulatory arrest. In patients who have suffered cardiac arrest, zone 1 aortic occlusion increases both coronary perfusion pressure and end-tidal CO_2 ($ETCO_2$), two measures that are independent predictors of ROSC [16,17]. Further, in one study of six swine receiving cardiopulmonary resuscitation (CPR) after prolonged ventricular fibrillation-induced cardiac arrest, zone 1 aortic occlusion significantly increased coronary perfusion pressure and $ETCO_2$, and three of the animals subsequently had ROSC [18]. However, less favorable results have been reported with REBOA in animal models of infradiaphragmatic NCTH [19].

Thoracic aortic occlusion also has several potentially adverse pathophysiologic effects. Complete zone 1 aortic occlusion induces supraphysiologic proximal aortic and aortic branch pressures and increases left ventricular (LV) afterload, wall tension, and subendocardial oxygen demand [15]. It also causes mesenteric, hepatic, renal, spinal cord (because of reduced intercostal, lumbar, and internal iliac arterial collateral flow to the anterior spinal artery), and lower extremity ischemia; therefore, prolonged inflation in aortic zone 1 may produce mesenteric infarction, acute kidney and spinal cord injury, and may potentially lead to limb loss [15]. In an ovine hemorrhagic shock model, all six sheep who had a zone 1 aortic occlusion time of 60 min died as compared with only one of six who had an occlusion time of 30 min [20]. Further, all animals with 60 min of zone 1 REBOA had renal histologic evidence of acute tubular necrosis [20]. Prolonged proximal aortic occlusion also induces a systemic inflammatory response that likely leads to an increased incidence of acute lung injury and acute respiratory distress syndrome (ARDS) [21]. In a swine hemorrhagic shock

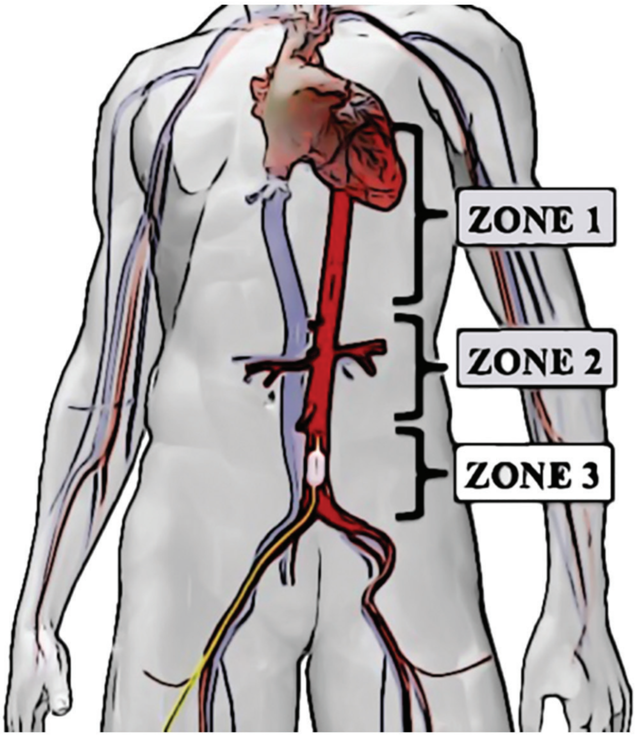

Figure 1 Aortic occlusion zones 1, 2, and 3.

model, when compared with 30 min of zone 1 REBOA, animals with 60 min and 90 min of zone 1 occlusion had significantly higher concentrations of systemic interleukin-6. There was also a trend toward a greater incidence of ARDS in these groups [21].

EDT

To prevent cardiovascular collapse during laparotomy, EDT with cross-clamping of the descending thoracic aorta was first advocated by Ledgerwood et al. in 1976 for hypotensive trauma patients with tense abdominal distention [9]. EDT consists of a left anterolateral or clamshell (i.e. bilateral anterior) thoracotomy performed in the Emergency Department (ED) [22,23]. In contrast, the term "resuscitative thoracotomy" (RT) refers to a thoracotomy performed in the operating room or intensive care unit (ICU) for delayed physiologic decompensation [22]. Importantly, in addition to cross-clamping the aorta, EDT is also indicated to release pericardial tamponade, temporarily control cardiac, mediastinal, pulmonary, or pulmonary hilar hemorrhage, evacuate air emboli, and perform open cardiac massage and defibrillation [22]. It has also been used to provide rapid, large-volume fluid resuscitation via a catheter sutured into the right atrial appendage [24,25].

