Resuscitative Endovascular Balloon Occlusion of the Aorta: Indications, Outcomes, and Training

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KEYWORDS

- Resuscitative endovascular balloon occlusion of aorta • Hemorrhagic shock
- Aortic occlusion • Aortic balloon • Noncompressible torso hemorrhage
- Resuscitative thoracotomy

KEY POINTS

- Resuscitative endovascular balloon occlusion of aorta (REBOA) is an adjunct to trauma hemorrhage control; it provides early aortic occlusion to improve blood pressure and stabilize patients to undergo definitive hemorrhage control.
- The 2 main indications for REBOA use in trauma are hemorrhagic shock related to pelvic hemorrhage or abdominal/torso hemorrhage.
- REBOA is deployed in aortic zone III for pelvic hemorrhage and zone I for abdominal or truncal hemorrhage; zone II is a zone of no occlusion.
- After REBOA placement and balloon inflation, definitive hemostasis must be achieved either in the operating room, hybrid suite, or interventional radiology.
- Appropriate implementation of REBOA requires adequate endovascular inventory (a REBOA kit) and a clear concise REBOA protocol so that the REBOA procedure is standardized. Advanced education and training are required for all practitioners responsible for REBOA insertion.

INTRODUCTION

Aortic balloon occlusion has been successfully used for ruptured abdominal aortic aneurysm control with increased survival,[1] aortoenteric fistula aortic hemorrhage control,[2] postpartum or abdominal/pelvic surgery hemorrhage,[3] hemoperitoneum owing to splenic artery aneurysm,[4] gastrointestinal hemorrhage, and for control of vascular injuries. Aortic balloon occlusion for treatment of ruptured abdominal aortic aneurysm is now the standard of care.[5] However, the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in trauma is relatively new. REBOA is an adjunct to trauma hemorrhage control, providing early aortic occlusion to improve blood

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Crit Care Clin 33 (2017) 55–70
http://dx.doi.org/10.1016/j.ccc.2016.08.011 **criticalcare.theclinics.com**

pressure and transiently stabilize patients to undergo definitive hemorrhage control. REBOA must be in the armamentarium of the trauma surgeon to assist in achieving prompt hemostasis.

HISTORY

Resuscitative balloon occlusion of the aorta for the treatment of traumatic hemorrhagic shock was first reported in 1954 by Lieutenant Colonel Carl W. Hughes, US Army (Walter Reed Army Medical Center) in 3 critically injured soldiers (**Fig. 1**). It was reported that, "It was arbitrarily decided that the catheter would be used only in moribund cases with evidence of intra-abdominal bleeding in which blood pressure could not be obtained after administration of 10 units of blood."[6] All patients died from major injuries and he recommended earlier use of aortic balloon occlusion may be beneficial.

In 1986, a preliminary report of the use of Percluder occluding aortic balloon in 23 patients included 15 trauma patients. Although all patients had an increase in arterial pressure with aortic occlusion, only 2 of the 15 trauma patients (13%) were long-term survivors.[7]

In 1989, Shaftan and colleagues[8] reported the use of intraaortic balloon occlusion in penetrating abdominal trauma in 21 patients with variable outcomes: group 1 (n = 5) cardiac rhythm, no systolic blood pressure (SBP), no survivors; group 2 (n = 6) SBP of less than 80 mm Hg, 3 survivors (50%); and group 3 (n = 10), hemodynamic deterioration to SBP of 80 mm Hg, 4 survivors (40%). These early REBOA patient series were fraught with problems related to delayed implementation of REBOA and prolonged aortic occlusion.

A recent systematic review of REBOA use in the management of hemorrhagic shock identified 41 studies with 857 total patients. Clinical settings included postpartum hemorrhage (n = 5), upper gastrointestinal bleeding (n = 3), pelvic surgery (n = 8), trauma (n = 15), and ruptured aortic aneurysm (n = 10). The overall mortality rate was 49.4%. REBOA did increase the SBP by 53 mm Hg in all patients.[9] However, it is not possible to determine whether REBOA had any positive impact on the ultimate outcome from these reports.

The first report of intraaortic balloon occlusion without fluoroscopy for the treatment of life-threatening hemorrhagic shock from pelvic fracture in 13 patients was published

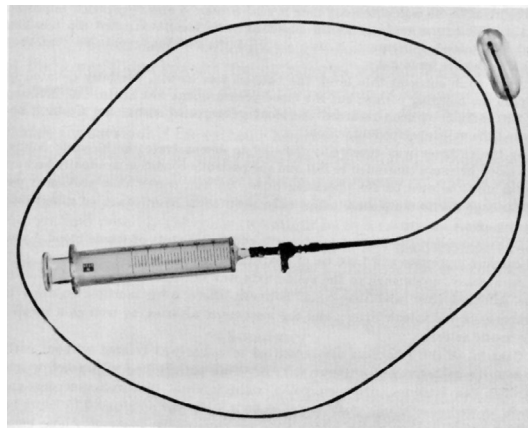

Fig. 1. Lt. Col. Carl W. Hughes' original balloon catheter for aortic occlusion. (*From* Hughes CW. Use of an intra-aortic balloon catheter tamponade for controlling intra-abdominal hemorrhage in man. Surgery 1954;36:65–8.)

in 2010, with successful placement of all aortic balloons and significant increase in SBP by 70 mm Hg.[10] Angiography confirmed arterial injury in 92% of patients requiring embolization and the survival rate was 46%. This report was the first to demonstrate that REBOA placement was life saving in that it permitted hemodynamic stabilization for safe transport to angiography. The survival rate was inversely related to duration of balloon inflation and the mean injury severity score.

Since 2010, there has been extensive experience with REBOA for the treatment of ruptured abdominal aortic aneurysm, significant improvements in technology, and increased endovascular education. The time is right to expand the use of REBOA into the trauma settings for the treatment of hemorrhagic shock, in particular owing to noncompressible torso hemorrhage and pelvic fracture hemorrhage.

