# JEVTM

# Journal of Endovascular Resuscitation and Trauma Management
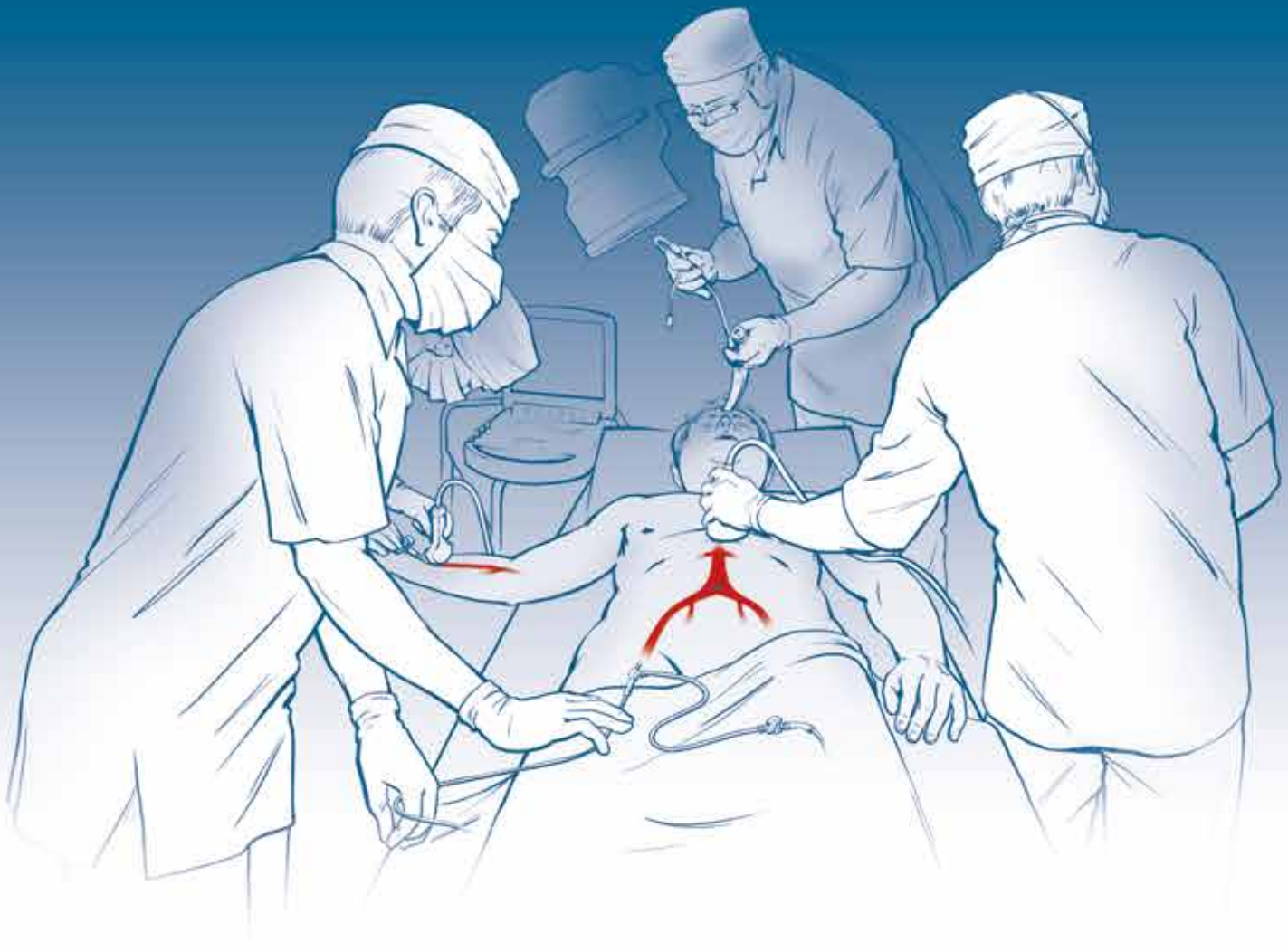
## Issue Highlights

Endovascular solutions for iliac and lower extremity junctional injuries
Contemporary management of blunt thoracic aortic injury
REBOA use in penetrating abdominal aortic injury
Endovascular resuscitation in non-trauma cases
Consensus nomenclature for REBOA



**Official publication of the Society of Endovascular Resuscitation and Trauma Management**

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# Journal of Endovascular Resuscitation and Trauma Management

**This is the** *Journal of Endovascular Resuscitation and Trauma Management*. We want to provide a truly Open Access platform for the dissemination of knowledge and peer-reviewed research in the field of endovascular and hybrid hemorrhage control.

To achieve this, we do not wish to be bound by medical discipline, country, resource or even the conventional rules of medical publishing. To achieve this goal, we have assembled an Editorial Board of clinicians and scientists who are experts within the field. This project is generously supported by a grant from Örebro University Hospital Research Unit.

We are keen to receive manuscript submissions that present new original findings, review important topics or educate our readers on any aspect of hemorrhage control, where an endovascular technique has been employed. This can either be in isolation or in combination with open surgical techniques (hybrid surgery). For further information for authors, please see *www.jevtm.com*.

As the subject of hemorrhage and resuscitation is a common problem across many medical disciplines, we encourage submissions from all specialties: vascular, trauma, acute care, obstetrics, emergency medicine, to mention a few.

The Journal will publish quarterly and will be truly Open Access. There will be no article processing charges or publishing fees. All articles will be published online and indexed using a digital object identifier. The Journal aims to be PubMed cited by 2019.

# II EVTM SYMPOSIUM

## 7-9 June 2018
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Endovascular hybrid Trauma and bleeding Management

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*≫ Editorial ≪*

# The Journal of Endovascular Resuscitation and Trauma Management: A Timely Endeavor

**Joseph DuBose MD, Managing Editor**

*Journal of Endovascular Resuscitation and Trauma Management*

It is with great pleasure that the editorial staff of the Journal of Endovascular Resuscitation and Trauma Management (JEVTM) welcomes your review of – and participation in – our exciting new endeavor. This initial release of the JEVTM represents the beginning of the first medical journal specifically dedicated to the examination of endovascular applications as tools for resuscitation, hemorrhage control, and definitive trauma management. It is an ambitious undertaking, but one for whose time has come.

Why is now the right time for the initiation of the JEVTM? The answer to this question involves an examination of several key concepts. These include the emergence of new technologies, changing clinical practices and a growing body of multi-disciplinary innovators dedicated to the exploration and study of an expanding set of endovascular capabilities.

### Emerging Technologies

The past decades have borne witness to an evolution in endovascular technologies. While many of these innovations were initially developed with the treatment of atherosclerotic and aneurysmal vascular disease pathologies in mind, the applications for hemorrhage control and vascular injury management were quickly appreciated. Endovascular balloons, known to potentially improve outcomes from ruptured abdominal aortic aneurysms, are now increasingly utilized as tools for bleeding control from non-compressible sites following trauma. Angio-embolization has become a mainstay of treatment capabilities for both pelvic and solid organ injury at most busy trauma centers. Endovascular stent grafts have emerged as the acute treatment of choice for blunt thoracic aortic injuries. Additionally, other endovascular adjuncts, including extra-corporeal membrane oxygenation and intra-aortic balloon pump devices, continue to evolve as tools of modern resuscitation.

Initially, many of these advances were achieved using devices that were largely designed for the management of chronic vascular disease. Increasingly, however, devices and capabilities are being engineered to specifically optimize their utilization for victims of trauma and other patients in need of resuscitative salvage. Continued engineering advancements and efforts to define optimal clinical utilization of these devices will require a platform for reporting and critical review. It is our hope that the JEVTM will serve as an effective vehicle for this study.

### Changing Practices

With the increasing inclusion of endovascular capabilities in algorithms for hemorrhage control, resuscitation and trauma management other questions regarding practice have emerged. What provider is best suited to employ these technologies? How should they be trained? What expertise is required? The answers to these questions have not been well elucidated, even as the use of endovascular technologies continues to grow.

Beyond the type of providers that should be involved, there also remain questions about the optimal care environment in which these technologies should be delivered. Is a hybrid-operating suite the optimal environment? How much imaging capability is really required? Can some of these capabilities safely be brought to the pre-hospital care environment? These questions are matters of active investigation that require examination in a venue like the JEVTM.

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### A Multi-Disciplinary Collaboration

The foundation for the creation of the JEVTM can be traced to discussions that culminated in the February 2017 Endovascular Hybrid and Trauma Management Meeting in Örebro, Sweden. This gathering, sponsored by the University of Örebro, brought together leaders in thought from nations throughout Europe, North America, and Asia. Their diversity in geographic representation was second only to their diversity of training backgrounds. Interventional radiologists, emergency medicine physicians, and surgeons (vascular, trauma and acute care) shared their clinical experiences with not only each other but also a large group of translational scientists working diligently to provide important foundational data for the next steps in endovascular applications.

In the context of this excellent exchange, many of these multi-disciplinary participants discussed work that had been presented at prestigious meetings and had been published in a wide array of medical journals scattered across a variety of disciplines. It became apparent, however, that there was a need for a platform that might serve as a common ground for this diverse group of providers striving to advance the safe and effective use of endovascular technologies in resuscitation and trauma management. It is our hope that the JEVTM will serve as that needed platform.

# Journal of Endovascular Resuscitation and Trauma Management (JEVTM)

## Todd E Rasmussen MD

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In February of 2017 more than 350 medical professionals representing a diverse number of disciplines in medicine and surgery from around the world convened in Örebro Sweden at the inaugural Endovascular Hybrid Trauma & Bleeding Management (EVTM) symposium. The event was the first of its kind, bringing together surgeons, interventionalists, anesthesia and critical care experts and emergency medicine providers, all with experience in caring for the severely injured or ill patient. Through a combination of clinical and scientific presentations, panel discussions and moderator-led debates, attendees advanced their common understanding of the capacity for catheter-based, endovascular approaches and new technologies to improve the survival and recovery of such patients.

The eventual size of the EVTM symposium, the diversity and international composition of attendees, and the fervent nature of discussion and interest in the program surpassed even the optimistic projections of event organizers. EVTM tapped and coalesced an otherwise underappreciated momentum in the area of endovascular techniques for injury and critical care, one that's been relatively overlooked by other professional organizations to which EVTM attendees belong. Beyond its clinical and scientific content, EVTM made clear that interest in endovascular approaches to advance injury and critical care (compared to those applied to age-related disease processes) lies at the margins of individual clinical disciplines, their established professional organizations and respective meetings and publication venues. EVTM exposed the challenge and provided a common forum to redress it.

As such, and as a logical extension of the 2017 EVTM Symposium, this new Journal of Endovascular Resuscitation and Trauma Management (JEVTM) is a well-planned and timely platform on which to continue the global discussion in this dynamic topic area. The JEVTM aims to capture and maintain the cross-disciplinary momentum on display at the 2017 symposium in Örebro and to serve as an electronic and print forum by which to disseminate knowledge from clinical experiences as well as that stemming from structured research, development and innovation activities. Through publication of case reports and results from original research and by providing profiles on new technology and innovation concepts, as well as modern reviews and commentaries in this space, JEVTM will establish itself as the common conduit for this topic area coursing through various established and otherwise fixed disciplines.

The originators of the EVTM Symposium and the editorial leadership of the new JEVTM are an energetic and highly qualified group of professionals from around the world and just the right team to lead this endeavor. This group will quickly expand a stimulating discussion of topics and controversies in the field, and like the EVTM symposium itself, tap a wealth of cross-disciplinary interest and knowledge content in the topic area. I'm excited about the potential JEVTM has to inform a global readership like no other publication forum and in doing so promote needed advances the field of injury and critical care. I'd encourage those who are in the clinical, scientific and innovative communities to engage the journal with submissions for publication and support its editorial leadership in conducting peer-review and publication processes. Congratulations to the leaders of the EVTM and to the originating editors of the JEVTM on this new and exciting milestone. Now let's get to work!

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# Contemporary Management of Blunt Thoracic Aortic Injury: Results of an EAST, AAST and SVS Survey by the Aortic Trauma Foundation

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**Objective:** To determine contemporary management practices for blunt thoracic aortic injury (BTAI) among trauma and vascular surgeons.

**Methods:** A survey of Eastern Association for the Surgery of Trauma, American Association for the Surgery of Traum and Society of Vascular Surgeons (SVS) membership regarding BTAI care was conducted.

**Results:** 404 respondents included trauma (52.5%), vascular (42.6%) and other specialty providers (4.5%) primarily from North American (90.6%) academic teaching institutions (71.0%) / American College of Surgeons Level I trauma centers (58.9%). Most respondents managed one to five BTAIs annually (71.6%). Preferred diagnostic modality was computed tomographic angiography (CTA) (99.8%), after which respondents stated they preferred to utilize personal knowledge of the literature and experience (50.5%), the SVS guidelines (27.4%) or institution specific guidelines (12.8%) to guide subsequent management. Respondents primarily agreed on the treatment of intimal tears (SVS G1) with medical management. For intramural hematoma (SVS G2), management choice was divided between medical (46.6%) and thoracic endovascular aortic repair (TEVAR) (46.3%). Both groups defined TEVAR as treatment of choice for hemodynamically stable patients with pseudoaneurysm (SVS G3) (93.5%) and rupture (SVS G4) (82.2%), although a greater number of trauma surgeons preferred open repair (20.4%) than vascular counterparts (4.1%) in stable G4 patients. Preferred medical management goals varied between mean arterial pressure (37.3%) and systolic blood pressure (62.3%) targets. Preferences also varied in adjuncts for open repair (left heart bypass 56.5%; clamp and sew 46.1%; cerebrospinal fluid (CSF) drainage 48.5%) and TEVAR (percutaneous puncture for arterial access 58.4%; open vascular exposure 65.5%, intravascular ultrasound 36.1%, CSF drainage 28.9%). Outpatient follow-up timing (2 weeks 37.0%, 1 month 37.2%) and initial type (clinical exam 36.6%, CTA 48.3%) also varied.

**Conclusions:** The survey of trauma and vascular surgeons illustrates controversy regarding SVS G2 treatment, surgical adjuncts and follow-up. Additional study is required to identify optimal BTAI management.

**Keywords:** *Trauma; Blunt Thoracic Aortic Injury; BTAI; Endovascular; Practice Patterns*

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**Author contributions:** JJB, AE, BS, and AA were responsible for the conception and design. ED and ML drafted the manuscript. ED, ML, JJB, AE, BS, and AA were involved in critical revision of the manuscript. ED has responsibility for the content.

**Conflicts of interest:** None.

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## INTRODUCTION

Blunt thoracic aortic injury (BTAI) is the second most common cause of death after blunt traumatic injury [1,2]. In recognizing the importance of managing these potentially life-threatening injuries, the Society of Vascular Surgeons (SVS) published a set of consensus guidelines in 2011 addressing various aspects of BTAI management [3]. Six years after the SVS guidelines were released there is still some areas of controversy regarding the management of BTAI and we lack a baseline understanding of practice patterns.

The SVS guidelines recommended expectant management of Grade I (intimal tear) injuries and endovascular repair of Grade II (intramural hematoma), Grade III (pseudoaneurysm) and Grade IV (rupture) injuries [3]. Despite these recommendations, the management of Grade II and Grade III injuries is still debated. It has also been suggested that the SVS 2011 guidelines are suboptimal since they consider the aortic lesion alone and do not account for associated traumatic injuries such as traumatic brain injury (TBI) [4,5].

We anticipate that there is a wide variation in contemporary BTAI management practices among different specialties and institutions, particularly with intermediate grade injuries. We surveyed vascular, trauma and cardiothoracic surgeons and interventional radiologists involved with the management of BTAI to determine compliance with SVS guidelines, and trends in goals of medical management, operative management, and follow up. We seek to identify areas in which consensus is lacking in order to focus future research toward standardized BTAI management and improved outcomes.

## METHODS

A survey instrument was developed to capture current practices for the management of BTAI. Provider demographics including specialty and years in practice were obtained. Institution characteristics were obtained including the number of annual trauma admissions, the number of BTAIs treated annually and which specialty performs open and endovascular repair of these injuries. Each participant was surveyed about diagnostic modalities used, management of Grade I through IV BTAI and their use of the SVS guidelines. With respect to medical management, each participant was asked about blood pressure goals and follow-up imaging. Operative decision making between open and thoracic endovascular aortic repair (TEVAR) was assessed as well as post TEVAR follow-up interval and imaging.

Surveys were sent via email to the membership of the Society for Vascular Surgery, the Eastern Association for the Surgery of Trauma (EAST) and the American Association for the Surgery of Trauma (AAST). The survey was open from December 2014 to May 2015 and was approved by the Boards of the SVS, EAST, and AAST for circulation to their respective memberships. Survey responses were collected in a Microsoft® Excel® spreadsheet for basic tabulation and statistical analysis.

## RESULTS

We received survey responses from 404 physicians. The specialties of the respondents included vascular (172), cardiothoracic (8), and trauma surgeons (212), interventional radiologists (5), and five others (two retired surgeons, two fellows, and one pediatric surgeon). Over half of the respondents (62.1%) had completed more than 10 years of clinical practice. The vast majority were located in North America (90.6%) and practiced in academic teaching facilities (71.0%). Most (58.9%) were at American College of Surgeons (ACS) Level I trauma centers with 66.1% having an annual trauma admission volume of less than 4,000. The majority of institutions (64.7%) had between one and ten cases annually with most participants (71.6%) managing one to five cases of BTAI annually (Table 1).

When asked about sources utilized when determining the need for repair of BTAI, 50.5% indicated the use of personal knowledge of the literature and experience. Only 27.4% cited the SVS guidelines in their decision making. Institutional protocols were cited by 12.8% of respondents with the remainder (9.3%) deferring to a consulting physician. Treatment preference for Grade I BTAI was primarily medical management with blood pressure control (81.3%). Simple observation was elected by 9.2% and 4.7% would repair Grade I injured with TEVAR. Grade II injury management was neatly split 46.6% for medical management and 46.3% for TEVAR. This split persisted when examining answers by specialty; 52.1% of trauma surgeons, 44.9% of vascular surgeons, and 57.1% of cardiothoracic surgeons selected medical management for Grade II injury. Grade III injuries were primarily managed with TEVAR (93.5%) with only 1.5% and 1.2% electing for open repair and medical management respectively. Most respondents indicated they would repair rupture (Grade IV) with TEVAR (82.8%). Open repair for Grade IV injury was elected by 13.2% of participants (20.4% of trauma surgeons versus 4.1% of vascular surgeons). Each grade of injury had 3.5% to 6.3% of respondents selecting "other management", but most of these indicated they would defer to consultant preference (Figure 1).

When asked about blood pressure control for medical management of BTAI, 37.7% of providers report following mean arterial pressure (MAP) compared to 62.3% who follow systolic blood pressure (SBP). For those using MAP, most selected a goal of <80 mmHg (88.4%) with a minority selecting a lower goal of <100 mmHg (11.6%). Of those managing BTAI based on SBP, most selected a goal of <120 mmHg (76.9%), and fewer selected the lower goal of <100 mmHg

***Table 1*** Respondent demographics.

| | |
|---|---|
| ***Profession*** | |
| Trauma Surgeon | 52.5% |
| Vascular Surgeon | 42.6% |
| Cardiothoracic Surgeon | 2.0% |
| Interventional Radiologist | 1.7% |
| Other | 1.2% |
| ***Years in practice*** | |
| < 5 years | 23.0% |
| 5–10 years | 14.9% |
| 10–20 years | 27.2% |
| > 20 years | 34.9% |
| ***Region of practice*** | |
| North America | 90.6% |
| South America | 3.2% |
| Europe | 4.2% |
| Asia | 1.0% |
| Other | 1.0% |
| ***Practice Environment*** | |
| Academic teaching facility | 71.0% |
| Community-based practice | 21.3% |
| Public/Government hospital | 5.7% |
| Military hospital | 1.0% |
| Other | 1.0% |
| ***Trauma center certification*** | |
| ACS Level I | 58.9% |
| ACS Level II | 14.7% |
| ACS Level III | 3.7% |
| Non-ACS trauma center | 17.7% |
| Not at a trauma center | 5.0% |
| ***Annual trauma admission volume*** | |
| < 2,000 | 28.4% |
| 2,000–4,000 | 37.7% |
| 4,000–6,000 | 10.7% |
| > 6,000 | 9.7% |
| Unknown | 13.5% |
| ***Number of BTAI cases annually*** | |
| None | 4.5% |
| 1–5 | 35.1% |
| 6–10 | 29.6% |
| 11–15 | 14.8% |
| 16–20 | 8.0% |
| > 20 | 8.0% |
| ***Number of cases assisted/performed by respondent*** | |
| None | 7.7% |
| 1–5 | 71.6% |
| 6–10 | 12.7% |
| 11–15 | 3.7% |
| 16–20 | 1.7% |
| > 20 | 2.5% |



***Figure 1*** Respondent management preference for Grade I–IV BTAI.

97.5% selecting computed tomographic angiography (CTA). For medically managed patients, the top indications for conversion to repair (open or TEVAR) were hemodynamic instability (74.2%), associated peri-aortic blood (53.8%), and associated mediastinal hematoma (42.1%). A third of participants indicated they would opt to repair patients with a need for other emergent operative procedures (32.9%) or associated TBI (32.4%).

For patients requiring intervention, open repair of BTAI was favored when the patient had a need for emergent open thoracic surgery for indications other than BTAI (52.9%). Patient instability (32.2%) and experience level of providers available to conduct the repair (31.9%) were also important considerations when choosing open repair. Close proximity to the left subclavian artery (23.4%) and higher grade of BTAI (21.0%) would also shift some toward open intervention. Of the providers performing open repair, 56.5% used cardiopulmonary bypass, 46.1% used a clamp and sew technique, 48.5% placed spinal cerebrospinal fluid drains, and 16.2% induced hypothermia. Open repair was primarily performed by cardiothoracic surgeons (80.7%) and vascular surgeons (44.6%, Table 2).

The most common indicators for TEVAR over open repair were provider expertise (54.6%), comorbid pulmonary disease (40.3%), and older patient age (35.4%). Both higher grade (24.6%) and lower grade (29.2%) of BTAI influenced the decision to perform TEVAR. Injury proximity to the left subclavian artery was a factor for 25.7% of providers. Access for TEVAR was mixed with 65.5% preferring open exposure and 58.4% preferring percutaneous puncture. Intraoperative angiography was routine (83.7%) and endovascular ultrasound was used by 36.1%. Cerebrospinal fluid drains were placed by 28.9% of providers after TEVAR. Endovascular repair was performed primarily by vascular surgeons (85.7%) followed by cardiothoracic surgeons (40.2%) and interventional radiologists (14.6%). Participants were asked

(23.1%). Most providers (88.0%) indicated they would repeat imaging within one week to evaluate for injury progression; 24 hours (16.3%), 48 hours (34.3%), 3 days (17.3%), and 7 days (20.1%). Only 5.0% indicated they would wait for up to 6 weeks to repeat imaging. Choice of imaging modality was nearly unanimous with

***Table 2*** Credentialing for open repair and TEVAR of BTAI.

| | |
|---|---|
| *At your institution, which specialists perform open repair?* | |
| Cardiothoracic Surgeon | 80.7% |
| Vascular Surgeon | 44.6% |
| Trauma Surgeon | 7.3% |
| *At your institution, which specialists perform TEVAR?* | |
| Vascular Surgeon | 85.7% |
| Cardiothoracic Surgeon | 40.2% |
| Interventional Radiologist | 14.6% |
| Interventional Cardiologist | 1.8% |
| Trauma Surgeon | 1.3% |
| *In your opinion, which specialties should perform TEVAR?* | |
| Vascular Surgeons | 84.6% |
| Cardiothoracic Surgeons | 43.3% |
| Trauma Surgeons | 11.6% |
| Interventional Radiologists | 11.1% |
| Interventional Cardiologists | 1.5% |
| Any provider w/ TEVAR training | 18.1% |

*Note: multiple selections are possible from a single respondent.*



***Figure 2*** Recommended annual number of TEVAR cases to maintain currency stratified by the specialty of the respondent.

how many TEVAR cases should be performed annually to maintain proficiency. Overall, 52.9% indicated that three to five TEVAR cases per year would be sufficient for maintaining proficiency, and this majority was maintained when separating the recommendation by specialty (Figure 2).

When presented with a patient requiring left subclavian artery coverage during the course of TEVAR, 39.8% planned on performing carotid-subclavian bypass for specific indications (for example, a known dominant left vertebral artery or patent left internal mammary artery in post-CABG patients). A third (35.2%) utilized watchful waiting and selectively revascularized only if symptoms occur in the post-operative period. Planned pre- or postoperative carotid-subclavian bypass was used by 10.4% of providers, and advanced endovascular techniques (branch grafts, fenestrated grafts) by 7.6%.

Most providers (73.0%) obtained post-TEVAR imaging prior to discharge with the most common modality being CT (96.5%). The post-op interval for obtaining the CT before discharge was variable with most performing any time prior to discharge (44.1%) while a quarter of participants advocated for 3 days (25.5%) and a quarter for 7 days (25.8%) after TEVAR. Initial outpatient follow-up interval was mostly (83.9%) within one month, with 9.7% following up at 1 week, 37.0% at 2 weeks, and 37.2% at 4 weeks. Most providers ordered a CTA (48.3%) or plain chest radiography (14.8%) or both, and 36.6% did not order imaging at the first postoperative visit.

## DISCUSSION

The SVS guidelines have been in place for six years, however, there are still areas of significant variation in practice patterns in the management of BTAI. While there was consensus on some topics (Grade I, III, and IV

management and the use of CTA for diagnostics), this survey identified differences in management of Grade II BTAI, blood pressure goals for medical treatment of BTAI, and the use of bypass when covering the left subclavian artery during TEVAR.

When presented with a Grade II injury, our participants were neatly split between medical (46.6%) and endovascular management (46.3%), a division that persisted when isolated by specialty. Medical management itself requires clarification as there was no clear consensus among providers regarding the use of MAP versus SBP and what the maximum pressure goal should be to limit the progression of injury. Additional research on BTAI should focus on management of intermediate grade injuries and determination of appropriate blood pressure goals in patients awaiting repair or undergoing medical management.

