Evidence-based approach to the trauma patient in extremis: Transitioning from exclusive emergency department thoracotomy use to protocolized approaches incorporating resuscitative endovascular balloon occlusion of the aorta

INTRODUCTION

The most severely injured patients who arrive to emergency departments (EDs) in extremis present the most difficult challenge to traumatologists. For decades, unacceptably high mortality rates in this subset of patients evaded even the most extreme and invasive life-saving intervention – the ED thoracotomy (EDT).\(^1\)\(^-\)\(^3\) The physiological premise behind the EDT is to perform three essential maneuvers: to relieve cardiac tamponade, to control hemorrhage, and to achieve temporary aortic occlusion.\(^4\) Aortic cross-clamping during EDT increases coronary blood flow, cardiac output, mean arterial pressure, carotid blood flow, and brain perfusion/oxygenation.\(^5\) The success of this procedure is varied depending on the cause of traumatic cardiac arrest, but a review of 868 patients from a single center showed an approximate 5% survival rate.\(^4\) According to literature compilation by Pust and Namias, average survival for blunt traumatic EDT was 1.6%, with corresponding figure being approximately 10 times higher (16.8%) for penetrating traumatic EDT.\(^6\) It has been postulated that significant contribution to morbidity and mortality within the EDT population may be associated with the thoracotomy itself,\(^6\) suggesting that the performance of EDT should be restricted to a subset of patients who – based on best available scientific evidence – have the most reasonable chance of survival. By any measure, the performance of EDT simply to ensure “procedural skills maintenance” is ethically questionable, and there are increasing doubts about the benefit of entering an uninjured body cavity to address an injury elsewhere.

Balloon occlusion of the aorta is an alternative to open aortic cross-clamping and dates back to the treatment of traumatic war injuries as early as the 1950s. It is now widely accepted it was Hughes who reported the initial experience with the primitive precursor of the “Resuscitative Endovascular Balloon Occlusion of the Aorta” (REBOA) during the Korean War.\(^9\) Several decades passed until the technique was proposed as an alternative to EDT and open aortic cross-clamping in penetrating abdominal trauma.\(^10\) However, this early experience with REBOA highlighted complications of paraplegia, thrombosis, and balloon misadventures that limited wide adoption. In contrast, more recent studies have highlighted the hemodynamic benefits of REBOA,\(^11\) relatively low complication rates,\(^12\) and broadening clinical indications.\(^13\)\(^-\)\(^15\) Gradually, studies comparing outcomes of REBOA versus EDT have been published.\(^14\)\(^-\)\(^16\)\(^-\)\(^17\) This commentary attempts to compile the best available evidence on this topic and present to the reader an argument that, given the more recent literature experiences and reports, reconsideration of REBOA and its reclassification from “adjunctive” to “primary” modality is warranted for patients with extra thoracic injuries who present in extremis.

NEUROLOGICALLY VERSUS NONNEUROLOGICALLY INTACT SURVIVAL

One major challenge faced by intensivists who provide care for patients who survive extreme traumatic injuries is the differentiation between individuals with meaningful functional survival and those who survive but are not neurologically intact.\(^18\) The finding of neurologically intact survival varies greatly across the literature and tends to be correlated to the mechanism of injury, the presence of signs of life (SOL), and time from injury to ED arrival.\(^9\) The Eastern Association for the Surgery of Trauma guidelines on evidence-based approach to EDT patient selection cite poor overall survival figures, both for neurologically intact and nonneurologically intact patients, especially in the setting of blunt trauma [Table 1].\(^18\)
Currently accepted definitions of what constitutes SOL tend to be vague and appear open to interpretation.[18-20] The fact that providers tend to resort to EDT based on liberal interpretation of existing guidelines means that various degrees of both overtriage and undertriage exist. For many trauma surgeons, the availability of an EDT as the “best option” creates a difficult medical and ethical choice: should one routinely perform EDTs for blunt trauma victims with <5% chance of survival and 2.5% neurologically intact survival [Table 1]?[19] Is the average number of 22 EDTs to save 1 life justifiable? What about the 42 EDTs to allow 1 patient to have a neurologically intact recovery? For some trauma surgeons, a procedure that may potentially save a life is justifiable no matter what the cost or consequences. For others, the overwhelming emotional burden of operating on a patient with such high degree of futility may add to the fairly recently described posttraumatic stress disorder among trauma practitioners.[21] Of importance, the risk of accidental health worker exposure to blood or bodily fluids during EDTs is substantial. Elevated prevalence of HIV and hepatitis C in some trauma populations, combined with a provider injury rate as high as 10% may create a potentially dangerous environment for the trauma team.[22,23] The risk-benefit ratio must be carefully weighed before triggering the decision to proceed. For many traumatologists, the driving force for performing EDTs in the setting of overwhelming futility may also be due to the additional concern of being judged by their peers for “not having done enough.” Some within the latter group revert to purely protocolized responses and simply “follow guidelines” and “implement recommendations,” which again may be prone to inconsistencies and are subject to a broad range of interpretations.

