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Techniques and Procedures

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA: A REVIEW FOR EMERGENCY CLINICIANS

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☐ **Abstract—Background: Non-compressible torso hemorrhage (NCTH) is difficult to control and associated with significant mortality. Resuscitative endovascular balloon occlusion of the aorta (REBOA) utilizes an infradiaphragmatic approach to control NCTH and is less invasive than resuscitative thoracotomy (RT). This article highlights the evidence for REBOA and provides an overview of the indications, procedural steps, and complications in adults for emergency clinicians. Discussion: Traumatic hemorrhage can be life threatening. Patients in extremis, whether from NCTH or exsanguination from other sites, may require RT with aortic cross-clamping. REBOA offers another avenue for proximal hemorrhage control and can be completed by emergency clinicians. The American College of Surgeons Committee on Trauma and the American College of Emergency Physicians recently released a joint statement detailing the indications for REBOA in adults. The evidence behind its use remains controversial, with significant heterogeneity among studies. Most studies demonstrate improved blood pressure without a significant improvement in mortality. Procedural steps include arterial access (most commonly the common femoral artery), positioning the initial sheath, balloon preparation and positioning, balloon inflation, securing the balloon/sheath, subsequent hemorrhage control, balloon deflation, and balloon/sheath removal. Several major complications can occur with REBOA placement. Future studies should evaluate training protocols, the role of simulation, and which target populations would benefit most from REBOA. Conclusions: REBOA can provide proximal hemorrhage control and can be performed by emergency clinicians. This article evaluates the evidence, indications, procedure, and complications for emergency clinicians. Published by Elsevier Inc.**

☐ **Keywords—resuscitative endovascular balloon occlusion of the aorta; REBOA; hemorrhage; junctional hemorrhage; aortic occlusion; catheter; balloon; complication**

INTRODUCTION

Trauma is the primary cause of death among patients aged 1–45 years, with more than 214,000 deaths in 2015 in the United States alone (1–4). Hemorrhage accounts for a significant proportion of preventable deaths in trauma and is the most treatable etiology (2,3). Early and aggressive intervention is important, as most deaths occur in the initial stages of trauma (3). Traumatic hemorrhage is categorized as compressible or non-compressible. Compressible sites involve anatomic areas amenable to direct pressure or a tourniquet (3–7). Hemorrhage from compressible sites is associated with lower mortality rates compared to non-compressible sites (8–13). Non-compressible sites include the pulmonary system, solid organs, axial torso vessels, and pelvic fractures with ring disruption. Junctional hemorrhage includes bleeding occurring at the junction of an

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extremity with the torso, preventing effective use of an extremity tourniquet (8,10). Non-compressible torso hemorrhage (NCTH), which includes junctional hemorrhage, is difficult to control and associated with mortality rates approaching 45% (8,9). Of the deaths associated with hemorrhage, 90% are from NCTH (11–13).

Obtaining hemostasis in NCTH often requires invasive procedures, such as a laparotomy or thoracotomy. Patients in extremis, whether from NCTH or exsanguination from other sites, may be candidates for resuscitative thoracotomy (RT) with aortic cross-clamping (14). Aortic occlusion using this approach provides supraceliac hemorrhage control for abdominal, pelvic, and junctional bleeding. However, RT is associated with high mortality rates, which may be due to injuries from the procedure itself (15–20). Therefore, resuscitative endovascular balloon occlusion of the aorta (REBOA) provides an avenue for infra-diaphragmatic hemorrhage control that is less invasive and may be performed more rapidly than RT (5–7,14,21,22). However, REBOA is not recommended for the management of supra-diaphragmatic injuries and does not serve to replace thoracotomy in the setting of thoracic injury (5–7,21). The procedure utilizes many skills emergency clinicians already possess, such as arterial line placement and the Seldinger technique (21).