We identified factors influencing open repair and TEVAR decision making which may be useful in developing guidelines which considering patient characteristics beyond the aortic lesion. A significant portion of respondents would convert medical management to operative (open or TEVAR) management in patients with hemodynamic instability, associated peri-aortic blood or mediastinal hematoma, TBI, and the need for other emergent operative procedures. Guidelines and algorithms should be tailored to account for the patient's traumatic burden, co-morbid conditions, and hospital capabilities. For instance, mid-grade injuries with concomitant TBI may be best managed with early repair since the goals of impulse pressure control run counter to maintaining adequate cerebral perfusion pressure.

Endovascular therapy is the preferred method of thoracic aortic repair in the absence of contraindications [3,6]. As this modality becomes more commonplace, it is important to identify proficiency goals for current and future practitioners. More than half of our participants felt that three to five TEVAR cases per year was adequate for ongoing proficiency. Incidentally, this closely correlates with the fact that most respondents only managed one to five cases of BTAI per year. Future credentialing requirements for the practice of TEVAR for

BTAI should balance the relative rarity of this injury and consider the inclusion of other aortic endovascular interventions such as abdominal aortic aneurysm repair when determining proficiency.

Despite the apparent disparities in the management of BTAI, there has been progress toward unifying our treatment practices. The Aortic Trauma Foundation (ATF) was formed in 2014 to foster collaborative efforts to improve BTAI outcomes including the creation of an aortic injury registry. The EAST published additional guidelines in 2015 promoting the use of CTA for evaluation, encouraging TEVAR for BTAI when not contraindicated, and advocating for delayed repair with appropriate blood pressure control [6]. The development of future comprehensive guidelines for BTAI will be dependent upon collaborative efforts of organizations like the ATF, vascular, trauma and cardiothoracic societies, and input from physicians responsible for these patients. The results of this survey should give direction to future research and educational activities focused on improving outcomes for patients with BTAI.

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*Original Article*

# "What's in a Name?" A Consensus Proposal for a Common Nomenclature in the Endovascular Resuscitative Management and REBOA Literature

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The emerging techniques of REBOA and other Endovascular Trauma Managment (EVTM) concepts has introduced new terminology to the medical vernacular. As research in this field continues, the authors propose a common base-line nomenclature for the initial core essentials of EVTM concepts.

**Keywords:** *REBOA; Endovascular Rususcitation; Trauma*

## INTRODUCTION

The emergence of endovascular devices for the management of hemorrhage holds considerable promise in both civilian and military settings, resulting in the increasing discussion of endovascular trauma management (EVTM; www.jevtm.com) concepts [1–13]. One early success of this innovation has been the development of the resuscitative endovascular balloon occlusion of the aorta (REBOA) technique. The goals of REBOA are to prevent or reverse hemodynamic collapse by minimizing ongoing bleeding from injured vascular beds and expediently restore adequate perfusion pressure to the heart, lungs, and brain. The application of this technique has demonstrated clinical successes for both trauma victims and non-trauma patients suffering from life-threatening hemorrhage due to gastrointestinal bleeding, obstetric bleeding, and iatrogenic vascular injury. Expanding indications may also include non-hemorrhagic scenarios, including cardiac arrest and sepsis.

Following these initial successes [1,2,4,6–12], innovators in both translational and clinical research have begun to explore potential improvements to the initially described technique for REBOA [3,5,12,13]. New low-profile devices specifically engineered for trauma use, novel techniques designed to mitigate the risks of prolonged aortic occlusion, and even the exploration of REBOA utilization in a variety of patient environments have all been described [5]. While this pace of innovation is exciting, it has also introduced new challenges in the form of a rapidly expanding lexicon of terms and acronyms that can prove confusing and inconsistent.

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While recognizing the dynamic nature of this clinical evolution, the authors propose the adoption of a common lexicon for use in the shared literature of endovascular resuscitation and REBOA use. Acronyms are wonderful tools when utilized discerningly. These literary devices save space in word limit restricted abstract and manuscript submissions and are often quite "catchy". Yet over reliance on acronyms, can contribute to significant confusion. As this specifically applies to the realm of endovascular resuscitation, we propose that the use of common acronyms be reserved primarily for the description of specific techniques, and more sparingly for basic physiologic tenets that support the conduct of these procedures.

The authors generally agree that the use of specific acronyms that describe the *location* of use for endovascular bleeding management adjuncts lends itself to the potential for a confusing litany of terms. For example, the terms "pre-hospital", "austere", "remote" and "out-of-hospital" could all serve as portions of REBOA acronym prefixes (i.e. PH-, A-, R- or OOH-REBOA). Similarly, a variety of location specific suffixes could contribute to confusion in the vernacular. It is our opinion that these types of acronym conventions should generally be avoided.

## PHSYIOLOGIC PRINCIPLES NOMENCLATURE

### Regional Endovascular Perfusion Optimization (REPO)

*Regional endovascular perfusion optimization*, or REPO, is a term designed to emphasize the hypotensive distal organ perfusion with optimization of proximal perfusion to critical organs (brain, heart) proximally. Many readers may be familiar with the term "hypotensive resuscitation" to not "pop the clot" as employed in the care of patients prior to definitive surgical control of hemorrhage. REPO represents a regional approach to the use of this physiologic principle afforded by the fact that the location of an endovascular occlusion can be variable within the vascular tree. As a principle, REPO (proximal to the bleeding site) could be considered the foundational principle behind the majority of endovascular bleeding management strategies described to date.

While REPO could, theoretically, be achieved by a variety of the techniques described later in this manuscript, the optimal goal of REPO is to introduce stable low volume flow to an injured vascular territory in such a way that minimizes hemorrhage but preserves organ viability. This strategy could be applied to the regulation of aortic flow at various levels or even in the endovascular control of more distal branch vessels. By maintaining a stable flow to the targeted injured vascular territory, fluid resuscitation can be performed in a judicious manner to promote normal physiology proximal to the level of flow restriction. Ultimately, the theoretical benefit of this therapeutic approach is to *optimize* perfusion to the greatest extent both proximal and distal to the level of

flow restriction in the face of uncontrolled vascular injury, while minimizing bleeding from the injured vessel. We recommend that the acronym REPO is utilized to describe the application of this specific physiologic principle.

### Endovascular Perfusion Augmentation for Critical Care (EPACC)

Although the authors generally agree that location specific nomenclature should not be used while describing techniques, *endovascular perfusion augmentation for critical care* (EPACC) has been developed to describe a physiologic state, the critically ill patient, and not a specific location, the Intensive Care Unit. This term describes the optimization of cardiac output, restoring euvolemia, and normal vascular tone, using endovascular adjuncts in critically ill patients with systemic hypotension from a non-hemorrhagic source or during the critical care phase after hemorrhage control has been obtained.

While vasopressors and fluid resuscitation have proven the mainstay of care in this unique patient population, responsiveness to these interventions is frequently protracted – with significant time spent outside the target hemodynamic endpoints. In many instances, these endpoints are never attained despite maximal intervention. For patients in distributive forms of shock, such as sepsis, ischemia-reperfusion injury, and anaphylaxis, the inability to restore adequate systemic vascular resistance can result in refractory hypotension. This common clinical scenario has led to some researchers considering the use of partial aortic occlusion to provide mechanical pressure augmentation and this technique has been described in large animal models. Initial clinical case reports have begun to describe the potential of this technology, even though this novel and emerging concept has not yet been refined to such an extent that it has seen mainstream acceptance. However, EPACC is likely to prove an important term in the evolving vernacular of endovascular resuscitative management. We recommend the term EPACC be used when describing the application of endovascular resuscitation in the care of critically ill patients without ongoing hemorrhage, analogous in many ways to the use of an intra-aortic balloon pump (IABP) and extra-corporeal membrane oxygenation (ECMO) in this setting.

## SPECIFIC TECHNIQUE NOMENCLATURE

### Resuscitative Endovascular Balloon Occlusion of the AORTA (REBOA) and Aortic Balloon Occlusion (ABO)

While the technique of balloon occlusion for the purpose of achieving hemorrhage control and restoring perfusion to the heart, lungs, and brain is far from a new concept, it is presently undergoing a clinical renaissance [1–13].

The term REBOA was first introduced in 2011 [14,15] and has gained progressive adoption internationally. Based on its original description and use of the term in the literature, REBOA represents *complete* occlusion of the aorta, such that there is no aortic flow permitted beyond the inflated balloon. As the name implies, this strategy is meant to serve as a resuscitative effort. In that context, REBOA embodies a therapeutic intervention that can be applied to the physiologically deranged patient. While it has been widely touted for use in hemorrhagic shock, the term REBOA may be appropriately applied to aortic balloon occlusion in alternate shock states. However, the term REBOA does not necessarily encompass the use of balloon occlusion for prophylactic purposes, such as in high-risk surgical interventions or for planned vascular control during elective vascular surgery.

This therapy does imply a specific balloon catheter type or manufacturer, but inherently it represents endoluminal occlusion of the aorta with a balloon or balloon catheter as opposed to some other occlusion device like open aortic clamping. Based on its present clinical use, REBOA represents an endovascular balloon fully inflated to result in complete occlusion.

Internationally, the term "aortic balloon occlusion," or ABO, has been applied in an analogous fashion, however, this terminology does not convey the clinical context within which the technique is applied clinically. In essence, the acronym "ABO" generally describes a generic "technique" that embodies complete aortic occlusion irrespective of the context, whereas REBOA is more descriptive in indicating the intent of that therapy. For the purposes of resuscitation from shock due to any cause, the term REBOA more accurately embodies the purpose of the intervention.

We recommend that the term REBOA should be applied to scenarios where complete balloon occlusion of the aortic is being performed for resuscitating a physiologically deranged patient, be it from hemorrhage, sepsis or cardiac causes. We propose that the acronym REBOA is utilized preferentially in this setting, largely replacing the older ABO acronym except in those specific settings where an aortic balloon is employed prophylactically for elective/preventative indications.

## Partial REBOA (P-REBOA)

Several clinical and translational reports suggest that partial aortic flow restoration via partial aortic occlusion may serve to simultaneously mitigate the adverse effects of aortic occlusion on both proximal and distal vascular beds, while aiming to limit ongoing hemorrhage in the bleeding patient [3,5,13]. In general, these researchers and clinicians have described this therapeutic strategy as partial REBOA or P-REBOA. However, application of P-REBOA has been heterogeneous and the methodology to perform it remains ill-defined. Currently, there is no clear consensus on how to titrate the

degree of balloon occlusion, nor is there a widespread acknowledgment of which physiologic parameters should be utilized to guide this titration (i.e. pressure above or below the balloon).

At least one method to manually titrate the degree of occlusion based on the pressure below the balloon has been described. It has also been shown in translational models that a direct linear correlation exists between distal aortic pressure and aortic flow beyond the balloon, allowing the end user to titrate downstream flow using conventional pressure-based monitoring techniques. Regardless of the technique used to perform P-REBOA, the current clinical experience is lacking and is confined to case reports.

Despite the difficulty in optimally codifying this technique, we recommend the term P-REBOA be used to describe the general approach of partial balloon catheter inflation for the purpose of resuscitating the physiologically deranged patient, with the dual goal of minimizing downstream ischemic injury while limiting hemorrhage. As no reporting standards currently exist, P-REBOA should be used to describe any attempt at partial balloon inflation/deflation within this clinical context.

## Intermittent REBOA (I-REBOA)

An alternative approach to mitigate the consequences of sustained aortic occlusion is the concept of intermittent REBOA or I-REBOA. I-REBOA represents the cyclical full inflation and full deflation of a balloon catheter in the care of the physiologically deranged patient. This represents a binary approach to resuscitation, where aortic occlusion is repeatedly toggled from "on" to "off" to minimize the ischemic burden to downstream tissues. As with P-REBOA, the application of I-REBOA remains ill-defined, with similar challenges regarding quantification, data capture, and reporting.

We recommend that the term I-REBOA should be used to describe the intentional cyclical and complete inflation and deflation of a balloon catheter in the care of the physiologically deranged patient.

## Endovascular Variable Aortic Control (EVAC)

As clinical and translational experience with endovascular trauma management continues to mature, investigators have suggested that the precise and responsive regulation of aortic flow may have significant utility in achieving more optimal regional endovascular perfusion optimization at a variety of anatomic locations and clinical settings. The term *endovascular variable aortic/arterial control* or EVAC refers to this emerging technique of precision flow regulation of the aorta or branch vessels across the full spectrum from full occlusion to the unimpeded restoration of arterial flow.

Translational data have demonstrated that EVAC can effectively be utilized to achieve REPO in experimental

large animal models. To date, experimental use of EVAC is reliant on intelligent automated physician-assist systems that can make microliter balloon volume adjustments every few seconds based on pressure/flow above and below the balloon. While the technologic requirements for this precise control are possible, they are not approved for use by the bedside provider, the impending nature of this innovation warrants inclusion of the term "EVAC" in the proposed common nomenclature of endovascular resuscitative management.

We recommend that the term EVAC is utilized to describe the technique of physician assist modalities that afford precise aortic or arterial flow regulation across the full spectrum of flow.

## CONCLUSION

Innovation in the development and employment of endovascular resuscitative adjuncts continues at an impressive pace. The evolution of devices and concepts involved in these efforts will, inevitably, lead to a growing lexicon of endovascular intervention for resuscitation. These present naming conventions represent only the beginning of what we believe to be a bright future for the field.

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# Practice Preferences using Resuscitative Endovascular Balloon Occlusion of the Aorta for Traumatic Injury Before and After the 2017 EndoVascular and Hybrid Trauma and Bleeding Management Symposium

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**Background:** Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a technique to aid in resuscitative efforts for hemorrhagic shock. The use of REBOA is not yet commonplace and there is little understanding of real-world practice patterns. The Endovascular and Hybrid Trauma and Bleeding Management Symposium is a large international conference specifically developed to discuss multidisciplinary, endovascular and hybrid approaches to hemorrhage management. We sought to evaluate provider opinions and practice patterns using REBOA for traumatic vascular injury before and after attending this conference.

**Methods:** A detailed survey was completed by a variety of providers before and after the conference. The survey was composed of demographic information, and focused on practice patterns and opinions regarding the implementation of REBOA.

**Results:** We received 186 survey responses (99 pre, 87 post). There was increased perception of feasibility for REBOA in all settings, with the largest increase for pre-hospital and austere military environments (53.5% pre, 67.8% post and 59.6% pre, 73.6% post respectively). While there was no consensus on tolerable occlusion times and indications for utilization, most participants felt that partial REBOA was the most viable technique for prolonging the benefits of REBOA, and more participants came to this conclusion after attending the conference (62.2% pre, 81.6% post, $p = 0.006$).

**Conclusions:** REBOA is an exciting and important advancement in the management of life threatening hemorrhage; however, its implementation has not been codified and there is much variation in practitioners' understanding of its use. Continued investigation is needed to determine the appropriate indications, methods, and practical limitations of REBOA as a new hemorrhage management paradigm.

**Keywords:** Trauma; Endovascular; REBOA; Practice Patterns

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**Conflicts of interest:** None.

## INTRODUCTION

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a technique to aid in resuscitative efforts for hemorrhagic shock [1–6]. Aortic occlusion balloon placement has a role in both elective and emergency surgery, including with management of placenta accreta [7–11], as a technique to decrease blood loss during orthopedic or pelvic tumor excisions [12–16], and for traumatic injuries [1,17–20]. Successful use has been reported in the prehospital setting both in austere military [17], and civilian environments [18]. Though the use of this technique has been increasing, it is not yet common practice and there has been controversy with regard to ideal settings and indications. Additionally, there is little understanding of real-world practice patterns and attitudes toward REBOA.

The EndoVascular and Hybrid Trauma and Bleeding Management (EVTM) Symposium is an international conference specifically developed to discuss multidisciplinary, endovascular and hybrid approaches to hemorrhage management, including techniques such as REBOA. World-renown experts in REBOA discuss indications and techniques for its use drawing from current literature and practical experience. Future directions for REBOA, emerging resuscitative techniques, and technological innovations for hemorrhage control are considered. The conference is attended by a wide range of specialties including trauma and vascular surgeons, anesthesiologists, emergency medicine physicians and interventional radiologists.

We sought to evaluate provider opinions and practice patterns using REBOA for control of hemorrhage due to trauma before and after attending the EVTM conference. Additionally, we aimed to characterize areas of consensus for the future development of practice guidelines and elucidate topics of significant discordance. Furthermore, we hypothesized that after hearing expert presentations on this technique, more providers would accept the multidisciplinary use of REBOA to manage bleeding caused by traumatic injuries.

## METHODS

A survey was distributed via email to registered participants before and after the inaugural EVTM Symposium in Orebro, Sweden which ran from February 2nd to February 4th, 2017. The survey was accessible online via Survey Monkey® and consisted of 18 identical multiple-choice questions for the pre- and post-conference surveys and an additional four agree/disagree questions for the post-conference survey (Appendix). Both pre- and post-attendance surveys contained questions regarding demographics (specialty, location and years in clinical practice), practice patterns, and the technique of REBOA. The post-conference survey included four additional questions regarding potential contraindications for REBOA, provider training, and scope of practice. Responses were collected by Survey Monkey® and entered into Microsoft® Excel® spreadsheets for tabulation and analysis. As emergency medicine physicians and trauma surgeons are most likely to be the initial provider for a patient with traumatic hemorrhage, a subset analysis of their selection of providers qualified to perform REBOA was completed. Statistical analysis was performed using Microsoft® Excel® and the chi-square test calculator available at Vassarstats.net. Fisher's exact probability test was used for instances where expected cell frequencies were less than 5. Otherwise, Pearson's p-value was used and significance was set at $p < 0.05$.

## RESULTS

### Participant Demographics

Participant demographics are described in Table 1. There were approximately 350 conference attendees. We received a total of 186 survey responses, 99 pre-conference and 87 post-conference for a response rate of 28.3% and 24.9%, respectively. The majority of participants were vascular surgeons (28.3% pre, 27.6% post), trauma surgeons (32.3% pre, 28.7% post) and emergency medicine physicians (17.2% pre, 12.6% post). Europe was the most represented region (61.9% pre, 72.4% post) followed by North America (16.5% pre, 12.6% post) and Asia (17.5% pre, 9.2% post). Most participants were in practice 0–10 years (44.9% pre, 45.9% post). A quarter were in practice longer than 15 years (27.6% pre, 22.4% post) and approximately 15% were trainees. There was no significant difference between the pre- and post-conference groups in specialty ($p = 0.68$), region of practice ($p = 0.24$), and years of training ($p = 0.85$).

### Which Specialty Should Perform REBOA?

Participants were asked which specialties should optimally perform REBOA for trauma victims. On subset analysis of emergency physicians and trauma surgeons, before the conference, providers most often selected their own specialty as the specialty that should be primarily responsible for the use of endovascular trauma management principles (58.8% of emergency physicians chose emergency physicians; 90.6% of trauma surgeons chose trauma surgeons). After the conference trauma surgeons increased their selection of multidisciplinary teams (31.3% pre, 60.0% post, $p = 0.03$) and emergency medicine physicians trended toward the same (52.9% pre, 81.8% post, $p = 0.23$).

There was an overall willingness by emergency physicians and trauma surgeons to accept REBOA performed by "any provider with appropriate training" regardless of specialty (emergency physician 82.4% pre, 90.9% post, $p = 0.64$; trauma surgeon 43.8% pre,

*Table 1* Demographics of respondents for surveys sent before and after the EVTM conference.

| | Pre-Conference | Post-Conference | p |
|---|---|---|---|
| *Specialty* | *n* = 99 (%) | *n* = 87 (%) | |
| Vascular Surgeon | 28 (28.3) | 24 (27.6) | 0.92 |
| Trauma Surgeon | 32 (32.3) | 25 (28.7) | 0.60 |
| Interventional Radiologist | 8 (8.1) | 11 (12.6) | 0.31 |
| Emergency Physician | 17 (17.2) | 11 (12.6) | 0.39 |
| Other | 14 (14.1) | 16 (18.4) | 0.43 |
| *Region of Practice* | *n* = 97 (%) | *n* = 87 (%) | |
| Europe | 60 (61.9) | 63 (72.4) | 0.13 |
| United Kingdom | 3 (3.1) | 3 (3.5) | 1.00 |
| North American | 16 (16.5) | 11 (12.6) | 0.46 |
| South America | 1 (1.0) | 0 (0) | 1.00 |
| Asia | 17 (17.5) | 8 (9.2) | 0.10 |
| Africa | 0 (0) | 2 (2.3) | 0.22 |
| *Years in Practice* | *n* = 98 (%) | *n* = 85 (%) | |
| In training | 15 (15.3) | 13 (15.3) | 1.00 |
| 0–5 years | 23 (23.5) | 18 (21.2) | 0.71 |
| 6–10 years | 21 (21.4) | 21 (24.7) | 0.60 |
| 11–15 years | 12 (12.2) | 14 (16.5) | 0.41 |
| >15 years | 27 (27.6) | 19 (22.4) | 0.42 |

56.0% post, *p* = 0.36). (Table 2). The vast majority of post-conference participants (93.1%) agreed that REBOA can be safely and effectively performed in a variety of settings and by providers of various clinical backgrounds provided that they have appropriate training and local protocols for use.

### REBOA Indications and Placement

In general, REBOA was widely accepted for non-compressible torso and junctional hemorrhage due to both blunt and penetrating trauma, with a slightly decreased confidence in its use in austere military environments (Table 3). After the conference, there was increased perception for feasibility in all settings, with the largest increase found for the prehospital and austere military environments (53.5% pre, 67.8% post, *p* = 0.047 and 59.6% pre, 73.6% post, *p* = 0.045, respectively).

Prior to the conference, 62.9% of providers favored common femoral artery access in anticipation of REBOA in every hypotensive trauma victim with a systolic blood pressure (SBP) less than 90 mmHg. After the conference, only 54% of providers favored this broad indication for early femoral access (*p* = 0.22). After the conference, more providers tended to support arterial cannulation prior to the onset of hypotension in patients with findings such as severe pelvic fractures and ultrasound demonstrating free abdominal fluid (53.6% pre, 65.5% post, *p* = 0.10). There was almost unanimous agreement (97% pre, 98.9% post, *p* = 0.62) that femoral access is appropriate in the emergency department. Following the conference, more providers tended to accept that femoral access is appropriate in the prehospital setting

as well (51.5% pre, 62.1% post, *p* = 0.15). Most participants indicated that external landmarks were adequate to confirm balloon location prior to inflation (60.2% pre, 60.9% post, *p* = 0.92).

When comparing REBOA to emergent resuscitative (ER) thoracotomy, approximately one-quarter of participants said the indications for both are the same. Over half of respondents preferred to choose between these modalities on a case-by-case basis.

### Contraindications for REBOA

For both blunt and penetrating trauma, most providers felt that bleeding in the neck and bleeding in the chest were contraindications for REBOA. Associated head injury was also identified as a common contraindication. After the conference, clinical suspicion for traumatic brain injury (TBI) was identified as a contraindication to REBOA by 50.6% of providers, whereas 64.4% of providers felt that occult TBI on imaging should contraindicate REBOA use. In general, post-conference, more participants felt that these injuries were contraindications compared to pre-conference results (Table 3).

### REBOA Techniques

We investigated the perceived maximum inflation time for both Zone 1 (distal to left subclavian, proximal to celiac axis) and Zone 3 (distal to renal arteries, proximal to aortic bifurcation). Most participants would not recommend Zone 1 occlusion for longer than an hour (53.6% pre, 50.0% post, *p* = 0.62), with a third of those surveyed recommending that Zone 1 occlusion be

*Table 2*  Emergency physician and trauma surgeon preferences regarding specialty responsible for endovascular trauma management and deployment of REBOA balloon catheters pre- and post-conference.

| What specialty should… | Emergency Physicians | | Trauma Surgeons | |
|---|---|---|---|---|
| | Pre *n* = 17 (%) | Post *n* = 11 (%) | Pre *n* = 32 (%) | Post *n* = 25 (%) |
| *… primarily be responsible for endovascular trauma management for trauma patients?* | | | | |
| **Vascular Surgeons** | 3 (17.6) | 2 (18.2) | 17 (53.1) | 10 (40.0) |
| **Trauma Surgeons** | 7 (41.2) | 4 (36.4) | 28 (90.6)* | 14 (56.0)* |
| **Interventional Radiologists** | 7 (41.2) | 2 (18.2) | 13 (40.6) | 6 (24.0) |
| **Emergency Physicians** | 10 (58.8) | 4 (36.4) | 6 (18.8) | 5 (20.0) |
| **Multidisciplinary team composed of the above** | 9 (52.9) | 9 (81.8) | 10 (31.3)** | 15 (60.0)** |
| *…optimally be performing REBOA for trauma victims?* | | | | |
| **Vascular Surgeons** | 6 (35.3) | 4 (36.4) | 19 (59.4) | 15 (60.0) |
| **Trauma Surgeons** | 7 (41.2) | 5 (45.5) | 16 (50.0) | 13 (52.0) |
| **Interventional Radiologists** | 7 (41.2) | 4 (36.4) | 25 (78.1) | 15 (60.0) |
| **Emergency Physicians** | 10 (58.8) | 5 (45.5) | 6 (18.8) | 8 (32.0) |
| **Any appropriately trained provider** | 14 (82.4) | 10 (90.9) | 14 (43.8) | 14 (56.0) |

*\* p = 0.007,  \*\* p = 0.03.*

limited to 30 minutes or less. As Zone 3 occlusion may confer less ischemic insult than Zone 1 occlusion, more participants were willing to leave a balloon inflated for 60 minutes or more (46.4% pre, 55.8% post, $p = 0.24$ Zone 3 *versus* 21.6% pre, 36.0% post, $p = 0.031$ Zone 1) In continuously unstable patients, some providers were willing to maintain occlusion without a defined time limit as needed to maintain hemorrhage control (16.5% pre,18.6% post, $p = 0.71$ Zone 1 *versus* 30.9% pre, 36.8% post, $p = 0.40$ Zone 3). However, nearly a third of respondents felt that there is still too little data available to determine a maximum occlusion time for either zone.

