Case Report

Vol. 6, No. 3; 2022; pp 144–147
DOI: https://doi.org/10.26676/jevtm.273

Prolonged Partial REBOA: A Practice Paradigm for Managing Hemorrhage from Abdominal Gunshot Wounds

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Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a valuable tool for management of life-threatening truncal hemorrhage. However, prolonged use of REBOA is limited by the ischemia that it causes distal to the occlusion. Partial REBOA (pREBOA) is a developing technique to inflate the balloon partially to allow for a variable degree of distal blood flow and mitigate some of the complications of prolonged occlusion of the aorta while also ameliorating ongoing blood loss. We describe a case of a patient who presented with a gunshot wound to the right upper quadrant of the abdomen with significant liver, kidney, and colon injuries. The patient was successfully treated with pREBOA for 20 hours without ischemic sequalae. This is the longest reported use of prolonged pREBOA and suggests that this technique may offer a means for hemorrhage control in the pre-/intra- and postoperative settings.

Keywords: *Resuscitative Endovascular Balloon Occlusion of the Aorta; REBOA; pREBOA; Penetrating Trauma; Hemorrhage Control*

Received: 28 November 2022; Accepted: 21 December 2022

INTRODUCTION

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a technique that can be utilized to assist with temporary control of noncompressible truncal hemorrhage [1]. It involves placement of a balloon catheter into the descending thoracic aorta (Zone 1) or just proximal to the aortic bifurcation (Zone 3) in order to arrest distal blood flow and ongoing hemorrhage. However, its use is associated with a range of possible complications such as liver failure, intestinal ischemia and limb loss due to ischemia downstream of the occlusive balloon [2]. Studies have demonstrated occlusive times beyond 60 minutes for Zone 1 and 90 minutes for Zone 3 are almost universally fatal [3]. Partial REBOA (pREBOA) has been proposed as a means to allow for control of life-threatening hemorrhage while maintaining some distal perfusion with encouraging results in animal models [4]. The time limits of partial aortic occlusion are not yet completely elucidated.

We present a case in which an ER-REBOA Plus catheter remained in place for 20 hours while the occlusive balloon was variably deflated without any ischemic complications following a gunshot wound to the right upper quadrant of the abdomen.

CASE REPORT

A 57-year-old man presented after a single high-velocity rifle wound to the right upper quadrant of the abdomen. On arrival at the hospital, he was lethargic and had abdominal tenderness with guarding. Initial blood pressure and pulse were 116/54 mmHg and 73 beats per minute, respectively. Bedside ultrasound showed free fluid in the abdomen and chest x-ray showed shrapnel in the right upper quadrant with a retained bullet in the mid back near L1. Computed tomography (CT) scan of the abdomen and pelvis showed a grade V injury to the right kidney, grade IV right hepatic lobe injury with active hemorrhage and a right colon injury (Figure 1*a*,*b*).

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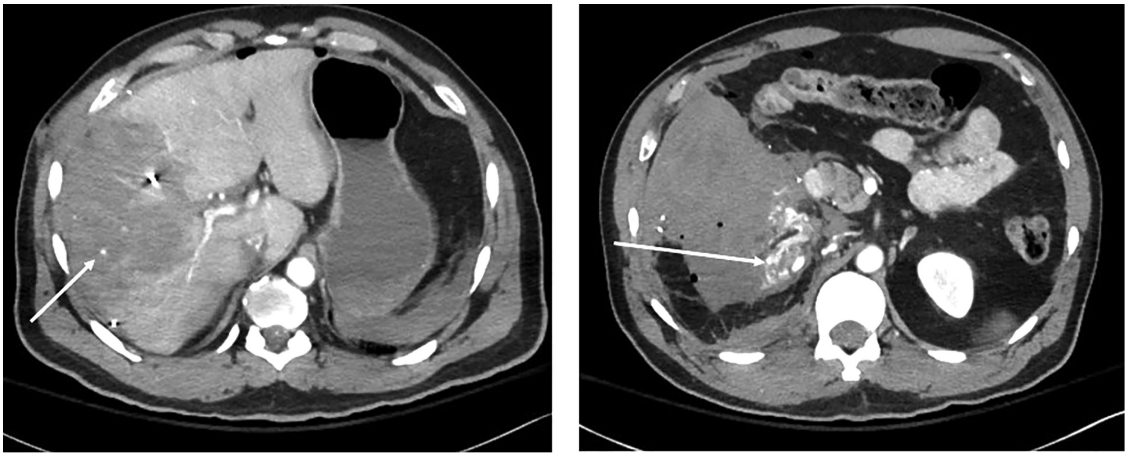
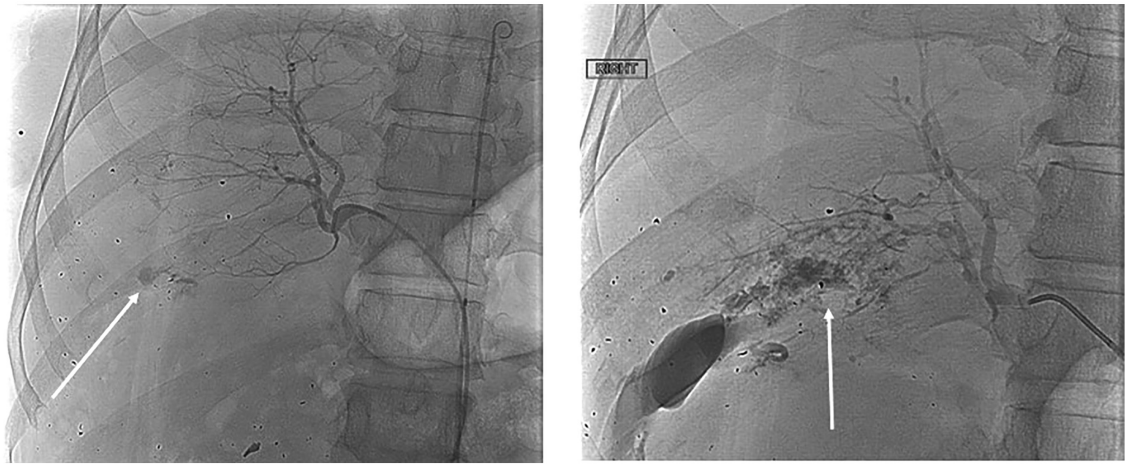