Intra-aortic balloon occlusion was first described in the 1950s during the Korean War (23). This was followed by several decades without advancement, until the publishing of a 23-patient case series on the Percluder device in 1986 (24). REBOA's utility has been described in oncologic resections, ruptured abdominal aortic aneurysm (AAA), and pelvic hemorrhage in the setting of gynecologic disease (22–32). Heimbecker utilized an aortic tampon for control of a ruptured AAA in 1964 (32). Over time, its use has expanded to a number of major trauma centers worldwide, and subsequent human and animal studies have evaluated REBOA as an adjunct in trauma resuscitation (4–7,22–32). REBOA involves temporarily occluding aortic flow by placement of an endovascular balloon within the aortic lumen via a peripheral artery, providing hemorrhage control and improving proximal perfusion, which increase cerebral and coronary circulation (4–7,14,33). This approach is only indicated for hemorrhage below the diaphragm, as injury proximal to the site of balloon inflation will be exacerbated by REBOA placement (14,21,22,32). If injury is present above and below the diaphragm, REBOA is not recommended due to worsening of the injury above the diaphragm (14,21,22). REBOA placement may cause fewer physiological disturbances and have greater success than RT with aortic cross-clamping for management of infra-diaphragmatic hemorrhage. Emergency clinicians possess the necessary skills to perform REBOA placement and play an integral role in resuscitation of critical patients.

This article will discuss the evidence and controversy of REBOA in adult patients, indications and contraindications, a guide for placing the REBOA device in adults, device complications, and future directions for REBOA.

DISCUSSION

Evidence and Controversy

The literature demonstrates conflicting results with REBOA, with some studies suggesting benefit and others finding increased mortality (4–7,28,33–40). Studies predominantly evaluate the following three properties of REBOA: ability to improve hemodynamic status, physiological effects, and mortality rate (37,38). Much of the published literature consists of case reports, case series, and retrospective cohort trials (37,38). Other studies have been conducted in animal models (6,20,36). This article will focus on studies primarily evaluating human patients.

Several systematic reviews and meta-analyses have been published on REBOA (37,38). The first was published in 2015 and consisted of 41 studies comprising 857 patients, though clinical setting varied in the included studies (37). Five studies involved patients with postpartum hemorrhage, 3 had upper gastrointestinal bleeding, 8 had pelvic surgery, 10 had a ruptured aortic aneurysm, and 15 had trauma. Shock was present in 75.6% of these patients when REBOA was utilized, and the overall mortality rate was 49.4%. Femoral access was utilized in 92.3% of patients, with the brachial artery accounting for the remainder. REBOA improved systolic blood pressure (SBP) by an average of 53 mm Hg. Three deaths were directly associated with the device itself, while other complications included femoral arterial injury, aortic injury, and thromboembolic events (37). However, meta-analysis authors did not find a clear reduction in hemorrhage-related mortality. Unfortunately, this meta-analysis had weak evidence quality, as well as significant bias and moderate heterogeneity (37). The most recent meta-analysis published in 2018 included 89 studies and 1,436 patients. Eighteen studies included trauma patients, 50 studies with ruptured AAA, and 21 studies with other causes (defined as gastrointestinal bleeding, postpartum hemorrhage, or pelvic surgery) (38). Hemorrhagic shock was present in 79.3% of patients receiving REBOA. The femoral artery was the access site in 96.8% of patients. SBP increased by a mean of 78.9 mm Hg in trauma patients, 56.1 mm Hg in ruptured AAAs, and 52.4 mm Hg in other types of shock with REBOA. Reported mortality was 63% in patients experiencing trauma and 90.9% in unstable trauma patients. Overall mortality was 49.2% in patients undergoing REBOA (38). Pooled results suggest a risk difference of 0.27, supporting REBOA in trauma. Iatrogenic injury related to REBOA occurred in 3.7% of trauma

patients, 2.6% of ruptured AAAs, and 5.3% in other sources of hemorrhage (38). Similar to the prior meta-analysis, risk of bias was high (37,38). Additionally, the majority of included studies did not have a control group, and occlusion time varied. Additional data with control groups and randomization, as well as further delineation of specific patient populations, operators, complications, and occlusion times are needed.