We investigated the most promising modality to extend REBOA times without incurring undue distal ischemic injury allowing participants to choose between intermittent REBOA (releasing the balloon completely for short durations to allow distal perfusion before reinflating completely) and early partial REBOA (transitioning to partial occlusion after a short period of full occlusion, but not letting the balloon down all the way or reinflating completely). By far participants favored partial REBOA over intermittent REBOA for reducing distal ischemia during balloon occlusion, a conclusion more people reached after attending the conference (62.2% pre, 81.6% post, $p = 0.004$) (Table 4).

## DISCUSSION

Despite the increasing popularity of REBOA, there has been difficulty identifying consensus criteria for its implementation. We sought to assess provider preferences regarding management and use of REBOA in trauma patients, and analyze the effect of attendance at the EVTM symposium on those beliefs.

Consensus from this survey demonstrated that REBOA may be indicated for bleeding due to blunt and penetrating trauma, even in an austere setting. The majority found REBOA to be most feasible in the emergency department and in the operating room. More than half felt REBOA was feasible in the prehospital environment or austere military environments. Most felt that early femoral access should be obtained in patients who are hypotensive and transiently or not responding to fluid/blood administration, and that it was appropriate to obtain arterial access in the emergency room. Most providers felt that endovascular management of traumatic injuries should be multidisciplinary, and many felt that REBOA could be performed by any appropriately trained medical provider.

We lack consensus on the use of REBOA in patients with concomitant TBI. Animal data have demonstrated a significant increase in intracranial pressure during occlusion, and case reports have documented worsening cerebral hemorrhage following REBOA [21–22]. Opinions regarding the use of REBOA in a polytrauma patient with TBI is mixed, with half of the providers identifying TBI as a contraindication for REBOA use.

There was also no clear consensus for maximum inflation times for REBOA in Zone 1 or 3, and a third of participants found the data insufficient to provide a recommendation. Partial REBOA is a strong advance in this technology, focused on extending the benefits of REBOA, and most participants felt that this will be the most viable technique for prolonging REBOA time. This was also one of the only areas of significant change in opinion during the EVTM symposium with intermittent REBOA falling out of favor on post-conference surveys. Ongoing research on partial REBOA and development of new occlusion catheters holds the promise of making this technique both practical and commonplace [23–26].

Based on this survey data, we have identified some consensus patterns in the use of REBOA. This study is limited in that it does not necessarily include providers

*Table 3* Indications, contraindications and deployment of REBOA selected by participants before and after EVTM conference.

| | Pre-Conference | Post-Conference | p |
|---|---|---|---|
| ***REBOA indicated for bleeding due to:** | *n* = 98 (%) | *n* = 87 (%) | |
| Blunt trauma | 88 (89.8) | 79 (90.8) | 0.82 |
| Penetrating trauma | 88 (89.8) | 75 (86.2) | 0.45 |
| Combat injury in austere setting | 69 (70.4) | 71 (81.6) | 0.08 |
| ***REBOA feasible in the:** | *n* = 99 (%) | *n* = 87 (%) | |
| Prehospital environment | 53 (53.5) | 59 (67.8) | 0.047 |
| Emergency department | 91 (91.9) | 84 (96.6) | 0.18 |
| Operating room | 84 (84.9) | 79 (90.8) | 0.22 |
| Intensive care unit | 49 (49.5) | 46 (52.9) | 0.65 |
| Austere military environment | 59 (59.6) | 64 (73.6) | 0.045 |
| ***Early femoral artery access should be obtained in:** | *n* = 97 (%) | *n* = 87 (%) | |
| Patients in extremis (no pulse, no BP) | 37 (38.1) | 31 (35.6) | 0.73 |
| Every trauma victim with SBP < 90 mmHg | 61 (62.9) | 47 (54.0) | 0.22 |
| SBP >90 mmHg with suspicious injury (pelvic fx, + FAST) | 52 (53.6) | 57 (65.5) | 0.10 |
| SBP <90 mmHg unresponsive to fluid/blood administration | 80 (82.5) | 70 (80.5) | 0.73 |
| SBP <90 mmHg transiently responsive to fluid/blood | 65 (67.0) | 64 (73.6) | 0.33 |
| ***Femoral access is appropriate in the:** | *n* = 99 (%) | *n* = 87 (%) | |
| Prehospital environment | 51 (51.5) | 54 (62.1) | 0.15 |
| Emergency department | 96 (97.0) | 86 (98.9) | 0.62 |
| Interventional suite | 75 (75.8) | 71 (81.6) | 0.33 |
| Operating room/hybrid suite | 88 (88.9) | 78 (89.7) | 0.86 |
| Intensive care unit | 60 (60.6) | 54 (62.1) | 0.84 |
| ***Confirmation of REBOA balloon location prior to inflation:** | *n* = 98 (%) | *n* = 87 (%) | |
| External landmarks only | 59 (60.2) | 53 (60.9) | 0.92 |
| Standard predetermined distances | 34 (34.7) | 26 (29.9) | 0.48 |
| Plain radiography | 40 (40.8) | 31 (35.6) | 0.47 |
| Fluoroscopy | 31 (31.6) | 32 (36.8) | 0.46 |
| Ultrasound | 36 (36.7) | 37 (42.5) | 0.42 |
| Computed tomography | 5 (5.1) | 4 (4.6) | 1.00 |
| *Indications for ER thoracotomy vs REBOA* | *n* = 99 (%) | *n* = 86 (%) | |
| Indications are largely identical | 27 (27.3) | 22 (25.6) | 0.79 |
| Indications are completely different | 10 (10.1) | 4 (4.7) | 0.16 |
| Decision should be individualized to each case | 57 (57.6) | 59 (68.6) | 0.12 |
| Insufficient data on REBOA for me to comment at this time | 23 (23.2) | 13 (15.1) | 0.16 |
| ***Contraindications to REBOA in blunt trauma** | *n* = 85 (%) | *n* = 82 (%) | |
| Bleeding in the neck | 61 (71.8) | 74 (90.2) | 0.002 |
| Bleeding in the chest | 55 (64.7) | 54 (65.9) | 0.89 |
| Bleeding in the abdomen or pelvis | 3 (4.1) | 1 (1.2) | 0.62 |
| Long bone fractures of extremities | 4 (4.7) | 6 (7.3) | 0.53 |
| Associated intracranial injury and/or bleeding | 40 (47.1) | 38 (46.3) | 0.92 |
| ***Contraindications to REBOA in penetrating trauma** | *n* = 84 (%) | *n* = 82 (%) | |
| Penetrating neck injury | 65 (77.4) | 70 (85.4) | 0.19 |
| Penetrating chest injury | 52 (61.9) | 59 (72.0) | 0.17 |
| Penetrating abdominal injury | 5 (6.0) | 2 (2.4) | 0.44 |
| Penetrating extremity injury with significant bleeding | 9 (10.7) | 7 (8.5) | 0.63 |
| Associated head injury | 33 (39.3) | 40 (48.8) | 0.22 |

*\* indicates multiple answers possible per participant.*

who are actively using REBOA, and therefore only reflects the opinions of attendees at the EVTM conference. Additionally, with a response rate of roughly 25%, this may not represent the opinions of the meeting attendees as a whole and hinders statistical comparisons between the pre- and post-conference groups. The majority of participants were European and as such the responses would be expected to reflect primarily REBOA practice patterns in Europe. As the survey was anonymous, there was no mechanism to identify any participants who completed the survey both before and after the conference. Therefore, we are only able to surmise the general group population and consensus before and after the event, with no means of analyzing individual changes in opinion. While this survey of an international cadre of providers interested in endovascular management of trauma was the first of its kind, further investigation is needed to generate societal consensus

*Table 4* REBOA time limits and preferred extension modality selected by participants before and after EVTM conference.

| | Pre-Conference | Post-Conference | p |
|---|---|---|---|
| **Maximum REBOA inflation time in Zone 1** | n = 97 (%) | n = 86 (%) | |
| **<30 minutes** | 37 (38.1) | 30 (34.9) | 0.65 |
| **<45 minutes** | 10 (10.3) | 8 (9.3) | 0.82 |
| **<60 minutes** | 5 (5.2) | 5 (5.8) | 1.00 |
| **No limit if patient remains unstable** | 16 (16.5) | 16 (18.6) | 0.71 |
| **Current data insufficient to provide recommendation** | 29 (29.9) | 27 (31.4) | 0.82 |
| **Maximum REBOA inflation time in Zone 3** | n = 97 (%) | n = 87 (%) | |
| **<30 minutes** | 10 (10.3) | 4 (4.6) | 0.14 |
| **<45 minutes** | 20 (20.6) | 18 (20.7) | 1.00 |
| **<60 minutes** | 15 (15.5) | 16 (18.4) | 0.60 |
| **No limit if patient remains unstable** | 30 (30.9) | 32 (36.8) | 0.40 |
| **Current data insufficient to provide recommendation** | 26 (26.8) | 25 (28.7) | 0.76 |
| **Most viable technique for prolonging REBOA time** | n = 98 (%) | n = 87 (%) | |
| **Intermittent complete occlusion (I-REBOA)** | 37 (37.8) | 16 (18.4) | 0.004 |
| **Complete followed by partial occlusion (P-REBOA)** | 61 (62.2) | 71 (81.6) | 0.004 |

guidelines, as well as future trials to develop criteria for optimal REBOA use.

## CONCLUSION

Meetings such as EVTM bring providers together to share their experiences, are paramount to the continued development of novel treatments, and represent unique opportunities to probe opinions and practice patterns. REBOA is an exciting and important advance in the management of life threatening hemorrhage, however, its implementation has not been codified and there is much variation in practitioners understanding of its use. There appears to be support for utilizing REBOA in the prehospital and austere environments, where patients may benefit the most. Additionally, a significant portion of providers favor a multidisciplinary team approach and are comfortable with multiple specialties performing REBOA as long as they are appropriately trained. Continued investigation is needed to determine the appropriate indications, methods, and practical limitations of REBOA within this new hemorrhage management paradigm.

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## APPENDIX

Survey questions 1–18 were administered pre-conference. Questions 1–22 were administered post-conference.

**Q1** **Which of the following best describes your professional practice?**

- Interventional Radiologist
- Trauma Surgeon
- Vascular Surgeon
- Emergency Physician
- Other

**Q2** **Which best describes your region of practice?**

- North America
- South America
- Asia
- Europe
- The United Kingdom
- Australia
- Africa
- New Zealand

**Q3** **How many years have you been practicing in your profession? (Years since COMPLETION of training)**

- I am still in training
- 0–5 years
- 6–10 years
- 11–15 years
- >15 years

**Q4** **Who should primarily be responsible for the use of endovascular trauma management principles for trauma patients? (select all that apply)**

- Vascular
- Surgeons
- Interventional
- Radiology
- Trauma surgeons
- Emergency medicine physicians
- A multidisciplinary team composed of a combination of the above

**Q5** **In your opinion, for which of the following patient populations is resuscitative endovascular occlusion of the aorta (REBOA) potentially indicated? (select all that apply)**

- Bleeding victims of blunt trauma
- Bleeding victims of penetrating trauma
- Bleeding victims of combat injury in austere settings

**Q6** **In your opinion, in which of the following settings is REBOA potentially a feasible tool of hemorrhage control? (select all that apply)**

- The prehospital environment
- The emergency department
- The operating room
- The intensive care unit
- An austere military environment

**Q7** Among bleeding trauma patients injured by BLUNT mechanisms, which of the following do you presently consider a contraindication to REBOA use? (select all that apply)

- Evidence of bleeding in the neck
- Evidence of bleeding in the chest
- Evidence of abdominal or pelvic bleeding
- Evidence of long bone fractures of the extremities
- Evidence of associated intracranial injury/bleeding

**Q8** Among bleeding trauma patients injured by PENETRATING mechanisms, which of the following do you presently consider a contraindication to REBOA use? (select all that apply)

- Penetrating neck injury
- Penetrating chest injury
- Penetrating abdominal injury
- Penetrating extremity injury with significant bleeding
- Evidence of associated head injury

**Q9** In your opinion, which of the following BEST describes the relationship between indications for emergent resuscitative thoracotomy and REBOA?

- The indications for these procedures are largely identical
- The indications are completely different
- The decision should be individualized in each instance
- There is insufficient data on REBOA for me to comment at this time

**Q10** In your opinion, which of the following BEST DESCRIBES the physiologic parameters to select patients for REBOA use? (select ALL that you feel apply)

- Patients in extremis only (no pulse, no blood pressure)
- Any unstable trauma victim with an initial systolic blood pressure <90 mmHg
- Trauma victims with systolic blood pressure >90 mmHg, but mechanisms of injury suspicious for high early bleeding risk (ex. severe pelvic fracture, positive FAST exam)
- Trauma victims with an initial systolic blood pressure <90 mmHg who do NOT respond at all to initial fluid or blood product administration
- Trauma victims with an initial systolic blood pressure <90 mmHg who respond transiently to initial fluid or blood product administration

**Q11** Femoral artery access is a precursor for potential REBOA use, but does not mandate subsequent REBOA. In your opinion, which of the following patient types should undergo EARLY femoral artery access? (Select all the apply)

- Patients in extremis only (no pulse, no blood pressure)
- Every trauma victim presenting with initial systolic blood pressure < 90 mm Hg
- Trauma victims with systolic blood pressure > 90 mm Hg, but mechanisms of injury suspicious for high early bleeding risk (ex. severe pelvic fracture, positive FAST exam)
- Trauma victims with an initial systolic blood pressure < 90 mm Hg who do not respond at all to initial fluid or blood product administration
- Trauma victims with an initial systolic blood pressure < 90 mm Hg who respond transiently to initial fluid or blood product administration

**Q12** In your opinion, in what settings is common femoral artery access for potential REBOA appropriate? (select all that apply)

- Prehospital
- Emergency Department
- Interventional Suite
- Operating room/hybrid suite
- Intensive Care Unit

**Q13** In your opinion, what is the ideal practice for confirming REBOA balloon position BEFORE INFLATION when this adjunct is used in an EMERGENT setting? (select all that you feel are appropriate if available)

- Using external body markings alone (ex. distance to xiphoid for Zone 1 or umbilicus for Zone 3) to determine insertion depth is appropriate in an emergency
- Using standard predetermined distances of insertion alone is appropriate in an emergency REBOA placement
- Plain radiography should routinely be used to confirm positioning before inflation
- Fluoroscopy should routinely be used to confirm positioning before inflation
- Ultrasound should routinely be used to confirm position before inflation
- Computed tomography should routinely be used to confirm position before inflation

**Q14** In your opinion, what should be the RECOMMENDED REBOA inflation time that should be

undertaken for aortic occlusion in Zone 1 of the aorta (descending thoracic aorta) – (select the single answer most consistent with your opinion/thoughts)

- Never more than 30 minutes
- Never more than 45 minutes
- Never more than 60 minutes
- The time should not be limited if the patient remains unstable despite aggressive efforts
- Current data is insufficient for me to provide recommendations

**Q15** **In your opinion, how long should the RECOM-MENDED maximum REBOA inflation time that should be undertaken for aortic occlusion Zone 3 of the aorta (infrarenal aorta)**

- Never more than 30 minutes
- Never more than 60 minutes
- Never more than 120 minutes
- The time should not be limited if the patient remains unstable despite aggressive efforts
- Current data are insufficient to provide recommendations

**Q16** **In your opinion, who should optimally be per-forming REBOA for trauma victims (select all that apply)**

- Vascular surgeons
- Trauma surgeons
- Interventional radiologists
- Emergency department physicians
- Any appropriately trained physician is appropriate

**Q17** **In your opinion, which of the following approaches is the MOST viable tool in prolong-ing the potential use of REBOA while attempting to avoid the dangers of distal ischemia? (Assum-ing that the patient tolerates either maneuver)**

- Intermittent occlusion – releasing the balloon completely for short durations to allow distal perfusion before reinflating completely
- Early partial occlusion – transitioning to partial occlusion after a short period of full occlusion, but not letting the balloon down all the way or reinflating completely

**Q18** **Who should be responsible for removing the REBOA and vascular access sheath when the device is no longer needed? (Select BEST answer in your opinion)**

- Any appropriately trained physician
- Vascular surgeon
- Trauma surgeon
- Interventional radiologist

**Q19** **Do you agree or disagree with the following statement? CLINICALLY OBVIOUS traumatic brain injury at presentation (altered pupillary exam, lateralizing signs on exam, depressed skull fracture, penetrating injury to the skull) should be considered a contraindication to REBOA at this time.**

- Agree
- Disagree

**Q20** **Do you agree or disagree with the following statement? Occult traumatic brain injury identi-fied on emergent head imaging (NO EVIDENCE of altered pupillary exam, lateralizing signs on exam, depressed skull fracture on physical exam, penetrating injury to the skull) should not be considered a contraindication to REBOA at this time.**

- Agree
- Disagree

**Q21** **Do you agree or disagree with the following state-ment? Penetrating thoracic injury should be con-sidered a contraindication to REBOA at this time.**

- Agree
- Disagree

**Q22** **Do you agree or disagree with the following statement? REBOA can be safely and effectively performed in a variety of settings and by provid-ers of various clinical backgrounds – PROVIDED THAT they have APPROPRIATE training and local protocols for use.**

- Agree
- Disagree

# Endovascular Solutions for Iliac and Lower Extremity Junctional Injuries

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Hemorrhage is the second leading cause of death in trauma and non-compressible torso hemorrhage is the leading cause of preventable death within this population. Vascular injuries to the pelvis and lower extremity junctional zone may be difficult to control with direct pressure and complex to approach with open surgery. Endovascular interventions such as balloon occlusion, stenting, and embolization are potential alternatives or adjuncts to traditional open surgery in patients with blunt or penetrating vascular injuries to the pelvis. This review of the literature will outline contemporary endovascular management strategies for iliac and junctional zone injuries.

**Keywords:** *Trauma; Endovascular; Iliac; Groin; REBOA; Non-Compressible Torso Hemorrhage; Junctional Zone*

## INTRODUCTION

Hemorrhage is the second leading cause of traumatic death after direct central nervous system (CNS)

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injury [1]. Unlike CNS injuries which are often difficult to treat and irreversible, hemorrhage is directly amenable to intervention, particularly when occurring in accessible regions of the body. Nonetheless, it still accounts for 35% of pre-hospital deaths and 40% of in-hospital deaths that occur within 24 hours of hospital arrival [2]. Currently, non-compressible hemorrhage from truncal and abdominal injuries is the leading cause of preventable deaths due to hemorrhage [3]. Although traditional techniques and technology have focused on the treatment of compressible sites of hemorrhage, novel endovascular adjuncts for hemorrhage control now allow for remote, yet direct treatment of these injuries, previously thought to be accessible only by open surgical exploration.

Over the last 15 years of combat operations, military surgeons have developed a wealth of practical experience in treating junctional hemorrhage. The success of deployed vascular surgeons applying endovascular techniques to the care of patients with vascular injuries has led to a broader reappraisal of the use of endovascular technology for the diagnosis and management of junctional and extremity injury [4]. While endovascular management of traumatic vessel injury is increasing overall [5], endovascular intervention for iliac vessel and junctional trauma within the civilian sector is not

***Figure 1*** CT angiogram slice from pelvis showing pelvic fracture and active bleeding.

yet commonplace [6,7]. This review will discuss the emerging role of endovascular technology for diagnosis, initial control, and definitive repair of junctional hemorrhage of the lower extremity in the civilian population.

### *Diagnosis of Injury*

Patients presenting with pelvic or lower extremity trauma are at risk for major vascular injury. While there is no consensus as to which patients require screening for vascular injury, indications to consider further investigation of vascular injury can be categorized as hard or soft signs [8]. Hard signs include pulsatile bleeding, expanding hematoma, the absence of distal pulse, or evidence of ischemia. Patients with hard signs of vascular injury require prompt intervention to prevent mortality and reduce morbidity from these injuries. Successful intervention typically requires invasive surgical treatment, either open, endovascular, or a combination approach. Soft signs indicating a risk of significant vascular injury include compelling mechanism, proximity of wound to major vascular structures, or selected orthopedic injuries. These cases may warrant additional diagnostic evaluation for vascular injury especially in instances of pelvic trauma where retroperitoneal hemorrhage can easily be masked. The choice of diagnostic testing and imaging modality depends on patient stability, comorbidities, concomitant injuries, and the available resources and expertise.

For stable patients, multidetector computed tomography (CT) has become the first line for imaging in trauma [9]. It is non-invasive, rapid, and can identify vessel injuries in addition to associated bone, soft tissue and other organ injuries (Figure 1). In an aging population, this modality also affords the diagnosis of underlying comorbid vascular diseases or aberrant anatomy that may inform endovascular treatment options. It also allows for preoperative planning to ensure appropriate

selection and sizing of endovascular devices prior to an intervention. CT angiography (CTA) has the disadvantage of requiring contrast without the benefit of affording therapeutic intervention. This increases the risk associated with contrast exposure in patients who may require subsequent administration during endovascular interventions under fluoroscopic guidance and may not be suitable for patients with renal disease. When used to assess blunt traumatic injuries to the pelvis, CTA is not 100% specific for excluding the need for angiography. The Eastern Association for the Surgery of Trauma guidelines for pelvic fracture hemorrhage noted a specificity of contrast extravasation on CT to predict the need for angiography of 85–98% [10].

An alternative imaging modality is diagnostic angiography. This can be performed in an interventional suite, hybrid operating room, or operating room equipped with mobile fluoroscopy arm. The resources and expertise available and patient physiology may dictate the appropriate setting for diagnostic angiography and its utility in combination with open surgery or other endovascular interventions. Access may be achieved with an arterial sheath placed away from the point of injury. An appropriate catheter can then be advanced close to the zone of injury to ensure that contrast reaches the site of interest in enough concentration to afford an accurate diagnosis. Measurements of vessel diameter and treatment length can be made using the fluoroscopic images or with an intravascular ultrasound (IVUS) catheter. IVUS can complement angiography for the diagnosis of subtle intraluminal injuries such as dissection flap or intramural hematoma [11]. In patients with significant renal impairment, contrast allergy, or in those who have already exceeded recommended doses of contrast administration, diagnosis can be achieved with intravascular ultrasound or carbon dioxide ($CO_2$) angiography. $CO_2$ angiography has been demonstrated to be as sensitive as traditional fluoroscopy without the risk of contrast nephropathy or contrast allergy [12].

A disadvantage of using angiography as the first line diagnostic modality in trauma patients is its invasive nature and inability to provide information about other non-vascular injuries. Apart from when an arteriovenous fistula is present, to exclude arterial or venous injury both arteriography and venography must be performed along the whole zone of injury, increasing the time required as well as the contrast and radiation exposure to the patient.

Surgical exploration may be the diagnostic modality of choice when patients are unstable or have hard signs of vascular injury. The traditional approach to vascular injury management involves proximal and distal control of injured vascular segments; however, this can be particularly challenging in cases of pelvic or lower extremity junctional injuries where adequate exposure can be time-consuming and sufficient vascular control can be difficult due to the presence of extensive branching

and natural collateralization. This frequently results in ongoing and significant hemorrhage during exploration. In the groin, control of the injured vessel may require dissection both above and below the inguinal ligament, leading to large and morbid wounds that are prone to complications such as infection, lymphocele, or seroma. Remote endovascular approaches (angiography or venography) allow for minimally invasive diagnosis of iliac or junctional injuries. If appropriate, the same access point can then be utilized for intervention and repair in many instances. Additionally, arterial sheaths can remain in place for hemodynamic monitoring and venous catheters can be used for resuscitation in the post-intervention period. Furthermore, post-intervention angiography can demonstrate the safety of access, effectiveness of the intervention as well as the adequacy of distal perfusion.

### Hemorrhage Control

Control of bilateral lower extremity, junctional, or pelvic hemorrhage can be challenging and time-consuming. Achieving this control by endovascular means can at times be more rapid and selective. Remote access with a vascular sheath must be achieved first. Sheath size and operator expertise will determine whether access is best achieved percutaneously or by open cut-down. Larger sheaths will allow for the employment of a greater range of endovascular devices, but will also carry a greater risk of complications. The selection, positioning, and deployment of the balloon will depend on the vessel to be occluded and the experience of the provider. In the elective setting, this technique is employed during major gynecological and orthopedic pelvic surgery by placing deflated occlusion balloons into the internal iliac arteries for rapid hemostasis in the event of major bleeding [13–16]. In trauma situations, it is more common to occlude the common iliac artery (CIA) or aorta.

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is the technique of occluding the aorta in either zone 1 (between the left subclavian and the celiac branches) or zone 3 (caudal to the most caudal renal branch) to both limit hemorrhage and restore proximal hemodynamics [17]. This can be performed with or without radiographic guidance and the catheter is often introduced via femoral artery access (Figure 2). The American College of Surgeons Basic Endovascular Skills in Trauma (BEST) course describes zone 3 REBOA for the control of pelvic trauma with hemodynamic instability or uncontrolled lower extremity junctional hemorrhage [18]. Zone 3 occlusion is generally well tolerated with published reports of survival following occlusion times in excess of an hour [19]. Distal ischemia during zone 3 occlusions can potentially be mitigated by employing the intermittent or partial REBOA (I-REBOA and P-REBOA) techniques when resuscitation efforts and the clinical situation permit [20,21].
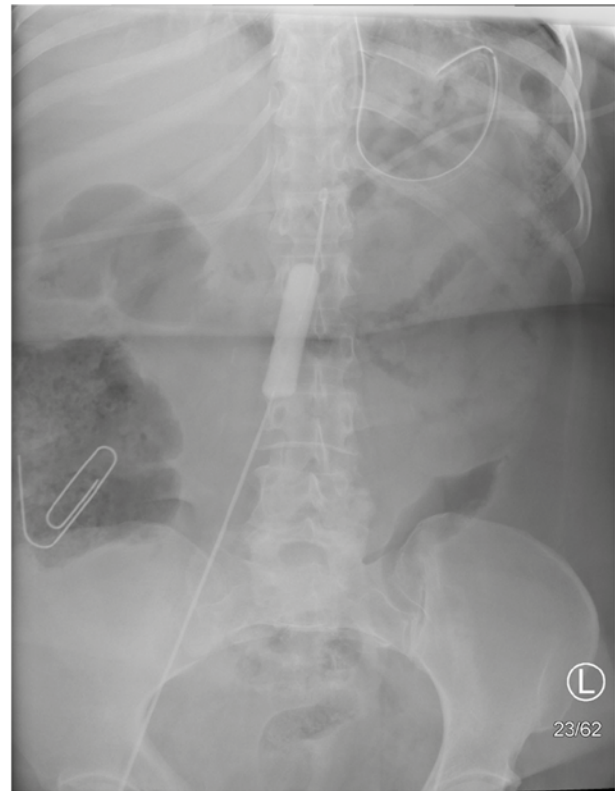


**Figure 2** Zone 3 aortic occlusion with non-radiographically placed ER-REBOA® catheter.

While not yet common practice, REBOA is rapidly gaining popularity and advances in technique and catheter technology may continue to expand its utility. As well as use in trauma centers, this technique has been used in the pre-hospital setting in both civilian and military environments [19,22]. Variations of its application and effects in trauma are being researched currently in animal studies [21] and monitored in human registries [23].

