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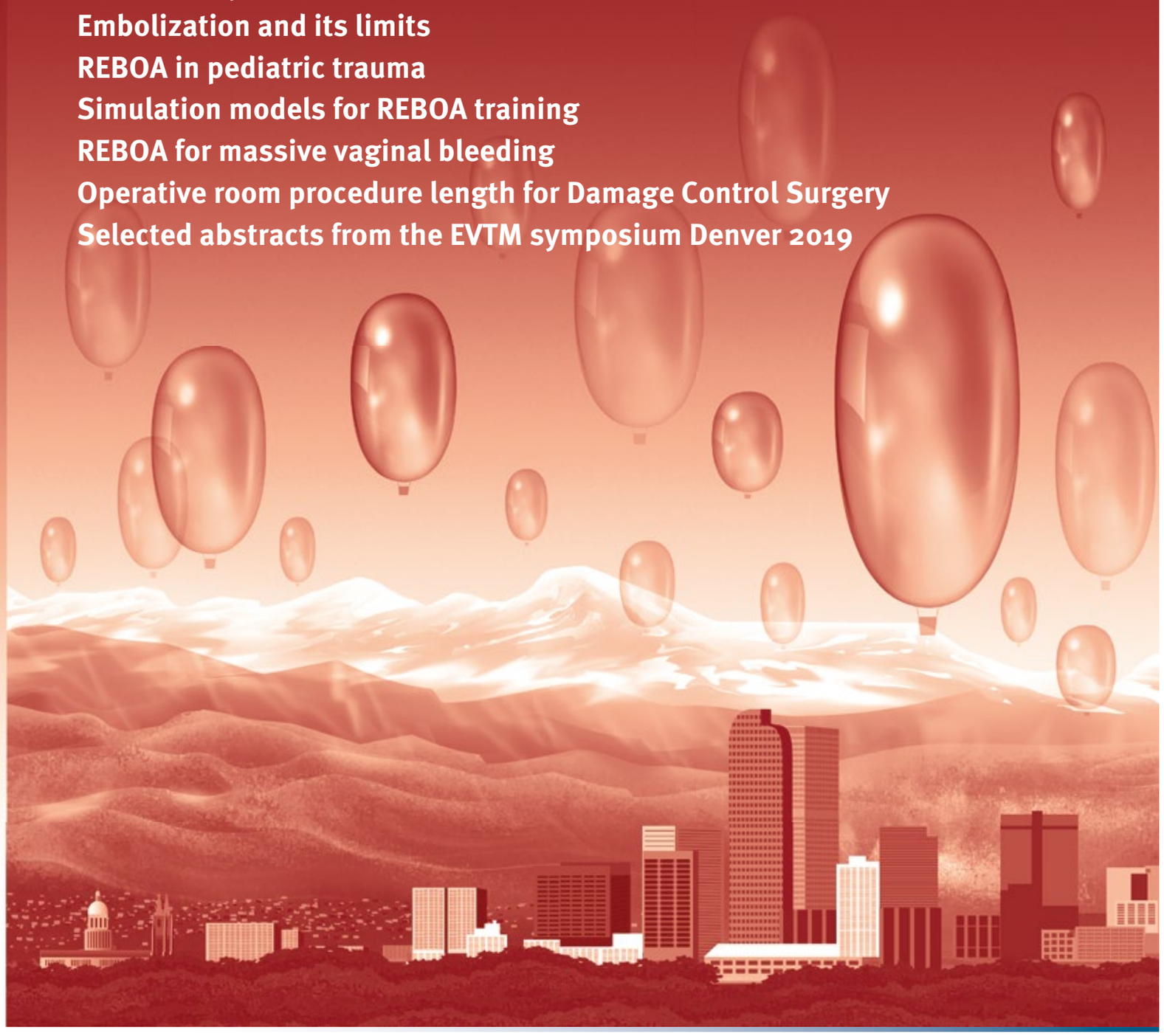
Issue highlights



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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.

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In cooperation with Örebro University Hospital and Örebro University, Sweden.

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Address:
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Dept of Cardiothoracic and Vascular Surgery
Örebro University Hospital and Örebro University
Södra Grev Rosengatan
703 62 Örebro
Sweden

Author Guidelines

A manuscript submitted to the Journal must constitute a unique piece of work that is not under consideration for publication, in part or whole, by another journal. Submissions should preferably be produced using Microsoft Word, although other formats will be considered.