Relevant Anatomy

The aorta is the primary endovascular target for REBOA, with device placement usually performed through the common femoral artery (CFA) (39–42). The external iliac artery becomes the CFA as it crosses the inguinal ligament, bifurcating into the superficial femoral artery (SFA) and profunda femoris artery 2–6 cm distal to the inguinal ligament in adults. For the purpose of REBOA, the aorta is divided into three main regions: zone I (from the origin of the left subclavian to the celiac artery, approximately 20 cm in length), zone II (from the celiac artery to the most caudal renal artery, approximately 3 cm in length), and zone III (from the most caudal renal artery to the aortic bifurcation, approximately 10 cm in length) (Figure 1) (14,21,39–42). In a supine patient, the location of zone I is reliably ascertained using external landmarks by measuring the distance from the insertion point to either the xiphoid or mid-sternum in adults (41,42). The location of zone III corresponds to the umbilicus (or just cephalad to it) as an external landmark (14,43). Balloon inflation in zone I is similar to an open thoracic aorta cross-clamp, while inflation in zone III may be used to control pelvic and junctional femoral hemorrhage, while minimizing gastrointestinal and renal ischemia (14,21,22). Balloon inflation in zone II is not advised (14,21,22).

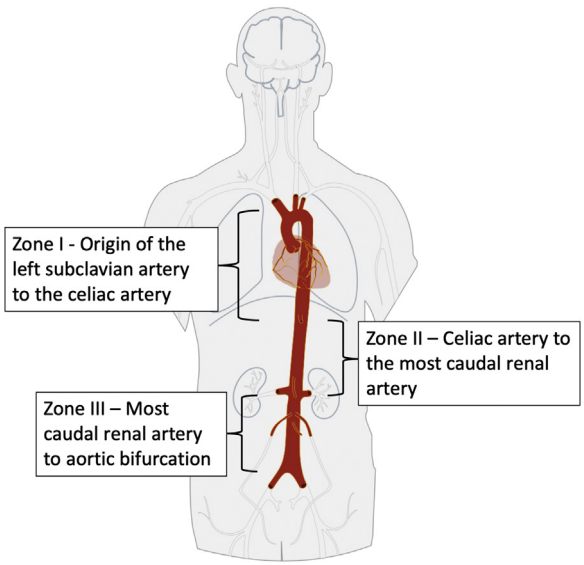

Figure 1. Zones of the aorta.

Indications

Though this article primarily discusses REBOA, initial management of NCTH due to trauma requires hemostatic resuscitation and early hemorrhage control, when possible (14,21,22). Candidates for REBOA include those patients with abdominal, pelvic, or junctional extremity hemorrhage. If the clinician is suspicious of thoracic vascular injury (ie, proximal aortic dissection, cardiac tamponade), REBOA should not be utilized due to the potential for worsening of the thoracic vascular injury (14,21,22).

REBOA can be utilized in several scenarios, including: 1) pulseless electrical activity (PEA) within 10 min of arrest secondary to hemorrhage from a sub-diaphragmatic source with femoral vessels identified on point-of-care ultrasound (POCUS); 2) severe hemorrhagic shock with a pulse; or 3) those in an agonal state with NCTH who do not respond to volume resuscitation (4,7,21,22). For this last indication, patients should have suspected or diagnosed intra-abdominal hemorrhage, pelvic fracture with suspected pelvic hemorrhage, or penetrating injury to the pelvic or femoral region with uncontrolled hemorrhage from a junctional injury (21,22). The literature suggests that patients with a low SBP but not yet in arrest benefit the most from REBOA (4,7,21,22,37,38). Thus, the procedure is best if considered as a proactive intervention, rather than a reactive intervention, with further operative control needed after REBOA placement. The formal indications and guidelines for use and implementation from the American College of Surgeons Committee on Trauma (ACS COT) and American College of Emergency Physicians (ACEP) are listed in Table 1 (21).

These societies' joint statement provides information on guidelines for implementation, transfer of patients, management of the patient with REBOA, REBOA complications, special circumstances, and REBOA training. Per the joint society statement, REBOA should be placed by providers who have undergone a formal course or training for REBOA at centers where definitive control is available. The statement recommends against transfer due to lack of prehospital provider experience with the REBOA device and potential for complications during transport (21). Authors of this review recommend implementation of a REBOA protocol with a multidisciplinary and interdepartmental team, not just vascular surgery, as discussed in the joint statement. While the joint statement recommends a surgeon who is immediately available, REBOA can be lifesaving in cases of severe hemorrhage at institutions that are not Level 1 trauma centers, but that are part of a trauma system that can rapidly transport

Table 1. American College of Surgeons Committee on Trauma/American College of Emergency Physicians Joint Statement on Resuscitative Endovascular Balloon Occlusion of the Aorta (14)