### Definitive Management

Endovascular management of iliac and junctional zone vascular trauma is most commonly utilized in blunt and iatrogenic injuries [6,7]. Embolization of arterial injury is quickly becoming the preferred method of management for hemorrhage following blunt pelvic trauma [24]. While less commonly performed, penetrating injuries of pelvic veins and arteries have also been embolized [7].

Guidelines from the Eastern Association for the Surgery of Trauma and the Western Trauma Association regarding the management of hemodynamically significant pelvic fractures both recommend selective angio-embolization as the treatment of choice [10,24]. This approach may be undertaken in lieu of or after pre-peritoneal packing and pelvic stabilization, depending on the urgency of the situation. Diagnostic angiography may be helpful in patients with persistent hypotension following resuscitation and stabilization of pelvic

fractures, to allow for identification and embolization of sources of continued bleeding. Arteries showing an abrupt cut-off of flow or vessel narrowing might also indicate an injury that requires intervention. In cases where selective embolization is not possible, non-selective occlusion of the internal iliac artery may be lifesaving but ischemic complications are more likely following this less-selective approach [25].

Endovascular management of iatrogenic iliac artery injury is well-established. Management of a ruptured or lacerated CIA or external iliac artery (EIA) using a covered stent has been widely reported during spinal and endovascular surgery [26–29]. In patients with underlying arterial disease, excessive manipulation of the pelvis may result in a dissection flap that can lead to significant distal ischemia. If recognized promptly, endovascular revascularization might be possible with a combination of thrombectomy, angioplasty, or stenting [30,31]. Arteriotomy defects formed during angiographic procedures can cause significant bleeding, arteriovenous fistulae or pseudoaneurysms if not closed. Covered stents are effective at closing these defects but need to be inserted from remote access sites such as the contralateral femoral artery [28]. Stenting has been described above, below and across the inguinal ligament [32].

Temporary endovascular revascularization for iliac and junctional zone artery trauma has only been sparsely described in the literature [33]. Placement of a femoral covered stent in lieu of an open intravascular shunt prior to fracture fixation has been described as a method to achieve revascularization of the lower extremity during repair of orthopedic injuries [34]. It may be possible to use this technique in pelvic vessels using a percutaneous, open, or hybrid approach instead of a shunt, patch or bypass. Temporary stenting could also be employed in a contaminated field. There have been mixed outcomes of this in other areas of the body and currently, there is no real consensus as to the management of a stent in an infected field [35].

As with iatrogenic injuries, stenting (Figure 3) and embolization are potential treatments for iliofemoral injury in trauma patients. Both covered and uncovered stents have been successfully deployed to treat iliac arterial and venous injury. In their case reports of successful endovascular treatments in blunt trauma patients with hemodynamically significant external iliac vein injuries, Merchant et al. used a covered stent from a contralateral approach and Sofue et al. used an uncovered stent from an ipsilateral retrograde approach [36,37]. The potential benefits of this technique in iliac veins include a reduction in the need for complex dissection and possible division of the iliac artery to access the vein for open repair and a significant reduction in blood loss which occurs when the retroperitoneum is opened. In open surgery, a venous injury might be controlled with ligation rather than repair meaning that stenting has the added advantage of maintaining outflow from the limb.
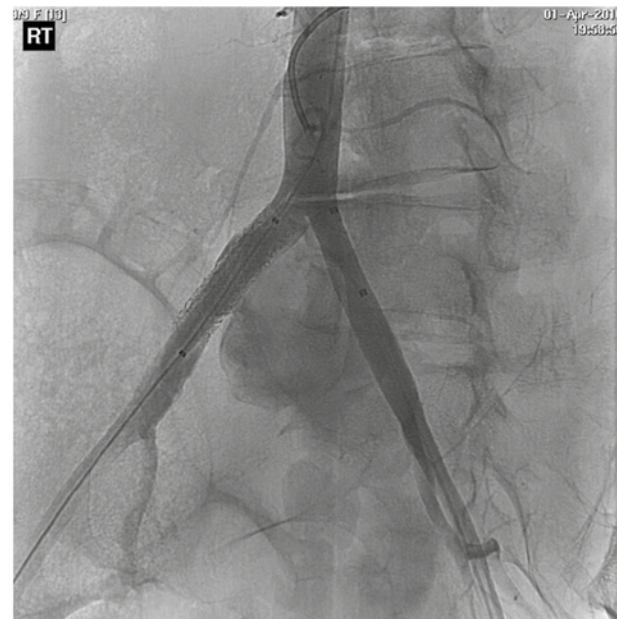


***Figure 3*** Right common iliac artery injury repaired with covered stent.

Endovascular surgery is not without its complications. Trauma patients can have a prothrombotic tendency due to factors such as pelvic fracture, blood transfusions, tranexamic acid administration, and surgery [38]. While venous thromboembolism may also be seen in surgery, introducing a foreign body into a vessel lumen and restricting flow increases this risk [39]. Thrombosis and arterial dissection during endovascular procedures leading to vessel occlusion and the need for extremity amputation are also documented in the acute setting. These complications may also be resolved with an endovascular procedure such as thrombectomy and stenting.

## DISCUSSION

The progression of endovascular techniques into trauma surgery and recent military experience has led to several exciting developments in both hemorrhage control and definitive management of pelvic vascular injury. Data from the US national trauma data bank registry from 2002–2006 showed 10% use in blunt iliac injury and 1.8% use in penetrating iliac injury [7]. This is consistent with an 11% endovascular intervention rate for blunt CIA and EIA injuries in a large series from Baltimore [6]. In this study, patients requiring intervention for bleeding from iliac branches, however, had a much higher endovascular rate (96%). With the ongoing development and uptake of REBOA and familiarity with endovascular techniques, intervention rates for CIA and EIA injuries may increase in similar registry reviews in the future.

We have described a range of emerging techniques for pelvic vascular trauma using technologies that are

already in common use for the treatment of vascular disease. It is difficult to directly compare the outcomes of endovascular management of pelvic trauma with traditional open surgery as registry groups and series are small and unmatched. As hybrid endovascular operating rooms become more available and trauma teams have better access to 24-hour endovascular expertise, the percentage of interventions may reach a level that permits trials. Despite a modicum of published literature, registry data and clinical reports show that in select patients, endovascular management of iliac and lower extremity junctional vascular trauma is possible as the sole treatment modality or as an adjunct to open repair.

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# Trauma Pan-Scan in Resuscitative Endovascular Occlusion: A Novel Strategy for Hemodynamically Unstable Polytrauma Patients

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The trauma pan-scan (TPS) offers particular benefits in trauma care. Resuscitative endovascular balloon occlusion of the aorta (REBOA) may provide an opportunity to scan hemodynamically unstable (HU) polytrauma patients; however, the benefits and risks of REBOA-TPS remain unknown. The rationale for TPS in HU patients is to choose the best intervention and to quickly achieve hemostasis rather than directly initiating surgery without scanning. TPS would most greatly benefit geriatric trauma patients and those with coagulopathies with unidentified bleeding sources, particularly noncavitary hemorrhage in blunt trauma and accompanying brain injury, because TPS may predict unexpected physiological collapse via anatomical imaging. Computed tomography (CT) is a common cause of flow disruption, but specific trauma team training was shown to reduce the time spent in the CT room from 16.8 to 7.3 minutes ($P < 0.001$). While REBOA-TPS cannot be utilized widely or indiscriminately, its appropriate use may increase the number of salvageable trauma patients.

**Keywords:** *Resuscitative Endovascular Balloon Occlusion of the Aorta; REBOA; Trauma Pan-Scan; Computed Tomography; Multidisciplinary Training; Hemorrhagic Shock*

## INTRODUCTION

Hemorrhagic shock is the leading cause of preventable trauma death [1,2]. The Advanced Trauma Life Support (ATLS) guidelines emphasize the importance of the initial assessment of shock and resuscitation. Chest and pelvic plain X-rays and focused assessment with sonography for trauma (FAST) are recommended during the initial assessment to identify the source(s) of bleeding [3].

Improvements in technology have altered the use of computed tomography (CT) in medicine. A survival benefit of whole-body CT, also called trauma pan-scan (TPS), has been reported [4-6], but the results have been inconsistent [7,8]. The ATLS guidelines also clearly note that definitive hemostasis should be started immediately, which indicates that surgery should be performed without scanning in hemodynamically unstable patients [3].

However, resuscitative endovascular balloon occlusion of the aorta (REBOA) [9] is increasingly accepted as a less invasive resuscitation procedure that offers several benefits [10]. REBOA effectively bridges definitive hemostatic care in exsanguinating patients [11]. Additionally, it elevates the blood pressure and provides an opportunity to scan hemodynamically unstable patients. In designated trauma centers, interventional radiology (IR) should be available early on, but arrival to angiography time has been reported as three to five hours even in high-volume trauma centers [12,13]. Currently, 24/7 in-house IR physicians are not common; therefore,

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REBOA in Zone III occlusion in life-threatening pelvic fracture is useful to salvage refractory hemorrhagic shock [14]. Moreover, TPS under REBOA (TPS-REBOA) while waiting for IR physicians may be acceptable for a certain duration, because infra-renal aortic clamping is preferable to supravisceral aortic clamping [15,16]. However, the benefits and risks of REBOA-TPS in Zone I occlusion have not yet been investigated or analyzed.

The use of REBOA to scan Zone I occlusion patients seems contraindicated according to the classical trauma dogma. Although we realize that REBOA-TPS cannot be used without clear purpose and preparation, we discuss this novel and aggressive strategy from the viewpoint of the radical use of diagnostic and interventional radiology in trauma settings, which focuses on prompt diagnostic imaging and rapid IR [17].

### *What is the Rationale for the Use of REBOA-TPS?*

TPS should not be performed simply to obtain anatomical information for reassurance before surgery. There is no room for discussion in early hemostasis. The "golden hour" theory proposed by Cowley has been widely accepted and states that trauma patients have better outcomes if they are provided definitive care within 60 minutes of the occurrence of their injuries [18]. In the pre-endovascular era, starting definitive care meant surgery, and early operation enabled early hemostasis. Cavitary hemorrhage, such as splenic injury, can be identified by FAST without CT imaging, and splenectomy can be performed very quickly. However, in the present day, we have more hemostasis options, including surgical, endovascular, or hybrid approaches. Undoubtedly, to "complete" hemostasis is more meaningful than to "start" procedures. TPS allows for the precise identification of the bleeding site and severity of the main or associated injuries that may not have been recognized in the primary survey. The first rationale is to choose the most appropriate strategy: the OR, IR, a hybrid intervention, or craniotomy. TPS may enable the selection of trauma patients for possible embolization. Secondly, because TPS elucidates the vascular anatomy for IR and may help identify the bleeding source, it may contribute to the earlier completion of hemostasis by reducing the procedure time. Subsequent arterial embolization of the hepatic artery after perihepatic packing helps to complete hemostasis. Most intercostal artery injuries do not require hemostatic procedures, though some do require surgery or embolization. Effective utilization of TPS data may contribute to the embolization of intercostal injuries even quicker than by performing surgery.

### *Who Benefits from the REBOA-TPS?*

### *Geriatric trauma and coagulopathies*

Japan has the longest life expectancy in the world (83.7 years) [19] and is currently the only country with a proportion of the population aged 60 years or older that exceeds 30% [20]. The process of aging brings inevitable physiological and anatomical changes, and associated comorbidities and medication use may affect the response to injury. Old populations typically have vulnerable loose tissue, which easily expands to form hematomas. Likewise, geriatric individuals often take anti-thrombotic agents, which may induce unexpected bleeding in unexpected sites, such as subcutaneous or intramuscular hematomas in the chest or abdominal walls or in the thighs without femur fracture. Additionally, individuals in this population often deteriorate and collapse unexpectedly due to slow but prolonged exsanguination when physicians underestimate the presence of compensated shock upon their arrival in the hospital. TPS may predict unexpected physiological collapse by way of rigorous anatomical imaging. While coagulopathy is measured by various laboratory tests or viscoelastic coagulation monitoring, many trauma patients are not recognized as having coagulopathy using these tests. Thus, REBOA-TPS is indicated in the context of not only abnormal coagulopathy tests but also anamnesis of anticoagulants administration or any suspicion of trauma-induced coagulopathy.

### *Unidentified bleeding sources and unknown mechanisms of injury*

In non-compressible blunt polytrauma patients, physicians need to prioritize the main bleeding source. Chest X-ray and FAST can reveal cavitary hemorrhage, while the pelvic X-ray shows pelvic fractures, which can be identified in the ED. However, noncavitary hemorrhage, including extra-pelvic retroperitoneal hemorrhage due to kidney injury, paravertebral hematoma, and lumbar artery injury, is often difficult to identify during the primary survey. Not all retroperitoneal bleedings are lethal, but some do require surgery or IR, particularly in elderly patients and/or those in a coagulopathic state. TPS may help arrive at a more precise interventional strategy.

### *Accompanying traumatic brain injury (TBI)*

Patients with mild TBI may not show a significantly altered mental status at initial presentation. Small brain contusions or subdural hematomas may grow rapidly, particularly in the context of coagulopathy [21,22]. TPS including brain CT provides a red flag for possible neurological deterioration that may result in earlier or simultaneous neurosurgical intervention. However, REBOA may induce hypertension above the balloon, resulting in increased intracranial bleeding, deteriorated brain edema, and elevated intracranial pressure. Partial occlusion may be required to avoid unnecessary hypertension.

***Table 1*** Tips and tricks for 'sub-5' scans by multidisciplinary trauma teams.

| Profession | Tips and Tricks |
|---|---|
| Physician | Early decision |
| | Clear declaration |
| Nurse | Choose the injection line and extend with a pressure resistance tube |
| | Arrange the tubes and lines |
| | Remove metal material upon exposure |
| | Connect to the oxygen cylinder during the initial assessment |
| | Avoid using a standalone IV pole |
| Radiology Technician | Ensure to remove any metal |
| | Confirm the oxygen supply flow |
| | Fix the upper extremities in the emergency department |
| | Pre-mark the backboard position |
| | Remove the contrast injection after the arterial phase (while wearing a lead protector) |

### How Can TPS Data be Utilized to Shorten the Procedure Duration?

TPS provides valuable information of the vascular anatomy. We have previously proposed the creation of virtual fluoroscopic images from the volume data of the arterial phase to guide the catheter to the target site on a 3D workstation, a method termed "pre-procedural planning" (PPP) [17]. PPP aids in elucidating the target injury and arterial route, as well as the best oblique angle. This method can reduce the need for mapping injection and blind cannulation. For example, pelvic angiography is usually performed in most elective cases to obtain the angiographic anatomy and diagnose the target vessels. However, pelvic fracture cases often require immediate hemostasis of the main injury, and PPP reveals the injured region and target vessels (usually internal iliac artery and its branch). Thus, we are able to omit the pelvic angiography and cannulate internal iliac artery directly. Intercostal or lumbar arteries are branched from the aorta directly. PPP allows the exact level and direction of the root of vessels to be determined, eliminating the need to search for the branch root by aortography. The "conductor" doctor can then indicate the exact vessel position, and the operator can aim for the target vessels directly. Although the procedure time is highly dependent on both the catheter manipulation skills of the operator and the patient's particular vascular anatomy, the single artery embolization time (total embolization time divided by number of embolized arteries) was reduced to as little as five to seven minutes in hemodynamically unstable trauma patients in the authors' institution. Consequently, the use of TPS may permit the earlier completion of hemostasis.

TPS data can be utilized with experts or supervisors to educate young or inexperienced operators, which would contribute to the standardization of these procedures.

### How to Achieve Safe and Quick Scans?

Recently developed CT instruments can scan the whole body within minutes, and yet scanning of patients is still considered to be a dangerous procedure. CT is a common cause of flow disruption in trauma care [23,24] and patients spend approximately 30 minutes in the CT scan room [25]. This duration may cause a critical delay in treatment in a location with poor monitoring and lack of resuscitative capability, which may place patients at risk of sudden deterioration or cardiac arrest.

### Multidisciplinary trauma team training: practice makes perfect

Although the benefits of TPS have been reported [4–6], no reports have specifically focused on trauma team training for the minimization of time spent in the CT room. To achieve safe and quick scans, the trauma team must include multidisciplinary professionals such as physicians (emergency medicine, trauma surgeons, and anesthesiologists), nurses, and radiology technicians (RT). When CT is ordered, nurses and RTs often play key roles in reducing transfer times and CT stay durations. However, the journey starts in the emergency department (ED) rather than in the CT scan room. Our trauma team introduced a "TPS transfer protocol" to shorten the overall process of TPS. Preparation in the ED is key to complete scans in less than five minutes ("sub-5" scans) (Table 1). The attending physician should make a prompt decision to scan the patient and declare it clearly to the team. Nurses then choose the IV line and extend it with a pressure resistance tube for contrast injection. Prior to leaving the ED, all of the tubes and lines are arranged and any metal materials have to be removed by the nurses and radiology technicians. The patient's upper extremities are also fixed in the ED, and the backboard position is pre-marked to set the scan range immediately. The trauma team practiced this transfer protocol using a mannequin to share the concept with their team members, with each one practicing at least once.

To verify the effectiveness of the multidisciplinary protocol, we analyzed the CT room duration (time from arrival at the CT room to discharge from it) before
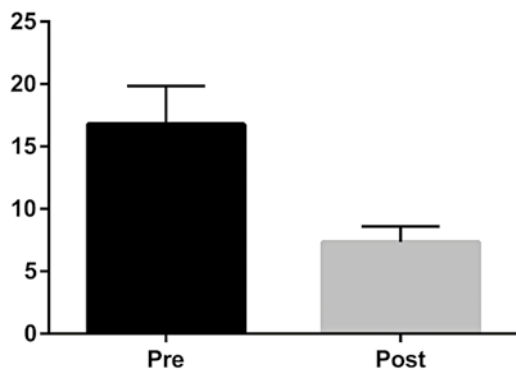
**Figure 1** Duration of time spent in the CT room.

Changes in the duration of time spent in the CT room by polytrauma patients. The CT room duration shortened from 16.8 ± 3.1 to 7.3 ± 1.3 minutes after the introduction of the trauma pan-scan protocol.

and after the training. The CT room durations of patients undergoing TPS were measured consecutively at St. Marianna University Hospital from September 2011 to September 2014 (pre-training period) and from October 2015 to March 2016 (post-training period). The inclusion criteria were adult trauma patients who underwent TPS (non-enhanced brain, arterial phase of the neck to the pelvis, and then delayed phase of the chest to the pelvis) after the trauma code was announced and for whom the TPS was ordered by the attending physician following the initial survey. In the study hospital, the trauma code is typically announced to the emergency medicine physicians, radiologists, and surgeons to request their attendance for suspected hemorrhagic shock prior to patient arrival. Although the CT scanner is shared among elective cases, emergency patients, and in-hospital patients, emergency patients are usually prioritized according to the level of urgency. The CT room is located next to the ED, but not within the ED area, and a multidisciplinary trauma team (physician, nurse, and RT) is available 24/7. Forty-four patients were enrolled (pre-training, $n = 23$; post-training, $n = 21$) and compared. The mean (standard deviation) CT room duration significantly decreased from 16.8 (3.1) to 7.3 (1.3) minutes after the training ($P < 0.001$, unpaired $t$-test). Our results suggest that the CT room stay duration may be shortened by approximately 10 minutes with the use of the multidisciplinary transfer protocol and training (Figure 1). We continue to aim for the "sub-5" scan.

After scanning the patient, the question of how much time and who is needed to interpret the results has an impact on the trauma care strategy. Accordingly, the authors have developed a three-step reading of the TPS images. The first step should be focused on the findings and has been named "Focused assessment with CT for trauma (FACT)". FACT orients the treatment approach; evaluation of intracranial area (midline shift, hematoma), left pulmonary artery region (aortic injury and

mediastinal hematoma), base of lungs and pericardium (hemopneumothorax, pericardial hematoma), pelvic floor (peritoneal hematoma), pelvis and spine, peritoneal and retroperitoneal organs (liver, spleen, kidney, pancreas, mesentery) occurs within two to three minutes on the CT console screen. The second step immediately follows the first step. It evaluates active bleeding (extravasation or pseudoaneurysm), intestinal perforation, and spinal injuries. The third step may be confirmed by radiologists or other readers after some time has elapsed in order to prevent missed injuries.

### How Should the REBOA-TPS be Performed?

A 47-year-old male had been injured in a motor vehicle crash. He presented with a systolic blood pressure (SBP) of 70 mmHg and a heart rate of 110 beats/min upon arrival. His SBP increased to 125 mmHg after complete inflation of a 7 Fr sheath-compatible REBOA catheter that was advanced over the wire (Rescue Balloon, Tokai Medical Products, Aichi, Japan). With a completely inflated REBOA, the contrast agent does not enhance the vessel and organs. Thus, partial occlusion must be performed during TPS with REBOA (Figure 2*a*, *b*), which permits distal perfusion; this is frequently observed in Japanese REBOA settings [26]. In the present case, TPS revealed small bowel mesentery and liver injury with partial REBOA. In general, the balloon should be titrated carefully by 1–3 mL and the target proximal systolic blood pressure is usually around 90 mmHg. Because the arterial flow is inhibited by REBOA, the contrast enhancement may be delayed; the arterial phase may seem non-enhanced and the portal venous phase may seem similar to the arterial phase. RTs and physicians need to closely watch the scanning on the CT console in order to judge the timing of the enhancement.

### Limitations and Possible Negative Consequences of REBOA-TPS

REBOA carries the potential risk of organ dysfunction and leg ischemia. TPS often provides useful information, but it is not a hemostasis technique. These risks should be carefully evaluated when using this approach. In addition, the use of REBOA-TPS becomes more equivocal in the following circumstances.

#### Hemothorax with multiple rib fractures

Hemothorax is a critical thoracic injury. Although thoracotomy and ligation of the artery to the rib is the classical approach, arterial bleeding from the intercostal arteries is treated more rapidly by IR [27,28]. TPS may accelerate the decision-making process or may prevent unnecessary thoracotomy. High Zone I REBOA may control the intercostal flow, but low Zone I REBOA may deteriorate proximal intercostal bleeding. The balance

(a)                                                                (b)



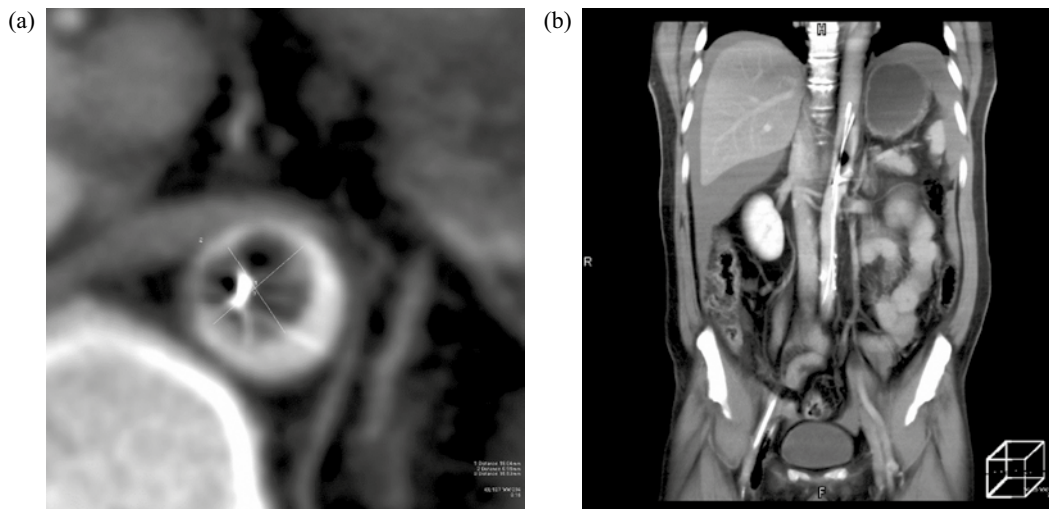**Figure 2**  CT image of REBOA-TPS.

A 47-year-old male had been injured in a motor vehicle crash. He presented with a systolic blood pressure (SBP) of 70 mmHg and a heart rate of 110 beats/min upon arrival. His SBP increased to 125 mmHg after complete REBOA inflation. TPS revealed small bowel mesentery and liver injury with partial REBOA, with a target SBP of 90 mmHg. He was taken to the operation room, where he underwent perihepatic packing and resection of the mesentery. (**a**) The balloon was partially inflated in the aorta. (**b**) Partial occlusion allows for the enhancement of the CT images.

between the risks and benefits in these situations requires further evaluation.

### Multiple penetrating injuries, uncertain trajectories

The choice of treatment strategy in hemodynamically unstable penetrating trauma with an apparent trajectory is simple: Call the operating room and grab a scalpel. Meanwhile, in cases of multiple stab wounds or gunshot wounds with unclear trajectories, TPS may provide crucial injury-related information, enabling a determination of the presence or absence of the bullet within the body, the location of the bullet (great vessel, spine), and the existence of unexpected injuries without an apparent trajectory.

