Case Report

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Resuscitative Endovascular Balloon Occlusion of the Aorta in Inter-Hospital Transfers: Two Case Reports

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Non-compressible torso hemorrhage (NCTH) remains a considerable source of potentially preventable death in both military and civilian trauma. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is one tool that can be used to treat or prevent hemodynamic collapse in hemorrhaging patients suffering from NCTH, but until now its use has been mostly as a bridge to definitive hemostasis within institutions and less so as temporizing intervention in the pre-hospital setting. The cases described here are the first reported uses of REBOA as a means of enabling inter-hospital transfer within a regionalized trauma system. This experience could help inform future patient selection, procedural technique and institutional readiness to fully realize the potential for REBOA in salvaging patients with NCTH.

Keywords: *REBOA; bleeding; Trauma*

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INTRODUCTION

Military experience from the Global War on Terror identified hemorrhage as the most significant source of preventable deaths in combat [1]. Modifications in field care, tourniquets use and hemostatic dressings improved outcomes in patients with readily accessible sources of hemorrhage while changes in resuscitation strategies better supported physiologic hemostasis in patients losing blood at a slower pace [2]. These improvements isolated a class of casualties who continued to die at alarming rates from what is still believed to be a preventable cause of death. By some estimates, non-compressible hemorrhage is responsible for up to fifty percent of preventable deaths in combat casualties [3,4], and the morbidity and mortality of this pattern of injury is similarly substantial in civilian trauma populations [5,6].

Non-compressible torso hemorrhage (NCTH) is formally defined by anatomic, physiologic and procedural contexts as shock secondary to pulmonary injury, solid organ injury, major vascular trauma and/or pelvic fracture requiring immediate intervention for hemorrhage control [7]. As recently as 2010, it had been believed that “a method for mechanically stopping non-compressible truncal hemorrhage before surgical hemostasis… remains in the distant future” [2]. However, beginning in 2012, Level I trauma centers in the US began to implement the technique known as resuscitative endovascular balloon occlusion of the aorta (REBOA) in patients with NCTH [8]. A clinical practice guideline for its use has since been incorporated into the military’s Joint Theater Trauma System [9], and the American College of Surgeons

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Committee on Trauma has both endorsed the Basic Endovascular Skills in Trauma course curriculum for teaching the REBOA insertion technique [10] and established a data repository for clinical experience with its use [11].

Until now, implementation of REBOA in the US has been as a temporizing bridge to definitive hemostasis within an institution. Limited experience with prehospital use has been described in both Japan [12] and the UK [13], although its role in field care remains largely undefined. Here, we describe the first reported uses of REBOA in the setting of inter-hospital transfer within a regional trauma system.

Case 1

A 43-year-old male was involved in a high-speed motor vehicle collision in which he was ejected from his vehicle and subsequently struck by another car. He arrived at a Level II trauma center hypotensive, tachycardic with a GCS 15 but in respiratory distress. He was intubated and bilateral chest tubes were placed. He was diagnosed with a scalp avulsion, bilateral flail chest, a Grade III liver laceration, a Grade II left renal laceration and an open book pelvic fracture with hemorrhage (Injury Severity Score 66). Massive transfusion was initiated, and his hemodynamics transiently improved. Because of the need for both interventional radiology and pelvic reconstruction the patient was scheduled for transfer to the regional Level I trauma center. Just prior to air evacuation, the patient's blood pressure fell to 70s/40s with a heart rate of 150. A REBOA catheter (ER-REBOA, Prytime Medical, Boerne, TX) was placed percutaneously through the right common femoral artery and inflated in Zone 1 to partial occlusion such that a faint contralateral femoral pulse could still be palpated. Paramedics were instructed to inject an additional 4 mL of saline into the balloon if the patient became hypotensive during transport, as this, the referring surgeon determined, was the volume necessary to proceed from partial to complete aortic occlusion. This step did prove necessary en route, and the paramedics, having no previous training or experience with REBOA, executed the instructions as directed. Total fluid and transfusion volumes provided at the referring hospital and during inter-hospital transport included six liters of crystalloid, 12 units of packed red blood cells, 12 units of fresh-frozen plasma, and three 6-packs of platelets.