Indications for REBOA	Guidelines for Use and Implementation
"Traumatic life-threatening hemorrhage below the diaphragm in patients in hemorrhagic shock who are unresponsive or transiently responsive to resuscitation." "Patients arriving in arrest from injury due to presumed life-threatening hemorrhage below the diaphragm. No evidence exists for the recommended duration of arrest and use of REBOA but should be used within the same time period as would resuscitative thoracotomy." "The balloon catheter may be inflated at the distal thoracic aorta (zone I) for control of severe intra-abdominal or retroperitoneal hemorrhage, or those with traumatic arrest." "The balloon catheter may be inflated at the distal abdominal aorta (zone III) for patients with severe pelvic, junctional, or proximal lower extremity hemorrhage."	"REBOA protocols should be developed in conjunction with vascular surgery." "REBOA should be performed by an acute care surgeon or an interventionalist (vascular surgeon or interventional radiologist) trained in REBOA." "An acute care surgeon must be immediately available to definitively address the specific cause of hemorrhage to avert the dire complications of truncal and spinal cord ischemia from prolonged aortic occlusion." "Emergency medicine (EM) physicians with added certification in critical care (EMCC) training in REBOA may train and perform REBOA, as long as the surgeon(s) is/are immediately available to definitely control the focused source of bleeding." "EM physicians with documented significant experience and training with REBOA during military deployment may train and perform REBOA in conjunction with an acute care surgeon or vascular surgeon trained in REBOA, as long as the surgeon(s) is/are immediately available to definitively control the source of bleeding." "EMCC-certified physicians trained in REBOA must not perform REBOA unless a surgeon is immediately available." "EM physicians without critical care training should not perform REBOA."

REBOA = resuscitative endovascular balloon occlusion of the aorta.

patients to an operating room (44,45). Other recommendations state emergency physicians should only place REBOA after emergency medicine critical care training. Residency-trained emergency medicine clinicians are experts in critical care and possess the necessary procedural proficiency to perform REBOA. With focused training in the procedure, emergency clinicians can safely execute REBOA placement (45).

REBOA contraindications include PEA arrest with femoral vessels not identifiable on POCUS; PEA arrest longer than 10 min; clinical suspicion of thoracic vascular injury resulting in hemorrhage, proximal aortic dissection, or cardiac tamponade; or the presence of a severe pre-existing illness or comorbidity (4,7,21,22,37,38).

Procedure

Importantly, procedural aspects involving REBOA insertion must not interfere with the standard trauma resuscitation. Optimally, the trauma team leader should simultaneously guide the resuscitation and oversee REBOA placement, which should be performed by a different provider if possible (7,21,22). If REBOA is being considered, pre-placement of an arterial line in the CFA may facilitate placement of the REBOA by allowing for a catheter-over-the-wire exchange.

When the decision to intervene is made, rapid CFA access is needed. Before the REBOA catheter is placed, the CFA should be identified with POCUS. If a unilateral junctional vascular injury is present or suspected, the clinician should place the REBOA on the contralateral side (7,21,22). Arterial monitoring in an upper extremity allows evaluation of arterial pressures with balloon inflation. Of note, the procedure can be performed safely with a pelvic binder in place. Equipment required for the procedure is described in Table 2.

Several aortic balloon occlusion devices are available, including ER-REBOA™ (Prytime Medical, Boerne, TX), Berenstein®, the Coda®, and the Reliant® (5,46–49). All devices are similar in their ability to occlude the aorta with balloon inflation. The ER-REBOA device differs slightly with respect to several factors, including an atraumatic flexible P-tip (a rounded catheter tip), a wire within the sheath, an arterial monitoring port proximal to the balloon (used to assess pre-balloon occlusion blood pressure and response to REBOA), and markings that assist with placement (46).

This next section will detail a step-by-step approach for REBOA balloon catheter placement (22,46–49). Though specific devices differ in several components, the major steps are similar among the devices.