### CONCLUSION

The rationale for REBOA-TPS is to choose an optimal treatment strategy with the earlier completion of hemostasis. Blunt polytrauma involving noncavitary hemorrhage with coagulopathy in geriatric populations is the most appropriate context for REBOA-TPS. TPS data can be utilized to shorten the hemostasis procedure and may lead to the earlier completion of hemostasis. Multidisciplinary trauma team training and pre-marking of the backboard resulted in a seven-minute CT room stay, which may be acceptable even in cases of refractory hemorrhagic shock. While REBOA-TPS cannot be utilized widely or indiscriminately, its appropriate implementation may increase the salvageable trauma population.

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# A Hybrid Bleeding Control Method for Retro-Peritoneal or Inguinal Bleeding After Endovascular Procedures

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With the vast increase in endovascular procedures and the use of percutaneous vascular closure devices, there is an increased risk of closure failure and bleeding that might require surgically demanding open surgical repair. We describe two ways, using a modern hybrid technique and tools (endovascular and open surgery), of controlling bleeding with minimal blood loss, which might facilitate the surgery.

**Keywords:** Bleeding; Iatrogenic Injury; Endovascular Procedure; Balloon Occlusion

## INTRODUCTION

Arterial bleeding after endovascular intervention (angiography, endovascular aortic repair (EVAR), percutaneous cardiac catheterization, or other procedures) is a common complication [1–5]. There are several ways to finish an endovascular procedure when the femoral artery is used for access. It is usually achieved today either by manual compression or by using a percutaneous vascular closure device (VCD). When larger VCDs are used for aortic valve replacement, EVAR or other major arterial repair, open cut-down might be used to close the hole in the artery. Alternatively, a larger VCD or double-closure device (such as Pro-glide) might be employed for percutaneous access. Newer methods, like

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fascia suture, are also available [6–8]. At times, VCDs might leak and create minor hematomas, which can be easily compressed manually. It is fairly common, however, for the hole in the femoral artery, especially when the puncture is in the upper-third of the common femoral artery, to cause bleeding into retroperitoneal space or the inguinal area [9,10]. The known failure rate of VCDs in different series may be as high as 8–10% [11,12].

The standard treatment to access bleeding after endovascular treatment is open surgical exploration with hematoma evacuation for repair of the artery. Uncontrolled bleeding after a percutaneous procedure with open surgical repair may be challenging, since an expanding hematoma or retroperitoneal bleeding causes tissue displacement and immense pain. Cut-down surgical repair during ongoing bleeding in the inguinal area or retroperitoneum requires experienced surgical hands.

Endovascular usage of balloon occlusion for arterial bleeding control was described as early as in the 1990s [13]. In recent years, as endovascular tools become smaller and better, and hybrid-suite availability and the multidisciplinary approach develop, there is a new interest in minimally invasive methods of bleeding control [14–16, personal communication at the EVTM Round Table Symposium, 2–4 February 2017].

Balloon placement might ease a surgical repair by decreasing or stopping ongoing bleeding, allowing for the controlled dissection toward the hole in the artery for definitive repair. As endovascular techniques develop, there is the possibility of using a stent graft

**Figure 1** Hematoma after an endovascular procedure and manual compression.



**Figure 2** Hybrid repair using a contralateral cross over a balloon in the external iliac artery and open cut-down repair.

(covered stent) to cover the hole and stop the bleeding [17,18, personal communication]. There are several disadvantages to this method. The femoral artery is highly mobile, and stent-graft placement might fail in the long run (due to kinking or thrombi formation). Another problem is that the deep femoral artery might be covered, which can compromise adequate circulation to the leg. A more practical problem is that the hematoma must usually be evacuated, as it causes great pain and takes a long time to absorb spontaneously, and there is also the risk of local infection (Figure 1).

We describe a method of controlling bleeding as a bridge to open surgical repair that involves placement of an arterial occlusion balloon at the site of the vessel puncture. Although partly described in recent publications, combinations of new endovascular tools are now in use and practical recommendations have not been described in detail before [13–18].

## METHOD DESCRIPTION

### Option Number 1 (Figures 2–4)

*Access from above the hole – proximal access*

A 6-7-8 Fr sheath is inserted in a retrograde manner via arterial puncture on the contralateral side, and a crossover wire is passed by fluoroscopic control (C-arm) to reach the ipsilateral common femoral artery. An intra-arterial balloon can be passed from above. The size of the balloon should be around 8–10 mm, and the manufacturer's instructions for the size of the sheath should be checked if needed. If completion angiography is anticipated, it might be beneficial to use a long sheath catheter (Table 1). This permits working with the balloon distally, and also securing its position and injecting contrast solution via the sheath (downstream). When the balloon is in place, open exploration of the ipsilateral common femoral artery is performed. When bleeding starts (or even before), the balloon should be gently inflated using a manometer. A low pressure of around 4–6 mmHg might be enough, and balloon inflation can be confirmed by angiography, or clinically when bleeding decreases or totally stops. Alternatively, the balloon might be inflated manually until bleeding stops, followed by the locking of a three-way stopcock. After cut-down and open exploration, the hole is sealed with 5.0 or 6.0 non-absorbable sutures. It is advisable to confirm flow when the balloon is deflated and that no bleeding is observed by hand-doppler or flow meter, and also to perform a clinical examination of distal extremity status and pulses. Another option is to perform a completion angiography through the catheter sheath, verifying that the hole is covered and normal flow maintained. After hematoma evacuation, the
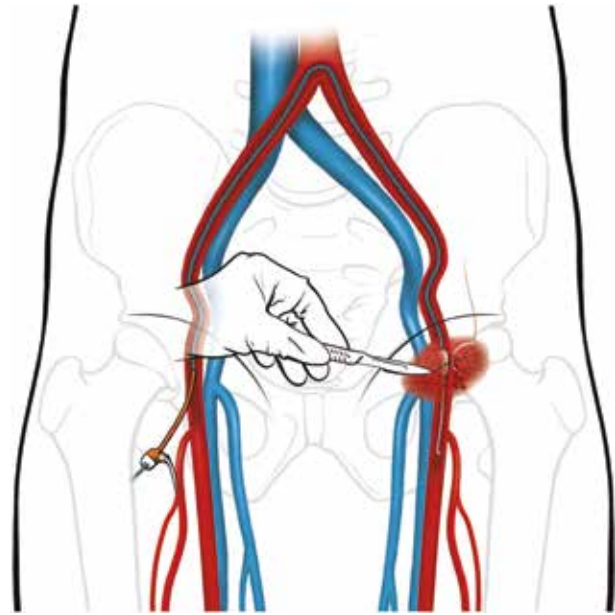
**Figure 3** Hand compression during bleeding after elective angiography with failure of the closure device.



**Figure 4** Illustration of method option no. 1 with balloon insertion from the contralateral femoral artery and balloon control over the puncture site before surgical cut-down and repair.

wound is closed in a standard fashion, with or without a drain. The contralateral access can be closed by a VCD or by manual mechanical compression. Obviously, the contralateral leg must be examined clinically to assure normal perfusion.

### Option Number 2 (Figure 5)

*Access from below the hole – distal access*

At times, for example, when a C-arm is not readily available or the surgeon doubts his/her ability to cross the aortic bifurcation with a guide wire, the vessel can be accessed from below the hematoma (distal puncture). Instead of the traditional way of opening the skin at the common femoral artery/hematoma location or above it for surgical vessel control, it can be started distally (in "virgin territory"). Open the skin a few centimeters below the common femoral artery, at the level of the superficial femoral artery (SFA) just around 7–10 cm below the inguinal ligament. By surgical cut-down, the SFA can be identified and controlled. A retrograde puncture is made using an 18 G needle, and a wire (any standard wire will do) is passed into the artery under direct vision, followed by a 6-7-8 Fr sheath placement. Then, over the wire, an arterial PTA balloon (8–10 mm in diameter) is inserted and advanced to the common



**Figure 5** Illustration of method option no. 2 with balloon insertion from the distal SFA and separate cut-down.

femoral artery under fluoroscopy guidance (i.e., C-arm). When positioned, the incision is extended proximally to reveal the bleeding artery, and open repair follows as described above. Theoretically, after preliminary measurement of the distances to the anatomical landmarks, the balloon can be inserted blindly and gently inflated manually in the injury zone without fluoroscopy. Fluoroscopy, however, is always recommended. When the

*Table 1*  A set of endovascular materials that can be used for temporary balloon control of bleeding from the iliac, femoral and SFA arteries.

| Description | Type (examples only) |
| --- | --- |
| Puncture needle 18 G | Cordis Endovascular, USA |
| PTA over-the-wire balloon catheter 6–12 mm × 4–10 cm | ev3, USA; Cordis, USA; Medtronic, USA |
| Sheath 6-7-8 Fr | Terumo, Japan or Cordis Endovascular, USA |
| Standard wire | Cook, USA |
| Hydrophilic wire | Terumo, Japan |
| Cross-over catheter | Contralateral Cordis Endovascular, USA |
| Guiding (introducer) sheath | Flexor Ansel Cook, USA |
| Destination Terumo, Japan Iodine contrast solution | Iohexol (Omnipaque) 300 mgI/mL, 100 mL |
| Saline solution | – |

main hole in the artery is treated, the distal arterial hole after sheath removal can be easily sealed with one or two non-absorbable stitches.

## SUMMARY

We describe a simple, up-to-date method of hybrid surgical repair to manage ongoing femoral artery bleeding, which might be used in other arteries as well (for example, the iliac arteries). The method can be used for both iatrogenic and traumatic injuries. Its success depends on the continuity of the vessels but might be useful for proximal control when open access is hard to achieve (due, for example, to obesity, unavailability of access, etc.). It is fast and effective and can probably decrease the volume of bleeding during surgical repair, and also provide technical help when dissecting to the artery and viewing the puncture hole. The advantages of temporary balloon occlusion as a bridge to repair may be obvious:

1   It controls unstable bleeding and converts the situation into a stable one;
2   It decreases bleeding during open repair;
3   It eases surgical cut-down and decreases pain by using local anesthetics, and might eliminate the need to convert to general anesthesia;
4   It gives time if surgical help is not available (at an angiography suite, for example).

Possible risks of balloon insertion include further injury to the vessel, such as intima dissection, but these can be prevented by gently manipulating the balloon and working with fluoroscopy. It should be borne in mind that full inflation is not needed for adequate bleeding control. You have to be careful when advancing the wire and balloon in the vessel, and confirm easy passage into the bleeding area. For these reasons, it is self-evident that the operator should be trained in interventional radiology, or at least has basic skills in endovascular surgery.

## CONCLUSION

Temporary arterial endovascular balloon occlusion may be helpful in certain patients for bleeding control by converting an ongoing bleeding problem into a controlled state, thereby facilitating open repair.

## ACKNOWLEDGMENTS

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# Use of Endovascular Balloons may Simplify Proximal and Distal Control in Complicated Vascular Trauma

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## INTRODUCTION

The optimal management of vascular injuries remains a significant challenge of modern trauma care, especially when the injuries are complex or located in anatomic areas that are difficult to surgically expose or control. The mortality rates from these injuries can be high, despite recent progress in the application of damage control management concepts [1,2]. As an additional challenge, many of these injuries may require initial management by trauma or vascular surgeons who do not routinely manage complex vascular injuries [3]. Advancements in endovascular techniques have introduced new alternatives to traditional open repair strategies that may prove useful in the setting of complex vascular injury [4], but the introduction of these novel strategies is not yet commonplace.

The basic tenet of proximal and distal vascular control prior to definitive repair remains an important strategy of vascular injury treatment. In practice, many patient factors such a body habitus and physiologic condition of the patient make less invasive options attractive. Intravascular balloon occlusion is a novel endovascular strategy that may be of particular use in these situations. This case report highlights successful utilization of this less invasive approach and affords an opportunity to review a simplified approach using endovascular balloons as proximal and distal control measures, in order to limit the challenges represented by more extensive anatomic exposures in a victim of trauma.

### Case Description

A previously healthy 20-year old male cyclist was severely injured when struck by a motor vehicle. In the prehospital phase of care, his vitals were: blood pressure, 110/74; heart rate, 114; GCS, 10; and reduced breath sounds bilaterally. Needle thoracostomy was performed bilaterally and the patient was transferred to a nearby hospital. Upon arrival to the trauma bay, the patient was intubated and ventilated. Thoracostomy tubes were inserted simultaneously to both sides of the chest, with the evacuation of a small amount of air and blood bilaterally. On physical examination, a large
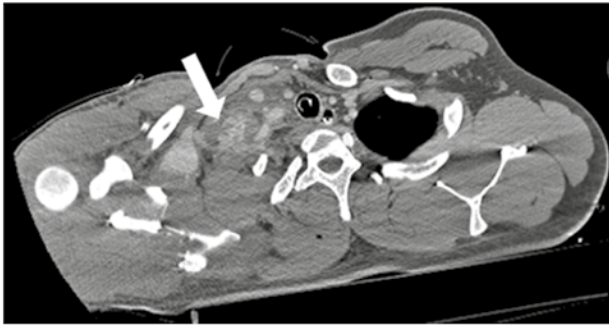
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**Figure 1** Contrast media extravasation to upper mediastinum hematoma in late phase chest CT angiography scan (white arrow).



**Figure 2** Contrast media extravasation (two small black arrows), proximal occlusion balloon (black arrow) and distal occlusion balloon (white arrow).

hematoma was noted on the right upper chest anteriorly above and below the right clavicle. Multiple bilateral rib fractures were clinically diagnosed. No radial pulse was able to be palpated in the right upper extremity. The remainder of the patient's physical examination was unremarkable. Focused abdominal sonography for trauma (FAST) did not reveal any sign of pericardial or peritoneal fluid. The patient remained stable and underwent additional imaging. Computed tomography (CT) of the brain, neck, and abdomen was interpreted as normal. Chest CT showed small bilateral pneumothorax, multiple right-sided rib fractures, a scapula fracture, and a displaced fracture of the right clavicle with surrounding large hematoma expanding to the neck, upper mediastinum, and right shoulder. Complete occlusion of the right subclavian artery (RSCA) with significant contrast extravasation was noted on CT angiography (Figure 1).

The patient was then taken to surgery were repeated attempts to traverse and repair the RSCA tear endovascularly, using both the femoral artery as well as right brachial artery approaches failed. The decision was made to attempt open exposure and the direct repair of the injury. Our operating room is not a hybrid room but allows the use of C-arm with high imaging quality. In order to reduce the blood loss during the subsequent open surgical exposure in a difficult anatomic location, proximal and distal arterial control was achieved with two percutaneous transluminal angioplasty balloons (Cordis PowerFlex Pro, Milpitas, CA, USA). An $8 \times 40$ mm$^2$ balloon was inserted percutaneously via a right femoral approach and placed in the proximal RSCA and a $7 \times 40$ mm$^2$ balloon, was inserted via the right brachial artery and placed in the right axillary artery (Figure 2). The femoral sheath used was 10 Fr and 80 cm length, and the brachial sheath was 6 Fr and 11 cm length. The RSCA was exposed using both supraclavicular and infraclavicular incisions, in order to prevent removal of the clavicle. No active bleeding was noted from the arterial injury. A 5-cm gap between the proximal and the distal edges was repaired using an 8-mm ringed
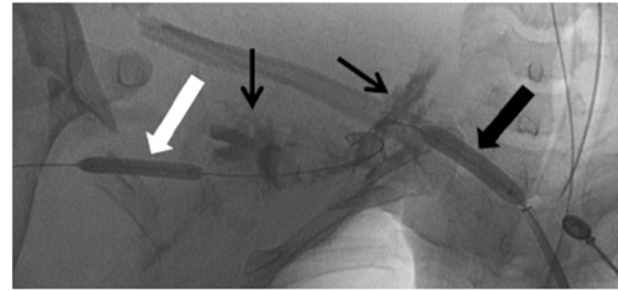
polytetrafluoroethylene (PTFE) interposition graft (WL Gore & Associates, Inc., Flagstaff, AZ, USA), which was tunneled under the clavicle. The total occlusion time was 1 hour and 45 minutes, with no vertebral artery occlusion. During the surgery, the patient received two units of blood and three units of fresh frozen plasma. The postoperative course was complicated by right femoral artery thrombosis, presenting on the second postoperative day, most probably associated with the duration of sheath utilization (8 hours), which was treated by thrombectomy. The rest of his course was uneventful and he was discharged home on postoperative day twelve.

## DISCUSSION

The most common causes of death among trauma patients, who arrive at the hospital alive, are brain injury and bleeding. These patterns of immediate (within 24 hours) deaths have remained consistent during the last three decades [5,6]. Among trauma victims dying from hemorrhage, the majority die from bleeding originating from large vessels in the torso [7]. The literature describes high mortality rates even in well-established trauma centers for this subset of patients. Asensio et al. reported 54% mortality rate in a study of 302 consecutive trauma patients with abdominal vascular injury and showed a strong correlation between mortality and the number of injured vessels [1]. The mortality secondary to neck and chest vascular injuries is similar, reported as 55% in one study of 165 trauma patients [8]. The reason for these poor results is likely to be multifactorial. The management of complex vascular injuries requires significant surgical skill and experience. Achieving control of vascular injury is very difficult at particular anatomic locations, including specific regions of the chest, and junctional regions such as zone 3 neck injuries. Treating surgeons may need to be experienced and facile with a number of different approaches, exposure types and extension adaptations.

The evolution of endovascular trauma management has recently gained popularity in the vascular and

trauma surgery community – either as a primary defini-tive treatment modality or as part of a hybrid approach combining endovascular and open treatment tools [9]. Several potential benefits of endovascular adjuncts in this setting have been proposed, including shorter hospital stays, lower morbidity and, potentially, even decreased mortality.

Although endovascular management has become the preferred treatment modality of many providers in spe-cific scenarios, it is important to note that the present day experience has primarily been accumulated among hemo-dynamically stable patients. The utilization of these adjuncts also has limitations in use that must be appreci-ated. As in our illustrated case, to be adequately addressed by endovascular means, lesions must be traversed by a guidewire for the majority of endovascular repair options to be adequately applied. For those patients who are not stable, or for whom a wire cannot be placed across the injury, open repair remains the standard of care.

Open surgical exposure mandates proximal and dis-tal control of the injured vessel prior to repair. Most optimally, these control locations are obtained in unin-jured "virgin" fields, away from the injured vessel which is surrounded by hematoma. This approach is pursued in order to minimize blood loss during repair. In specific anatomic locations, however, such pristine distal and proximal exposures are challenging. Notorious loca-tions in this regard include the tight anatomic confines of the thoracic inlet, within the thoracic cage and the pelvic region.

The use of two endovascular balloons as measures of gaining proximal and distal control, as was done novelly in this case, limits the amount of dissection that must be done outside the field of injury among hemodynami-cally stable patients. Once active bleeding is arrested in this fashion, operative incision and exposure of the injury itself can be undertaken in a more controlled fashion that affords thoughtful consideration and mini-mizes risk to adjacent anatomical structures that may be obscured by the hematoma or other sequelae of injury.

The outlined case demonstrates a successful collabo-ration between the trauma surgeon, vascular surgical providers, and the invasive radiologist to achieve opti-mal repair of a difficult injury using a hybrid endovascu-lar/open approach to injury control and repair. While additional study is required to define the optimal utiliza-tion of similar applications, this type of approach warrants communication and additional study.

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≋ *Case Report* ≋

# Endovascular Resuscitation with Aortic Balloon Occlusion in Non-Trauma Cases: First use of ER-REBOA in Europe

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**Background:** Resuscitative endovascular balloon occlusion of the aorta (REBOA) is currently evolving and being used worldwide for trauma management. Smaller sheath devices for REBOA and new advances in endovascular resuscitation methods suggest the potential for the procedure to be utilized in hemodynamically unstable non-traumatic patients.

**Methods:** We describe five adult patients that underwent hemodynamic control using the 7 Fr sheath ER-REBOA™ catheters for non-traumatic hemorrhagic instability at Örebro University Hospital between February 2017 and June 2017.

**Results:** The ER-REBOA™ catheter was inserted and used successfully for temporary blood pressure stabilization as part of an endovascular resuscitation process.

**Conclusion:** The ER-REBOA™ catheter for endovascular resuscitation may be an additional method for temporary hemodynamic stabilization in the treatment of non-traumatic patients. Furthermore, the ER-REBOA™ catheter may be a potential addition to advanced cardiac life support in the management of non-traumatic cardiac arrest.

**Keywords:** REBOA; Hemorrhage; Hemorrhagic Shock; Endovascular Resuscitation

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## INTRODUCTION

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is currently evolving and being described

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worldwide as a potential primary alternative to resuscitative thoracotomy (RT) in the treatment of uncontrolled hemorrhagic shock [1–4]. This minimally invasive technique helps to provide temporary hemodynamic stability, in particular for patients presenting with non-compressible torso hemorrhage (NCTH). By controlling distal bleeding and sustaining carotid and coronary perfusion, definitive open surgical and/or endovascular intervention, such as endografts or embolization, may be performed [5,6]. Advances in endovascular techniques as well as in REBOA technology and smaller balloon systems has allowed the procedure to be utilized more frequently, in different settings and by various medical professionals [7–12].

REBOA has not only been useful for temporary control of traumatic NCTH but also non-traumatic cases such as postpartum hemorrhage (PPH), one of the leading causes of maternal mortality and morbidity, and non-traumatic cardiac arrest (NTCA) [13–15]. The treatment of hemodynamically unstable non-traumatic

**Figure 1** CT showing blood extravasation from the hepatic artery pseudoaneurysms in Patient 1.



**Figure 2** Deflated balloon in zone I during angiography for cannulation of the celiac trunk for bleeding control, by brachial access with a 6 Fr catheter in Patient 1.

patients might also be facilitated by using a multidisciplinary endovascular and hybrid trauma management (EVTM) concept combining open surgery and endovascular procedures. This is part of the emerging concept of endovascular resuscitation [16,17].

Different techniques for the use of REBOA have been suggested. Partial REBOA (pREBOA) has shown promising results, decreasing the risk of organ failure but at the same time giving the possibility of prolonging occlusion time. Another technique described in former case series is intermittent REBOA (iREBOA) [8,9,18–21].

The Prytime ER-REBOA™ catheter (Boerne, TX, USA) has been optimized for use in the emergency setting, while also simplifying the procedure [22,23]. Using a smaller 7 Fr sheath and having an atraumatic tip is said to decrease the risk of arterial damage as well as total femoral artery occlusion. In addition, there are external length markers to assist the positioning of the device, and without the need for a guidewire or fluoroscopic placement verification, allowing quicker hemodynamic control. The possibility of systolic blood pressure (SBP) monitoring proximal to the balloon combined with sheath SBP measurements facilitates verification of pREBOA and iREBOA. Finally, after removing the device, surgical repair is not mandatory as a closure device can be used.

The aim of this study is to report to the best of our knowledge the first cases of the ER-REBOA™ being used to treat non-traumatic hemodynamically unstable patients in Europe.

## PATIENTS AND METHODS

This is a description of a clinical case series of ER-RE-BOA™ performed on five adult patients (four males, one female) at Örebro University Hospital between February 2017 and June 2017. Regional Ethics Committee approval (No 2014/210) was obtained for the REBOA procedure patients. Data was prospectively and retrospectively analyzed by reviewing patients' medical journals. All patients were treated with REBOA procedures performed by the on-call vascular surgeon using a Prytime ER-REBOA™ catheter with a 7 Fr sheath. In all cases but one (Patient 4), the 7 Fr sheath was placed blindly. All vascular accesses were completed in single attempts. Two locations of REBOA were used, either supra-celiac (zone I) or infra-renal (zone III) [1]. In all cases except two (Patient 3 and 4), after removal of the catheter and sheath the vascular access was closed with 6 Fr AngioSeal™ (St. Jude Medical, Little Canada, MN, USA), a method only recommended for experienced users. Distal ischemia was later excluded by palpation of pulsations in the popliteal-, posterior tibial- and dorsalis pedis arteries.

## RESULTS

### *Patient 1 (Figures 1–3)*

A 76-year-old male with a pancreatic tumor underwent a Whipple procedure with subsequent complications requiring a total pancreatectomy. The patient was discharged but presented to the emergency department a week later in a deteriorated condition with pus exuding

**Figure 3** Deflated balloon in the aorta with a balloon in the celiac artery for bleeding control and contrast extravasation seen from the pseaudoaneurysmspseudoaneurysms in Patient 1.

from the surgical wounds and anemia, where hemoglobin had decreased to 58 g/L from 102 g/L on discharge. On day 3 after readmission, the patient reported abdominal pain and was passing bright red blood per rectum. His SBP was 80 mmHg and heart rate (HR) was 90 beats per minute (bpm). A computed tomographic angiography (CTA) showed a ruptured pseudoaneurysm of the hepatic artery with contrast extravasation. The patient was taken to the intensive care unit (ICU) where his SBP further decreased (70 mmHg) despite rapid infusion of fluids and blood transfusion products; a total of nine units of packed red blood cells (PRBC) and four units of fresh frozen plasma (FFP) were given. A 7 Fr sheath was placed blindly in the left femoral artery and zone I REBOA was performed with an immediate increase in the patient's SBP. The patient was then transferred with REBOA to the hybrid operating theater where coil embolization of the hepatic artery was performed. During the procedure, the balloon ruptured but was immediately replaced. Further selective catheterization of the celiac artery enabled insertion of a smaller, selective balloon that replaced the REBOA during embolization. After endovascular intervention, the patient remained hemodynamically stable but needed temporary hemodialysis due to renal failure. At 30 days post intervention the patient was recovering well and no longer in need of dialysis.
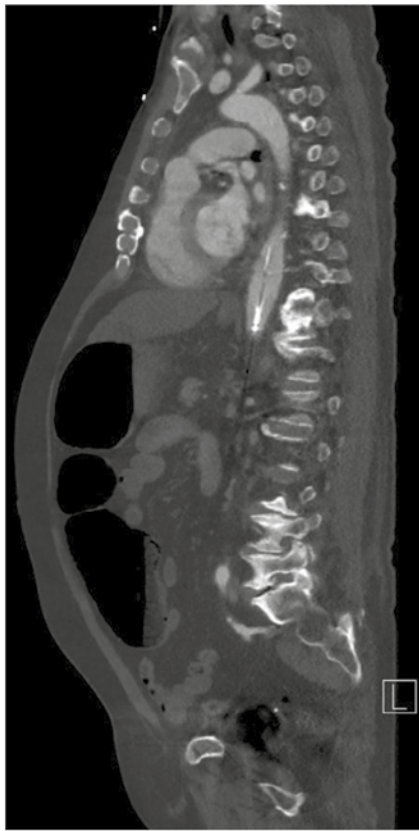
### Patient 2

A 62-year-old male was admitted due to abdominal pain and underwent surgical repair of a perforated peptic ulcer, with complications causing reoperation to be performed following multiple wound dehiscence.