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA PROCEDURE

REBOA can be a life-saving adjunct for the treatment of hemorrhagic shock and appropriate knowledge of the critical steps of the procedure is required. REBOA will be deployed in aortic zone III (from the lowest renal artery to the aortic bifurcation) for pelvic hemorrhage and aortic zone I (take-off of the left subclavian artery to the celiac trunk) for abdominal or truncal hemorrhage. Aortic zone II (from the celiac trunk to the lowest renal artery) is a zone of no occlusion (Fig. 2).

Appropriate implementation of REBOA requires adequate endovascular inventory (a REBOA kit) and a clear concise REBOA protocol (Fig. 3) so that the REBOA procedure is standardized. Advanced education and training are required for all practitioners who will be responsible for REBOA insertion.

Two catheters are used for REBOA in the United States—the CODA balloon catheter (Cook Medical, Bloomington, IN) and the ER-REBOA™ catheter (Prytime Medical Devices, Inc., Boerne, TX; Fig. 4). The CODA balloon catheter comes in 9 and 10 Fr sizes, and requires a stiff guidewire for placement and arterial sheaths of 12 or 14 Fr for insertion. Use of the large introducer sheaths mandates open arterial repair after sheath removal.

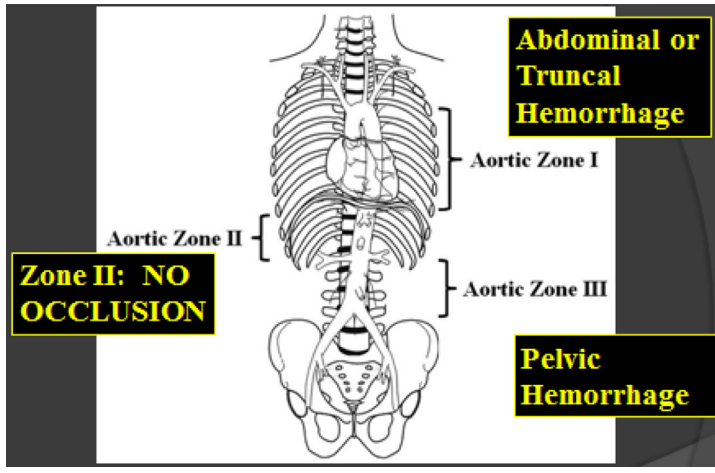

Fig. 2. Aortic zones for REBOA balloon inflation. If abdominal or truncal hemorrhage, the REBOA balloon is inflated in zone I; for pelvic hemorrhage, the REBOA balloon is inflated in zone III. REBOA, resuscitative endovascular balloon occlusion of the aorta. Zone 1: take-off of the left subclavian artery down to the celiac trunk; Zone 2: from the celiac trunk to the lowest renal artery; Zone 3: from the lowest renal artery to the aortic bifurcation.

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Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) as Adjunct for Hemorrhagic Shock

Similar to resuscitative thoracotomy with aortic clamping for traumatic arrest due to hemorrhage, REBOA is used for temporary aortic occlusion. REBOA supports proximal aortic pressure and minimizes hemorrhage until hemorrhage control and hemostasis are obtained. REBOA can be used instead of resuscitative thoracotomy in hemorrhagic shock.

REBOA Steps:

1. **Arterial access and Sheath Placement**
   a. Ultrasound-guided femoral arterial access with Micropuncture kit (21 gauge needle, 4 or 5 French catheter and dilator, 0.018 inch guidewire)
   b. Or Femoral arterial cut-down, proximal/distal control for direct puncture
   c. Upsize to 12/14-French Introducer Sheath with Amplatz guidewire (0.035 in)
   d. Confirm Amplatz guidewire position in proximal aorta – digital radiography
2. **Balloon selection and positioning**
   a. Cook Medical CODA Balloon 10 Fr (32 mm diameter, 120cm length)
   b. Cook Medical CODA Balloon 9 Fr (can use with 12 Fr Introducer sheath)
   c. Compliant, low-atmosphere, high volume balloon, max diameter 40 mm
3. **Balloon inflation**
   a. Use the minimal pressure to gain wall apposition, to prevent aortic injury.
   b. 30-60cc syringe – fill with NS or ½ NS/Contrast for visualization and hand-inflate. Balloon maximum inflation volume is 40cc (9Fr, max 30cc volume).
   c. All attempts should be made to minimize the time of balloon inflation
4. **Balloon deflation**
   a. Intermittent deflation of REBOA can be used to optimize visceral perfusion, goal SBP > 90 mm Hg
5. **Sheath removal – Primary arterial repair needed after 14Fr sheath removal**

REBOA INTRA-AORTIC PLACEMENT

The placement of the balloon is determined by the location of the injury and ongoing hemorrhage:

Zone 1 Descending Thoracic Aorta (origin of left subclavian artery to celiac artery) is used for truncal hemorrhage control

Zone 2 Para-visceral Aorta (celiac artery to lowest renal artery): **NO-OCCLUSION ZONE**

Zone 3 Infra-renal Aorta (lowest renal artery to aortic bifurcation) for pelvic hemorrhage and junctional bleeding.

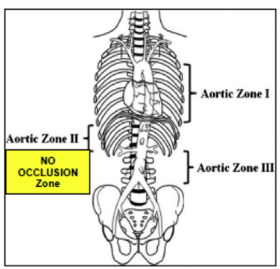

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Fig. 3. REBOA kit and cart in Royal London Hospital emergency department. University of Michigan REBOA protocol. REBOA, resuscitative endovascular balloon occlusion of the aorta. (*Courtesy of* University of Michigan Health System, Ann Arbor, MI.)