Establish Arterial Access

The clinician may access the CFA with a blind percutaneous approach, POCUS with percutaneous access, or surgical cut-down (7,22). However, using POCUS is strongly recommended, as it allows definitive

Table 2. Required Equipment for Performing a Resuscitative Endovascular Balloon Occlusion of the Aorta Procedure

Equipment
18-gauge arterial line set (or echogenic 18-gauge needle, Seldinger type) or a 5Fr micropuncture introducer set (preferred) for CFA access
Guide wire
7Fr (minimum) arterial sheath (refer to individual product specifications for sheath compatibility)
REBOA balloon device
Ultrasound with linear probe and sterile probe cover
10–20 mL syringe
Contrast (1:1 solution of sterile saline and iodinated contrast)
Three-way stopcock device
Sterile drape with chlorhexidine gluconate skin preparation
Suture or central line–securing device
Sterile dressing
Arterial line pressure transduction setup
Standard sterile personal protective equipment

CFA = common femoral artery; REBOA = resuscitative endovascular balloon occlusion of the aorta.

identification of the femoral artery proximal to the takeoff of the profunda femoris artery, minimizing the risk of arterial injury and fistula formation from inadvertent venous access (50–53). POCUS also allows identification of the femoral artery in patients with no palpable pulse due to severe hypotension or anatomical factors (eg, large body habitus) (7,21,22). If POCUS is not available, a landmark approach may be utilized (7,22). Following identification of the CFA, the clinician should access the vessel.

If an open cutdown approach is used, either a vertical or transverse incision may be made. A vertical incision may be easily extended in either direction if the initial incision does not provide adequate exposure to the CFA due to habitus or anatomic variation; however, literature for elective vascular surgery has shown that transverse incisions result in fewer wound complications (54,55). Regardless of the incisional direction, once the CFA is exposed, it should be accessed directly.

Selecting and Positioning the Initial Sheath

Most balloon devices use an over-the-wire approach for balloon placement, such as the Cook Coda 14Fr, Medtronic Reliant 12Fr, and Equalizer balloon 14Fr. The ER-REBOA possesses a wire within the device and a 7Fr sheath. Following catheter placement, the clinician will perform graded dilatations using the Seldinger technique. Micropuncture with dilatation of the arterial puncture site to a 7Fr sheath (using one dilator) is recommended to decrease the risk of vascular injury. The guide wire should move freely with each dilatation. The guide wire should have an atraumatic J-tip, which reduces risk of perforating the arterial wall. A smaller than recommended wire can be used, but not a larger one, which prevents movement within the sheath. When inserting any sheath, the internal dilator hub must be held firmly against the sheath's hemostatic valve hub to ensure a smooth taper from the wire up to the outer sheath diameter, minimizing the risk of arterial injury. The sheath's side-port should be in the "off" position to avoid bleeding through the port.

Balloon Preparation

To prepare the balloon device, attach a 30-mL syringe to the balloon port and ensure that all air is removed from the balloon and balloon catheter. For the ER-REBOA device, the orange peel-away sheath should be present and slid onto the catheter, but other devices do not have the peel-away sheath. The stopcock should be turned to the "off" position, which allows the balloon to pass into the peel-away sheath. The pressure sensor and tubing can be attached to the catheter's arterial stopcock and flushed with saline if pressure monitoring is to be performed (7,22).

Balloon Positioning

The length of the inserted catheter needed to achieve aortic zone I placement is approximated by measuring the distance from the skin insertion point to the midsternum or xiphoid process (with the proximal edge of the balloon at the xiphoid), following the course of the iliac artery to aortic bifurcation near the umbilicus. This measures between 46 and 50 cm in most individuals (4,7,21,22). Zone III placement is achieved by measuring the distance from the skin insertion point to the umbilicus (with the proximal edge of the balloon just above the umbilicus), which is approximately between 26 and 28 cm in most individuals (4,7,21,22). Placement and inflation of the balloon in zone II is not recommended. Insertion depth is determined by the centimeter length markings present on the shaft of the ER-REBOA catheter, but placement requires ultrasound (US) or fluoroscopic guidance for other devices.

When using the guide wire–free ER-REBOA system, once the 7Fr sheath is in place, the wire and introducer are removed. Other devices require catheter introduction over the wire to the desired balloon site. If using a device other than ER-REBOA, the physician advances the balloon catheter to the desired location over the wire. The wire should remain within the catheter to assist in maintaining a stable position for the catheter. The ER-REfBOA does not require the wire for advancement and is packaged with a peel-away sheath on the catheter, which is advanced over the tip of the catheter, straightening the curved P-tip. The peel-away sheath tip is

inserted into the arterial sheath's hemostatic valve and advanced 5 mm, after which the catheter is advanced between 10 and 20 cm. The peel-away sheath is then removed by pulling the splayed flap ends in opposite directions, perpendicular to the catheter trajectory. The balloon catheter is advanced to the desired depth. Confirmation of correct positioning for any balloon device is made with a portable radiograph, fluoroscopy, or POCUS. Radio-opaque markers are present on the balloon catheter, which can help identify the balloon location on radiograph.