Upon the patient's arrival, surgeons at the Level I center discovered the previously undisclosed REBOA catheter in Zone I. Despite the intent of the referring surgeon to progress to complete occlusion for en-route hypotension, a faint but palpable contralateral femoral pulse was present on initial assessment at the receiving hospital. According to records, the REBOA had been in place for 113 minutes at the time of arrival.

The patient was taken urgently to a hybrid OR suite. Exploratory laparotomy with liver packing, pelvic packing, supra-pubic catheter insertion, and renal fossa packing was performed. The pelvis was bound and the REBOA catheter gradually deflated over 10–12 minutes. Arteriography demonstrated vascular patency with three-vessel run-off to both lower extremities, and both the REBOA catheter and its 7 French sheath were removed. The following day, all packing was removed, external pelvic fixation and traction were applied, and his scalp wound was formally closed.

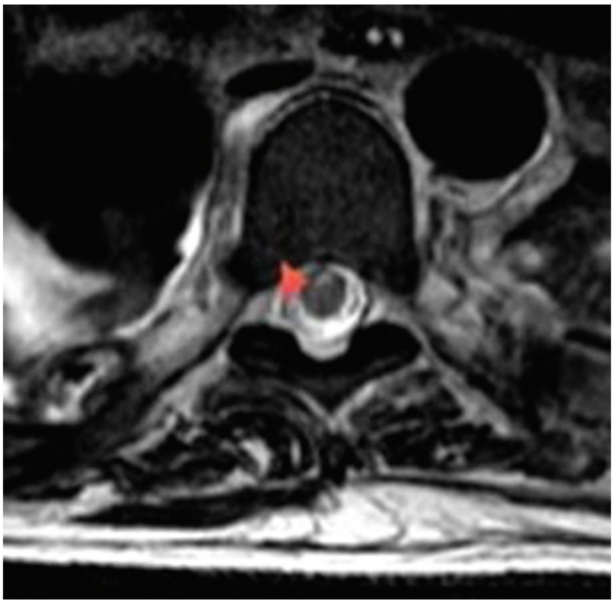

Figure 1 T2 weighted axial MRI illustrating increased signal intensity in the anterior aspect of the spinal cord at the level of T6, consistent with ischemic spinal cord injury.

The patient's subsequent clinical course was complicated by early septic shock on post-injury day 2, prolonged adrenal insufficiency, and multisystem organ failure requiring renal replacement therapy and 127 hours of veno-venous extra-corporeal membrane oxygenation (VV-ECMO) for refractory hypoxemic, hypercapnic respiratory failure. Following medical stabilization, the patient preserved baseline mental acuity but suffered bilateral lower extremity paralysis without tissue loss or compartment syndrome (Figure 1). His renal function improved, and renal replacement therapy was discontinued on post-injury day 30. He was ultimately discharged to rehabilitation on post-injury day 68.

Case 2

A man thought to be in his 60s was struck by a motor vehicle at a high speed. The patient presented to the outside hospital both hypotensive and tachycardic. Massive transfusion was initiated, and his hemodynamics transiently responded. A CT scan demonstrated a complex pelvic fracture with active arterial extravasation. The patient lost his pulses in radiology despite ongoing resuscitation. A REBOA catheter was placed percutaneously through the right common femoral artery, and the balloon inflated. The patient was taken to the OR where his pelvis was packed, and his hemodynamics stabilized. The balloon was deflated but the catheter was left in place. Total occlusion time was 23 minutes. The surgeon then accompanied the patient to the Level 1 trauma center via air transport, guiding the ongoing resuscitation and prepared to manage the REBOA catheter en route, as needed. Shortly after arrival, the patient again lost pulses and required CPR. The REBOA balloon was re-inflated resulting in the immediate return of spontaneous circulation. The patient was taken to the OR for re-exploration, and his pelvis was re-packed. The REBOA balloon was slowly deflated over 8–10 minutes, and the catheter was ultimately removed. Total occlusion time for this episode was 24 minutes. Preparations were made for pelvic angioembolization, but in the interim the patient suffered a cardiac arrest not directly attributable to hypovolemia and could not be salvaged.