In 2015, the Eastern Association for the Surgery of Trauma (EAST) published a clinical practice guideline on patient selection for EDT [26]. The authors conducted a systematic review of published EDT studies and used the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework to determine whether patients who present to hospital pulseless should undergo EDT based on the mechanism of injury and signs of life [26]. Ultimately, they included 72 cohort studies published between 1974 and 2013 that enrolled 10,238 patients who underwent EDT for traumatic circulatory arrest [26]. Based on these studies, EAST provided one strong (based on moderate quality evidence) and five conditional recommendations (based on low to moderate quality evidence) regarding the use of EDT [26]. They also reported estimates of in-hospital and neurologically intact survival associated with the use of these indications across the included studies [26].

In 2018, DuBose et al. and the American Association for the Surgery of Trauma (AAST) Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) study group conducted a retrospective cohort study of the AORTA registry to determine if publication of the EAST guideline was associated with changes in EDT practice or outcomes [27]. This registry included data on 310 patients who underwent EDT across 16 American College of Surgeons (ACS)-verified level I or II or active Canadian trauma centers between November 2013 and December 2016 [27]. Most patients were injured by penetrating mechanisms (64%), had received prehospital CPR (58%), and had signs of life upon presentation (47%), including organized electrical activity, pupillary response, spontaneous movement, or appreciable pulse/BP [27]. When compared with the systematic review conducted by EAST, there was no difference in in-hospital or neurologically intact survival among patients included in the AORTA registry when EDT was conducted for any of the indications recommended by EAST (Table 1) [27]. In both this study and the EAST systematic review, the estimated survival associated with conducting EDT for patients with blunt mechanisms of injury or without signs of life was dismal (<5% for all indications) [27].

The precise safe duration of thoracic aortic cross-clamping in trauma patients is largely unknown and likely dependent on a number of factors [26–28]. Data from studies published decades ago suggest that, although thoracic aortic cross-clamp durations up to 60 min are likely safe, shorter durations are associated with a higher probability of survival [9,29]. The original EDT study by Ledgerwood et al. reported that thoracic aortic cross-clamp durations ranged from 7–60 min and averaged 27 min among trauma patients who survived after EDT before or after trauma laparotomy [9]. Millikan and Moore subsequently reported that nearly one-third of 39 patients with significant hemodynamic instability before or after trauma laparotomy survived following cross-clamping of the descending thoracic aorta for an average of 56 min or 58 min, respectively. Further, the average cross-clamp duration was 29 min among survivors versus 57 min among patients who died.

Table 1 Estimates of hospital and neurologically intact survival after EDT for select indications conditionally recommended by EAST [26,27].

	Estimate of Survival – No./Total (%)			
Indication	*In-Hospital (AORTA Registry, 2013–2016)*	*In-Hospital (EAST Systematic Review, 1974–2013)*	*Neurologically Intact (AORTA Registry, 2013–2016)*	*Neurologically Intact (EAST Systematic Review, 1974–2013)*
Penetrating extrathoracic injury with signs of life on admission	4/32 (13)	25/160 (16)	4/32 (13)	14/85 (17)
Penetrating extrathoracic injury without signs of life on admission	1/64 (2)	4/139 (3)	1/64 (2)	3/60 (5)
Blunt injury with signs of life on admission	3/68 (4)	21/454 (5)	1/68 (2)	7/298 (2)
Blunt injury without signs of life on admission	0/45 (0)	7/995 (1)	0/45 (0)	1/825 (0.1)

AORTA: Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery; EDT: emergency department thoracotomy; EAST: Eastern Association for the Surgery of Trauma.