The advent of REBOA has created another pathway to aortic occlusion for those who consider EDT to be overly aggressive and unjustifiably invasive. Moreover, with the overall reported survival of all REBOA patients rivaling or exceeding survival rates of the “most favorable” EDT outcome group (e.g., victims of penetrating thoracic injuries with SOL present on arrival), indications for EDT are bound to become inherently constrained in the era of wider availability of the less invasive option [Figure 1 and Table 1].[14-18] REBOA is contraindicated in the setting of suspected intrathoracic injury, specifically in patients with clinical/anatomic evidence of proximal traumatic aortic injury. Placement of a REBOA in these circumstances increases the risk of exacerbating such proximal injuries.[24]

Insertion of the REBOA catheter requires common femoral artery (CFA) access, either percutaneously or through a cut-down approach. More recently introduced REBOA devices provide greater flexibility than earlier models in that they are amenable to insertion through a 7- or 8-French sheath in the CFA, without the need for fluoroscopy or specialized guide wires. Aortic occlusion is accomplished by filling the balloon on the device at one of two locations, Zone 1 or Zone 3, depending on the suspected source of hemorrhage [Figure 2]. Zone 1 includes the vessels beginning from the origin of the left subclavian artery to the celiac artery. The balloon is inflated at the distal portion of Zone 1 for suspected intra-abdominal hemorrhage. Zone 3 includes the aorta from below the renal artery to the aortic bifurcation; the balloon is inflated here in the setting of suspected pelvic hemorrhage. Zone 2 includes the aorta from the celiac artery to renal arteries and is avoided during balloon occlusion to prevent injury to the associated critical vessels and organs.[25]

Table 1: Descriptive survival rates for EDT, derived from Seamon, et al. J Trauma Acute Care Surg 2015;79(1):159-173. Although evidence for any of the interventions and scenarios listed is of poor quality, important survival-related trends emerge, suggesting that the EDT is most indicated for patients suffering from penetrating chest or non-compressible extrathoracic trauma

| Pulmonary causes of death | Overall survival | Neurologically intact survival |
|---------------------------|-----------------|-------------------------------|
| | 182/863 (21.3) | 53/454 (11.7) |
| | Overall survival | 76/920 (8.3) |
| | Neurologically intact survival | 25/641 (3.9) |
| | Overall survival | 25/160 (15.6) |
| | Neurologically intact survival | 14/86 (16.5) |
| | Overall survival | 4/139 (2.9) |
| | Neurologically intact survival | 3/60 (5.0) |
| | Overall survival | 21/454 (4.6) |
| | Neurologically intact survival | 7/298 (2.4) |
| | Overall survival | 7/995 (0.7) |
| | Neurologically intact survival | 1/825 (0.1) |

AC: Aortic cross-clamping; EDT: Emergency department thoracotomy; SOL: Signs of life

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA: INDICATIONS

Currently accepted indications for REBOA are the same as for EDT, with the exception of suspected intrathoracic injury. This specifically includes those patients presenting with cardiac arrest of <10 min secondary to exsanguination, or patients in hemorrhagic shock from suspected intra-abdominal or pelvic hemorrhage who are partial or nonresponders to resuscitation. Placement

RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA: CLINICAL CONSIDERATIONS

There are several very important considerations when using REBOA, each associated with a significant
potential to affect patient outcomes. For example, time to initiation of REBOA therapy (e.g., “time to balloon inflation”) has been noted to be significantly longer in nonsurvivors (91 min) when compared to survivors (46 min) in a small study of patients with severe pelvic fractures.[26] This may be partly due to increased difficulty in obtaining CFA access in patients who are in hemorrhagic shock or pulseless. Of note, once arterial access is obtained, time to aortic occlusion is significantly less with REBOA compared to EDT.[24,25] In the context of this particular observation, it may be that REBOA should be utilized earlier and more liberally, with the primary goal of preventing trauma-related cardiac arrest, as opposed to being a “rescue therapy” that is deployed as a “last ditch” effort. Further research will be needed to better answer this question, but experiences with other intravascular support modalities for trauma patients suggest “that the earlier the deployment, the better.”[27]

Results using hybrid approach combining REBOA and EDT have been described, but reported data are difficult to interpret due to higher overall Injury Severity Score and Abbreviated Injury scale - chest scores among patients undergoing simultaneous EDT and REBOA.[28] Extreme caution is required when employing endovascular and direct aortic vascular occlusion concurrently, with special attention needed to avoid mechanical complications of mistakenly cross-clamping the intra-aortic balloon, or creating iatrogenic injuries that contribute to further blood loss and propagation of the hemorrhagic shock.

Finally, it has been recently suggested that there is no significant difference between properly performed external chest compressions and open cardiac massage in terms of clinical outcomes.[29] The latter point puts into question the use of EDT as a maneuver to perform “more effective” cardiac compressions. Based on the above evidence, REBOA combined with external chest compressions may be “as good as” direct cardiac massage and would simultaneously control nonthoracic hemorrhage and achieve temporary aortic occlusion, bypassing the morbidity of an EDT. Again, expedient yet careful consideration must be made whether to proceed with EDT or REBOA, weighing pertinent risks and benefits, preferably by a provider who is experienced and comfortable with both decisional and technical aspects involved in such intervention(s).

THE IMPORTANCE OF DEDICATED CLINICAL TRAINING

Increasing availability and decreasing invasiveness of REBOA devices created immense need for wide-scale
dissemination of didactic and technical training. The Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS) course is one of the best established and most comprehensive programs within this niche.\[30\] Other courses such as the basic endovascular skills for trauma or similar “training packages” are available for physician and practitioner training as well. In general, REBOA education should incorporate required reading materials, familiarization with equipment, standardized procedural training, written and practical assessments, scripted scenarios, and a certificate of completion.\[31,32\]

More specialized courses covering REBOA deployment specifically for Zone III of the Aorta [Figure 2] in the setting of pelvic and groin hemorrhage have been developed in the United Kingdom.\[32\]

In terms of overall educational effectiveness, the ESTARS course in particular has shown significant improvement in both knowledge and procedural task times among acute care surgeons who completed the curriculum.\[30,31\] There appears to be no correlation between REBOA proficiency and the learners’ experiences in residency, frequency of line placement, or other tested parameters. These educational data are encouraging to both inexperienced trauma surgeons with limited exposure and those who only infrequently utilize endovascular techniques.

**RESUSCITATIVE ENDOVASCULAR BALLOON OCCLUSION OF THE AORTA: CLINICAL OUTCOMES**

In terms of overall clinical outcomes, evidence comparing EDT and REBOA continues to be limited, with substantial biases inherent to methodological deficiencies. Reported survival rates vary significantly between studies from the US, Japan, and Europe (range, 13% to 67%), likely because of differences in methodology, inclusion criteria, and the interventions performed. However, important generalizations can be made with a reasonable margin of confidence. First, the overall survival, as reported in each individual study, is universally better for patients treated with REBOA than for those managed with EDT [Figure 1 and Table 2]. In addition, available data regarding the proportion of survivors discharged to home appear to favor REBOA over EDT [Table 2]. At the same time, there are important considerations and biases that make direct comparison of the two management approaches less meaningful, including the potential for patient selection bias and severity of injury/illness differences. In any case, even if one assumes that the actual risk-adjusted survival for patients undergoing REBOA is as much as 30%–50% lower than currently reported, aggregate outcomes following endovascular balloon placement are still superior to those of EDT.