Balloon Inflation

A 1:1 solution of sterile saline and iodinated contrast is used for inflation. The assistant should fill the 30-mL syringe with a maximum of 24 mL of this solution, purging all air from the syringe. Though using contrast facilitates visualization of balloon inflation on radiograph, sterile saline may be used alone for inflation. The approximate aortic diameter in zone I is 20 mm, so only 8 mL of solution is needed (46,56). The zone III diameter is approximately 15 mm, corresponding to approximately 3 mL of the solution for balloon inflation. Balloon overinflation must be avoided, as this can rupture the balloon or vessel, or both.

Balloon inflation in the correct zone will result in improved proximal blood pressure (ideally by evaluating invasive arterial blood pressure in an arm) and loss of palpable lower extremity pulses. If the balloon is placed in zone I, the maximum amount of solution instilled for balloon inflation is 8 mL, while in zone III, the maximum amount approximates 3 mL. Balloon inflation should occur without delay to improve proximal blood pressure, which may increase as much as 50 mm Hg. Inflation with excess solution resulting in balloon overdistension is not recommended, as this may result in balloon or vascular rupture. Imaging to evaluate for appropriate placement includes POCUS, fluoroscopy, or radiography. If fluoroscopy is available, the balloon outer edges should be parallel to the aortic wall when inflated. When the appropriate balloon location and hemodynamic response are achieved, the balloon three-way stopcock should be turned to the "off" position. If real-time imaging was not used on initial catheter placement, radiograph, fluoroscopy, or POCUS is recommended at this point (22).

Secure the Balloon and Sheath

To prevent migration of the balloon, the catheter must be secured. A central line–securing device can be utilized, sutured as close to the sheath as possible, and covered with an occlusive dressing. Regardless of the device used, both the sheath and the catheter itself should be secured with suture in multiple sites. If inflation time is expected to be short, an assistant may hold the device until balloon deflation. Three factors should be monitored and communicated: mean arterial pressure, balloon position, and occlusion time.

Subsequent Hemorrhage Control

Following balloon catheter placement, prompt management of bleeding should be conducted in the operating room (OR) or angiography suite. Although an active area of research, occlusion duration times and their impact on ischemic burden are not well-established (21,22,57). If aortic zone I is occluded, the start time of the subsequent operation should optimally be within 15 min (22,58). Occlusion in zone III can be tolerated for longer periods (22). The balloon should not be inflated in zone II.

Balloon Deflation

After definitive hemorrhage control is obtained, the balloon can be deflated. This will typically occur in the OR. Close communication is required with the surgical or interventional radiology team and the anesthesiologist. The balloon should be deflated slowly because deflation will result in an abrupt decrease in afterload with toxic metabolite release and the possibility of refractory hypotension and reperfusion injury (57). Intermittent or partial deflation of the REBOA balloon may decrease the adverse effects of aortic occlusion and limit ongoing hemorrhage; however, this strategy is not fully understood and is currently being explored (36,59–61).

Balloon and Sheath Removal

When aortic occlusion is no longer needed, the catheter with the deflated balloon should be removed from the arterial sheath, which is completed after hemorrhage control in the OR or intensive care unit. The sheath should be removed expediently if able, to avoid vascular injury and thrombus formation. Prior to sheath removal, the sheath should be flushed with 100 mL heparinized saline. At the time of sheath removal, direct pressure should be held over the arterial entry site as opposed to the percutaneous skin entry site (62). Open approach requires closure of the arteriotomy, typically in the OR.

REBOA Complications and Pitfalls

Due to the invasive nature of the procedure, the urgency with which it is typically performed, and the physiologic alterations that take place with balloon inflation, numerous complications may occur. These primarily involve vascular injuries, embolization (air, thrombus,

or foreign material), and ischemia (33,37,38,59). Complications can be classified as local vascular, distant vascular, and non-vascular; however, many of these complications are avoidable with appropriate technique in REBOA placement.

