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

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Temporary occlusion of the aorta as an operative method to increase proximal or central perfusion to the heart and brain in the setting of shock is not new.[1] Resuscitative aortic occlusion with a balloon was reported as early as the Korean War and has been described in more recent publications.[2–5] Despite potential advantages over thoracotomy with aortic clamping, resuscitative endovascular balloon occlusion of the aorta (REBOA) for trauma has not been widely adopted. Broader application of this procedure may have lagged because of latent technology, a poorly understood skill set, or anticipated ineffectiveness of the technique. However, the recent evolution of endovascular technology and its clear benefit in managing vascular disease such as ruptured abdominal aortic aneurysm suggest that a reappraisal of this technique for trauma is needed. The objective of this report is to provide a technical description of REBOA.

To simplify, this maneuver can be considered in the following five steps each with specific procedural considerations (Table 1):

1. Arterial access
2. Balloon selection and positioning
3. Balloon inflation
4. Balloon deflation
5. Sheath removal

STEP 1: ARTERIAL ACCESS AND POSITIONING OF INITIAL SHEATH

Establishing Arterial Access

At this time, access to the arterial circulation for REBOA for trauma should be obtained through the femoral artery. At the completion of this initial step, a 10- to 15-cm-long sheath will be positioned in the femoral and external iliac artery. Access to the femoral artery can be obtained using one of three techniques: percutaneous, open exposure (i.e., cut down), or exchange over a guidewire from an existing femoral arterial line. Percutaneous access is now commonly accomplished under ultrasound guidance using the same probe applied for the focused abdominal sonography for trauma or focused assessment with sonography for trauma examination. In this scenario, a straight or linear array transducer is superior to a curvilinear transducer. Ultrasound or direct surgical identification of the femoral artery lateral to the vein is especially important in the hypotensive patient without a palpable pulse. Once identified, the artery should be entered at a 45-degree angle with a hollow 18-gauge needle through which a 0.035-inch wire can be passed. After the wire has been passed into the artery, the needle is removed and a small incision made at the interface of the wire and the skin. Next the sheath is placed over the wire into the artery. It is important that any time a sheath is passed over a wire into the arterial system, the sheath's internal dilator is firmly in place to allow a smooth reverse taper from the wire to the diameter of the sheath. Once the dilator and sheath have been advanced over the wire through the skin into the artery, the dilator is removed leaving the sheath as a working port through which other maneuvers can be accomplished. To avoid bleeding from the side port of the sheath after the dilator is removed, it is important that the operator assure that the stopcock is in the "off" position to the patient.

Selection and Positioning of Initial Sheath

Sheaths are measured as French (Fr) (1Fr = 0.333 mm) and are sized based on their internal diameter. Common initial sheaths are 5 Fr to 8 Fr and come in lengths from 8 cm to 15 cm. As long as the operator is confident that the femoral artery has been accessed and the 0.035-inch starter wire passes without resistance, placement of this short sheath can be accomplished without fluoroscopic guidance. As noted, the initial sheath can also be placed after removing an existing arterial line over a wire (i.e., "rewiring"). This maneuver is accomplished by placing a wire greater than 2× the length of the existing arterial catheter through its inner lumen allowing the catheter to be removed over the wire while maintaining arterial access. After a larger opening is created at the wire/skin interface, the short working sheath with its internal dilator in position can be inserted over this wire as previously described.

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TABLE 1. Sequence of Steps for Performance of REBOA Along With Technical Considerations, Potential Hazards, and Maneuvers to Reduce the Risk of Complication