Four days post discharge the patient presented to the emergency department hemodynamically unstable (SBP 75 mmHg, HR 110 bmp) with decreased consciousness, hematemesis, and melena. His hemoglobin had decreased to 64 g/L from 130 g/L on discharge. The patient was transferred to the operating theater where a 4 Fr sheath was placed blindly in the right femoral artery. Simultaneously, a gastroscopy was performed revealing a massive blood clot filling the ventricle. The general surgeon performed a gastrostomy to remove the clot and repair the initial perforated peptic ulcer. During the procedure, the patient's SBP decreased (70 mmHg) and the 4 Fr sheath was replaced with a 7 Fr. Zone I REBOA with total occlusion for 2 minutes was performed with an immediate increase in SBP (95 mmHg). Thereafter, pREBOA was performed for 11 minutes before gradual deflation and removal once SBP had stabilized (125 mm Hg). The remainder of the patient's in-hospital care was uneventful and at 30 days post intervention he was recovering well.

### Patient 3

A 73-year-old male with multiple illnesses, including liver cirrhosis with esophageal varices, and receiving anticoagulation treatment for atrial fibrillation, presented to the emergency department hemodynamically unstable (SBP 90 mmHg, HR 100 bpm) with decreased consciousness, high fever, and massive melena. He was admitted to the ICU and a CTA was performed showing massive bleeding from both the ventral and dorsal rectal wall. SBP continued to decrease (60 mmHg) despite receiving blood transfusion products, a total amount of 22 units PRBC, 20 units FFP and seven units of platelets (PLT). He was transferred to the operating theater where a 7 Fr sheath was placed blindly in the left femoral artery. Zone III REBOA was performed with an immediate increase of SBP (100 mmHg). Simultaneously the general surgeon tried to further identify and attempt to treat the source of bleeding. After total occlusion for 60 minutes, the balloon was partially deflated (pREBOA) and positioned just proximal to the aortic bifurcation with the patient remaining hemodynamically stable. While changing the position, the balloon ruptured but was immediately replaced and zone III pREBOA was continued for an additional 30 minutes. The balloon was subsequently deflated with no further bleeding per rectum. The balloon ruptured once again but as the patient remained hemodynamically stable there was no need for further replacement. As the ER-REBOA™ catheter could not easily be withdrawn from the sheath, surgical cut-down and repair of the common femoral artery were performed. The patient remained hemodynamically stable but developed multiple organ failure. A CT was performed showing a large cerebral infarct and the patient died 12 days later.

*Figure 4* CT of Patient 4 showing a distended colon and pREBOA.



*Figure 5* Patient 4 during a pause in CPR for a pulse check in the emergency department. Notice the bilateral ultrasound assisted femoral artery access performed.

### Patient 4 (Figures 4 and 5)

A 69-year-old male arrived at the emergency department hemodynamically unstable with a distended abdomen and decreased consciousness after experiencing back pain for 2 days. The patient went into cardiac arrest upon arrival and cardiopulmonary resuscitation (CPR) was initiated. A 7 Fr sheath was placed in the right femoral artery using ultrasound guidance and zone I REBOA with total occlusion was performed. A 5 Fr sheath was also placed using ultrasound guidance in the left femoral artery for BP monitoring. After a few minutes, an increase in SBP (80 mmHg) was seen with the return of spontaneous circulation (ROSC). As the patient stabilized, the balloon was partially deflated (pREBOA) with overall occlusion time around 10 minutes before deflation. While performing a CT, which revealed a distended colon, the patient again became hemodynamically unstable and pREBOA was re-inflated, increasing SBP (90 mmHg). The patient was transferred to the ICU and, using both pREBOA and iREBOA together with adrenalin infusion for an additional 60 minutes, the patient was stabilized. He was then taken to the operating theater where a laparotomy confirmed severe colonic ischemia and a total colectomy was performed. The patient died a few hours later before the ER-REBOA™ catheter was removed. Post-mortem examination of the CT showed a small dissection of the right iliac artery (used for REBOA access).

### Patient 5

A 31-year-old pregnant female with total placenta previa was planned for a caesarian section and hysterectomy due to placenta accreta, increta, and percreta. Due to the risk of hemorrhagic instability by both procedures, a 7 Fr sheath was placed blindly in the right femoral artery and a deflated balloon was positioned in zone III. A caesarian section was performed successfully by the gynecologist who then continued with a hysterectomy. During the following procedure, iREBOA was used for 5–10 minutes per inflation in conjunction with periods of hemorrhage. The patient remained hemodynamically stable throughout the whole procedure and the remainder of the patient's hospital stay was uneventful and at 30 days post intervention, she was recovering well.

### Additional traumatic patient illustrating the use of ER-REBOA™

A 21-year-old female arrived at the emergency department unconscious and hemodynamically unstable with severe penetrating brain injury (PBI) after being hit in the skull with an axe. The patient went into cardiac arrest upon arrival and CPR was initiated with ROSC. While a CT was being completed CPR was again initiated and a 7 Fr sheath was placed blindly in the left femoral artery and zone III REBOA was performed. An immediate increase in SBP with ROSC was seen and total occlusion was continued for 15 minutes. Subsequently, the balloon was deflated but later re-inflated during surgery because of continued hemodynamic instability. Throughout the surgery, iREBOA was continued

in conjunction with hemodynamic instability to facilitate central circulation with a total occlusion time of 40 minutes. Thereafter, the ER-REBOA™ was repositioned and inflated in the left common iliac artery for an additional 2 minutes. The patient remained hemodynamically stable (SBP 110 mmHg) but died two days later due to massive brain injury.

## DISCUSSION

The use of REBOA in traumatic exsanguinating patients dates back to the Korean War [24]. However, since then, RT with aortic cross-clamping has been the method of choice, despite very poor survival rates [25]. Further development, as a result of military conflicts in Iraq and Afghanistan [26] and advances in vascular surgery in the last few decades [27,28], has permitted renewed interest in the application of REBOA for hemodynamic control. In 2011, Stannard et al. released a detailed report on the clinical use of REBOA and there have since been several studies reporting a possible increased survival rate for REBOA compared to RT in treating traumatic hemorrhagic shock [1,3,29,30]. Further use of REBOA has also been reported in patient series when treating PPH, pelvic surgery, iatrogenic injuries and other hemodynamic instabilities [13,31–33].

We present here to the best of our knowledge the first series of clinical cases using the Prytime ER-REBOA™ device through a 7 Fr sheath for endovascular resuscitation in non-traumatic hemodynamically unstable patients in Europe. All five non-traumatic patients received REBOA either to facilitate the treatment of, or proactively prevent, hemodynamic instability.

Using a multidisciplinary team approach (EVTM), open surgery or endovascular embolization was performed simultaneously with REBOA to gain temporary endovascular hemorrhage control [16]. Rapid first attempt percutaneous arterial access was achieved in all cases, despite hemodynamic instability or ongoing CPR. The use of the ER-REBOA™ catheter immediately improved hemodynamic stability with an increase of SBP and was used for proximal control and as a resuscitative adjunct, to proactively facilitate definitive surgery in these severely hemodynamically unstable non-traumatic patients. In two cases, REBOA during CPR probably aided in ROSC by increasing carotid and coronary perfusion, and allowed the anesthetist to gain increased vein access to stabilize the patient, suggesting an improved outcome [15,34]. The use of REBOA during CPR in these patients (Patient 4 and additional traumatic patient) further demonstrates its potential use as an adjunct in advanced cardiac life support (ACLS) for ROSC in both traumatic cardiac arrest and NTCA. Furthermore, as demonstrated in Patient 5 and previously performed by Cui et al. [35] and our own Institute (personal communication), REBOA was used as a prophylactic adjunct in an elective procedure to diminish the possibility of hemodynamic instability during a procedure with high risk of increased hemorrhage. This further establishes the benefits of using REBOA in both traumatic and non-traumatic patients to prevent hemodynamic instability for both elective and immediate surgical intervention and as part of the EVTM concept [16,17,22,36].

Previous studies have shown that REBOA causes less ischemic insult with increased occlusion time in comparison to RT [21,37]. Despite this, occlusion time should still be kept as short as possible to decrease the risk of organ failure or spinal cord ischemia [38]. In this report, we have demonstrated successful utilization of both pREBOA (Patient 2, 3 and 4) and iREBOA (Patient 4, 5 and the additional traumatic patient) using the ER-REBOA™ catheter. After regaining hemodynamic stability in Patients 2, 3 and 4, pREBOA allowed us to continue to maintain this control while minimizing distal ischemia. The benefit of using iREBOA in Patient 5 was through proactively minimizing times of increased hemorrhage when needed during the procedure, decreasing the potential risk of hemodynamic instability.

REBOA is not without risk of complications [39]. To avoid these, the technique should be performed by an experienced medical professional with appropriate training [3,16,40]. Several possible complications were noted in this study. Balloon rupture was seen in Patients 1 and 3, most probably because of multiple atherosclerotic plaques, fast replacement of the catheter is essential in such events (personal communication). Difficulties with balloon and sheath removal and the need for surgical cut-down and repair in Patient 3 and a small iliac artery dissection noted in Patient 4 were seen as complications possibly caused by the vascular access. We have noted that flushing with saline fluid while removing the balloon and sheath might help to prevent these complications, as well as removing both balloon and sheath simultaneously together with manual compression. Renal failure in Patient 1 and multiple organ failure in Patient 3 could have been a consequence of REBOA usage but might have occurred due to prolonged hemorrhagic shock. SBP monitoring proximal to the balloon was at times problematic due to clot formation (personal communication).

During this study period, the ER-REBOA™ catheter was also used in one patient with a traumatic hemodynamic instability (Additional traumatic patient). This was briefly described as we consider the reason for the patient's hemodynamic instability not to be due to hemorrhage from the PBI, but instead a neurologic response to the traumatic insult. REBOA was useful for ROSC and SBP elevation as part of the EVTM concept.

## LIMITATIONS

In this case series, only the direct postoperative period is described and the patients have not been observed for long-term complications post 30-days.

## CONCLUSION

The ER-REBOA™ catheter for endovascular resuscitation might be an additional method for temporary hemodynamic stabilization in the treatment of non-traumatic patients. Furthermore, the ER-REBOA™ catheter might be a potential addition to ACLS in the management of NTCA. Additional studies for further modification of optimal patient selection are needed, fundamental in the use of any procedure, to further investigate, evaluate and define the effectiveness and optimal role of REBOA.

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# GUEST EDITOR COMMENTARY on:

## Endovascular Resuscitation with Aortic Balloon Occlusion in Non-Trauma Cases: First use of ER-REBOA in Europe, by David McGreevy, et al.

I read with great interest the article by McGreevy et al., published in this first issue of the JEVTM, reporting the first European experience with ER-REBOA™ in a non-traumatic setting. Without a doubt, wide-spread awareness and the experience gained has resulted in expanded use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in various indications [1, 2]. This article demonstrates that a simple procedure and thinking "out of the box" may save the lives of dying people.

I have several comments.

Firstly, as we understood from the paper, REBOA was performed in various hospital sites: the operating room, the angio-suite and even in the intensive care unit.

Does this mean that the hospital team made the decision to equip the entire hospital with endovascular balloon sets or was this done as a part of a planning study? In some described cases there is no exact information regarding the blood product replacement. In patient 1, the aortic occlusion was performed after 9 units of Packed Cells (PC), while patient 3 received 22 units of PC before balloon insertion. Such information is missing regarding the other patients. Was the REBOA performed too early or too late? How will the above described patients be managed next time?

Regarding partial REBOA: there are some very interesting studies evaluating the effectiveness of partial

aortic balloon occlusion [3–5]. Is its use related to balloon type or volume/pressure inflation numbers? However, there has been no clear parameter or recommendation recently published regarding how to perform this procedure in the "live scenario" of a middle-of-the night bleeding patient.

Timing of REBOA: in this study, as in most previously published studies, the authors report an almost immediate increase in systemic blood pressure. However, in this study after achieving the target in patient 2, total occlusion was performed for only 2 minutes, which was then changed to partial occlusion for an additional 11 minutes. In patients 4 and 5, the inflation time was also very short. The question that I want to raise for possible reader discussion: how far do we need to go with REBOA? Does it make sense to make such efforts, to achieve a reasonable blood pressure in a critically ill patient and 10 minutes later to deflate the balloon, probably paying the price of repeat rapid deterioration? Is blood pressure the single parameter which we use to come to a decision? From my personal veteran trauma surgeon point of view, I am never "in a rush" with my patients. In this way, one can make the best decisions. If 30 minutes has been shown to be a safe time, either for total or partial occlusion, I would try to receive the maximum information about all possible physiologic parameters within this time span. Furthermore, I believe that future research will help to define "markers" for possible aggravation after REBOA deflation.

I think that authors' conclusion that REBOA may be a part of advanced cardiac life support is too premature. This study was performed only on patients with severe bleeding and even described cardiac arrest resulting from hemorrhage. On other hand, I think we should think together regarding where the timing of REBOA should be placed within a massive blood transfusion protocol. This is a highly appreciated pioneer paper. The use of REBOA in non-trauma bleeding patients has only begun to be investigated. There are too many questions and too few answers. The contribution of this paper has opened a great perspective for fruitful discussion and the exchange of ideas within the pages of this journal.

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**≫ Case Report ≪**

# Penetrating Injury to the Proximal Descending Aorta: Can we do Better in the Endovascular Era?

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## INTRODUCTION

Penetrating thoracic aortic injuries are very rare, comprising only 1% of all thoracic vascular injuries and 13% of penetrating injuries to the thoracic aorta [1,2]. These injuries are usually fatal on the scene and have a very high mortality rate, 55%, even among the few who are alive when they arrive at the emergency room (ER) [3]. Most patients who reach the ER are in shock due to intrathoracic hemorrhage and as such should be transferred immediately to the operating room (OR). However, most trauma patients around the world are treated in hospitals which lack cardiac and vascular surgeons who are familiar with this complicated area of the aorta. Endovascular treatment, either as temporary bleeding control or as a definitive measure, seems a promising option. We hereby report a case of a patient with several stab wounds, to the thoracic inlet, with proximal descending aortic injury. The clinical course and therapeutic dilemmas are discussed.

### Case Description

A 17-year old, previously healthy, male was found by Magen David Adom technicians (Israeli Emergency Medical Technicians) on scene lying in a puddle of blood. Three stab wounds to the left chest cavity were noted – one in the thoracic inlet, above the left clavicle, one below the left nipple, 4th intercostal space, and the third on the posterior axillary line on the 9th intercostal space. Needle decompression was performed on both sides of the chest, and the patient was transferred to the ER of a nearby level 2 trauma center.

On arrival to the trauma bay, the patient was intubated and ventilated. His blood pressure and pulse oximetry were not measurable and only filiform rapid carotid pulse was palpated. Breath, as well as heart sounds, were normal. On physical examination, three stab wounds to the left thoracic inlet and bilateral needle thoracostomy were noted. Chest drains were inserted simultaneously to both sides of the chest, without any evidence of pneumothorax or hemothorax on any side. Focused assessment sonography for trauma (FAST) did not reveal any sign of pericardial or peritoneal fluid. Two units of O-positive packed cells (PC) and one liter of crystalloids were immediately administered and the patient's blood pressure was raised to 90/60. Suddenly a massive arterial bleeding arising from the left thoracic inlet wound was noticed. The bleeding was controlled by direct digital pressure and the patient was transferred to the OR, 35 minutes after his admission.

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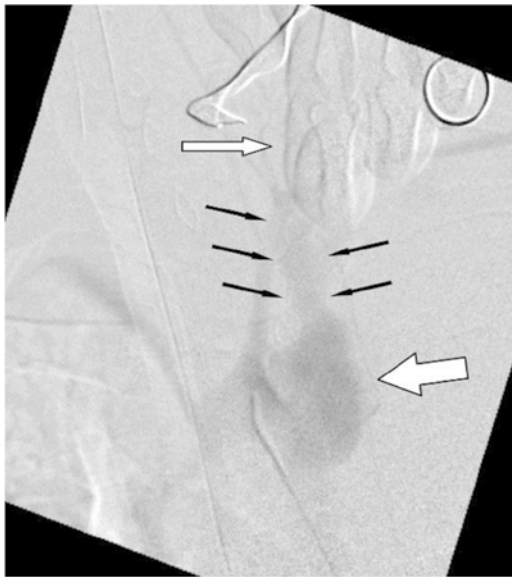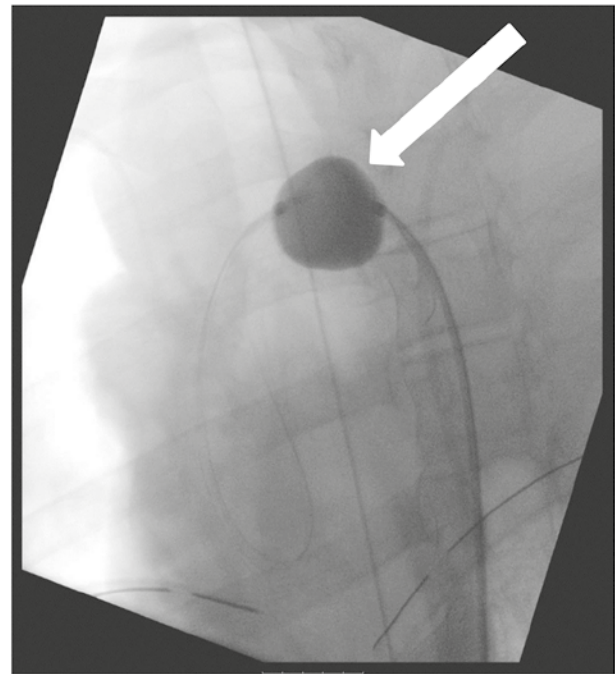
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*Figure 1* Extravasation from the proximal descending aorta, distal to the LSCA orifice (LSCA - lt. Subclavian artery), despite manual compression. The big white arrow shows extravasation, black arrows show the tract of bleeding, and the small white arrow shows fingers compression.



*Figure 2* Occluding balloon located in the distal aortic arch. The white arrow shows the inflated balloon.

On arrival to the OR, the patient's blood pressure was 120/74 mmHg. Vasopressors were not used at this stage. On-table angiography was performed, via the right common femoral artery. Extravasation originating a few millimeters distal to the left subclavian artery (LSCA) orifice was noted. No bleeding was noticed from the LSCA or the left common carotid artery (Figure 1). The vascular surgeon's decision was to treat the lesion by using a stent graft (SG). The SG, which was unavailable on the shelf, was ordered with an estimated arrival time of one hour. However, the patient's condition deteriorated gradually despite continuous administration of blood products. At that time, the patient received eight units of PC, eight units of fresh frozen plasma and eight units of platelets. A decision to treat the patient by open surgical repair was taken due to a steep hemodynamic deterioration. The decision for open surgical repair was made and a 12 French intra-aortic balloon (Reliant Balloon Catheter to Expand Vascular Prosthesis, Medtronic, USA) was inserted via the left femoral artery and inflated proximal to the bleeding site in the aortic arch as pre-incision preparation for proximal control (see Figure 2). This procedure only required femoral sheath changes from 6 French to 12 French and the balloon insertion, which took a few minutes. Then an emergency sternotomy with a left "trap-door" extension was performed. On entering the chest, a large mediastinal hematoma was seen. There was no blood in the pleural or pericardial cavities. While trying to get proximal control, the hematoma ruptured and the patient expired almost immediately.

## DISCUSSION

Hillel Yaffe Medical Center is a regional level 2 trauma center, serving a catchment area of approximately 600,000 inhabitants. The trauma unit, led by a certified trauma surgeon, admits approximately 180 major trauma cases (ISS 16 and above) annually. Our medical center lacks cardiothoracic surgeons as well as related devices, such as a heart–lung machine.

Thoracic aortic injury is usually fatal, with most patients dying at the scene. The few who survive long enough to reach the hospital are kept alive by contained hematoma, which prevents massive uncontrollable bleeding to the pleural cavity with immediate death ensuing. According to the accepted treatment protocols, most trauma surgeons would consider ER thoracotomy as the initial step of dealing with a patient presenting in extremis or without vital signs in the setting of penetrating thoracic trauma such as in this case. The decision of the very experienced trauma surgeon, who managed this case, not to follow the strict rules and not to perform ER thoracotomy was because the thorax did not drain blood. This fact led to the assumption that the cause of the hemodynamic instability was secondary to mediastinal hematoma. In such a scenario, opening the chest would most probably lead to relief of the tamponade effect and secondary rupture of the contained hematoma. This will invariably lead to the patient's death. Even if this is not the case, putting a clamp on the descending aorta will increase the afterload and as such will increase the risk of secondary hematoma rupture, which once again would lead to the same conclusion.

The option of treating the aortic injury directly would not have been the smartest thing to do without proximal or distal control. In order to gain proximal and distal control, the best option would be a clamshell thoracotomy which will almost invariably lead to the rupture of the hematoma and the patient's death. It seems that if the patient is likely to survive, it would be with a minimal procedure that will lead to the best consequences, which in the current era is the endovascular option.

Inserting an occlusion balloon as a temporary measure seems to be the most logical thing to do in this scenario. This is a common practice undertaken by vascular surgeons dealing with ruptured abdominal aortic aneurysms. Therefore, if it works for them why should it not work in this case? Furthermore, there was no indication to inflate the balloon on this occasion as the patient was stable, and it was left there for safety if needed until the SG arrived. In the pre-endovascular era, the only therapeutic option was open surgical repair. Such cases require very high surgical competence, of extremely experienced cardiac and vascular surgeons, and in many cases, mainly when the proximal aorta is involved, the application of a heart–lung machine, and probably temporary or permanent cardiopulmonary bypass [4]. Worldwide, most patients with aortic injury reach hospitals with no such facilities. The evolution of endovascular surgery has made a dramatic change in patients' prognosis. Endovascular repair of thoracic aortic injuries is entirely different than opening the patient's chest in order to repair injuries. Endovascular treatment allows an experienced team of trauma and vascular surgeons in cooperation with an interventional radiologist to deal with injuries which were once only dealt with by cardiothoracic surgeons.

One should be familiar with hemodynamics and not fall into the trap of figures. A patient with a consistent systolic blood pressure of 70 mmHg is someone that the treating physician should try to keep as such and not attempt to normalize the figures. In our opinion, the chance of the patient's survival, while waiting for an SG to be delivered, are much higher in such a scenario of controlled hypotension than when the patient is given vasopressors and blood in order to see appealing figures on the screen. Some studies indicate that the patients who are most likely to benefit from hypotensive resuscitation are those in hemorrhagic shock caused by uncontrolled sources of bleeding [5,6]. Particularly, in the case of large vessel penetration injury, this strategy may prevent rupture of a contained hematoma which is the only thing keeping the patient alive. Using this strategy requires strict monitoring and assessment of end organ perfusion. However, Carrick et al. in a randomized study on 168 trauma patients treated by two resuscitation strategies, did not find significant differences in acute myocardial infarction and stroke rates, as well as in incidence of acute renal failure [7].

Temporary measures such as balloon occlusion of the tear, even using two balloons, proximally and distally to the tear, should be kept in mind as a bailout procedure when necessary. If the balloon can occlude the root of the LSCA (Zone "0" occlusion), this maneuver should be used for hemorrhage control. We may only assume why the balloon occlusion did not work in this particular case. There are several potential reasons. First, the balloon probably migrated downstream due to aortic pressure and as a result could not occlude the LSCA. Second, even if the balloon was properly located, the aortic arch is not a flexible area and, therefore, the chances of occlusion are reduced.

In our case, the resuscitative endovascular balloon occlusion of the aorta (REBOA) site confirmation during the operation was based on no inflow; just an enormous amount of backflow which led to the patient's death almost immediately after the hematoma was entered. This lesson was learned and we are currently using a double balloon technique, both proximal and distal to the injury site.

Our case demonstrated a new possibility in dealing with an aortic injury that was previously considered almost unsalvageable. There is no question that open surgery remains the treatment of choice. However, development of an endo vascular trauma management approach opens new treatment horizons, such as temporary balloon occlusion and the use of endovascular SG. The balloon occlusion, which we believe should be based on the use of two occlusion balloons, is the preliminary step of hemorrhage control until an SG is available for definitive treatment. Even for those scheduled for surgery, using balloons may be very helpful as a temporary control measure.

We believe that future research will confirm the "viability" of our pioneer approach.

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# A Case of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) Use in Penetrating Abdominal Aortic Injury

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We present the successful utilization of resuscitative endovascular balloon occlusion of the aorta (REBOA) in a case of penetrating abdominal aortic injury. This allowed for hemorrhagic control and exposure of a large aortic defect at the level of the celiac access, which otherwise would have been difficult to control in an open fashion. Although use in this specific injury pattern in the literature is limited, REBOA can be a life-saving maneuver.

**Keywords:** Trauma; Penetrating; REBOA; Aorta

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## INTRODUCTION

Hemorrhage remains a leading cause of death among victims of trauma, particularly when significant bleeding from non-compressible locations is instigated. Penetrating abdominal aortic injuries are a particularly devastating source of significant hemorrhage in this group, associated with an exceptionally high mortality. The expected mortality of those who survive transport to a medical facility after sustaining penetrating aortic injuries may range from 62% to over 75% [1,2].