Local Vascular Complications

This category encompasses those occurring at the access site for device insertion or distal to it, but directly a result of device insertion.

Venous access. In a pulseless and hypoxic patient, venous access may be obtained inadvertently. If the device is inserted into the venous system, this can result in ineffective occlusion or caval injuries (14,33,37,38,59,63). The risk of this complication can be mitigated by using ultrasound guidance and careful insertion.

Improper arterial access site. Accessing the CFA too proximal may result in an arteriotomy being made on a non-compressible portion of the artery. Sheath removal in this circumstance can lead to ongoing bleeding and retroperitoneal hematoma. Accessing the SFA increases the risk of arterial dissection/intimal flaps, thrombus formation, arterial rupture, and distal ischemia secondary to reduced flow past a large sheath. The risk of an improper access site may be reduced by the use of ultrasound and by ensuring that the arterial access site occurs at the level of the femoral head (37,38,59,63–67).

Arterial dissection, thrombosis, and embolic events. The creation of an intimal flap or dissection plane is possible whenever an arterial wall is violated (22,59,62–67). Arterial dissection and thrombosis were common in one 5-year retrospective study, especially with patients with long periods of aortic occlusion (66). This risk is increased in small-caliber, tortuous, or calcified vessels. US guidance may identify these factors before access is made and alter the approach or management. Graded dilatation of the arteriotomy using a micropuncture kit further reduces this risk (64–67). Any disruption in arterial continuity and the presence of a foreign device induces a local hypercoagulable state, which may result in thrombosis at the site and the potential for distal embolization. This is limited by minimizing trauma to the artery (ie, the number of attempts at cannulation and wire passage) and by removing the sheath as soon as possible (22,37,38,59).

Vessel rupture or transection. This complication can occur with inappropriate catheter placement or excess balloon inflation; however, this complication is uncommon and can be avoided with an appropriately sized sheath placed in the correct anatomical position with proper technique (22,37,38).

Bleeding. Continued bleeding from the access site, hematoma formation, retroperitoneal hematoma, and pseudoaneurysm are more likely to occur with larger sheath sizes, in coagulopathic patients, after sheath removal with inadequate pressure, or after access in an improper site (37,38,63–67). This can be avoided with proper insertion technique, use of POCUS, and appropriate use of pressure after removal.

Distant Vascular Complications

This category includes those vascular complications unrelated to device insertion.

Aortic injury. Dissection or rupture of the aorta may occur as a result of overinflation of the catheter balloon (59,63–67). One systematic review found three deaths due to balloon-related complication from 83 studies (n = 857 patients), with two cases from balloon ruptures and one occurring from aortic injury (37). Understanding approximate aortic diameters and corresponding balloon volumes is important. The balloon should be inflated slowly until a distal pulse is lost or an arterial waveform is lost if a distal arterial monitoring line is present, in order to avoid this complication (7,21).

Worsening proximal bleeding. Aortic occlusion distal to a vascular injury will result in this complication. This may occur with zone I placement and an unrecognized thoracic injury; inadvertent zone II placement for an intended zone I placement; distal balloon migration; or inadvertent iliac occlusion for an intended zone III placement (7,21,37,38,59). These risks may be mitigated by following proper trauma algorithms to identify proximal injuries and avoiding REBOA if not indicated. The use of POCUS, fluoroscopy, or post-procedure radiographs to confirm correct balloon placement and adequate securing of the sheath and catheter can also reduce this risk.

Ischemic injuries. This includes visceral, spinal, pelvic, or limb ischemia (37,38,59). A certain degree of global hypoperfusion or organ-specific ischemia may be present initially as a result of hypotension, blood loss, vascular injury, or organ injury. Leg ischemia can occur secondary to aortic occlusion or vascular injury and may require revascularization procedures, fasciotomies, or amputation (37,38,41,59). One study found 2 out of 24 patients experienced lower limb ischemia (67). This same study found acute kidney injury occurred in 9 patients and multi-organ failure in 9 patients (67). These injuries are exacerbated by aortic occlusion. The varied nature and

severity of the initial ischemic insult make defining safe aortic occlusion duration difficult, and the joint ACS COT/ACEP guidelines state that the balloon should not be inflated in zone I if the operation cannot commence within 15 min (14). Otherwise, occlusion duration should be as limited as possible to reduce the risk of complications. The literature suggests shorter occlusion may improve survival, while longer inflation times are associated with increased release of cytokines, a greater incidence of acute respiratory distress syndrome, and increased vasopressor use (7,14,22,59,67). Ischemia may also occur as a result of thrombosis along the catheter or balloon within the aorta and subsequent embolization. Flushing the device with heparinized saline before removal can assist in decreasing the risk of thrombus formation and embolization.