At the same time, it is important to note that REBOA is not without its own unique morbidity profile. Most common complications are related to vascular access and ischemia-reperfusion injury. Technical complications include femoral artery pseudoaneurysm, distal embolism, and limb ischemia.\[24,33\] A comparison of complications related to REBOA versus EDT is provided in Table 3.

There are also aortic complications related to balloon inflation and occlusion of different aortic zones [Figure 2]. Zone 1 deployment is associated with elevated risk of organ ischemia, especially with aortic occlusion times greater than 1 h. Zone 3 deployment allows for longer occlusion time compared to Zone 1 placement but provides less support for myocardial and cerebral perfusion. Balloons that are placed in improper zones may result in unwanted and increased hemorrhage proximally, as well as ischemia distally. Because balloon positioning is “blind”, overinflation or inadvertent migration of the device can result in aortic intimal injury.\[24\]

Furthermore, REBOA-related complications may be compounded when performed under emergency conditions.
situations by providers with limited experience. As such, REBOA should only be utilized by providers who have received adequate training and understand the risks, benefits, and complications associated with both REBOA and EDT.[64]

CONCLUSION

In the presence of increasing device availability and easily attainable training for REBOA, the current set of indications for EDT should be carefully reevaluated in the context of the overall risk-benefit equation. Patients with blunt extrathoracic traumatic injuries may represent the subset that benefits the most from REBOA placement. Although reported experiences comparing EDT with REBOA are certainly imperfect in terms of both quality and quantity, absolute differences in survival, especially for penetrating and blunt extrathoracic injuries, demonstrate similar magnitude of benefit across all published sources for patients who present in extremis. It must be emphasized that EDT remains a valuable primary therapeutic modality for patients with penetrating thoracic and extrathoracic injuries who present with SOL, as well as in carefully selected blunt trauma patients with certain readily correctable physiologic conditions (e.g., noncompressible hemorrhage, cardiac tamponade).

M. Chance Spalding, Peter G. Thomas1, M. Shay O’Mara, Christine L. Ramirez1, Franz S. Yanagawa1, Heidi H. Hon1, Brian A. Hoey1, William S. Hoff1, James Cipolla1, Stanislaw P. Stawicki1, OhioHealth Grant Medical Center, Grant Level I Trauma Center, Columbus, Ohio, Level I Regional Trauma Center and Network, St. Luke’s University Health Network, Bethlehem, Pennsylvania, USA

Address for correspondence: Dr. Stanislaw P. Stawicki, Level I Regional Trauma Center and Network, St. Luke’s University Health Network, 801 Ostrum Street, Bethlehem, Pennsylvania, USA. E-mail: stawicki.ace@gmail.com