EDT is associated with an increased risk of provider occupational injury and exposure to trauma patient blood-borne illnesses [26,30]. Studies conducted in the United States have reported that the prevalence of human immunodeficiency virus (HIV) and hepatitis C virus infection among trauma patients may approach 4.3% and 14%, respectively [30]. In a multicenter prospective cohort study conducted across 16 predominantly level 1 American trauma centers, 7.2% of 305 EDTs were complicated by occupational exposures [30]. Those providers who suffered exposures were primarily trainees (68%) who endured percutaneous (86%) (i.e. needlestick or cut with a sharp object) injuries [30]. In this study, full personal protective equipment (PPE) was utilized by only 46% of exposed providers, and utilizing more PPE items during EDT was independently associated with a lower odds of occupational exposure [30].

Survivors of EDT may suffer a number of post-procedural complications. In a retrospective cohort study conducted across two level 1 trauma centers in Houston, Texas, 32% of 298 patients who underwent an RT after traumatic arrest survived to ICU admission and 9.4% to discharge [31]. The most common complications among patients admitted to the ICU after RT included acute kidney injury (10.4%), ventilator-associated pneumonia (8.3%), ARDS (7.3%), deep surgical site infection (7.3%), and deep venous thrombosis (7.3%). For the 28 patients who survived to hospital discharge, the average number of per-patient complications was 1.9, and the mean length of ICU and hospital stay was 24 and 44 days, respectively.

REBOA

In 1954, Lieutenant Colonel Carl W. Hughes was the first to report the use of an intra-aortic balloon catheter to control infra-diaphragmatic NCTH in injured patients [32,33]. For decades after this, little was written regarding the use of intra-aortic occlusion balloons for trauma because of a limited availability of balloon catheters [33]. However, with innovations in vascular and endovascular surgery came the development of commercial, compliant aortic balloon catheters that could be inserted over stiff wires through 12 or 14 French sheaths during elective and emergent repair of abdominal aortic aneurysms [33–35]. Surgical experience gained from the Iraq and Afghanistan military conflicts led to increased interest in using REBOA in military and civilian settings as an alternative to EDT for proximal aortic control, particularly for patients with pelvic fracture-related hemorrhagic shock [33,36].

The Basic Endovascular Skills for Trauma (BEST™) course has developed a REBOA decision-making algorithm for hypotensive patients [37]. Before deciding to use REBOA in patients who do not respond, or only partially respond, to traditional resuscitation measures, trauma providers must assess for signs of thoracic aortic injury or intrathoracic pathology that may produce hemodynamic compromise (e.g. cardiac tamponade or tension pneumo- or hemopneumothorax) [33,37,38]. An extended focused assessment with sonography for trauma (eFAST) examination (or bilateral finger or tube thoracostomy in patients who have suffered cardiac arrest) may be used to rule out hemopneumothoraces while eFAST/cardiac ultrasound is used to exclude pericardial tamponade [33,37,39]. A relative contraindication to REBOA is chest X-ray findings suggestive of thoracic aortic injury (widened mediastinum, opacified aortopulmonary window, irregular aortic arch, blurred aortic contour, rightward tracheal deviation, and left apical pleural hematoma/cap) [37,40].

In 2018, the ACS Committee on Trauma and the American College of Emergency Physicians (ACEP) issued a joint statement outlining indications for REBOA [41]. They also provided guidelines for REBOA use and implementation, patient transfer and management during and after REBOA, REBOA training and credentialing, and REBOA quality assurance, maintenance of competence, performance improvement, and patient safety. They outlined that while REBOA will be uncommon in most settings, it is currently standard practice for select patients at a small number of trauma centers where surgeons are immediately available. Further, they recommended REBOA for traumatic life-threatening infra-diaphragmatic hemorrhage in patients arriving in arrest or hemorrhagic shock who are unresponsive or transiently responsive to resuscitation. The balloon catheter was suggested to be inflated in zone 1 for control of intra-abdominal or retroperitoneal hemorrhage or those with traumatic arrest and zone 3 for control of severe pelvic, junctional, or proximal lower extremity hemorrhage. The second edition of the guideline also emphasized the need for rapid definitive hemorrhage control, advocating that complete occlusion be <30 min in zone 1 and <60 min in zone 3 [42]. The guideline also recommends that REBOA not be performed in locations where definitive hemorrhage control cannot begin within 15 min for patients with REBOA in zone 1 and/or 30 min for those with REBOA in zone 3.