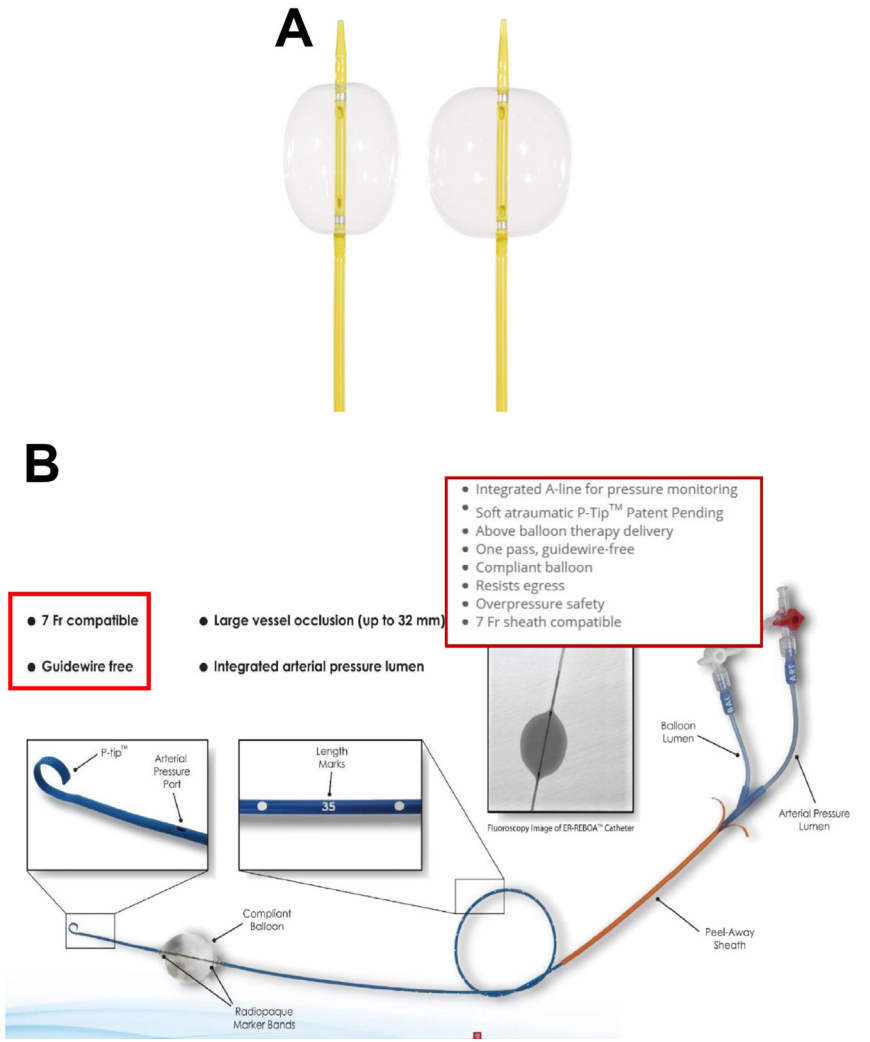


Fig. 4. REBOA catheters available for use in Trauma. (*A*) Cook CODA Balloon catheter, can occlude aortic diameters up to 40 mm. A 9 Fr CODA balloon catheter requires a 12 Fr arterial sheath. A 10 Fr Coda balloon requires a 14 Fr arterial sheath. Both require open primary arterial repair after sheath removal (www.cookmedical.com). (*B*) ER-REBOA™ Catheter (approved by the US Food and Drug Administration in October 2015), can occlude aortic diameters of up to 32 mm. It requires a 7 Fr arterial sheath. No guidewire is required for placement. It has length markings on the catheter, integrated arterial pressure lumen for arterial pressure monitoring, and does not require arterial repair after sheath removal (ER7232A; available: www.pryormedical.com). (*Courtesy of* Prytime Medical, Lakewood, CO; http://prytimemedical.com/.)

The ER-REBOA™ catheter (see **Fig. 4**) is a new smaller aortic occlusion balloon that is now available (received approval from the US Food and Drug Administration in October 2015). This REBOA catheter allows for percutaneous access through a 7-Fr sheath, can be placed without guidewire, has integrated arterial pressure

monitoring, and has distance markings on the catheter to facilitate appropriate length of placement. Arterial repair is not required after removal.

Since 2013, Japan has used 7 Fr REBOA catheters (non–heparin-bonded polyurethane balloon catheter inserted over a 0.025-in guidewire; Rescue Balloon, Tokai Medical Products, Kasugai, Japan) through a 7-Fr sheath for refractory traumatic hemorrhagic shock. A report from January 2014 to June 2015 at 5 hospitals in Japan confirmed that percutaneous arterial access without fluoroscopy was achieved in all 33 patients. Of 33 REBOAs, 20 were performed by emergency medicine practitioners (10 with endovascular training) and 3 by interventional radiologists. No complication related to sheath insertion or removal was identified during the follow-up period, including dissection, pseudoaneurysm, retroperitoneal hematoma, leg ischemia, or distal embolism.[11]

The specific REBOA insertion steps (**Table 1**) are different depending on which REBOA catheter is used. After the aortic occlusion catheter is in place, the subsequent steps are the same for both catheters. Once the REBOA balloon is inflated (**Fig. 5**) and placement is confirmed by portable radiograph, the exact time of aortic balloon inflation is marked, commonly directly on the patient's catheter dressing. The REBOA device must then be stabilized and the patient transported to the appropriate location for definitive hemorrhage control (**Box 1**) depending on institutional resources and trauma team training.

Early aortic occlusion in severe hemorrhagic shock restores increased central aortic pressure, and carotid and brain perfusion. The REBOA balloon ideally should be inflated until definitive hemorrhage control is established. However, sustained aortic occlusion leads to multiple organ ischemia and failure and ultimately death. Intermittent deflation of the REBOA balloon, therefore, is commonly used to provide organ reperfusion.

