



Review article

Resuscitative endovascular balloon occlusion of the aorta[☆]

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ABSTRACT

The management of non-compressible torso hemorrhage can be problematic. Current therapy requires either open or interventional radiologic control of bleeding vessels and/or organs. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a new tool to stabilize patients in shock by achieving temporary inflow occlusion of non-compressible torso hemorrhage. This proactive technique represents a paradigm shift in achieving hemodynamic stability in patients as a bridge to definitive hemostasis. REBOA is applicable by trauma professionals, including emergency physicians, at the bedside in the emergency department, but its use needs to be considered within the context of available evidence and a robust system encompassing training, accreditation, multidisciplinary involvement and quality assurance. We review the evolving role of REBOA and discuss unanswered questions and future applications.

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Introduction

Uncontrolled hemorrhagic shock is a significant contributor to early mortality.¹ In particular, non-compressible torso hemorrhage (NCTH) is not amenable to local hemostatic maneuvers such as direct pressure. Controlling NCTH requires either an open approach or in selected cases, radiologic intervention of the bleeding vessels.

Techniques previously employed in the operating room (OR) have now migrated to the emergency department (ED) and the prehospital care arena. The use of tourniquets is a good example of potentially lifesaving therapy, now commonly used much earlier in a patient's care than in the past.² Endovascular techniques to treat hemorrhage in the pelvis, spleen, liver and kidney also continue to evolve. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is the newest endovascular technique of achieving inflow control to temporarily slow NCTH. It involves placing a balloon occlusion catheter into the aorta via the common femoral artery (CFA). Commonly employed in the OR in the setting of repair of abdominal aortic aneurysms (AAA), it has recently evolved into a proactive means of hemorrhage control in the ED. As improvements in REBOA design and use continue, the emergency physician (EP) will need to become familiar with the indications and

technical aspects of its use. This article explores the evolution of REBOA, outlines training in the procedure, and explores future applications and implications for the EP as they help bring this new technique to the bedside as part of a multidisciplinary resuscitation team.

Defining the problem

Hemorrhagic shock is a leading cause of early death after injury. Mortality is likely to be highest in the first six hours after injury, especially in patients with hemorrhage in the chest, abdomen or pelvis.^{3,4} Every effort must be made to diagnose the cause of torso hemorrhage early and provide rapid hemostasis.

Laparotomy is the primary method for arresting intra-abdominal hemorrhage, allowing identification and treatment of all bleeding sites. Interventional radiologic methods have proved helpful in certain injury patterns, for example pelvic fractures. However, both these interventions require the mobilization of key resources and transfer to either the OR or the interventional radiology (IR) suite. The ED resuscitation phase, utilizing critical care principles such as damage control resuscitation, is mainly aimed at achieving enough stability until arrangements for definitive hemostasis can be achieved, and in most cases this suffices.⁵

The group of patients with NCTH who present in refractory hemorrhagic shock, however, may develop sudden cardiovascular collapse followed by cardiac arrest. Resuscitative thoracotomy can be employed to provide inflow control and temporary

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hemostasis through aortic cross-clamping. This indication for thoracotomy is controversial, reactive, and highly morbid, creating a great anatomic and physiologic insult to the patient with generally poor outcomes and potentially significant risks to the provider.⁶ REBOA presents a markedly less invasive and proactive approach for NCTH in the setting of both refractory shock and traumatic arrest with the potential for improved outcomes.

History and evolution of REBOA

Hughes described use of endovascular aortic occlusion techniques during the Korean War, applying this method to three critically injured soldiers.⁷ Although two survived to surgery, all died from major injuries. He suggested earlier deployment of the device might have proved more beneficial.

The next several decades saw only scattered reports, primarily small case series, of REBOA use in various forms. Low et al. reported on outcomes in 23 patients with either traumatic or non-traumatic NCTH.⁸ They found that although the use of the aortic occlusion device universally improved blood pressures in those patients who had vital signs at time of insertion, overall survival was only 26%. Gupta et al. described a series of 21 patients with torso hemorrhage from penetrating trauma.⁹ Twenty patients had increases in blood pressure with balloon occlusion, and seven survived to hospital discharge, a 33% survival rate. None of the patients who had suffered a traumatic pulseless electrical activity (PEA) arrest survived.