Non-Vascular Complications

Acute hypertension proximal to balloon. Rapid resuscitation in conjunction with aortic occlusion may result in an acute elevation in proximal blood pressures with severe end-organ effects, such as heart failure or central nervous system injury (59). Therefore, it is also important to monitor blood pressure in a proximal extremity.

Metabolic disturbances. The combination of inflow cessation, anaerobic metabolism, and continued venous return may result in acidosis and hyperkalemia. Ischemia may be exacerbated following restoration of flow secondary to the inflammatory response as a result of the generation of reactive oxygen species during reperfusion (22,59). Minimizing balloon inflation time and obtaining control of the site of hemorrhage can reduce metabolic disturbances.

Refractory hypotension. Balloon deflation results in rapid restoration of distal flow, immediate afterload reduction, and vasodilatation secondary to the release of ischemic cellular byproducts (22,59). One study conducted in patients with pelvic fractures found 6 out of 13 patients experienced hypotension with balloon deflation (65). Communication among members of the surgical team is needed before deflation to ensure the team is prepared for balloon reinflation if needed, as well as other resuscitative measures.

Wound complications. The risk of wound infection is increased due to the lack of a controlled, sterile environment and operative site preparation; lack of preprocedure antibiotics; massive blood loss; and foreign device insertion (22,59). These complications are minimized by monitoring the device site for evidence of infection and other complications.

The Future of REBOA

There are many patients who suffer wounds that might benefit from REBOA, with a retrospective study suggesting that 1 in 5 combat casualties experience wounds that could be treated with REBOA (68). However, this therapy is still controversial without clear and convincing outcomes data supporting mortality reductions and improved quality of life among survivors compared to nonapplication (37,38). Future studies should determine the timeframe for which REBOA demonstrates the greatest benefit, as well as which populations would benefit most from REBOA, with further data on civilian populations. Training for surgeons and emergency clinicians is necessary and ongoing, with REBOA training courses available for physicians. Studies are also needed that evaluate placement using external landmarks (69–72). Future studies should focus on the ideal training protocol, the role of simulation in training, emergency medical services transport of patients with REBOA, and the number of procedures to attain and maintain competence. Emergency clinicians play an integral role in resuscitation and management of critically ill patients and possess the necessary procedural skills to successfully place the REBOA device with appropriate training (45). Emergency medicine specialty organizations should acknowledge the need for REBOA placement by emergency clinicians.

CONCLUSIONS

Hemorrhage is one of the major causes of mortality in trauma. Non-compressible sites (e.g., pulmonary injury, solid organ injury, axial torso vessel, pelvic fractures with ring disruption) can be difficult to control, often requiring RT. REBOA offers a less invasive means of occluding the aorta and can be placed rapidly using percutaneous vascular access techniques.

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ARTICLE SUMMARY

1. Why is this topic important?

Non-compressible torso hemorrhage (NCTH) is deadly, and resuscitative endovascular balloon occlusion of the aorta (REBOA) is a procedure that may be used to control NCTH.

2. What does this review attempt to show?

This article provides an evaluation of REBOA, the procedure, and its complications.

3. What are the key findings?

REBOA can provide proximal hemorrhage control performed by the emergency clinician without resuscitative thoracotomy. The evidence behind its use remains controversial with significant heterogeneity among studies, with most studies demonstrating improved blood pressure without significant mortality improvement. The procedure includes arterial access (most commonly the common femoral artery), positioning the initial sheath, balloon preparation and positioning, balloon inflation, securing the balloon/sheath, subsequent hemorrhage control, balloon deflation, and balloon/sheath removal. Several major complications may occur with REBOA placement. Future studies should evaluate training protocols, the role of simulation, and what target populations would benefit most from REBOA.

4. How is patient care impacted?

REBOA enables proximal hemorrhage control performed by emergency clinicians, though surgical control is definitively required later.