(a) (b)

Figure 1 CT images showing (**a**) a grade 4 right hepatic lobe injury and (**b**) a grade 5 injury to the right kidney with active hemorrhage, and a right colon injury at the hepatic flexure. The arrows point to areas of active arterial hemorrhage.

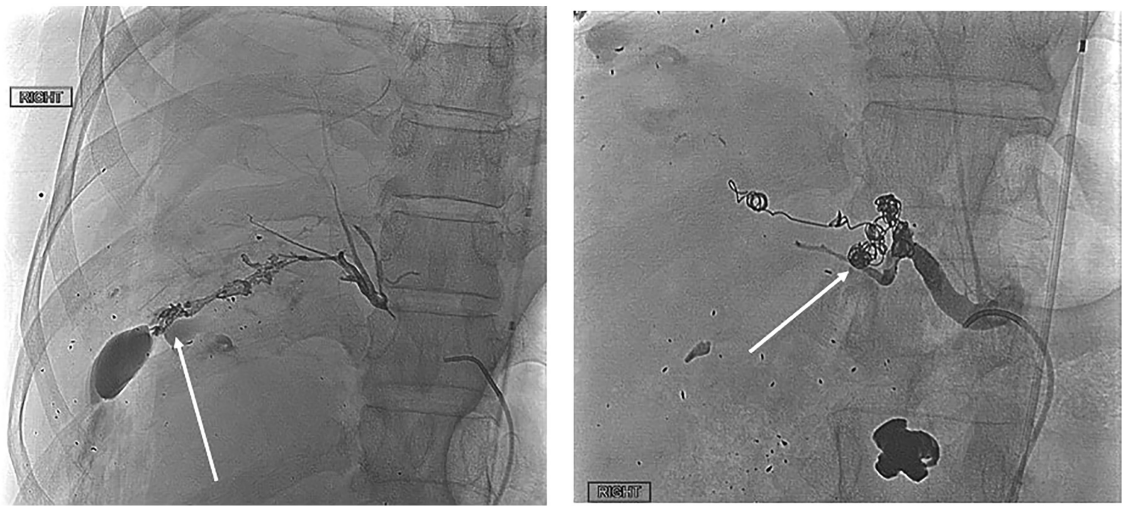


(a) (b)

Figure 2 Selective angiography of the liver showing (**a**) hemorrhage from the area of segment 8 and (**b**) the right kidney showing multifocal arterial hemorrhage. Shrapnel is seen throughout the right upper quadrant of the abdomen, predominantly over the liver. The arrows point to areas of active arterial hemorrhage.

Interventional radiology was consulted for embolization of the right hepatic and right renal arteries, massive transfusion was started and the patient received tranexamic acid. His blood pressure decreased to 90/50 mmHg shortly after CT scan. Therefore, right common femoral arterial access was obtained, and an ER-REBOA Plus catheter with full balloon inflation (8 ml) was placed in Zone 1 with improvement in the patient's blood pressure to 102/46 mmHg prior to transport to interventional radiology. He underwent embolization of the right hepatic and right renal arteries (Figures 2*a,b* and 3*a,b*), which took 70 minutes and received 3 units of packed red blood cells and 3 units of plasma during this time. The balloon was deflated during the interventional radiology procedure.