Table 1
REBOA insertion steps

CODA Balloon Catheter (9 Fr or 10 Fr)	ER-REBOA™ Catheter (7 Fr)

• Micropuncture – common femoral artery (4–5 Fr)
• Advance Guidewire (SuperStiff Amplatz, 0.035 in × 260 cm, Boston Scientific)
• Confirm location of guidewire tip in proximal aorta (portable digital radiology)
• Up-size to 12 Fr or 14 Fr Introducer Sheath
  ◦ 12 Fr sheath for 9 Fr CODA
  ◦ 14 Fr sheath for 10 Fr CODA
• Advance Coda Balloon over guidewire into introducer sheath
  ◦ Zone 1 to above xiphoid, approximately 50 cm
  ◦ Zone 3 to just above umbilicus, approximately 40 cm
	• Micropuncture – common femoral artery
	• Terumo pinnacle introducer sheath 7 Fr
	• Slide peel-away sheath toward catheter distal tip to fully enclose/straighten P-tip
	• Connect and flush the arterial line via the 3-way stopcock
	• Insert peel-away sheath and catheter into the 7 Fr introducer sheath approximately 5 mm or until the peel-away sheath hits a stop
	• Advance the catheter 10–20 cm, then slide peel-away sheath away from the catheter
	• Advance catheter to appropriate position
	  ◦ Zone 1 to above xiphoid, approximately 50 cm
	  ◦ Zone 3 to just above umbilicus, approximately 40 cm

• Obtain digital radiograph to ensure that catheter is within aorta • Inflate REBOA (30 mL syringe, 50/50 contrast/NS) until resistance met • Repeat portable digital radiograph with balloon inflated to ensure proper location • Secure catheter to patient to prevent device migration • Note time of balloon inflation, minimize aortic occlusion time, consider partial occlusion	

Abbreviation: REBOA, resuscitative endovascular balloon occlusion of the aorta.

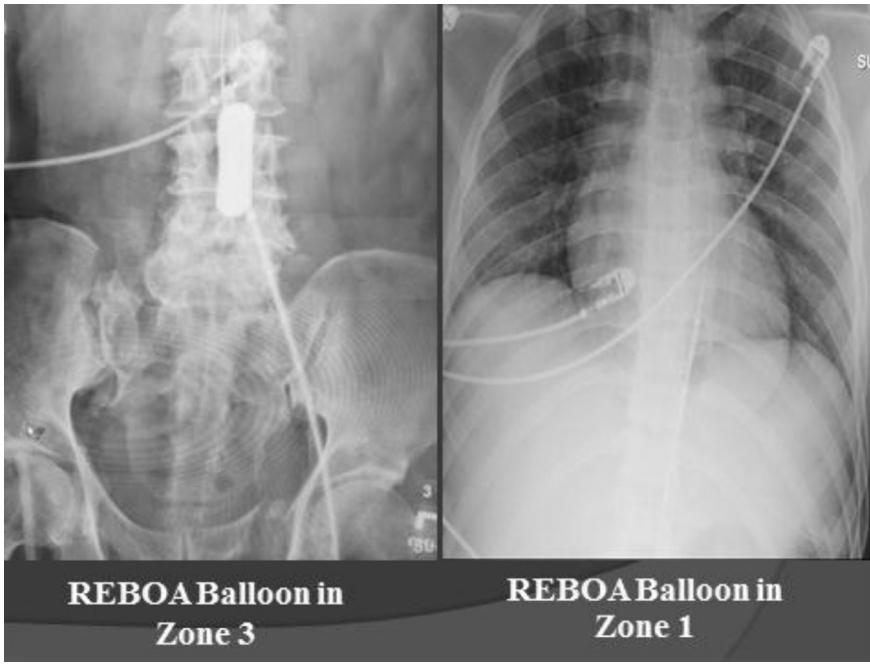


Fig. 5. REBOA balloon inflated in zone 3 (with contrast filling balloon) versus zone 1 (saline filling balloon). REBOA, resuscitative endovascular balloon occlusion of the aorta.

Partial REBOA has been advocated to mitigate the ischemia–reperfusion injury associated with total aortic balloon occlusion.[12] This technique is in common practice in Japan, with intermittent aortic balloon deflation to promote reperfusion or organs when feasible.

Once definitive hemorrhage control is established, the REBOA balloon catheter is removed. The femoral sheath can remain in place as arterial access for arterial blood pressure monitoring and/or for concern that the patient may require additional angiographic evaluation for recurrent hemorrhage. A 7-Fr femoral arterial sheath does not require open arterial repair, and can be removed with use of a closure device or direct pressure for 20 minutes.

Box 1
After REBOA insertion in emergency department

- Definitive hemorrhage control
- Either OR or IR or hybrid suite
- If IR, angioembolization can sometimes be performed via same sheath as REBOA
- After definitive hemorrhage control, REBOA removal must be performed in OR; open repair of femoral artery required if arterial sheath is 12 to 14 Fr, not required if 7 Fr sheath.

Abbreviations: IR, interventional radiology; OR, operating room; REBOA, resuscitative endovascular balloon occlusion of the aorta.

INDICATIONS FOR RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA USE IN TRAUMA

There are 2 main potential indications for REBOA use in trauma: hemorrhagic shock related to pelvic hemorrhage or abdominal/torso/truncal hemorrhage. In civilian trauma, it seems that REBOA use in pelvic hemorrhage will be a stronger indication, given the evidence of a persistently high mortality rate in these patients and substantial delay to angioembolization in most institutions.