Steps	Options	Considerations	Hazards	Measure to Avoid
Arterial access	Ultrasound-guided percutaneous	18-gauge hollow needle and 0.035-inch wire into common femoral artery. The initial sheath is 5–8 Fr and 8–15 cm long; considered as the initial sheath	High (proximal) entry into iliac artery or low (distal) entry into superficial femoral artery Assuming groin crease is the inguinal ligament Inadvertent entry into venous system	Draw line marking the inguinal ligament and access artery 1 cm below this line Ultrasound-guided access to artery, identification of pulsatile blood return, or direct visualization of artery via open cut down
	Open exposure (cut down) Use of existing arterial line	Line between anterior superior iliac spine and pubic tubercle marks the inguinal ligament and proximal common femoral artery		
Balloon selection and positioning	Position with fluoroscopic guidance to aortic zone I or III	Preceded by placement of long (260 cm) working wire into the aortic arch	Inadvertent movement of stiff wire too proximal or distal risking injury to aortic root or carotid arteries	Fluoroscopic guidance and marking of length of wire outside of entry site when in desired position
		Followed by removal of the initial sheath and placement of large diameter long sheath over this wire		"Pin" or secure wire to prevent advancement or withdraw as devices are positioned over its axis
		Finally, large diameter, compliant balloon is placed over wire under fluoroscopic guidance		Create generous skin opening around the wire entry site with scalpel
Balloon inflation	Inflate with fluoroscopic guidance using mixture of contrast and saline	Inflate balloon until it adopts the aortic wall profile and then stop and turn stopcock to maintain inflation	Overinflation of balloon and damage to aortic wall	Inflate under fluoroscopic observation and stop when balloon adopts the aortic wall profile
		Inflation and balloon occlusion may result in dramatic increase in central aortic pressure	Distal migration of balloon, sheath, and wire with pulsation against the inflated balloon	Assign an assistant to secure apparatus in desired location and communicate arterial pressure
Balloon deflation	Turn stopcock and deflate balloon port	Deflate slowly after communication with anesthesia and members of resuscitation team	Profound hypotension Loss of desired balloon and wire position	Slow or gradual deflation in communication with resuscitation team being prepared to reinflate the balloon to support central pressure
Sheath removal	Open exposure or cut down on sheath entry site	Proximal and distal control above and below the sheath entry site and closure with 5-0 or 6-0 monofilament following its removal	Loss of arterial control upon removal Ineffective arterial closure	Wide proximal and distal exposure and arterial control to allow safe, hemostatic removal and effective sheath removal and arterial closure

TABLE 2. Examples of Endovascular Tools (Wires, Sheaths, and Balloons) Used To Accomplish REBOA

	Description	Size	Length (cm)
Wire	Amplatz Stiff Wire Guide (Cook Medical)	0.035 inch	260
Sheaths	Initial (starter)	5–6 Fr	8–15
	Delivery and support	12–14 Fr	45–60
Balloons	Coda balloon (Cook Medical)	14 Fr (32–40 mm diameter)	120
	Reliant (Medtronic)	12 Fr (10–46 mm diameter)	100
	Berenstein (Boston Scientific)	6 Fr (11.5 mm diameter)	80

STEP 2: SELECTION AND POSITIONING OF THE BALLOON

Selection of a Balloon

A balloon inflated inside the aorta to occlude flow must be soft or compliant and of large diameter. It is critical that stiff or noncompliant balloons be avoided in this scenario as their inflation inside of the aorta poses a higher risk of damage including dissection or rupture. Examples of compliant balloons with their range of diameter and required sheath sizes are as follows (Table 2): (1) Coda balloon (Cook Medical): 32 mm to 40 mm, 14 Fr; (2) Reliant balloon (Medtronic): 10 mm to 46 mm, 12 Fr; and (3) Berenstein balloon (Boston Scientific): 11.5 mm, 6 Fr.

Positioning of the Balloon (Zones of the Aorta)

To select the most appropriate compliant balloon, the user needs to decide which aortic zone is to be occluded.

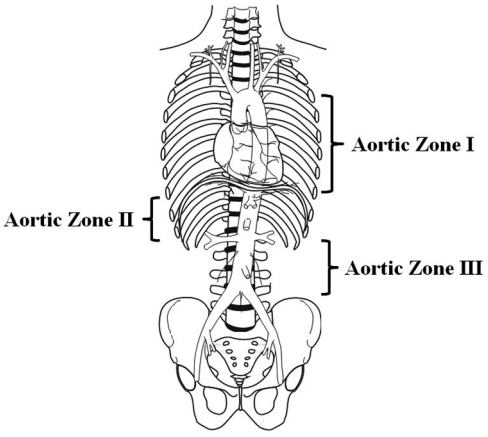

Figure 1. Aortic zones related to REBOA. Zone I extends from the origin of the left subclavian artery to the celiac artery and is a potential zone of occlusion. Zone II extends from the celiac artery to the lowest renal artery and is a no-occlusion zone. Zone III exists from the lowest renal artery to the aortic bifurcation. REBOA in this zone may provide particular utility for instances of pelvic and junctional femoral (contralateral) hemorrhage.[6]