The above joint statements recognized that no high-grade evidence demonstrates that REBOA improves outcomes or survival compared with standard treatments for severe hemorrhage [41,42]. A randomized controlled trial evaluating the safety, effectiveness, and cost-effectiveness of REBOA in injured patients with NCTH has not yet been completed. There have, however, been a number of observational studies that have evaluated the safety and effectiveness of REBOA. Results of these studies have been summarized across one scoping and four systematic reviews [43–47]. In the scoping review, Bekdache et al. included 105 articles that enrolled 8,741 trauma patients [43]. Most articles included patients with blunt abdominal or pelvic trauma who had REBOA inserted percutaneously in the ED by trauma and acute care surgeons. The majority of current articles reported using the 7 French catheter in zone 1 or 3. Aortic occlusion times ranged from 10–60 min, with 20 min being most commonly reported.

Results of systematic reviews of case reports/series and cohort studies on the use of REBOA are summarized in Table 2 [44–47]. These studies reported that REBOA deployment was associated with a median 53–79 mmHg increase in systolic BP, and that it may be associated with improved mortality when compared with alternate methods of proximal aortic occlusion [44–47]. In contrast, in a propensity score-matched retrospective cohort study by Joseph et al. published in 2019, the use of REBOA in severely injured trauma patients was associated with a higher risk of mortality, acute kidney injury, and lower extremity amputation when compared with no use of REBOA [48]. However, the study was unable to consider certain critical variables such as duration of aortic occlusion, physiology at the time of REBOA, size of introducer sheaths, and others that have been demonstrated to correlate with morbidity and mortality [49]. Patients who received REBOA after 60 min were also not included despite representing a critical subset of patients who come to the ED normotensive and receive REBOA after that time. A multi-institutional study demonstrated that up to 60% of patients who receive REBOA are not admitted with a systolic BP of >90 mmHg [50]. Patients who were dead-on-arrival (DOA) were also excluded, although in some high volume REBOA centers approximately half of REBOA patients were DOA or in arrest at the time of the procedure.

REBOA complications may occur among 4–5% or more of patients treated [44–47]. These most frequently include arterial access complications (e.g. pseudoaneurysm) and arterial thrombosis or thromboembolic events, which may ultimately require lower extremity amputation [44–47]. In the above scoping review, complications reportedly associated with use of REBOA in trauma patients most commonly included distal ischemic events and amputations (12%), pseudoaneurysm formation (7%), and balloon migration (0.15%) or rupture (0.07%) [43]. However, lower extremity compartment syndrome, intracranial hemorrhage, acute kidney injury, multisystem organ failure, and balloon catheter exit through an aortic injury have also been described [43].

PARTIAL AND INTERMITTENT REBOA

Two alternate methods of aortic balloon occlusion that aim to improve the balance between minimizing ongoing hemorrhage and lessening distal ischemia-reperfusion injury include partial and intermittent REBOA [51,52]. A common method of performing partial REBOA is to serially deflate the completely inflated aortic occlusion balloon by incrementally removing small volumes of saline until minimum arterial waveforms appear distal to the balloon (measured via the side-port of the REBOA insertion sheath or via a second sheath placed in the contralateral CFA) [51,52]. As compared with complete REBOA, animal studies have reported that partial or intermittent REBOA may extend the safe duration of aortic occlusion, mitigate the potentially detrimental effects of supraphysiologic proximal arterial pressures, reduce the distal ischemia-reperfusion injury, the inflammatory and metabolic insult, and infra-diaphragmatic end-organ injury, and possibly improve survival [13,51,53–59]. Animal studies have also suggested that precipitous proximal arterial BP drops are reduced with partial REBOA; further, weaning REBOA may be better tolerated after a period of partial REBOA [13,51,53–59]. To facilitate partial REBOA, a commercial partial REBOA catheter was recently developed that features a semi-compliant balloon that allows for small adjustments in balloon volume and more accurate control of distal aortic flow [60].

Table 2 Principal results of systematic reviews of the safety and effectiveness of REBOA for management of trauma patients.