He was then taken to the operating room for a nonanatomic right hepatectomy and perihepatic packing, right nephrectomy, right colectomy, and placement of temporary abdominal dressing. Throughout the 147-minute operation, the REBOA balloon was intermittently partly deflated to 3–5 ml volume and re-inflated to 8 ml (100%) occlusion to allow perfusion of the abdominal viscera while minimizing ongoing blood loss from the liver. There were no overt signs of bowel ischemia, but the team was concerned about the ramifications of prolonged ischemia on the remaining kidney, liver, lower extremities as well as the alimentary tract. At the conclusion of the case, the REBOA balloon remained inflated with 4 ml of fluid. He received a total of 39 units packed red blood cells, 28 units plasma, 5 units platelets, 10 units cryoprecipitate and was maintained on a continuous plasma infusion for the next 4 hours in the intensive care unit (ICU) due to ongoing severe



(a) (b)

Figure 3 Angiography images following selective coil and ethylene vinyl alcohol copolymer Onyx (Medtronic, Minneapolis, MN). (**a**) Embolization of the right hepatic and right distal renal arteries. (**b**) The retained bullet fragment is seen overlying the vertebral body at the bottom of the image.

coagulopathy. The REBOA balloon remained inflated with 4 ml of fluid for 6 additional hours in the ICU and then was sequentially deflated, first to 3 ml of fluid for 2 hours and then completely deflated. In total, the REBOA catheter was in place and variably inflated from 0% to 100% for 20 hours while the femoral sheath remained in place for a total of 24 hours. Twenty-four hours after arrival, he returned to the operating room for repair of a diaphragm laceration, creation of an end ileostomy, placement of perihepatic drains, and abdominal closure. Intraoperatively, there was no evidence of bowel necrosis or ischemia. Post-intervention, there were also no access site-related complications or ischemia to the extremity.

His hospital course was complicated by transient renal failure and a bile leak, which was treated with biliary stent and sphincterotomy. He was ultimately discharged neurologically intact to rehabilitation after a 25-day hospitalization. He is now home, off dialysis, and on a regular diet.

Ethical Approval and Informed Consent

The study was deemed to be exempt from IRB review and the need to obtain informed consent.

DISCUSSION

The most common cause of preventable death following injury is hemorrhage. Control of hemorrhage within the torso requires urgent embolization and/or operative intervention. Hemorrhage control from the liver is particularly difficult due to its dual blood supply from the portal vein and hepatic artery as well as inability to resect the organ entirely. Embolotherapy offers a means to control solid organ arterial bleeding, but requires time and is relatively contraindicated in hemodynamically unstable patients. REBOA offers a means to control aortic blood flow using an endovascular approach and pREBOA offers a means to allow some ongoing blood flow to the body while minimizing blood loss [5]. Zone 1 placement involves balloon positioning in the mid descending thoracic aorta to control blood loss in the abdomen. pREBOA offers the ability to control distal blood flow dynamically based on a patient's hemodynamics and ongoing blood loss. In this case, placement of a REBOA catheter with partial inflation afforded us the time and hemodynamic stability necessary to proceed with embolotherapy. We also embolized the kidney despite knowing that the patient would require nephrectomy in order to minimize blood loss. This procedure required little additional time. By initially embolizing the injured organs, we mitigated the risk of uncontrolled arterial hemorrhage at the time of laparotomy. We were able to titrate the degree of balloon occlusion based on the patient's blood pressure without rapid exsanguination from injured organs, and could restore full aortic occlusion when blood loss was excessive while transfusion was ongoing. As time elapsed, we partly deflated the balloon to allow for distal flow and titrated the degree of deflation based on the impact this had on his blood pressure. Even following operation, the patient required prolonged partial aortic occlusion due to his severe hepatic injury, blood loss, and shock which resulted in a severe coagulopathy.

Studies on REBOA have not consistently found a mortality benefit [6]. Mortality may not be the appropriate endpoint to assess this modality. Rather, time to and degree of hemorrhage control, which are highly

associated with death, may be better measures of efficacy. In this case, we were able to slow ongoing hemorrhage, which was initially due to organ injury and then due to coagulopathy, to allow time for embolotherapy, operative intervention, and repletion of coagulation factors while simultaneously allowing for distal aortic blood flow. Deflation of the balloon during operation and shortly after arrival to the ICU resulted in recurrent, severe hypotension. We suggest that this supports our belief that prolonged partial REBOA was necessary.

This is the first report of prolonged use of a REBOA catheter with partial aortic occlusion. Current guidelines recommend maximum 30–60 minute Zone 1 aortic occlusion to avoid organ ischemia. However, these guidelines are based on complete aortic occlusion. pREBOA allows for partial occlusion and thus a variable degree of distal blood flow [7–9]. A flow rate of 0.5 L/min has been shown to be effective at preventing ischemia while minimizing hemorrhage in swine [10]. The current pREBOA catheter, which is not the catheter used in this case, allows for measurement of aortic pressure across the balloon. Studies are now needed to compare pREBOA with direct (open) hemorrhage control in terms of blood loss/transfusion need and organ ischemia as well as to correlate distal aortic pressure with actual flow and ischemic threshold. Use of prolonged pREBOA may represent a minimally invasive means to slow down hemorrhage in order to offer endovascular means for definitive hemorrhage control and/or to minimize intraoperative and postoperative blood loss following severe injury in select cases.

Ethics Statement

(1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
(2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors have no financial conflicts of interest.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Author Contributions

All authors contributed equally to the project.

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