Despite highlighting a potential advantage of inflow control and improved central aortic pressure through a method other than thoracotomy, the procedure did not become popular due to limited demonstration of efficacy, the high possibility for complications, lack of sophisticated devices and inexperience with the technique at the time. Over the next two decades however, advances driven by vascular surgeons reinvigorated the interest in the use of REBOA in trauma.

Greenberg et al. and Malina et al. published early reports of good outcomes following balloon occlusion in the distal descending thoracic aorta for hemorrhage control from ruptured AAA, and in fact this and other endovascular techniques have now become the accepted strategy for this pathology.^{10–12} Muira also showed its usefulness to control massive uncontrolled hemorrhage in hepatobiliary surgery.¹³ This success, in addition to the rising military deaths from conflicts in the Middle East and Asia, prompted a reappraisal of REBOA's potential role in traumatic NCTH.

Initial animal data showed promising results. Spence et al., using a canine model of cardiac arrest, demonstrated that transfemoral balloon occlusion in addition to cardiopulmonary resuscitation (CPR) caused a marked increase (130%) in mean arterial pressures, improving both cerebral and cardiac blood flow when compared to CPR alone.¹⁴ Sesma's group also demonstrated this with a porcine model of balloon occlusion during CPR.¹⁵ Morrison et al. further showed a clear survival advantage of REBOA in a porcine model of abdominal hemorrhage.¹⁶ Despite similar resuscitation techniques used in all animals, REBOA use improved mortality rates to 25% compared to 100% without it.

White et al. attempted to answer the question of whether REBOA was superior to thoracotomy for achieving inflow control in NCTH.¹⁷ Using a swine model, they showed that REBOA use not only had similar improvement in cerebral and cardiac perfusion compared to open cross-clamping, but also had significantly better pH and lactic acid levels and required less fluid and vasoactive medications. Although Markov et al. appeared to show a conflicting result by noting increased lactic acid levels after REBOA in their animal model, a critical finding was that this appeared to be directly proportional to duration of occlusion, and that levels cleared rapidly to normal within a short time of continued resuscitation.¹⁸

Human reports of REBOA have currently been limited to small case series. Brenner et al. reported the use of REBOA performed by acute care surgeons in six patients at two US centers, demonstrating its effectiveness in both penetrating and blunt trauma.¹⁹ This series showed no procedure-related complications or hemorrhage-related mortality with REBOA use despite patients sustaining severe trauma. Ogura et al. report on a series from Japan of seven hemodynamically unstable patients with solid organ injuries in whom REBOA was used to assist in facilitating angioembolization.²⁰ Six of their patients were alive at 28 days (one died of severe brain injury), and in those there were no procedure-related complications. Morrison et al., on retrospectively reviewing the UK Joint Theatre Trauma Registry to identify UK combat casualties who may have benefited from REBOA, found that almost 20% had injury patterns potentially amenable to this procedure.²¹

Two recent papers highlight the potential for harm in utilizing REBOA. The Japanese trauma systems from which both originate have been utilizing REBOA for several years, and it is a core skill in their EM training program. Norii et al. retrospectively reviewed prospectively collected trauma registry data to compare survival to discharge in blunt trauma patients who did or did not receive REBOA.²² Of over 45,000 patients who met inclusion criteria, 1% received REBOA and were noted to have higher Injury Severity Scores (median 35 versus 13) and mortality (76% versus 16%) than those who did not. They attempted to match the two groups by utilizing propensity scoring, and calculated an odds ratio of survival by REBOA of 0.30. Saito's group retrospectively evaluated the use of REBOA in 24 blunt trauma patients over a 6-year period, with an overall survival rate of 29.2%.²³ Their paper reported important procedural complications associated with death and disability: in 5 deaths, the balloon could not be deflated; in three cases lower limb amputation was required due to either vascular injury or limb ischemia. These studies need to be understood in the setting of Japan's trauma system, which uncommonly has continuous in-house trauma surgery presence, sees little severe trauma overall, and often has older patients than seen in other developed trauma systems worldwide. Additionally, Norii contemplated whether REBOA was utilized as a "last ditch" effort to achieve hemorrhage control in the intervention group, and thus this group may have had a high mortality anyway despite the procedure.