Aortic zones can be considered I, II, and III spanning from cranial or proximal to caudal or distal (Fig. 1). Zone I is the descending thoracic aorta between the origin of the left subclavian and celiac arteries. Zone II represents the paravisceral aorta between the celiac and the lowest renal artery and zone III the infrarenal abdominal aorta between the lowest renal artery and the aortic bifurcation. In most instances of shock and pending cardiovascular collapse, the aim will be to position the compliant balloon to occlude zone I. In this case, a larger diameter balloon and a longer sheath will be advanced into the thoracic aorta. REBOA in zone I requires a longer sheath (45–60 cm) to be positioned in the descending thoracic aorta to support or hold the balloon against aortic pulsation once it is inflated. Inflation of a compliant balloon in aortic zone III may provide specific utility in cases of pelvic or junctional femoral hemorrhage.[6] In this instance, a smaller diameter balloon may be sufficient. Because the aortic bifurcation will support or hold the inflated balloon against pulsation, this maneuver can be accomplished using a large diameter but shorter (10–15 cm) sheath.

Wire Control and Positioning of the Large Sheath and Balloon

Positioning of the balloon in the aorta must take place over a 0.035-inch wire and through an appropriately sized sheath (diameter and length). The sheath through which the balloon will be introduced takes the place of the previously described initial sheath. To accomplish this maneuver, a 260-cm long, 0.035-inch wire (e.g., Amplatz Stiff Wire Guide; Cook Medical) (Table 2) should be inserted through the initial sheath in the femoral artery. The wire should be advanced under fluoroscopic guidance or visualization such that the floppy tip is in the distal aortic arch. The extent of the wire outside of the sheath at this point should be noted and marked so that the wire is not advanced or withdrawn significantly (>5 cm). Failure to maintain control of the wire's insertion depth during this and subsequent maneuvers may result in inadvertent injury to coronary or cerebral vessels if it is advanced too far or inability to advance the balloon to the occlusion zone if it is withdrawn.

At this stage, the small diameter sheath in the groin should be removed and backed off of the wire with pressure held proximally over the femoral artery for hemostasis. Once the sheath clears and is removed from the end of the wire, the larger sheath led by its internal dilator is advanced over the stiff wire through the skin opening and into the femoral and iliac artery. This maneuver plugs the opening of the femoral artery and allows the operator to stop and ready him or herself for the next step. It is important to emphasize that as sheaths or balloon catheters are advanced over this wire, the wire itself does not change its position (i.e., is not advanced or withdrawn more than 3–5 cm). To accomplish this, the fingers grasping or "pinning" the wire are held fixed against the patient's leg with the wire straight and taut. In this position, the wire acts as a rail over which the large sheath or balloon catheter can be advanced or withdrawn as the operator focuses on the fluoroscopic image.

To occlude zone I, the larger, longer sheath should be advanced over the stiff wire under fluoroscopic guidance into the thoracic aorta to the desired location of occlusion. Fluoroscopically, zone I can be estimated to exist above the 12th rib and below the medial head of the clavicle. Next, the internal dilator should be removed from the sheath and the back end of the extended wire. To avoid significant bleeding after the internal dilator is removed, it is important that the stopcock on the side port of the sheath is in the "off" position to the patient. The balloon is next loaded on and advanced over the stationary wire into and through the sheath. Under fluoroscopic visualization, after the balloon advances from the end of the sheath, it is ready to be inflated. It is worth repeating that these steps (advancing the sheath and the balloon catheter) must be done with care not to advance or withdraw the wire. To occlude zone III requires a large diameter but shorter sheath (10–25 cm) to allow passage of the balloon into the terminal aorta under fluoroscopic visualization. The concept in this scenario is that once the balloon is inflated, any aortic pulsation will push the balloon to the terminal aorta and its bifurcation.[6]