DISCUSSION

In the first case of inter-hospital REBOA transfer, there is substantial room for improvement in the coordination between the sending and receiving facility. The patient was transferred with the balloon inflated, and the total occlusion time of nearly two hours is substantially longer than in any previously reported REBOA survivor in the US. The patient's tolerance of the prolonged balloon inflation may be due to the fact that the balloon was not completely occlusive as evidenced by the presence of a faint contra-lateral femoral pulse. Prolonged REBOA inflation may be possible with incomplete occlusion, although clearly this technique did not spare our patient from the consequences of distal ischemia. It can be argued that some of the more profound and more permanent consequences of prolonged aortic occlusion could have been avoided with timely laparotomy and judicious packing.

In its present state, REBOA should not be used as a means to defer operative hemostasis, as the highly morbid and potentially mortal metabolic consequences of aortic occlusion begin to accumulate the moment the balloon is inflated. Instead, REBOA is a tool that may enable carefully selected patients to survive to definitive hemostasis in a salvageable condition when they otherwise would have died before hemorrhage could be definitively controlled. The objective of REBOA, then, once deployed, is to achieve such hemostasis before the resulting metabolic derangement exceeds the patient's capacity to recover; otherwise all we would have accomplished with the investment of considerable resources is deferment of an early hemorrhagic death to a delayed but inevitable metabolic one. REBOA, however, may expand patient salvageability in the face of hemorrhage in the way balanced resuscitation, renal replacement therapy, and ECMO have expanded salvageability in the face of metabolic derangement, and it may prove critical to realizing the full potential of each of these capabilities to recognize them all as part of one larger, more comprehensive, strategy in severely injured patients with sufficient physiologic resilience.

In most instances of NCTH, the factor most predictive of survival is the presence of measurable blood pressure upon arrival at a facility equipped to achieve definitive surgical or endovascular hemostasis [14]. Those that arrive with cardiopulmonary resuscitation in-progress secondary to hemorrhagic shock and exsanguination rarely survive. REBOA is a tool that unquestionably enables proximal blood pressure augmentation [15]. What remains to be seen is whether selective enhancement of proximal perfusion, shunting intravascular oxygen carrying capacity to the heart, lungs, and brain, could offer a potential for survival to grievously injured patients at an acceptable expense of transient spinal, splanchnic, and lower extremity ischemia [16].

Spinal cord ischemia secondary to aortic manipulation is multifactorial, incorporating risks associated with vascular obstruction, hypotension, and thromboembolization [17]. The anterior spinal artery is the major source of spinal cord perfusion; however, its variable caliber throughout its course makes it dependent on circulation through a system of radicular arteries derived from segmental branches of the aorta. The largest of these, the great radicular artery (also known as the artery of Adamkiewicz), is located between T9 and T12 in three-quarters of cases [18]. Collateral circulation to the distal portion of the anterior spinal artery is through the iliolumbar and lateral sacral branches of the internal iliac arteries [19]. With REBOA placement in Zone 1, there is inadequate flow to the anterior spinal artery through both radicular arteries and internal iliac collaterals, raising the risk of spinal cord ischemia particularly with long periods of occlusion. With Zone 3 placement, radicular arteries remain patent with conceivably augmented circulation owing to distal aortic occlusion, so risks of spinal cord ischemia should be negligible in the absence of systemic vascular disease. Lumbar drainage could be considered in patients with prolonged Zone 1 occlusion or those manifesting signs of spinal cord damage not explained by direct trauma [20], although it is unclear if such cerebrospinal fluid drainage truly protects patients from ischemic complications [21].

Partial REBOA (P-REBOA) is a technique postulated to augment proximal perfusion of the brain and heart while "creating permissive regional hypoperfusion to [distal] areas of uncontrolled hemorrhage" [22]. In this technique, the balloon is inflated to achieve full occlusion as indicated by the loss of a contralateral femoral pulse on palpation or the dissipation of an arterial waveform transduced through a distal arterial pressure line or through the sidearm of an upsized sheath around the REBOA catheter itself. After allowing 10 minutes for optimal resuscitation and clot formation at the site of distal hemorrhage, the balloon is slowly deflated, 1 mL at a time, until a faint distal pressure is perceived on palpation or waveform analysis [23]. Current recommendations suggest 30 minutes of complete occlusion for Zone 1 REBOA placement and up to 60 minutes for Zone 3; however, these guidelines have not been scientifically validated and it remains unclear whether the P-REBOA technique would meaningfully extend these timelines by moderating the metabolic consequences of ischemia distal to complete aortic occlusion.