Despite these limitations, what is clear is that there is a need for robust human research with sufficient patient numbers to clarify benefits, further define ideal utilization, and importantly disclose the complications involved with this technique. Multicenter collaborative efforts will be key. Currently a prospective observational study, the AORTA trial, is ongoing through the American Association for the Surgery of Trauma, aiming to prospectively compare outcomes from open or endovascular aortic occlusion.²⁴

Technique, current limitations, and complications of REBOA

REBOA technique for trauma is deliberately modified from that employed in vascular surgery due to the lack of ready access to fluoroscopy. We describe our institutional technique below.

The CFA is identified by palpation, ultrasound, or direct cutdown techniques, and accessed using a standard arterial line catheter. A stiff wire with a floppy tip, such as the Amplatz Super Stiff wire (Boston Scientific, MA, USA) is inserted to the level of the proximal descending thoracic aorta (identified by external landmarks as the level of the second rib), and the arterial line is upsized to a 12-French introducer sheath. After removing the dilator, the balloon catheter is inserted to the indicated level and inflated until

moderate resistance is felt. The zone of insertion is dependent on the bleeding source, with zone 1 lying from the left subclavian artery to the celiac artery, and zone 3 lying between the lowest renal artery and the bifurcation of the aorta. The balloon catheter is measured externally against defined anatomical landmarks (the xiphoid process for zone 1, and the umbilicus for zone 3), and a plain radiograph is used to confirm initial wire position. Stannard et al. present a more detailed review of the relevant anatomy and technique.²⁵

At the time of writing, in the United States (US) a 12-French introducer sheath is used during REBOA. This necessitates specific access of the CFA to prevent catastrophic iatrogenic vascular injury, and removal of the sheath in the operating room with surgical closure of this arteriotomy site. During removal, the presence of clots within the lower limb arterial system should be actively sought and lower limb perfusion ensured. Specialist expertise must therefore be present at institutions incorporating REBOA.

Specific complications of REBOA placement include accessing the wrong vascular tree, misplacement of the wire or balloon within the arterial system, the creation of dissection flaps or other arterial injury, retroperitoneal hemorrhage, the development of lactic acidosis and organ dysfunction, and the development of clots which may lead to limb ischemia.

Considerations for training in REBOA

Adequate and appropriate training in REBOA is critical to its successful implementation within a trauma system. Non-surgical specialties do not benefit from a common pathway or guidance to develop competency in peripheral endovascular techniques such as those needed for REBOA. Although surgical training programs do provide formal general didactics, we feel these may not be adequate.

Holcomb et al. suggest several steps in establishing competence amongst non-traditional users of REBOA.²⁶ These include the need for establishing minimal training and experiential requirements, clear definitions of patient selection, appropriate certification of physician competence, and evidence-based practice. REBOA training, credentialing, and use should be established within a closely collaborative network of trauma professionals encompassing the specialties of emergency medicine, acute care surgery and vascular surgery.

For those with limited previous endovascular skills, attendance at established procedural courses provides one way to gain competence. Examples in the US include the Basic Endovascular Skills for Trauma (BEST ©) course, held at our institution, and the Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS ©) course. The former uses a mixture of didactic lectures, virtual reality simulation, and cadaveric instruction, while the latter utilizes simulation and live animal models to establish procedural competence.^{27,28} The authors are instructors on the BEST © course, representing the specialties of emergency medicine, trauma surgery, vascular surgery, and surgical critical care. Brenner et al. showed that despite little previous experience, novice interventionalists were able to effectively acquire these skills after attending such a course.²⁷

Regardless of the volume of trauma seen at any institution, individual EPs may not use REBOA often, raising a valid concern of competency maintenance. This argument can also extend to other rarely performed, technically advanced procedures such as resuscitative thoracotomy and perimortem Caesarian-section, whose use is rare despite being within the majority of emergency medicine training curriculums.²⁹ The continued use of educational tools such as in situ simulation scenarios and, where available, cadaver labs is vital in ensuring optimal individual and team performance in such techniques.^{30,31}

Future directions for research and implementation

Although the existing animal and human data is very promising, it does also raise some conflicting issues and concerns about the use of REBOA. Nevertheless, we feel with continued use within well-established trauma systems and collaborative data sharing, these concerns will continue to be addressed. The following discussion reviews what we feel are some key unanswered questions about the implementation and evolving role of REBOA, and represents current best available evidence and our consensus opinion.