REFERENCES

1. Ledgerwood AM, Kazmers M, Lucas CE. The role of thoracic aortic occlusion for massive hemoperitoneum. J Trauma 1976;16:610-5.
2. Rabinovici R, Bugaev N. Resuscitative thoracotomy: An update. Scand J Surg 2014;103:112-9.
3. Rhee PM, Acosta J, Bridgeman A, Wang D, Jordan M, Rich N, et al. Survival after emergency department thoracotomy: Review of published data from the past 25 years. J Am Coll Surg 2000;190:288-98.
4. Cothren CC, Moore EE. Emergency department thoracotomy for the critically injured patient: Objectives, indications, and outcomes. World J Emerg Surg 2006;1:4.
5. Dunn EL, Moore EE, Moore JR. Hemodynamic effects of aortic occlusion during hemorrhagic shock. Ann Emerg Med 1982;11:238-41.
6. Branney SW, Moore EE, Feldhaus KM, Wolfe RE. Critical analysis of two decades of experience with postinjury emergency department thoracotomy in a regional trauma center. J Trauma 1998;45:87-94.
7. Pust GD, Namias N. Resuscitative thoracotomy. Int Surg 2016;93:202-8.
8. Valkenburg A, Bennett D, Bishop J, Smith G. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock. J Emerg Med 2011;40:1-2.
9. Hughes CW. Use of an intra-aortic balloon catheter tamponade for controlling intra-abdominal hemorrhage in man. Surgery 1954;36:65-8.
10. Gupta BK, Khaneja SC, Flores L, Eastlick L, Longmore W, Shaften GW, et al. The role of intra-aortic balloon occlusion in penetrating abdominal trauma. J Trauma 1989;29:861-5.
11. White JM, Cannon JW, Stannard A, Markov NP, Spencer JR, Rasmussen TE, et al. Endovascular balloon occlusion of the aorta is superior to resuscitative thoracotomy with aortic clamping in a porcine model of hemorrhagic shock. Surgery 2011;150:400-9.
12. Brenner ML, Moore LJ, DuBose JJ, Tyson GH, McNutt MK, Albarado RP, et al. A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. J Trauma Acute Care Surg 2013;75:506-11.
13. Stannard A, Eliason JL, Rasmussen TE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock. J Trauma 2011;70:1869-72.
14. Moore LJ, Brenner M, Kozar RA, Pasley J, Wade CE, Baraniuk MS, et al. Implementation of resuscitative endovascular balloon occlusion of the aorta as an alternative to resuscitative thoracotomy for noncompressible truncal hemorrhage. J Trauma Acute Care Surg 2015;79:523-30.
15. Morrison JJ, Galgon RE, Jansen JO, Cannon JW, Rasmussen TE, Eliason JL, et al. A systematic review of the use of resuscitative endovascular balloon occlusion of the aorta in the management of hemorrhagic shock. J Trauma

Table 2: Comparison of cumulative experiences with resuscitative endovascular balloon occlusion of the aorta and emergency department thoracotomy; pooled data were compiled from multiple sources (see figure legend for details)

| Category                      | EDT/AC (%) | REBOA (%) |
|-------------------------------|------------|-----------|
| Overall survival              | 447/4830 (9.3%) | 499/1,515 (32.9%) |
| Current analysis*             | 65/545 (11.9%) | 333/933 (35.7%) |
| Discharge to homea,b           | 20/301 (6.6%) | 87/653 (13.3%) |
| Discharge to facilitya         | 2/68 (2.9%) | 9/46 (19.6%) |

*a Data derived from current meta-analysis sources, *a Data from Abe, et al, J Trauma Acute Care Surg 2016;20:400. *b Data from DuBose, et al. J Trauma Acute Care Surg 2017;81:409-19; *b Combined data from Morrison, et al. J Trauma Acute Care Surg 2016;80:324-34 and all current meta-analysis sources; Combined data from Seamon, et al. J Trauma Acute Care Surg 2015;79:159-73 and all current meta-analysis sources. AC: Aortic cross-clamping, EDT: Emergency department thoracotomy, REBOA: Resuscitative endovascular balloon occlusion of the aorta

Table 3: Comparison of complications of resuscitative endovascular balloon occlusion of the aorta versus emergency department thoracotomy

| Category                      | EDT/AC | REBOA |
|-------------------------------|--------|-------|
| Retained hemothorax requiring surgery | 1/68 (1.4%) | 0/46 (0%) |
| Empyema                       | 0.68 (0%) | 1/46 (2.2%) |
| Local wound infection requiring surgery | 2/68 (2.9%) | 0/46 (0%) |
| Extremity ischemia             | 0/46 (0%) | 0/46 (0%) |
| Stenosis                      | 0/46 (0%) | 0/46 (0%) |
| Distal embolism               | 2/46 (4.3%) | 0/46 (0%) |
| Infection                     | 0/46 (0%) | 0/46 (0%) |
| Need for patch angioplasty    | 0/46 (0%) | 0/46 (0%) |
| Need for arterial bypass       | 0/46 (0%) | 0/46 (0%) |