In combat casualty care, REBOA indications may differ somewhat based on the injury patterns seen. A recent gap analysis of severely injured UK combat casualties identified that 18.5% of patients had injury patterns with potential indication for REBOA. In this patient cohort, 25% of deaths occurred en route to hospital with the median time to death of 75 minutes. The authors concluded that 1 in 5 severely injured UK combat casualties have a focus of hemorrhage in the abdomen or pelvic junctional region potentially amenable to REBOA deployment, and that REBOA should be explored as a potential en route hemorrhage control and resuscitation adjunct.[13]

The Joint Theater Trauma System Clinical Practice Guideline: Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for Hemorrhagic Shock was established in June 2014 to provide guidance for use of REBOA in trauma. This guideline includes the Traumatic Arrest Algorithm (**Fig. 6**) and the Algorithm for the Management of Profound Shock (**Fig. 7**).[14] Contraindications to REBOA include blunt cardiac or aortic injury, and penetrating neck or chest trauma where resuscitative thoracotomy may have an advantage in the provision of definitive hemorrhage control. The University of Maryland Shock Trauma algorithm for REBOA use has "possible Aortic injury on chest radiograph" as the only contraindication to REBOA use (**Fig. 8**). It is important for

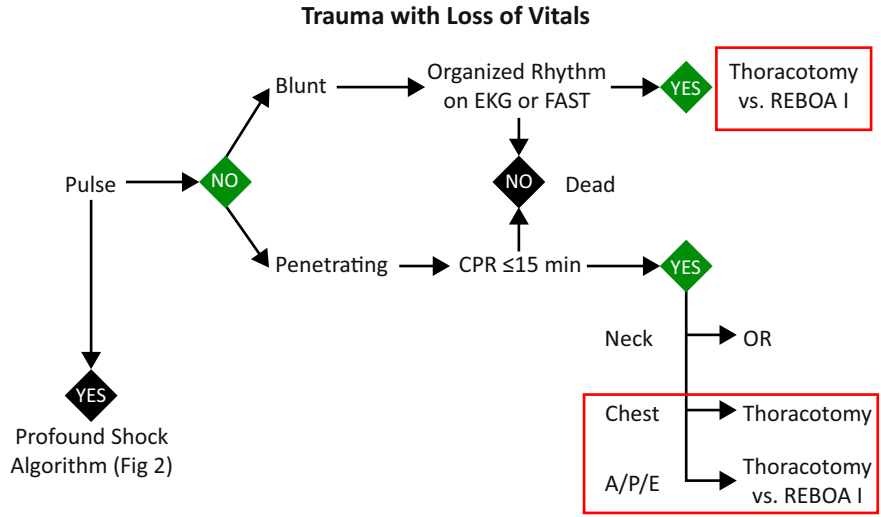


Fig. 6. Joint theater trauma system clinical practice guideline: resuscitative endovascular balloon occlusion of the aorta (REBOA) for hemorrhagic shock. Traumatic arrest algorithm. A/P/E, Abdomen/pelvis/extremity; CPR, cardiopulmonary resuscitation; EKG, electrocardiograph; FAST, focused assessment with sonography for trauma; REBOA I, Placement of aortic balloon in the thoracic aorta (2–8 cm above the xyphoid). (*From* U.S. Army Institute of Surgical Research. Joint Theater Trauma System Clinical Practice Guideline. Available at: http://www.usaisr.amedd.army.mil/assets/cpgs/REBOA_for_Hemorrhagic_Shock_16Jun2014.pdf. Accessed August 25, 2016.)

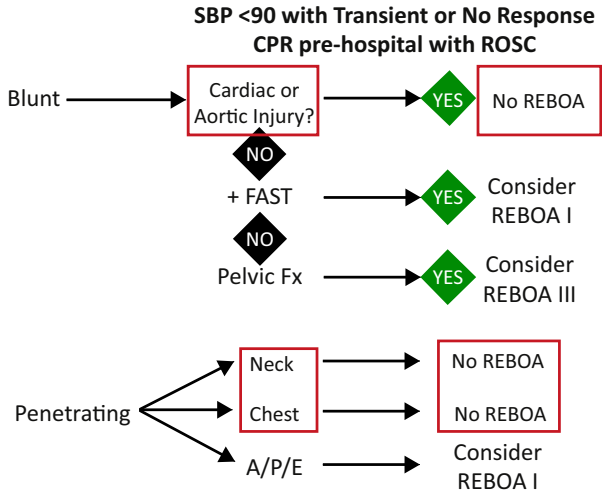


Fig. 7. Joint theater trauma system clinical practice guideline: resuscitative endovascular balloon occlusion of the aorta (REBOA) for hemorrhagic shock. Algorithm for the management of profound shock. A/P/E, Abdomen/pelvis/extremity; CPR, cardiopulmonary resuscitation; Fx, fracture; REBOA I, placement of aortic balloon in the thoracic aorta (2–8 cm above the xyphoid); REBOA III, placement of aortic balloon directly above the bifurcation (1–2 cm above the umbilicus); ROSC, return of spontaneous circulation; SBP, systolic blood pressure. (*From* U.S. Army Institute of Surgical Research. Joint Theater Trauma System Clinical Practice Guideline. Available at: http://www.usaisr.amedd.army.mil/assets/cpgs/REBOA_for_Hemorrhagic_Shock_16Jun2014.pdf. Accessed August 25, 2016.)