Recent advances in balloon catheter design and endovascular techniques have facilitated expedient control of hemorrhage from non-compressible sources. The use of resuscitative endovascular balloon occlusion of the aorta (REBOA) has grown in popularity over the last decade for this purpose. Balloon catheters for REBOA can be positioned using either fluoroscopic guidance or external anatomic landmarks – making this hemorrhage control adjunct practical in the field, emergency room, or intraoperative settings. While more commonly

**Figure 1**  Preoperative computed tomographic angiography (CTA) imaging of the aortic transection. (**a**) Sagittal and (**b**) axial sections showing the injury just cranial to the celiac axis. Active extravasation is seen into the retroperitoneum (white arrows). (**c**) 3D reconstructed image of the aortic injury (white arrow).

employed following blunt trauma, REBOA also has potential life-saving uses after penetrating injury, including some penetrating aortic injuries.

We describe a case where intraoperative zone I REBOA (mid-descending thoracic aorta) was used to provide proximal hemorrhage control for surgical repair of a ballistic injury to the supraceliac aorta.

### *Case Description*

A previously healthy 24-year-old man with a self-inflicted gunshot wound to the anterior chest presented initially to a community hospital. He had a systolic blood pressure of 97 mmHg and heart rate of 130 beats per minute (bpm) on arrival. His hemoglobin level was 9.9 g/dL. During the initial resuscitation, he received two units of packed red blood cells (pRBCs), as well as tranexamic acid. Computed tomographic (CT) angiography demonstrated a large aortic pseudoaneurysm at the level of the celiac artery, with associated retroperitoneal hematoma. The superior mesenteric artery, renal arteries, and infrarenal aorta were patent (Figure 1).

He was transferred to our American College of Surgeons Level I verified trauma center, arriving approximately 3 hours after initial injury. He was conscious upon arrival at our facility, with a Glasgow coma score of 15. Blood pressure was 102/78 mmHg with a heart rate of 134 bpm. After rapid evaluation, he was expediently taken to the operating room by trauma and vascular surgeons. Femoral and pedal pulses were absent bilaterally. His lower extremities were cool, pale, and without sensation or volitional movements.

A median sternotomy and laparotomy were performed. Percutaneous right common femoral arterial access was simultaneously obtained using ultrasound guidance. He developed profound hypotension after opening the abdomen, and an intra-aortic balloon (ER-REBOA, Prytime Medical Devices, Boerne, TX) was placed and inflated in the mid-descending thoracic aorta (based on external landmarks). His blood pressure stabilized after this intervention.

A left medial visceral rotation was then performed, facilitating the division of the left crus of the diaphragm and exposure of the aorta. A large posterio-lateral aortic defect was evident at the level of the celiac artery with contusion of the proximal celiac artery. The ER-REBOA catheter was visualized within the lumen of the aorta. The aorta was mobilized and compressed manually allowing the balloon to be deflated and withdrawn. A cross-clamp was then placed and the aorta was transected proximal to the injury. A 16-mm Dacron interposition graft (HEMASHIELD, Maquet) was anastomosed proximally to the descending thoracic aorta with continuous running 3–0 polypropylene suture and interrupted 4–0 pledgeted reinforcing sutures. The clamp was moved distally onto the graft. The aorta was then divided distal to the celiac artery. By transecting the aorta obliquely, the superior mesenteric artery (SMA) origin was preserved. The graft was tailored in a similar fashion and sewn end-to-end, again with running 3–0 polypropylene suture, incorporating the SMA origin into the suture line. The clamps were then slowly removed to allow for gradual restoration of distal aortic flow. The combined aortic balloon occlusion and cross-clamp time was approximately 60 minutes.
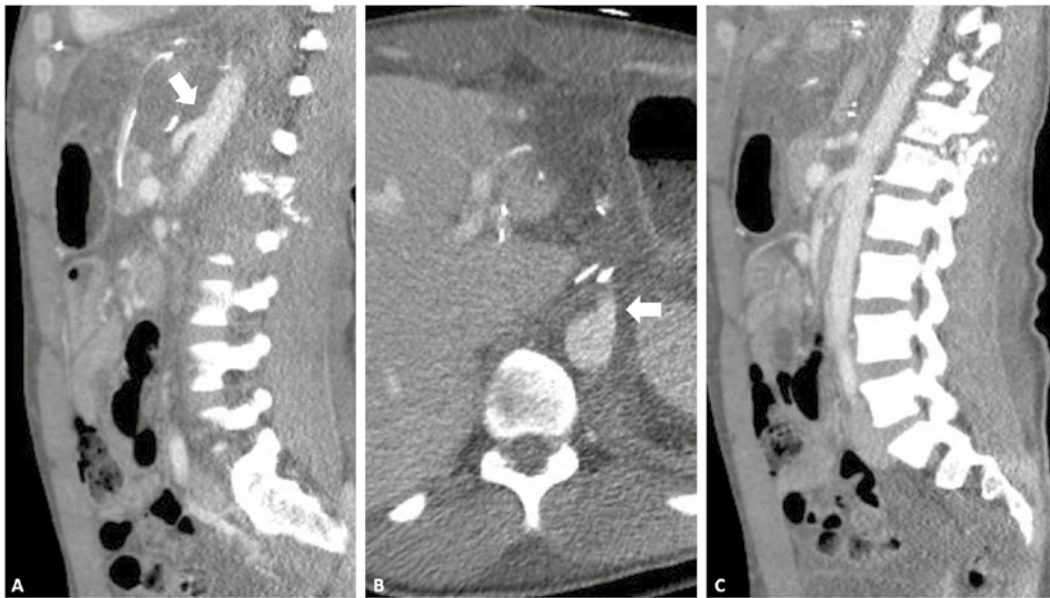
**Figure 2** Postoperative CTA imaging of the repaired aorta. The patent aorto-celiac bypass is seen in both sagittal (**a**) and axial (**b**) views (white arrows). (**c**) shows the intra-abdominal aorta in its entirety.

After the restoration of aortic continuity, an aorto-celiac bypass was constructed with a 6-mm polytetra-fluoroethylene graft (GoreTex, WL Gore & Associates) using partial aortic graft clamping. In addition, partial hepatectomy for a grade 5 liver laceration and bilateral tube thoracostomies were performed. Injured splenic and left gastric arterial branches were ligated. An excess of 50 units of blood products were transfused during the operation, including 2.2 L autologous recovered blood (Cell Saver®, Haemonetics), 36 units of pRBCs, 20 units of fresh frozen plasma, four units of platelets, and one unit of cryoprecipitate. Other identified injuries not addressed during his initial operation included T12/L1 vertebral fractures and a left perinephric hematoma.

After aortic repair and management of intra-abdominal injuries, he was noted to have persistent absence of pedal pulses and no Doppler signals at the level of the ankles, but duplex ultrasound demonstrated patent arterial flow bilaterally to the level of the popliteal arteries. Given his profound peripheral vasoconstriction associated with intraoperative hemorrhagic shock and ongoing hypothermia and coagulopathy, the decision was made to continue resuscitation and warming and observe for improvement.

Postoperative monitoring during resuscitation in the intensive care unit (ICU) revealed lower extremity mottling with early right ankle rigor. The femoral sheath utilized for REBOA access had been left in place due to coagulopathy. It was noted that a transduced arterial waveform could no longer be transduced from its side port connection. A repeat duplex ultrasound scan in the ICU demonstrated thrombosis of the right external iliac artery. He was then returned immediately to the operating room. Thrombectomy was performed through a right common femoral arteriotomy, retrieving extensive thrombus from the proximal and distal vessels. A second incision below the knee was performed for tibial artery thrombectomy through a popliteal arteriotomy. A two-incision, four-compartment fasciotomy was performed, with findings of non-viable soleus muscle.

Surgical exploration of the contralateral (left) popliteal artery was also performed. There was minimal thrombus retrieved from the popliteal and tibial arteries. Doppler signals were obtained at the left ankle level after thrombectomy, and posterior compartment musculature exposed through the incision appeared healthy. No fasciotomy was performed on the left side.

Anticoagulation was initiated postoperatively, however, arterial signals did not return in the distal right lower extremity, despite arterial patency to the level of the popliteal artery. A staged right above the knee amputation was performed two weeks later, after clear demarcation of the level of viability.

The patient spent 10 days in the ICU. His course was complicated by acute renal failure requiring temporary hemodialysis. He was diagnosed with an incomplete T11 spinal cord injury with minimal sensation below the injury level. He underwent two weeks of inpatient rehabilitation and was discharged home mobile in a wheelchair and able to perform minimal assist transfers. Postoperative CT imaging at 2 weeks showed a patent aortic reconstruction without dissection or aneurysmal dilatation (Figure 2).

## DISCUSSION

This case describes a patient who suffered a self-inflicted penetrating aortic injury from a gunshot wound. Aortic

hemorrhage was initially contained due to tamponade by the closed abdomen, but upon surgical exploration active hemorrhage ensued. REBOA served as a life-saving adjunct for the rapid control and hemodynamic support of this uncontrolled hemorrhage in an anatomically unfriendly situation.

Recent clinical series have demonstrated the potential utility of REBOA for control of hemorrhage at non-compressible sites. Still, there remain practical concerns about hazards with REBOA use. This case illustrates one of these hazards – that the inserted catheter may traverse a segment of known or unrecognized aortic disruption. This risks an extra-luminal passage of the balloon catheter, which would render balloon occlusion ineffective for vascular control, as well as have the potential to extend the aortic injury or even cause *de novo* injury to surrounding structures. In this case, the balloon was correctly positioned without difficulty or technical complication.

There is a paucity of literature on REBOA use in penetrating abdominal aortic injury. Gupta et al. reported their experience with intra-aortic balloon occlusion in patients after penetrating missile injuries to the abdomen [3]. This early series offers examples of several cases where REBOA was successfully utilized in penetrating aortic trauma. Eleven patients sustained injuries to the abdominal aorta. Of those, two arrived with pulseless electrical activity and were declared dead after initial attempts at surgical resuscitation. Three patients arrived in profound shock (systolic blood pressure less than 60 mmHg) and underwent balloon occlusion pre-operatively. Two of those three survived to discharge and the third died on postoperative day 3 due to coagulopathy and multiple system organ failure. Of note, one of the two survivors failed balloon placement due to the catheter exiting the aorta at the site of injury, and underwent thoracotomy with aortic cross clamping instead. The remaining six patients underwent balloon placement intra-operatively for hypotension unresponsive to resuscitation. Three of those six survived to discharge. In one case the balloon did exit through the injury during the celiotomy but was able to be successfully redirected. One patient died intra-operatively, while the remaining two died on postoperative days 39 and 92.

Our case was complicated by lower extremity ischemia and the need for amputation. Factors contributing to the severe acute limb ischemia included the severity of shock, temporary aortic occlusion with REBOA use and subsequent clamping, and continued presence of a 7-French sheath in the common femoral artery in the hours after operation. The risk of this complication may have been increased by a postoperative hypercoagulable state, due to physiologic responses to injury and resuscitation with plasma, cryoprecipitate, platelet transfusions, and tranexamic acid administration.

There are other cautionary tales regarding common femoral access in the trauma setting. Saito et al. retrospectively reviewed their REBOA use for trauma in Japan from 2007 to 2013 [4]. Twenty-four blunt trauma patients underwent balloon occlusion for hemodynamic instability with hemoperitoneum or pelvic ring fractures or both. The balloon was placed through a 10-French sheath after either ultrasound guidance or blind percutaneous arterial access. Three patients (12.5%) required amputation on the side of vascular access. In one case, access followed multiple unsuccessful attempts, and angiography revealed a concomitant vascular injury that, although repaired, contributed to the need for amputation two days later. The other two patients each sustained injury to the amputated side: one had a femur fracture with extensive soft tissue damage, one had a pelvic fracture requiring embolization for bleeding and open common femoral access through the injured groin.

Recent retrospective studies suggest that limb ischemia after REBOA is a rare event with appropriate training and careful access. The Aortic Occlusion for Resuscitation in Trauma and Acute care surgery (AORTA) registry reported their initial experience with 46 patients in which REBOA was utilized across eight trauma centers [5]. Over 50% of the access sites in this series utilized a 12-French or larger sheath. Percutaneous femoral artery access was guided by palpation or external landmarks alone in 28%; ultrasound guidance was used in 11%; fluoroscopy was used in 2%. In the majority of cases, however, surgical exposure of the femoral artery was used for access. Access site complications included one pseudoaneurysm and two cases of distal embolization, but no patients required amputation. It is important to note that all providers who placed the devices in these 46 patients were either board certified vascular surgeons or trauma/acute care surgeons who had been trained in REBOA use with a standardized curriculum and practical instruction. Another recent retrospective review also showed that REBOA can be implemented safely. This paper looked at 48 patients over a 5-year period where both 7-French and 14-French systems were utilized, and although the 14-French sheaths required arteriotomy repair after removal, no amputations were seen [6]. While complications do appear to be minimized through the use of a smaller sheath size, our case highlights that they still can occur, especially when compounded by an extended duration of use.

To minimize the risk for access site and limb ischemia complications of REBOA, safe arterial access practices should be followed. This includes the use of ultrasound-guided access whenever feasible, use of the smallest sized sheath needed to accommodate the balloon catheter, and early sheath removal once the balloon is no longer needed. One way to implement this is to remove the sheath prior to leaving the operating room after repair. One of the most common complications of early sheath removal is likely to be pseudoaneurysm, which by comparison may be less morbid than an ischemic limb from arterial thrombosis or embolism. Direct catheter arteriography or duplex ultrasound scanning should be used if there is any concern for arterial thrombosis or embolization. As a matter of

practice, adequate training is also likely to mitigate the risk for complications of REBOA use, including instruction provided by the American College of Surgeons Basic Endovascular Skills for Trauma (BEST) course [7].

## CONCLUSION

REBOA can provide expedient and effective control of hemorrhage from non-compressible sources. In the vascular surgery realm, REBOA has already demonstrated the ability to dramatically decrease mortality in ruptured aneurysm management [8] compared to traditional options for proximal control approaches via either thoracotomy for aortic clamping or laparotomy and supraceliac exposure. Some traumatic aortic injuries may be analogous, presenting a similar challenging source of non-compressible hemorrhage. Trauma surgeons should be trained in the use of REBOA and should have this option in their armamentarium for surgical management of aortic injury.

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≫ *Case Report* ≪

# Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) as an Adjunct to Damage Control Surgery for Combat Trauma: A Case Report of the First REBOA Placed in Afghanistan

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This case report details a trauma case – transpelvic gun shot wound with hemorrhagic shock- treated with REBOA as an adjunct to resuscitation. This is the first reported case of REBOA in Afghanistan at the Role 3 Multinational Medical Unit in Southern Afghanistan.

**Keywords:** *REBOA; Balloon Occlusion; Combat; Austere*

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## INTRODUCTION

Balloon occlusion of the aorta for hemorrhage control in the combat setting has been well described, its first use was during the Korean War [1]. Recently, balloon control of aortic bleeding saw a resurgence in the vascular community for the treatment of ruptured abdominal aortic aneurysm (AAA) [2–5]. Landmark studies in 2011 [6,7], defined as 'resuscitative endovascular balloon occlusion of the aorta' and coining the acronym 'REBOA,' paved the way for clinical trials that compared balloon versus open aortic occlusion for traumatic hemorrhage [8]. New devices enabling fluoroscopy and wire-free placement, as well as continuous arterial monitoring (Figure 1) [9], allowed care to move further forward in the military environment. In line with military applications, clinical practice guidelines for deployed providers supported the use of REBOA as an alternative to thoracotomy for aortic occlusion [10].

With general enthusiasm and promising preclinical and clinical data for REBOA use in non-compressible torso hemorrhage (NCTH), reports of in-theater usage began to emerge. The first four cases reporting successful placement and outcomes in a far forward setting were released in 2017 [11]. We report the first use of REBOA
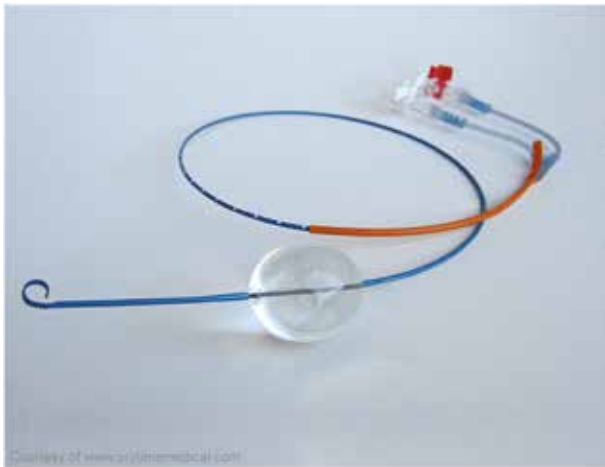
**Figure 1** Fluoroscopy-free ER-REBOA device (Prytime Medical Inc., Boerne, TX, USA).

during combat operations in Afghanistan, used as a bridge to definitive hemorrhage control for an abdominopelvic gunshot wound with exsanguinating hemorrhage.

## Case Report

This patient was an approximately 18-year-old casualty injured during combat operations in southern Afghanistan. He received a gunshot wound from a high velocity round, with a periumbilical entry wound, trans-abdominopelvic trajectory and exit out the inferior left sacroiliac joint. Field care included placement of an abdominal dressing and immediate transfer to a forward surgical team. On arrival, he was confused with a blood pressure of 76/50, a heart rate of 120, and with evisceration of his abdominal contents through his abdominal wall. He was taken emergently to the operating room (OR) where he underwent a damage control laparotomy. Massive pelvic bleeding was encountered, primarily reported as low rectal and presacral plexus bleeding, temporarily controlled with packing. A temporary abdominal closure was performed with an Ioban occlusive dressing. The patient was then transferred to our facility for further surgical and critical care.

The patient arrived with a blood pressure of 147/102, a heart rate of 115, and was taken directly to the OR. Upon transfer from the gurney to the OR table, 18 minutes after arrival, the patient was noted to have a systolic blood pressure of 62/38. Anesthesia was being prepared in the ventilator, and instruments were still being opened at this point, so the decision to proceed with balloon occlusion over open vascular control was made. Simultaneously, while one surgeon was preparing the abdomen for laparotomy, a second surgeon rapidly performed a cut down over the right groin. The patient was quite thin and the common femoral artery was isolated in approximately one minute. A 21-gage micropuncture needle was used to access the vessel, and a 5 Fr
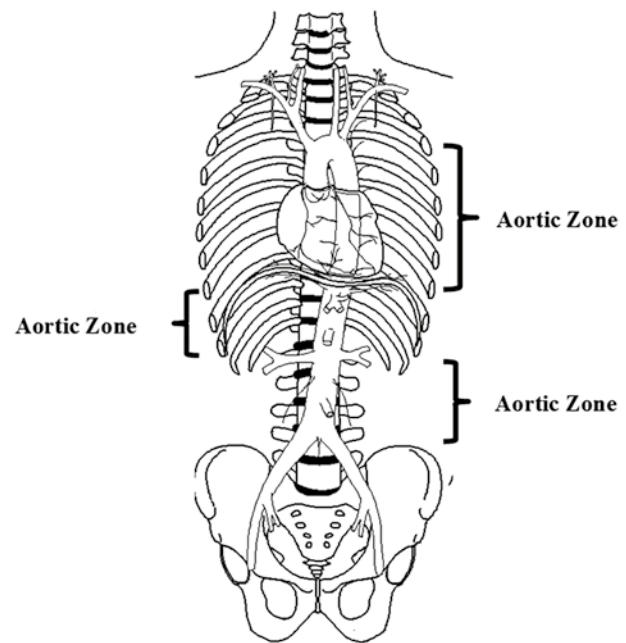


**Figure 2** Zones of aortic occlusion recommended by clinical practice guidelines.

Zone 1 is above the diaphragm, Zone 2 between the renal arteries and diaphragm, and Zone 3 is below the renal arteries in the abdominal aorta, above the iliac bifurcation.

introducer sheath was placed over a wire. This was immediately upsized to a 10 Fr sheath (no 7 Fr sheath was available). An ER-REBOA catheter was selected, measured for Zone 1 occlusion (45 cm from xiphoid to the tip of the sheath in this case), and placed through the sheath (Figures 2 and 3). No attempt was made to obtain radiographic confirmation of position. Unable to get an arterial tracing through the arterial port, the arterial line tubing was moved from the arterial port on the ER-REBOA to the side port of the 10 Fr sheath, and the ER-REBOA balloon was inflated until the arterial tracing was lost, indicating proximal aortic occlusion. 10cc of saline was required to achieve occlusion. Upper extremity arterial pressure reading recovered to a systolic blood pressure of 110 with balloon occlusion.

With hemodynamic stability achieved, the patient was re-explored. Approximately 1000 cc of blood was evacuated from the pelvis. No arterial bleeding was encountered, only a large non-expanding large retroperitoneal hematoma and brisk venous pooling. The left and right common iliac arteries were easily identified and exposed at the iliac bifurcation and encircled for inflow control. Alternatively, adjustment of the balloon to a Zone 3 position would have been possible, but after rapid open vascular control was obtained the need for this maneuver was obviated. At this point, the ER-REBOA balloon was deflated and the patient remained hemodynamically stable (total occlusion time was 10 minutes). A left iliac vein laceration was identified and repaired, and pelvic venous bleeding was controlled with additional
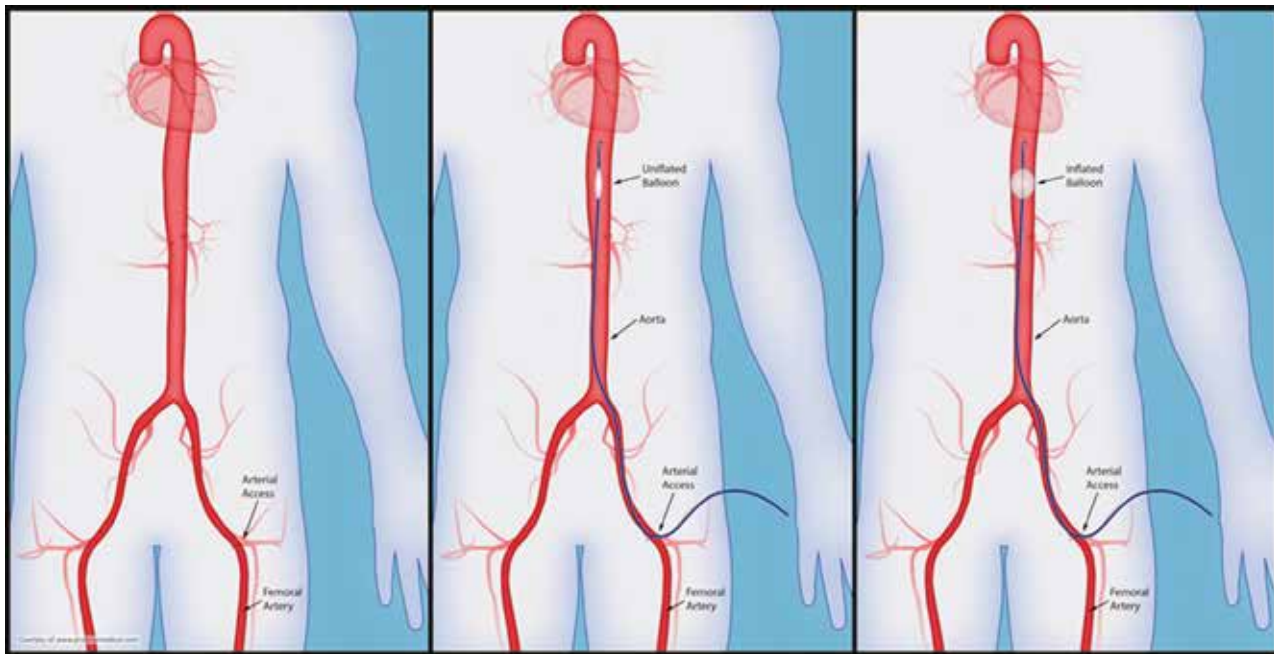
**Figure 3** Zone 1 balloon occlusion of the aorta, above the diaphragm via femoral artery access (Prytime Medical Inc., Boerne, TX, USA).

packing. Additionally, a large rectal injury was excluded, and several enterotomies were stapled. A temporary abdominal dressing was applied.

A completion angiogram of the right iliofemoral vessels was performed through the indwelling sheath to evaluate for distal embolism which was negative. However, the sheath was noted to be near occlusive, so it was removed and the arteriotomy closed. The patient was then taken to the ICU for further resuscitation.

Over the first 24 hours after arrival at the Role 3, the patient received an additional 22 units of packed red blood cells (pRBCs), 12 units of fresh frozen plasma (FFP), 12 units of platelets, and four units of cryoprecipitate. His lowest pH was recorded at 7.11, lowest base deficit −10, highest international normalized ratio was 2.4 mg/dL, and highest lactate 8.4 mg/dL. All physiologic and lab values normalized over the patients subsequent intensive care. He returned to the OR multiple times for restoration of intestinal continuity, diverting colostomy, abdominal and sacral irrigation and debridement, abdominal closure, and advancement flaps to cover his open sacral fracture. The patient was ambulatory (with a partial left sacral nerve palsy) and tolerating oral intake, with normal cognition upon transfer to a local national hospital.

## DISCUSSION

As has been well defined by the current conflicts in Iraq and Afghanistan, hemorrhage, and particularly NCTH, are the leading causes of preventable death on the battlefield [12–15]. Aortic occlusion can be required to control exsanguinating hemorrhage from these injuries and preserve cardiac and cerebral blood flow. Besides cardiac massage, the above goals can be achieved via balloon occlusion. Despite conclusive prospective data, many trauma centers have adopted REBOA for a multitude of indications [16–18].

With the hallmark injury pattern of modern conflicts being complex lower extremity blast injuries, a combined blunt and penetrating mechanism leading to NCTH, the application of REBOA in the military setting appears to be logical. REBOA has been used in the prehospital civilian setting [19], in the deployed setting [11], and it has been demonstrated that experienced medics are capable of fast and accurate REBOA placement [20], allowing the technology to move closer to the point of injury.