Can we further refine the indications and contraindications for REBOA, in particular patient selection and benefit over resuscitative thoracotomy? REBOA has thus far primarily been used and studied in the setting of traumatic hemorrhage. Biffi et al. describe an algorithm for its role in NCTH, and we further suggest that it be utilized in any patient with exsanguinating torso hemorrhage even if in cardiac arrest.³² In addition, the authors have experience and case reports already exist of its effective use in non-traumatic NCTH such as gastrointestinal, vascular, and obstetric hemorrhage.^{33,34} These increased indications for ED use may well also address issues surrounding skill retention. Defining specific blood pressure triggers is not yet well-supported and needs to take into account the overall individual clinical picture and time to definitive hemostasis. As data from the AORTA trial and other sources becomes available, protocols will be tailored to achieve maximum benefit from REBOA and more clearly outline its place over thoracotomy. Individual centers will need to appraise their available resources and further refine protocols accordingly.

Will newer devices facilitate easier and timelier placement by the trauma professional? Technologic advancements have allowed the use of smaller introducer sheaths and balloon catheters in the international community, and these are currently awaiting approval for use in the US. As catheter technology develops, several advantages will likely become apparent, including decreased risk of arterial injury; elimination of the need for formal vascular repair during removal; reducing the number of steps and therefore time to inflow control; and possibly negating the need for radiologic confirmation of placement.³⁵ Importantly, these advances will facilitate bringing REBOA out of level 1 centers to community hospitals and physician-staffed prehospital care systems.

What are the true anatomic and physiologic consequences with balloon inflation and what is the maximal balloon occlusion time? Animal studies show the development of lactic acidosis, hyperkalemia, and organ dysfunction following REBOA, with the degree of the inflammatory response having a direct relation to occlusion time.^{36–38} Existing data appears to show clear physiologic benefit over open aortic clamping following thoracotomy. What is less clear is the ultimate short- and long-term outcome effect of this transient acidosis.³⁶ Defining ideal occlusion time is critical, especially if REBOA is implemented in the field or in a community hospital where transfer to tertiary care is required. Although Avaro suggests 40 minutes may be an ideal time, we have performed balloon occlusion for longer periods without significant procedure-related complications.

The complications of REBOA, in particular the potential for limb ischemia, need to be fully disclosed and investigated in future studies. Current best practice with the 12-French sheath is to remove the device in the OR with active identification of adequate perfusion. Smaller catheters within the arterial system likely still have the potential for clot development, and this must be kept in mind at the time of removal to minimize the risk of ischemic injury.

Will the development of innovative catheters allow us to refine and evolve our approach to resuscitation? Catheters in development may allow the incorporation of continuous in situ arterial pressure monitoring, the ability to initiate targeted temperature management, and be a conduit for drug or blood product delivery. This may

minimize the need for multiple vascular access catheters and allow the practitioner to combine such concepts as selective aortic arch perfusion and REBOA into a single device.³⁹ Such advancements will allow us to rethink our approach to the future management of decompensated shock and cardiac arrest from both traumatic and non-traumatic etiologies, as well as be a bridge to modalities such as extracorporeal membrane oxygenation.

Is there a role for modalities such as ultrasound in REBOA placement or balloon localization? Ultrasound, whose use is fairly ubiquitous in emergency medicine, has the advantage of rapid bedside availability; repeatability; and can obviate dependence on radiology staff and equipment. Its use during REBOA placement can include CFA identification and balloon position confirmation, as well as the identification of contraindications to placement such as a pericardial effusion or abnormal aortic root dilatation.

It is clear that further human trials are required to clearly define the ideal use of REBOA as technological advances continue to push the envelope of our ability to use this technique. Efforts such as the AORTA trial are an important step. As more centers begin implementing REBOA into their own trauma systems, we hope that both continued research endeavors and collaborative information sharing will help to refine and improve its role in resuscitation practice.

Conclusion

REBOA presents an exciting paradigm shift for the proactive management of critically ill patients with torso hemorrhage. Continuing research and technologic development will further identify and expand its possible uses while outlining incidence and consequence of complications. Practitioners will need to attain and maintain the required skills, carefully consider the currently available evidence, and coordinate the implementation and use of REBOA within a collaborative multidisciplinary trauma/resuscitation network.

Conflicts of interest statement

None declared by any author.

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