In the second case of inter-hospital REBOA transfer, communication, coordination, and oversight during transport were significantly improved, with clear communication between the referring and receiving surgeons, and surgeon accompaniment of the patient for air evacuation. Repeated aortic occlusion has been necessary in 9.6% of patients in the AAST Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery registry, including 4.3% of REBOA patients [11], but the cumulative physiologic stress of intermittent occlusion has not been studied. It is reasonable to conclude that REBOA did facilitate hemorrhage control, preventing the patient from exsanguinating. However, prolonged periods of aortic occlusion have been associated with higher degrees of coronary ischemia in animal studies, conceivably secondary to rapid fluctuations in afterload [24]. This patient's demise appeared more directly related to cardiac failure than hemorrhage, and while age is not an absolute determinant of REBOA eligibility, it is worth considering whether such a technique would have been employed were it known in advance that the patient was 87 years old.

Use of REBOA for inter-hospital transfer is not currently part of regional trauma management algorithms or informal arrangements amongst institutions. Our experience with such is purely a product of the specific circumstances surrounding these two particular patients. In both instances, it was the conclusion of the transferring surgeons that the patient's injuries would have been imminently non-survivable based on the capabilities of their institution and that transfer offered the most expeditious route to definitive hemostasis.

REBOA has been used in the military for the successful transfer of patients to higher echelons of care [25], but as the trauma community, both military and civilian, continues to explore the potential life-saving implications of endo-aortic occlusion, survival to transfer cannot be the intended goal of this intervention. Such an attitude would come with tremendous expenditure of resources without meaningfully impacting overall survival. Since ultimate survival is inversely proportional to balloon occlusion time [26], the planning for timely REBOA removal must commence with the decision to place the REBOA, and trauma system characteristics such as travel distance, evacuation time, and en-route capabilities must be considered in deciding when, where, and how to field REBOA beyond the walls of a single institution. Military–civilian cooperation will be critical to the optimal incorporation of this technology in organized trauma systems and mission planning.

One animal study suggested that aortic occlusion should be limited to less than 40 minutes for there to be any survival advantage [24], and such considerations are essential to the responsible deployment of REBOA, particularly regarding pre-hospital and inter-hospital utilization. It is unclear whether this timeline can be extended with the technique of P-REBOA.

CONCLUSION

We have reported here the first two instances of REBOA utilization for inter-hospital transfer. If the conclusions of the referring surgeons regarding the imminent death of both patients secondary to uncontrolled hemorrhage are accepted, then REBOA enabled the salvage of one and at least the opportunity of salvage for the other.

An ideal candidate for REBOA-facilitated inter-hospital transfer would be a patient estimated to possess the substantial physiologic resilience required to overcome profound metabolic disturbances associated with prolonged aortic occlusion. As illustrated in our lone survivor, this potentially life-saving intervention did accompany a period of physiologic decompensation and end organ injury, some of which proved irreversible. The implications of spinal cord ischemia must be included in the risk assessment along with bowel, kidney, and lower extremity malperfusion when considering partial or complete aortic occlusion.

The constellation of injuries for which REBOA-facilitated inter-hospital transfer could be considered includes sub-diaphragmatic injuries resulting in hemorrhagic shock that cannot be controlled sufficiently or more quickly with standard damage control surgical techniques.

An optimal referring provider would be one experienced with the technique of REBOA placement, but for whom the time to definitive hemostasis would be shorter through transfer to another facility than it would be to mobilize local institutional resources. REBOA should not defer the time to operative hemostasis but rather facilitate patient arrival in a physiologic state compatible with survival at a setting where definitive hemostasis can be reliably achieved.

An optimal receiving facility would be one well-versed in REBOA placement and removal, able to rapidly mobilize surgical or endovascular resources to minimize the time to definitive hemostasis, and prepared to provide the most elaborate means of life support for potentially prolonged periods of multi-system organ failure, including renal replacement therapy, cardiopulmonary bypass, and extra-corporeal life support.

If fully optimized in terms of patient selection, procedural technique, and efficiency of transport to definitive hemostasis, REBOA could provide a valuable tool in the management of non-compressible truncal hemorrhage, which remains a source of considerable "preventable" mortality in both military and civilian trauma. New insights are required to harness the full capability of regionalized trauma systems for this pattern of injury, and any tool or technique with the potential to extend the reach of surgical and endovascular trauma management and delay the time from injury to hemodynamic collapse warrants aggressive exploration.

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