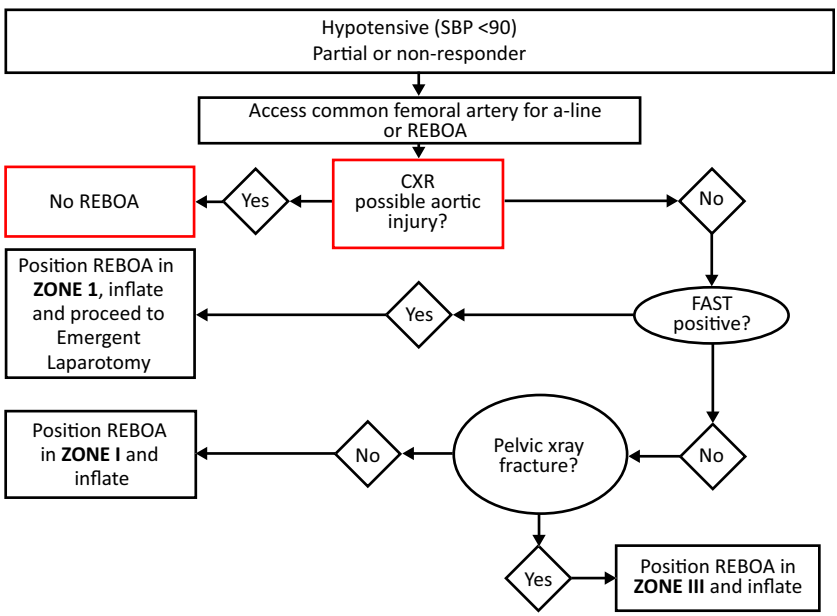


Fig. 8. University of Maryland Shock Trauma Center algorithm for REBOA use in hemorrhagic shock. CXR, chest radiograph; REBOA, resuscitative endovascular balloon occlusion of the aorta; SBP, systolic blood pressure. (*Courtesy of* University of Maryland Medical Center, Baltimore, MD. Available at: http://umm.edu/programs/shock-trauma. Accessed August 25, 2016.)

each institution to devise algorithms for REBOA use depending on local institutional and trauma team resources and strengths.

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA USE IN PELVIC FRACTURE HEMORRHAGE

Current management of hemorrhage related to severe pelvic fractures is quite variable. The report of the American Association for the Surgery of Trauma multicenter prospective, observational study of patients with pelvic fracture from blunt trauma included 1339 patients from 11 level I trauma centers, with an in-hospital mortality rate of 9.0%. In this study, 178 patients (13.3%) were admitted in shock, 24.7% underwent angiography with contrast extravasation identified in 62%, and 68% were treated with angioembolization. REBOA was used in only 5 patients in shock by only one of the participating centers. Mortality was 32.0% for patients with pelvic fracture admitted in shock.[15]

Angioembolization is the mainstay of treatment for pelvic fracture hemorrhage, but even in mature level I trauma centers there is significant delay in time to angiography and definitive hemostasis for hemorrhage control. The R. Adams Cowley Shock Trauma Center reported their 10-year experience with 344 pelvic hemorrhage patients who underwent pelvic angiography, documenting a median time to hemostasis with embolization was 344 minutes (interquartile range, 262–433). In this trauma center with robust trauma resources, the median procedure time for embolization was 51 minutes (interquartile range, 37–83), confirming that time from admission to angiography took nearly 4 hours. Overall mortality was 18% owing to hemorrhage (16%) and multiple organ failure (43.5%), documenting the high mortality rate.[16]

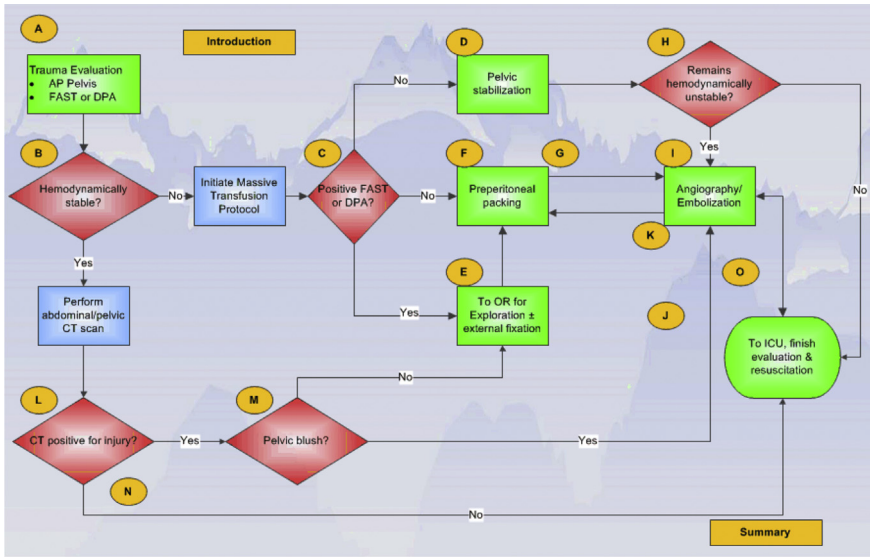
For exsanguinating pelvic hemorrhage from blunt trauma, REBOA inflated at zone III above the aortic bifurcation is very effective at hemorrhage control (**Box 2**). Once a massive transfusion protocol is initiated in patients with pelvic fracture and severe hemorrhagic shock, REBOA performed in the emergency department and inflated in REBOA zone III is the most efficient method by which to provide early transient control of the source of hemorrhage to transport the patient to the appropriate site for definitive hemorrhage control.

The Western Trauma Association Algorithm for Management of Pelvic Fracture with Hemodynamic Instability (**Fig. 9**) has now incorporated REBOA after initiation of massive transfusion protocol, as an adjunct or alternative to pelvic preperitoneal packing.[17] Similarly, the Denver Health Medical Center incorporated REBOA into the algorithm for management of these patients (**Fig. 10**).[18] These algorithms are useful to review when establishing our own institutional algorithms for severe pelvic hemorrhage management.

Box 2
For exsanguinating pelvic hemorrhage from blunt trauma

- REBOA (zone III, above aortic bifurcation) is less invasive than resuscitative thoracotomy.
- REBOA is more effective at aortic control than thoracotomy with aortic compression.
- REBOA is quicker to perform than resuscitative thoracotomy.
- REBOA is easier to control, that is, intermittent balloon deflation to provide perfusion.