Author, Year	Search Period	No. Articles	No. Pts	Trauma Pts (%)	Access	Occlusion Time	Safety	Effectiveness
Borger van der Burg et al., 2018 [44]	1900–2017	89	1,482	59	NR	Median zone 1 = 59 min, zone 2 = 4 min, and zone 3 = 68 min	Iatrogenic injuries = 4%	REBOA associated with a mean increase of 79 mmHg (95% CI = 59–99) in systolic BP Use of REBOA instead of other methods of aortic occlusion associated with improved mortality (OR = 0.25; 95% CI = 0.11–0.56)
Manzano-Nunez et al., 2018 [45]	Database inception–2018	13	424	100	Percutaneous = 73% and cut down = 27%	NR	Incidence of complications = 5% (95% CI = 3–9%) Lower limb amputation required in 2% of patients Incidence of groin access complications was 0%, 5%, and 16% when REBOA was inserted by ED physicians, trauma surgeons, and anesthesiologists or radiologists, respectively The incidence of complications was 2% in studies where REBOA was inserted percutaneously versus 5% when both both percutaneous and surgical cutdown techniques were reported, and 11% when only surgical cutdown was used	NR

Author, Year	Search Period	No. Articles	No. Pts	Trauma Pts (%)	Access	Occlusion Time	Safety	Effectiveness
Gamberini et al., 2017 [46]	Database inception–2016	61	1,355	100	NR	Mean occlusion time ranged from 20–65 min	There may be a significant correlation between total occlusion time, serum lactate, and shock index	NR
							Distal ischemia/thromboembolic events (0.7%), intracranial hemorrhage (0.07%), access pseudoaneurysm (0.2%), renal failure (0.9%), balloon migration (e.g. into zone 2) (0.2%), infection (0.3%), retroperitoneal hematoma (0.07%), insertion failure (0.07%), balloon rupture (0.07%)	
							Risk factors for complications include increased BMI, thrombocytopenia, emergency procedures, large introducer size, and use of antiplatelet drugs	
Morrison et al., 2016 [47]	1946–2015	41	857	15/41 studies	Percutaneous=77% when prophylactic arterial access was obtained in anticipation of major hemorrhage and only 56% when patients were in hemorrhagic shock	Median zone 1 = 63 min (IQR = 33–88)	Overall rate of morbidity within the reporting literature = 4%, arterial injury = 3%, amputation = 1%, and nonfatal embolic events = 0.8%	REBOA associated with a mean increase of 53 mmHg (95% CI = 44–61) in systolic BP
						Median zone 3 = 45 min (IQR = 30–105)	There were no reports of lower extremity paralysis	Cohort studies reported variable associations between REBOA and mortality

BMI: body mass index; BP: blood pressure; CI: confidence interval; ED: Emergency Department; IQR: interquartile range; NR: not reported; OR: odds ratio; Pts: patients; REBOA: resuscitative endovascular balloon occlusion of the aorta.

REVERSING AORTIC OCCLUSION AFTER EDT AND REBOA

Strategies for reversing aortic occlusion include the gradual release of the aortic cross-clamp or deflation of the balloon, volume loading, and administration of vasoconstricting agents [61]. Typically, longer periods of aortic occlusion require more gradual weaning and increased fluid resuscitation and vasopressor support [51]. For complete and partial REBOA, the suggested goal for reversing aortic occlusion is to increase the systolic arterial BP distal to the balloon by 50% from baseline every 5 min to allow distal ischemic metabolites to be washed out into the central circulation between deflations [51].

EDT VERSUS REBOA FOR MANAGEMENT OF NCTH

There are several potential advantages of REBOA over EDT for proximal aortic occlusion in patients with NCTH. REBOA is less invasive, may be associated with less aortic endothelial damage, and in skilled hands may be more rapidly performed when compared to RT [41,62]. Use of REBOA instead of EDT for proximal aortic occlusion may also be safer for trauma providers, as it avoids risk of transmission of HIV, hepatitis B and C, and other blood borne viruses that may occur during EDT [26]. REBOA also avoids opening the thoracic cavity and therefore may be expected to be associated with a lower loss of heat and incidence of severe hypothermia after injury when compared with EDT (a finding associated with an increased incidence of traumatic coagulopathy, further blood loss, and the vicious cycle of hypothermia, acidosis, and coagulopathy) [63,64]. Finally, incrementally removing small volumes of saline from the aortic occlusion balloon during the transition from complete to no REBOA may allow for a safer or more precise method of reversing aortic occlusion than gradually removing an aortic cross-clamp during EDT.