STEP 3: INFLATION OF THE BALLOON AND SECURING OF THE APPARATUS

Inflation of the Balloon

Similar to step 2, inflation of the balloon should be accomplished under fluoroscopic guidance (Table 1). A large-volume syringe (usually 30–60 mL) is filled with a ½ and ½ solution of sterile saline and iodinated contrast. This mixture allows visualization of the balloon inflation as well as more rapid inflation and deflation times by reducing viscosity. With fluoroscopy, the balloon is inflated until the outer edges of the balloon change from convex to parallel as the balloon takes on the contour of the aortic wall. One may notice that during systole, the balloon will change shape and create a "mushroom cap" as it is pulsed inferiorly. In zone I

occlusion, the previously positioned long sheath can then support the balloon and maintain its position within the aorta. When inflation appears adequate to gain aortic wall apposition and augment central blood pressure, the three-way stopcock on shaft of the balloon should be turned off toward the balloon to maintain inflation and occlusion while other maneuvers are undertaken.

Securing the Inflated Balloon, Sheath, and Wire Apparatus

It will next be important to hold the balloon, sheath, and wire securely so that none change position as the central aortic pressure returns pushing the balloon caudal. Although the balloon, sheath, and wire can be secured with sutures or an occlusive dressing that pin the apparatus to patient, these need to be observed continuously to assure no downward or caudal migration. If zone I REBOA is accompanied by a return of a central aortic pressure, the most reliable way to keep the inflated balloon, sheath, and wire in the desired location is to assign an assistant the task of holding the apparatus until balloon deflation is desired. This assistant should monitor and communicate the "big three" factors imperative to maintenance of successful REBOA: mean arterial pressure, maintenance of position, and maintenance of occlusion (balloon inflation).

STEP 4: DEFLATION OF THE BALLOON

Communication with the assistant holding the apparatus and the anesthesia team is critical before consideration of balloon deflation. Once a decision to attempt deflation is made, care must be taken to turn the three-way stopcock and deflate the balloon slowly as this step can be anticipated to result in a significant decrease in afterload and hypotension. Generally speaking, the main operator should be the person to deflate the balloon while the identified assistant continues to hold the balloon, sheath, and wire in the desired location. After prolonged balloon inflation or in situations where incomplete resuscitation has occurred, deflation of the balloon can be expected to result in reperfusion, washout of metabolic byproducts, and acidosis. As such, intermittent balloon inflation and deflation may be necessary until some hemodynamic stability is restored.

STEP 5: REMOVAL OF THE BALLOON AND SHEATH

After REBOA is no longer required, the deflated balloon and wire may be removed from the large sheath which should then be flushed with 100 mL of heparinized saline (1,000 units of heparin in 1 L of saline). The large diameter sheaths required to deploy currently available compliant balloons are best removed with open surgical exposure of the femoral artery. This can be accomplished using a longitudinal or transverse groin incision with dissection through the soft tissues overlying the femoral sheath. The femoral artery proximal and distal to the sheath entry site should be exposed to allow control. Proximally, this often requires dissection for 2 cm to 3 cm underneath the inguinal ligament as an assistant uses a narrow handheld retractor (e.g., short Wylie renal vein retractor) to lift the inguinal ligament off of the femoral sheath. During this maneuver, the surgeon must be mindful of the circumflex iliac veins which course over the top of the distal external iliac and proximal common femoral artery. Exposure distal to the sheath entry site often requires identification and control of both the superficial and profunda femoris arteries.

Once proximal and distal exposure and control have been accomplished, the sheath may be removed. The resulting arteriotomy should be closely examined and tailored with Potts scissors if necessary to allow primary transverse closure. Closure of the arteriotomy should be performed using 5-0 or 6-0 permanent monofilament suture in either an interrupted or running fashion with care to capture all layers of the arterial wall with passage of the needle. Before closing the last of the suture, fore bleeding and back bleeding of the arterial segments should be allowed followed by flushing of the surface with heparinized saline. Restoration of flow through the arterial segment can be confirmed using manual palpation for pulses and use of continuous wave Doppler of both the artery and more distal extremity. Closure of the femoral artery exposure is accomplished in layers using absorbable suture in the soft tissues and skin.

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