Abbreviation: REBOA, resuscitative endovascular balloon occlusion of the aorta.



Expanded from zoomed area of Davis algorithm. Decisions will be based on local resources.

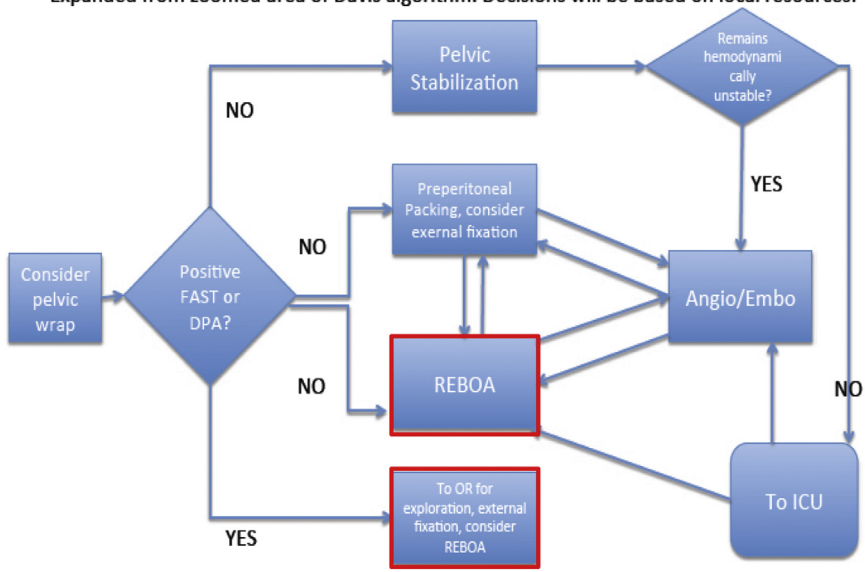


Fig. 9. Western Trauma Association (WTA) algorithm for management of pelvic fracture with hemodynamic instability. AP, anteroposterior; CT, computed tomography; DPA, diagnostic peritoneal aspiration; ICU, intensive care unit; OR, operating room. (*From* Western Trauma Association Algorithms. Available at: http://westerntrauma.org/algorithms/WTAAlgorithms_files/gif_2.htm. Accessed August 25, 2016.)

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA OUTCOMES IN TRAUMA

Japan has had the most experience with REBOA in trauma to date. An analysis of the Japan Trauma Data Bank (2004–2011) compared mortality in adult patients who received REBOA with those who did not. Only 1% of trauma patients received REBOA

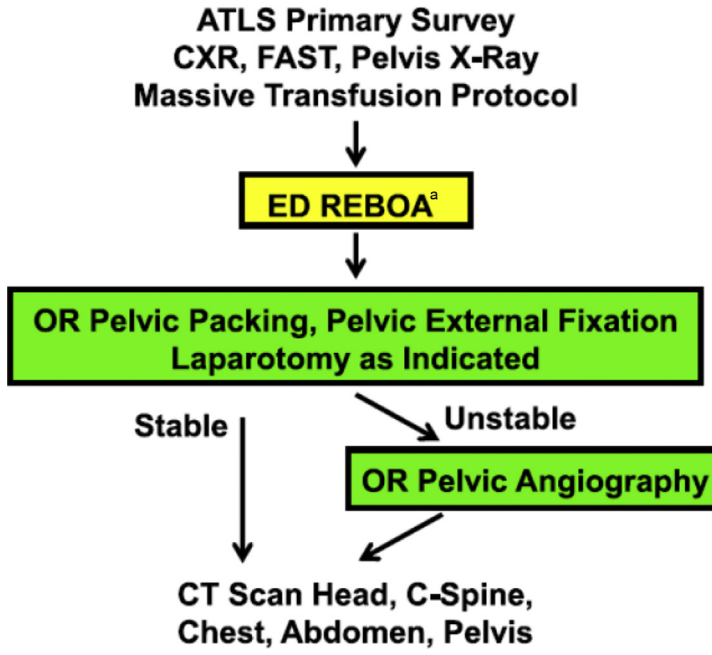


Fig. 10. Revised Denver Health Medical Center (DHMC) algorithm for the management of hemodynamically unstable patients with mechanically unstable pelvic fractures. [a] Zone I if FAST (+), zone III if FAST (−). ATLS, Advanced Trauma Life Support; CT, computed tomography; ED, emergency department; REBOA, resuscitative endovascular balloon occlusion of the aorta. (*From* Biffl WL, Fox CJ, Moore EE. The role of REBOA in the control of exsanguinating torso hemorrhage. J Trauma Acute Care Surg 2015;78(5):1056; with permission.)

and had higher Injury Severity Score (median, 35 vs 13) and higher mortality (76% vs 16%) than those who did not. Although they calculated the likelihood of REBOA treatment via a propensity score using available pretreatment variables and matched treated with untreated patients, this analysis is not helpful in determining the utility of REBOA in trauma. In fact, the authors stated that, "The higher observed mortality among REBOA treated patients may signal 'last ditch' efforts for severity not otherwise identified in the trauma registry."[19]

A retrospective review of REBOA in 24 blunt trauma patients in Japan over a 6-year period included indications of hemorrhagic shock owing to pelvic fracture or hemoperitoneum, with an overall survival rate of 29.2%. Procedural complications were reported in 3 cases (12.5%) with 1 external iliac artery injury and 2 lower limb ischemia, with lower extremity amputation required in all 3 patients.[20] Similarly, a review of the Japan Trauma Data Bank compared in-hospital mortality in patients who underwent REBOA versus those who did not. In-hospital mortality was significantly greater in patients who underwent REBOA (61.8% vs 45.3%), but the etiology of this excess mortality is not clear.[21]

The first report of patient outcomes with REBOA implementation in 2 US civilian trauma centers was a descriptive case series (December 2012 to March 2013) with 6 patients. Mean SBP at the time of REBOA was 59 mm Hg, and mean base deficit was 13. Arterial access was accomplished using both direct cutdown (n = 3) and percutaneous (n = 3) access to the common femoral artery. Time to aortic occlusion

was 4 to 6 minutes in all patients. REBOA resulted in a mean SBP increase of 55 mm Hg, and the mean aortic occlusion time was 18 minutes. There were no REBOA-related complications and no hemorrhage-related mortality. This report confirmed that REBOA was an effective means of traumatic hemorrhage control in mature civilian trauma systems.