We describe the first case of REBOA in the Afghanistan theater. A basic endovascular capability 14 Fr sheaths, stiff wires and a 30 mm CODA balloon- were available for use. We prioritized upgrading to the fluoroscopy-free ER-REBOA system and trained available surgeons and emergency providers in the indications and steps for REBOA, reinforcing the Joint Theater Trauma System relevant to Clinical Practice Guideline on REBOA for hemorrhagic shock with all providers.

The patient, in this case, would be considered a 'transient responder,' displaying hemodynamic lability even after initial abdominal packing and receiving a massive transfusion. The addition of coagulopathy and acidosis to ongoing hemorrhage placed the patient at high risk for cardiovascular collapse. The placement of the REBOA balloon allowed near immediate proximal control of bleeding and improved the patient's hemodynamics. It took approximately 2–3 minutes to obtain occlusion,

verified by loss of arterial pulsatility on the arterial line. Ultrasound is readily available in the Role 3 setting, but was not routinely turned-on in the OR, leading to the choice for femoral cutdown. The unavailability of a 7 Fr sheath (on order and pending delivery at the time) forced an upsizing to a 10 Fr size. The small diameter of the ER-REBOA balloon catheter makes the arterial port less reliable when not well flushed, as was the case here. The alternative of using the sheath side port for an arterial tracing, and subsequently evaluating for LOSS of an arterial tracing (and improvement in proximal blood pressure), worked well in this case to confirm occlusion.

Though bleeding was not arterial in this case, we feel that aortic occlusion did allow for controlled entry into the abdomen, safe dissection, and control of the iliac vessels, and provided time for anesthesia to 'catch up' with resuscitation. Control of venous bleeding with REBOA has been demonstrated previously [21]. After operative control of the iliac vessels, we were able to deflate the balloon without further hemodynamic compromise. Total balloon time was estimated to be 10 minutes, well within the times generally considered safe [16].

We elected to perform a completion angiogram of the access vessel. The small caliber of the patient's vessels made the 10 Fr catheter nearly occlusive, and we elected to remove the sheath. The site was repaired operatively, which we recommend for a 10 Fr arteriotomy in the setting of coagulopathy. In retrospect, the use of an 8.5 Fr Cordis introducer catheter (although not optimal is nearly universally available) may have allowed for adequate access and prevented the need for open repair. Despite reduced access compilations with newer devices [22], multiple experts (personal communication with Megan Brenner MD and Joseph DuBose MD. March 2017) recommend routine angiography of the access site prior to removal of the sheath, and we agree. Despite the smaller catheter size of the ER-REBOA, access complications are still possible, and if not completely preventable can at least be mitigated with careful attention to closure.

## CONCLUSION

Balloon aortic occlusion is a technique with great potential for treating or temporizing NCTH, perhaps especially so, in the military setting. Increasing exposure to the technique, supported by preclinical and clinical data, will further define the ideal role for balloon occlusion. This case represents the first described REBOA in Afghanistan, demonstrates its usefulness in a combat casualty, and further supports increased consideration for use of REBOA in the forward setting.

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# COMMENTARY on:

## Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) as an Adjunct to Damage Control Surgery for Combat Trauma: A Case Report of the First REBOA Placed in Afghanistan, by Jacob Glaser, et al.

This dramatic description of the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) to save the life of a young man who most certainly would have died from a high velocity gunshot wound to the abdomen and pelvis underscores the game-changing value of this technique in treating non-compressible torso hemorrhage (NCTH) on the battlefield.

Although the use of endovascular balloon aortic control for hemorrhage is not new, recent advances in equipment (balloons) and techniques have enabled REBOA to be used dependably without wire guidance or fluoroscopy. This is truly a landmark achievement which will result in the saving of many lives that would otherwise be lost in both battlefield and civilian settings. It will have particular value in younger individuals whose arteries are not tortuous and in whom external landmarks can guide accurate balloon positioning.

Although the experience in the successful use of REBOA is just beginning, cases like this prove the unique value of the technique. Since life-threatening uncontrollable hemorrhage from traumatic injuries will continue to occur in increasing numbers in our supposedly civilized world, this technique will gain greater acceptance and be used increasingly to save lives that would otherwise be lost. The horrible trans-pelvic gunshot injury sustained in the attempted assassination of one of our leading Congressmen in the United States, Steve Scalesi, is only one striking example.

REBOA is a most substantial advance in the treatment of traumatic injuries, and it will quickly gain increasing recognition as a major development in trauma surgery.

**Prof. Frank J Veith,** Division of Vascular Surgery, New York University-Langone Medical Center, New York, NY; Division of Vascular Surgery, Cleveland Clinic, Cleveland, Ohio.
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≽ *Case Report* ≼

# Vascular Damage Control Approach Using Direct Deployment of Self-Expanding PTFE Stent Graft as an Alternative to Intra-Arterial Shunt

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The use of intravascular shunts for damage control purposes has been well described both in the battlefield and in the civilian environment. In this report, we present a case in which a self-expanding polytetrafluoroethylene (PTFE) stent graft was used as an alternative to traditional damage control intra-arterial shunt to successfully control bleeding and reestablish arterial flow in the aortoiliac segment. A 50-year-old male presented in extremis after sustaining multiple abdominal gunshot wounds. After resuscitative thoracotomy, laparotomy demonstrated transection of the right common iliac artery at its origin, destructive pancreatoduodenal injury with associated superior mesenteric vein injury, and multiple small bowel and colonic injuries. Because of the location of the injury at the aortoiliac junction, temporary intra-arterial shunt placement was not possible as no residual iliac cuff was available to secure a tie around the shunt proximally. A self-expanding PTFE stent graft was introduced and directed across the injury under direct visualization and deployed to bridge the defect from the aortic bifurcation to the right common iliac artery. After deployment, the stent was hemostatic and pulses were palpable in bilateral iliac and common femoral arteries. The associated intra-abdominal injuries were addressed and the abdomen packed and temporarily closed. Total operative time was 65 minutes. After a 4-hour period of resuscitation in the ICU, the patient became hemodynamically unstable and was re-explored. Diffuse bleeding was identified in all raw surfaces of the retroperitoneum, abdominal wall and chest wall. The area of the stent was hemostatic. The right colon was massively dilated from intraluminal bleeding, so a right hemicolectomy was performed. Despite resuscitative efforts and more than 100 units of blood products the patient expired. In this report, we described the use of direct endovascular repair using a self-expanding PTFE stent graft in the aortoiliac location as an alternative to temporary intra-arterial shunt placement. This technique allowed quick hemostasis and reestablishment of arterial flow in an area in which traditional intra-arterial shunts would not be feasible.

**Keywords:** *Abdominal Vascular Injury; Gunshot Wound; Endovascular; Stent; Damage Control; Intravascular Shunt*

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## INTRODUCTION

Aortoiliac injuries are commonly associated with massive blood loss and high mortality rates ranging from 43% to 82% [1–3]. For patients who reach the hospital alive, the presence of shock, acidosis, and associated injuries pose significant challenges to the resuscitation efforts and definitive management of these complex injuries [1].

The role of damage control surgery is well established for patients in whom definitive repair cannot be achieved at the time of presentation due to precarious physiologic condition and/or overwhelming injury burden.

In addition to hemorrhage and contamination control, maintenance of arterial flow is important to preserve limb and life. Although ligation is the most straightforward damage control strategy for vascular injuries, the interruption of arterial flow may result in limb loss or death. For critically ill patients, however, definitive vascular reconstruction may not be possible at the initial operation, particularly if a significant burden of associated injuries is present. In those cases, time-consuming reconstructions may aggravate the commonly present triad of acidosis, hypothermia, and coagulopathy, resulting in further morbidity or death. The use of intravascular shunts for damage control purposes has been well described both in the battlefield and in the civilian environment [4–7]. These intravascular shunts can temporarily reestablish blood flow until definitive vascular repair is possible.

In this report, we present a case in which a self-expanding polytetrafluoroethylene (PTFE) stent graft was used as an alternative to traditional damage control intra-arterial shunt to successfully control bleeding and reestablish arterial flow in the aortoiliac segment.

## CASE DESCRIPTION

A 50-year-old male presented to the emergency room after sustaining multiple abdominal gunshot wounds. Pre-hospital time was 18 minutes. Upon arrival, the patient was in extremis without palpable pulses. After cardiac motion was identified on ultrasound, a left anterolateral resuscitative thoracotomy was performed with cross-clamping of the descending thoracic aorta and internal cardiac massage concurrently with venous access establishment and massive transfusion protocol initiation. Return of spontaneous cardiac activity was identified and the patient was taken emergently to the operating room.

The abdominal cavity was entered through a midline laparotomy, and massive hemoperitoneum was encountered and evacuated. Active bleeding from the area of the aortic bifurcation was identified. The bleeding was controlled with direct manual pressure and the retroperitoneum was exposed with a Cattell-Braasch maneuver. Complete transection of the right common iliac artery at its origin from the aorta was identified. Vascular clamps were applied to the infrarenal aorta and to the left common iliac artery, controlling the bleeding and allowing removal of the thoracic aortic cross-clamp and quick assessment of the additional intra-abdominal injuries, which were extensive including a complex duodenopancreatic injury and multiple small bowel and colonic injuries.

While ongoing balanced ratio blood product resuscitation was being performed, the need for damage control approach was determined. The area of the duodenopancreatic complex was packed to control active bleeding and attention was redirected to the aortoiliac injury.

Because of the location of the injury at the aortoiliac junction, temporary intra-arterial shunt placement would not be possible as no residual iliac cuff was available to secure a tie around the shunt proximally. The decision was made to proceed with a self-expanding PTFE stent graft to bridge the defect from the aortic bifurcation to the right common iliac artery.

First, a Fogarty thromboembolectomy catheter was passed distally into the right common iliac artery and a small amount of thrombus retrieved resulting in brisk back bleeding from the right common iliac artery. Heparinized saline solution was locally injected into the right common iliac artery and a vascular clamp applied. Systemic heparinization was not performed. Using Seldinger technique the infrarenal aorta was directly accessed with a micropuncture access kit in an antegrade fashion and a 5 Fr micro sheath introduced over the wire. A 0.035" J wire was advanced into the aorta and manually directed through the injury and into the right common iliac artery under direct visualization. The 5 Fr sheath was exchanged over the wire for a 12 Fr sheath and a 13 mm × 100 mm self-expanding PTFE stent graft (Viabahn Endoprosthesis, WL Gore & Associates, Flagstaff, AZ) was introduced and directed across the injury under direct visualization. For stent sizing, we decided to use a diameter to achieve approximately 20–30% common iliac oversizing and length to bridge the gap between the aorta and the right common iliac artery without covering the right internal iliac artery. Stent position was confirmed with manual palpation and direct visualization. The stent was successfully deployed under direct visualization (Figure 1) and the deployment system removed through the sheath. Vascular clamps were then released and flow reestablished. Palpable pulses were confirmed in bilateral iliac arteries and bilateral common femoral arteries. No significant bleeding was identified at the proximal and distal stent attachment sites. To avoid migration of the stent at the proximal attachment site, the stent was secured to the arterial wall with three stitches using 6-0 polypropylene suture. The wire and sheath were removed from the aorta and hemostasis at the access site achieved with a 5-0 polypropylene stitch.

After the aortoiliac injury had been controlled and flow reestablished to the right lower extremity, the remainder of the intra-abdominal injuries were fully addressed. Complete assessment of the duodenopancreatic region revealed a destructive pancreatic head injury with associated superior mesenteric vein (SMV) injury and devascularization of the second and third portions of the duodenum. The SMV was primarily repaired with a running suture of 6-0 polypropylene and a duodenopancreatectomy was performed and left in discontinuity. Multiple small bowel resections and a sigmoidectomy were then performed using GIA staplers and left in discontinuity. The retroperitoneum was packed and a negative pressure dressing was placed over both the midline
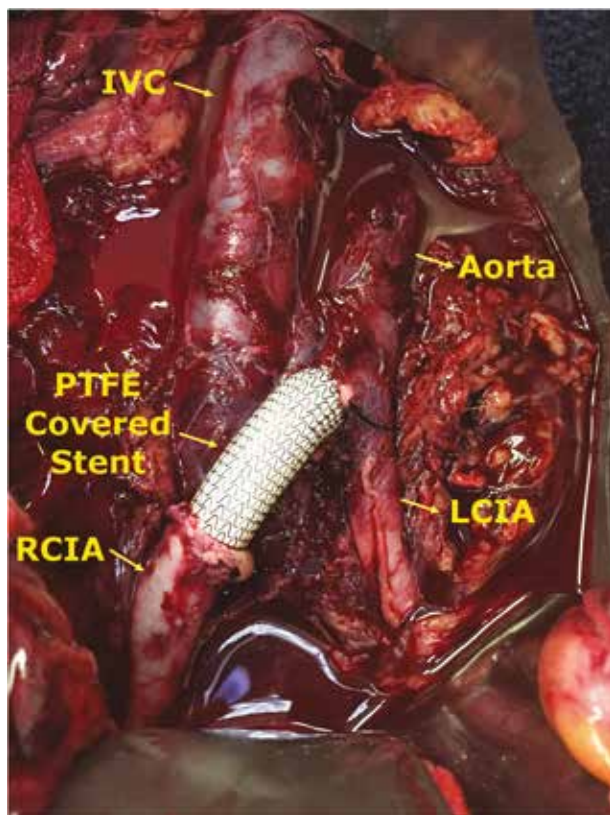
**Figure 1.** Self-expanding PTFE stent graft successfully deployed, bridging the gap between the aorta and the right common iliac artery and achieving adequate hemostasis. IVC, inferior cena cava; RCIA, right common iliac artery; LCIA, left common iliac artery.



**Figure 2.** Blood products being used as part of the massive transfusion protocol.

laparotomy and left thoracotomy sites for temporary closure. Total operative time was 65 minutes.

The patient was taken to the surgical intensive care unit (ICU) for ongoing resuscitation, with the intent of returning him to the operating room as soon as the coagulopathy, acidosis, and hypothermia were corrected. In the ICU, he continued to require multiple blood products for hemodynamic instability and diffuse bleeding. Although this bleeding and his acidosis had improved initially, over the next four hours his condition became unstable again, thus warranting immediate re-exploration. Upon return to the operating room, diffuse bleeding was identified in all raw surfaces of the retroperitoneum, abdominal wall and chest wall. There was no evidence of bleeding in the area of the stent. The right colon was found to be massively dilated from intraluminal bleeding. A right hemicolectomy was performed. The patient briefly lost pulses but regained them with initiation of advanced cardiovascular life support protocol and internal cardiac massage. However, his diffuse coagulopathy resulted in continuous diffuse bleeding from all raw surfaces. While packing was being performed to control the diffuse bleeding another episode of asystole occurred. Despite resuscitative efforts

and more than 100 units of blood products at this point (see Figure 2), the patient expired.

## DISCUSSION

Although the use of intravascular shunts can be traced back to the early part of the previous century [6] the demonstration of its safety as a temporary bridge for definitive vascular repair did not occur until they began to be used as part of a damage control strategy in the battlefields of Iraq and Afghanistan. Since then, safe and successful use of intravascular shunts as part of a damage control strategy has been demonstrated in the military as well as in the civilian setting [4–7].

In this report, we described the use of direct endovascular repair using a self-expanding PTFE stent graft in the aortoiliac location as an alternative to temporary intra-arterial shunt placement. This technique allowed quick hemostasis and reestablishment of arterial flow in an area in which traditional intra-arterial shunts would not be feasible. Although this patient did not survive due to the extreme severity of his injuries and physiologic derangement, the use of the aforementioned technique is noteworthy as it allowed quick and effective
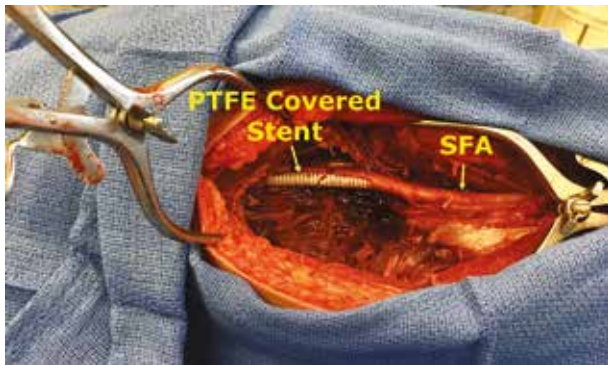
**Figure 3.** Self-expanding PTFE stent graft directly deployed in the femoropopliteal segment. SFA, superficial femoral artery.

control of his major arterial injury, respecting damage control principles.

A similar approach has been described for extremity vascular trauma by Davidson et al., who elegantly described their proposed technique of direct site deployment of self-expanding stent grafts as an alternative to shunting [8]. Their proposed technique involves removing the endoprosthesis from the deployment system and inserting the stent directly into the injured vessel and deploying the device under direct visualization. In our case, wire advancement across the injured segment under direct visualization using antegrade aortic wire access resulted in a safe platform for stent positioning and deployment. This allowed quick stent deployment without the need for fluoroscopy and avoided the back-table preparation of the device described by Davidson et al. In fact, we have recently used the technique presented in this case report in the femoropopliteal segment with success (Figure 3).

Potential limitations of this technique include the possibility of inaccurate stent deployment with coverage of the right internal iliac artery if deployed too low and jailing of the left common iliac artery if deployed too high, extending far into the aorta. Unilateral coverage of the internal iliac artery in this scenario would carry minimal consequence. Occlusion of the left common iliac artery, on the other hand, would not be acceptable and stent removal would be required.

Had this patient survived to definitive repair, a decision would have to be made regarding management of the stent graft. Because of the limited proximal seal zone, the possibility of distal migration would be high. After adequate resuscitation, the options for definitive repair would include removal of the stent graft and in-situ repair with a synthetic graft or an extra-anatomical bypass followed by stent removal, primary closure of the aorta and ligation of the right common iliac artery. Due to the extensive contamination and the significant risk of pancreatic leak after Whipple reconstruction, our preference would be to create a femoro-femoral bypass with an 8 mm PTFE graft followed by stent removal, primary

closure of the aorta and ligation of the right common iliac artery.

Mortality for patients requiring damage control intra-arterial shunts for truncal vascular injuries is higher (50%) compared to those patients in which the shunt is used in peripheral vessels (10%) [7]. The presence of complex associated intracavitary injuries such as those exemplified in the reported case is likely the reason for that higher mortality [1].

A significant proportion of patients with penetrating abdominal vascular injuries die prior to reaching the hospital. Ball et al. demonstrated that a decrease in pre-hospital time was associated with both an increase in the incidence and mortality of abdominal vascular injuries [9]. In the case presented here, a resuscitative thoracotomy was performed for a patient with abdominal gunshot wounds who was pulseless on arrival to the hospital after a short pre-hospital time. Because the survival rate for patients undergoing resuscitative thoracotomy for penetrating abdominal vascular injury is 2% [3] critics of resuscitative thoracotomy indication may view this intervention as futile in this setting. At our institution, however, we have a liberal indication policy for resuscitative thoracotomy, but use the presence of cardiac activity on ultrasound to select those patients who may have a chance of survival [10].

The use of endovascular devices and techniques for the management of traumatic vascular injuries is one of the most exciting developments in the field of trauma care. The endovascular approach has become the primary treatment modality for blunt thoracic aortic injuries [11–14] and there is growing interest in the application of endovascular strategies in other arterial anatomic locations, particularly those areas of challenging access [15–19]. As the field of endovascular surgery continues to expand, advances in equipment and technique follow, and surgeons experience develops, opportunities for creative application of these techniques, devices, and strategies will become commonplace in the care of the injured patient.

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Trauma Innovation, 11-15 September 2017
London, UK - www.traumainnovation.com/

AAST, 13-16 September 2017
Baltimore, USA - www.aast.org/Meetings/AnnualMeeting/Default.aspx

ESVS annual meeting, 19-22 September 2017
Lyon, France - www.esvs.org/lyon-2017

CIRSE, 16-20 September 2017
Copenhagen, Denmark - www.cirse.org/?pid=1327

Endovascology, 12-15 October 2017
Shanghai, China - http://endovascology.org/webcn/

Veith 44 th annual symposium, 14-17 November 2017
NYC, USA - http://www.veithsymposium.org/index.php

KARPET (Korean Association for Research, Procedures and Education on Trauma), 16 November 2017
Incheon, Korea - http://karpet.or.kr/conference/symposium/03.html

DIRECT Diagnostic Imaging workshop,18-19 November 2017
Koriyama, Japan - http://direct.kenkyuukai.jp/about/?l=2

DIRECT Diagnostic Imaging workshop, 20-21 January 2018
Koriyama, Japan - http://direct.kenkyuukai.jp/about/?l=2

LINC Leipzig Interventional course, January 30th-February 2nd 2018
Leipzig, Germany - http://www.leipzig-interventional- course.com/

DIRECT REBOA workshop, Februay 23 2018,
Chiba, Japan - http://direct.kenkyuukai.jp/about/?l=2

EVTM workshops 2018 (dates not available yet)
Örebro, Sweden - www.jevtm.com/workshop

BEST REBOA courses (USA)
www.facs.org/quality-programs/trauma/education/best/courses

# II EVTM SYMPOSIUM

## 7-9 June 2018
### Örebro, Sweden

Endovascular hybrid Trauma and bleeding Management

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Endovasucular and hybrid techinuqes for bleeding control & hemodynamic control
Vascular injuries EVTM treatment- open and endo; viceral bleeding
Endogarafts and embolization in bleeding patients
Non-trauma and CPR REBOA;  What to do and when?
Complications, anesthisiological  and ICU aspects; medical treatment and other adjuncts in bleeding
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# The Bi-annual EVTM Workshops

Endovascular and hybrid solutions for the bleeding patient; Aorta balloon occlusion (REBOA) usage, vascular access and techniques.

Hands-on workshop
Örebro, Sweden, twice a year



Dept. Cardiothoracic and Vascular Surgery
Dept. of General Surgery
Dept. of anesthesia and intensive care
Örebro University Hospital and University, Sweden

**The main aim of the workshops** (WS) is to discuss and practice the platform of endovascular and hybrid trauma and bleeding management (EVTM) using a multidisciplinary approach. A main issue is the vascular access, obtained by different methods (blind, Doppler, ultrasound, fluoroscopy and surgical access), usage in bleeding patients for temporary and permanent bleeding control. The usage of Aorta Balloon Occlusion (ABO/REBOA), as well as endografts and embolization methods will be practiced. Bailout and alternative methods will be discussed and practiced. Basic postoperative considerations as intra-abdominal pressure monitoring will be discussed as well. Participant's cases as well as ABOTrauma Registry cases will be discussed. The WS includes basic material knowledge, dry models as well as intensive training on live tissue. The WS give the basics for building a "REBOA or EVTM service" adjusted to the participants needs.

The workshop is built for experienced physicians and adjusted to individual level during the practical moments. Participants will get all basic training and knowledge for REBOA placement as part of the EVTM concept.

## Basic schedule for the workshop september 7-8 2017

**Day 1**: Endovascular trauma algorithm, theory on access and methods, physiology of REBOA/pREBOA/iREBOA and literature. Use of access, aortic/arterial balloon occlusion and other tools for the bleeding patient. Dry model training and Mentice© simulator training. Group discussion of participant's cases and ABOTrauma registry cases. Building a REBOA/EVTM service. Usage of endovascular tools (endografts, embolization material etc).

**Day 2**: Animal lab: Hands-on animal lab including vascular and endovascular access. REBOA principles and practice. Basic angiography training and embolization. Basic ultrasound guided access. Hybrid procedures. Every station with highly experienced faculty and one-on-one training as well as group scenario discussions on live tissue. Practical training points in the animal lab:
1) Material usage in bleeding patients, general considerations. The trauma-bay kit.
2) Vascular Access basic principles. Dissection techniques for access, Endoshunts (and shunts), hybrid procedures and other techniques. Puncture; Seldinger technique, ultrasound, blind, fluoroscopy, cut down.
3) Upgrading/introducers/guide wires. The failing access/alternatives including retroperitoneal, conduit, axillar etc. Access on venous side.
4) REBOA: Material and REBOA kit, practical deployment and using the ABO. Deflation and re-position issues; Intermitted/Partial inflation with MAP as target - pREBOA). Ongoing bleeding practice! Anesthetic issues during REBOA. CPR REBOA.
5) Balloons in other locations (Iliac, Subclavian, and Brachiocephalic trunk/zone I neck), Sizing and techniques. Double balloons.
6) Aortography and Angiography considerations (type, volume etc.) Embolization in target vessels: Material, access, coils, Onyx. Stent graft deployment (basic issues) practice. Pelvic bleeding. Bleeding management scenarios on live tissue will be in cooperated.
7) Endografts and embolization techniques for bleeders. Basic and advanced methods (individually tailored). The practical training is built on individual field of interest and capacity

All participants will get the "Top Stent" handbook and a workshop certificate.
Workshop director: Tal Hörer, Örebro University Hospital, tal.horer@regionorebrolan.se
+46196024632 (direct) /+46702383495 (cellular) or via switchboard: +46196021111
Workshop secretary and registration: Taina Pålsson taina.palsson@regionorebrolan.se
More info on www.jevtm.com under workshops

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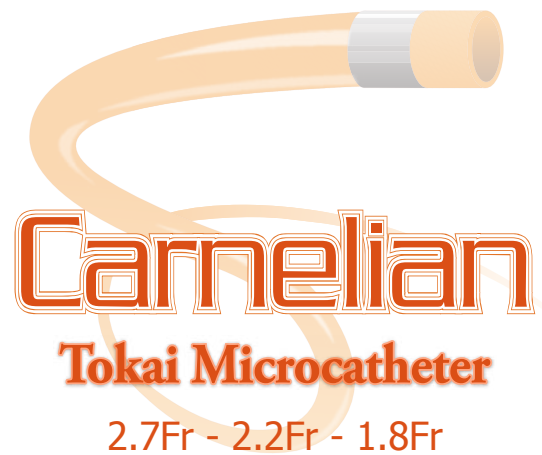efficiency in the OR.

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