In patients who have suffered a traumatic circulatory arrest, some clinical data also exists to suggest that REBOA is associated with improved CPR and a higher probability of ROSC when compared with EDT [65,66]. In one cohort study, Teeter et al. used multiview, time-stamped videography to compare total cardiac compression time (TCCT) (the total time that closed compressions (for REBOA patients) or that closed compressions and open cardiac massage (for RT patients) were performed) and total cardiac compression fraction (TCCF) (the time compressions occurred during the entire resuscitation phase) between patients who received aortic occlusion after cardiac arrest via REBOA or RT [65]. The authors reported that TCCT and TCCF were higher in those who underwent REBOA; further, the total duration of interruptions of cardiac compressions (e.g. for procedural tasks) was shorter in patients who received REBOA before and during resuscitation with aortic occlusion [65]. Another cohort study by the same group reported that in patients with traumatic arrest, patients who underwent REBOA instead of RT had a higher $ETCO_2$ and TCCF prior to and after aortic occlusion [66]. Moreover, when compared with those who received RT, ROSC was more common in patients who received REBOA and more patients survived to operative intervention [66].

Perhaps because of the previously mentioned potential advantages, a systematic review and meta-analysis reported that use of REBOA over aortic cross-clamping during RT in patients with NCTH may be associated with improved in-hospital mortality (67). This systematic review included three cohort studies (two retrospective and one prospective) published between 2016 and 2017 enrolling 1,276 trauma patients with NCTH, including 873 (68%) who underwent REBOA and 403 (32%) who underwent RT [68–70]. When compared with those who received RT, patients who received REBOA had significantly higher systolic BPs, a higher probability of survival on admission, and more often underwent arterial embolization. Using a random-effects model, the pooled adjusted odds of in-hospital mortality was non-significantly lower among patients who underwent REBOA instead of RT. Further, in sensitivity analyses where results were pooled after excluding a study at higher risk of bias or using risk ratios or propensity score-adjusted risk ratios, the risk of in-hospital mortality was significantly lower in patients who underwent REBOA instead of RT.

Importantly, the outcomes of REBOA may be predicated on obtaining early and rapid CFA access [71–73]. In one recent cohort study conducted at an American level 1 trauma center, time to aortic occlusion in trauma patients was faster with RT than REBOA [71]. However, approximately 50% of the overall procedural time was attributed to obtaining CFA access, with no significant difference reported between percutaneous access and surgical cut-down. Therefore, proactive CFA access in injured patients who are thought to possibly need aortic occlusion may be associated with improved outcomes [72,73]. In support of this, in one cohort study of 109 injured patients who presented to one of 23 hospitals in Japan, a shorter hospital arrival to CFA access time in patients managed with REBOA was associated with improved survival [72,73]. Further, patients who achieved CFA access within 22 min of arrival had significantly shorter times to definitive hemostasis and a higher survival at 30 days.

CONCLUSION AND RECOMMENDATIONS

In patients presenting with profound hemorrhagic shock or traumatic circulatory arrest, REBOA may provide a less invasive alternative to EDT that reduces occupational risks and insensible heat losses. REBOA does not appear to be inferior to EDT for patients with traumatic arrest and may permit higher quality CPR and be associated with a higher probability of ROSC. However, the outcomes of REBOA are likely predicated on obtaining early, rapid CFA access and avoiding access-related complications. Therefore, REBOA may afford a potentially less morbid option for proximal aortic control when performed by experienced providers.

Ethics Statement

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

Conflicts of Interest

Dr. Brenner is a Prytime Medical Inc. (the manufacturer of the ER-REBOA™ catheter) Clinical Advisory Board Member. The other authors have no conflicts of interest to declare.

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Author Contributions

MLB conceived the idea for the manuscript. DJR and MLB performed the literature search. DJR wrote the manuscript, which was critically revised by all authors. All authors reviewed and approved the final manuscript.

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