A trauma registry report comparing patients undergoing resuscitative thoracotomy (n = 72) or REBOA (n = 24) during an 18-month period from 2 level I trauma centers, documented a significantly greater number of deaths in the emergency department among the resuscitative thoracotomy patients compared with REBOA patients (62.5% vs 16.7%; $P < .001$). Furthermore, REBOA had fewer early deaths and improved overall survival as compared with resuscitative thoracotomy (37.5% vs 9.7%; $P = .003$).[22]

The Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) Registry provided some data regarding aortic occlusion and REBOA use from 8 American College of Surgeons level I trauma centers. Aortic occlusion patients (n = 114; 46 REBOA, 68 open) most commonly was performed in the emergency department (73.7%) and overall survival was 21.1%. REBOA was inserted by femoral cutdown in 50% of patients. Complications of REBOA were uncommon (pseudoaneurysm, 2.1%; embolism, 4.3%; limb ischemia, 0%). There was no difference in time to successful aortic occlusion between REBOA and open procedures (REBOA, 6.6 $\pm$ 5.6 minutes; open occlusion of the aorta, 7.2 $\pm$ 15.1; $P = .842$). There was no difference in mortality (REBOA, 28.2% [13 of 46]; open occlusion of the aorta, 16.1% [11 of 68]; $P = .120$).[23]

An interesting report of nonoperative management of hemodynamically unstable abdominal trauma patients with angioembolization and REBOA documented that REBOA can be performed by well-trained physicians in the intensive care unit or the emergency department under ultrasound guidance. These patients were severely injured with an Injury Severity Score ranging from 25 to 75, all hypotensive owing to hemorrhagic shock from trauma, and total aortic occlusion times of 33 to 150 minutes. Only 1 of 7 patients died with an inability to achieve hemorrhage control, and inability to deflate the REBOA balloon.[24]

At present, we do not have high-quality Level I evidence for REBOA efficacy in the treatment of traumatic hemorrhagic shock, and additional research is clearly warranted. But this was true of endovascular aortic repair for blunt traumatic aortic injury as well; a randomized trial has never been performed yet endovascular aortic repair is the current standard of care.[25] Additional advances in REBOA technology and increased use and experience with prospective monitoring of outcomes is necessary.

PREHOSPITAL RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA

The world's first prehospital REBOA was performed by London's Air Ambulance in June 2014 after 2 years of development with the Royal London Hospital.[26–28] The patient had fallen 15 m and had catastrophic internal hemorrhage owing to pelvic fractures. He was treated by the physician–paramedic team with insertion of a REBOA balloon catheter at the scene to control likely fatal exsanguination. The patient survived transfer to hospital, emergency angioembolization, and subsequent surgery. He was discharged neurologically normal after 52 days and went on to make a full recovery. This group was masterful in establishing the appropriate education and training to safely accomplish prehospital REBOA. There are clearly significant challenges to prehospital REBOA and guidelines will be required to enable safe implementation more widely for the future of trauma patient care.

EDUCATION AND TRAINING

Appropriate education and training for REBOA are required to be able to perform this invasive procedure safely, particularly because it will be performed in patients who are critically ill and hemodynamically unstable owing to hemorrhagic shock.[29] We strongly recommend collaboration with both vascular surgery and interventional radiology at each institution to optimally train trauma surgeons in these endovascular techniques, because it is very important to obtain increased exposure to these techniques in patients commonly managed by these 2 specialty groups.

At present, there is no common standard for competency assessment and credentialing for REBOA insertion and catheter-based hemorrhage control in the United States. We must work toward this goal with inclusion of trauma and acute care surgeons in the provider group for these important skills.

A number of REBOA courses are available for optimal education, including the Endovascular Skills for Trauma and Resuscitative Surgery Course,[30] the BEST course,[31] and others. These courses have confirmed that damage control endovascular procedures can be effectively taught using virtual reality simulation and live animal laboratories.[31,32] By the end of the Endovascular Skills for Trauma and Resuscitative Surgery course, students were able to achieve the first 3 steps of REBOA (vascular access, balloon positioning, balloon inflation) in 2 minutes. Each institution will need to determine optimal training for their trauma team members.

SUMMARY

Exsanguinating torso hemorrhage is a leading killer of trauma patients. The most appropriate means of torso hemorrhage control must be tailored to the clinical situation by the trauma team. Trauma surgeons should have expertise with all approaches for prompt hemorrhage control, including trauma laparotomy, REBOA, and resuscitative thoracotomy. REBOA is an exciting endovascular advancement as an adjunct in traumatic hemorrhage control because it can be deployed quickly, can be placed percutaneously, has a high rate of technical success, balloon inflation/deflation can be varied depending on the patient's physiology, and advances in technology have markedly decreased the size of the aortic balloon catheters. Balloon occlusion of the aorta is equivalent to cross-clamping the aorta. REBOA is effective in hemorrhagic shock as a bridge to definitive hemostasis. REBOA has been used successfully in vascular surgery for the last 20 years and is now expanding to trauma applications. Endovascular training is important for trauma surgeons caring for these critically ill patients at high risk of death from traumatic hemorrhage.

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