Data derived from DuBose, et al. J Trauma Acute Care Surg 2011;81:409-19. AC: Aortic cross-clamping, EDT: Emergency department thoracotomy, REBOA: Resuscitative endovascular balloon occlusion of the aorta
Acute Care Surg 2016;80:324-34.
16. Teeter WA, Romagnoli A, Li HC, Yang S, Hu PE, Stein D, et al. Paradigm shift in hemorrhagic traumatic arrest: REBOA is at least as effective as RTACC. J Am Coll Surg 2016;223:S155-6.
17. Abe T, Uchida M, Nagata I, Saitoh D, Tamiya N. Resuscitative endovascular balloon occlusion of the aorta versus aortic cross clamping among patients with critical trauma: A nationwide cohort study in Japan. Crit Care 2016;20:400.
18. Seamon MJ, Haut ER, Van Arendonk K, Barbosa RR, Chiu WC, Dente CJ, et al. An evidence-based approach to patient selection for emergency department thoracotomy: A practice management guideline from the eastern association for the surgery of trauma. J Trauma Acute Care Surg 2015;79:159-73.
19. Powell DW, Moore EE, Cothren CC, Ciesla DJ, Burch JM, Moore JB, et al. Is emergency department resuscitative thoracotomy futile care for the critically injured patient requiring prehospital cardiopulmonary resuscitation? J Am Coll Surg 2004;199:211-5.
20. Menaker J, Cushman J, Vermillion JM, Rosenthal RE, Scalea TM. Ultrasound-diagnosed cardiac tamponade after blunt abdominal trauma-treated with emergent thoracotomy. J Emerg Med 2007;32:99-103.
21. Joseph B, Pandit V, Hadeed G, Kulvatunyou N, Zangbar B, Tang A, et al. Unveiling posttraumatic stress disorder in trauma surgeons: A national survey. J Trauma Acute Care Surg 2014;77:148-54.
22. Sikka R, Millham FH, Feldman JA. Analysis of occupational exposures associated with emergency department thoracotomy. J Trauma 2004;56:867-72.
23. Grossman MD, Stawicki SP. The impact of human immunodeficiency virus (HIV) on outcome and practice in trauma: Past, present and future. Injury 2006;37:1117-24.
24. Davidson AJ, Russo RM, Reva VA, Brenner ML, Moore LJ, Ball C, et al. The pitfalls of resuscitative endovascular balloon occlusion of the aorta: Risk factors and mitigation strategies. J Trauma Acute Care Surg 2018;84:192-202.
25. Romagnoli A, Teeter W, Pasley J, Hu P, Hoehn M, Stein D, et al. Time to aortic occlusion: It's all about access. J Trauma Acute Care Surg 2017;83:1161-4.
26. Martinelli T, Thony F, Declèpy P, Sengel C, Broux C, Tonetti J, et al. Intra-aortic balloon occlusion to salvage patients with life-threatening hemorrhagic shocks from pelvic fractures. J Trauma 2010;68:942-8.
27. Hughes R, Cipolla J, Thomas PG, Stawicki SP. Extracorporeal Membrane Oxygenation in Traumatic Injury: An Overview of Utility and Indications. In: Extracorporeal Membrane Oxygenation, Firstenberg MS (Ed). Rijeka, Croatia: InTech 2016. p. 211-38.
28. Matsumura Y, Matsumoto J, Kondo H, Idoguchi K, Funabiki T; DIRECT-IABO investigators, et al. Partial occlusion, conversion from thoracotomy, undelayed but shorter occlusion: Resuscitative endovascular balloon occlusion of the aorta strategy in Japan. Eur J Emerg Med 2017.

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

Cite this article as: Spalding MC, Thomas PG, O'Mara MS, Ramirez CL, Yanagawa FS, Hon HH, et al. Evidence-based approach to the trauma patient in extremis: Transitioning from exclusive emergency department thoracotomy use to protocolized approaches incorporating resuscitative endovascular balloon occlusion of the aorta. Int J Crit Illn Inj Sci 2018;8:57-62.