The submission process requires three discreet documents:

1. Cover Letter
2. Title Page
3. Manuscript (including Abstract, Tables and Figures)

Cover Letter
This should be written by the corresponding author and must contain the following:

1. The type of manuscript submission (Original Article, Review Article etc)
2. A sentence or two on the subject of the study.
3. Confirmation that the study is not under consideration for publication by another journal.
4. Confirmation that all of the authors have made a substantial contribution to the manuscript and that they have seen and approved the submission draft.
5. A conflict-of-interest statement regarding the authors. Where there is none, this should be clearly stated.

Title Page
This should consist of the following:

- Title: This should be concise and reflect the type and purpose of the study.
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- Funding Declaration: Any grant funding should be listed.
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Main Body
This should consist of text in 12 pts, double spaced with a justified margin, written in US English. While each article type has specified headings, the use of sub-headings is encouraged to aid clarity. These should be formatted as follows:

Main Heading Bold
Sub-Heading Bold and Italicized
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Abstract
The abstract should be a maximum of 250 words and consist of the following headings:

Background
Methods
Results
Conclusions

Original Studies
Manuscripts reporting unique scientific studies should be no longer than 3000 words. They should consist of the following sections:

- Introduction: This should concisely present the background to the problem that the study hopes to answer. A hypothesis should be clearly stated.
- Methods: This section should be suitably detailed to permit replication of the study. The regulatory permissions for the study should also be detailed, e.g. Institutional Review Board, ethical committee etc... including a protocol/registration number. Where animal research has been undertaken, the institutional animal care and use guidelines that have been followed should be clearly stated.
- Results: These should involve the reporting of the salient positive and negative findings of the study in clear language. The use of images, figures and tables are encouraged, of which the data should not be duplicated in the prose. There is no maximum number of figures or tables, but these should be appropriate to the study. should be reported to three decimal places.
- Discussion: This should place the reported study findings in the context of the literature. Limitations and future direction should also be discussed. Authors must be careful to ensure that conclusions are not overstated and are supported by data.

Editorials
Short, focused Editorials on an important aspect of endovascular hemorrhage control are welcomed. These should endeavor to bring attention to an important topic, or accompany an article published within the journal. The latter will be invited by the Editor. Submitted manuscripts should be no longer than 1500 words.

Narrative Review Articles
This style of article can afford the author considerable latitude in examining a pertinent topic in endovascular hemorrhage control. The literature should be examined objectively and presented to the reader in the context of current understanding. The author should be able to synthesize a narrative, which leaves the reader with a good understanding of an emerging or controversial topic. The author is welcome (and encouraged) to express an opinion, but where this is the case, it should be clearly stated.

Articles should be a maximum of 5000 words. There is no formal structure; however, the use of logical headings/sub-headings is important to enable readers to follow the article easily. The abstract should also be unstructured and be a maximum of 150 words.

Systematic Reviews and Meta-Analyses
Where there is a topic within the subject area of endovascular hemorrhage control that has a substantial evidence base, a Systematic Review with/without a Meta-Analysis is considered more appropriate than a narrative review article. These articles should follow the methodology established by PRISMA. Submission should be a maximum of 5000 words and authors should include a PRISMA checklist in their submission. The overall aim is to provide a pooled analysis that enables firm conclusions to be drawn on a particular subject.

Tips and Techniques
In the evolving world of endovascular hemorrhage control, 1the advice and opinion of actively practicing clinicians is of great importance. Both solicited and unsolicited submissions are reviewed, both on major or minor components on endovascular techniuqes . This can be presented in the context of â€œevidenceâ€ or just as an opinion. The use of quality images and diagrams is encouraged. The submission should be a maximum of 1500 words.

Author Guidelines

Images of Interest
Rather than accept case reports, the Journal will prefere images of interest, which include a short commentary. The aim of this section is to demonstrate and illustrate an educational message, rather than just to demonstrate dramatic pathology. Images can be submitted as a multi-panel with a series of scans/photographs in order to support the message presented in the narrative. The submission should be a maximum of 250 words.

Resident Corner
Short article managed and written by residents (no senior authors) with educational value (max word count 1500)

Support for Language and Article Content
The aim of the Journal, in addition to the dissemination of peer-reviewed evidence, is to support English-second-language authors and early career scientists. Provided that a submitted manuscript has good scientific merit, the Journal is able to provide a free language editing service. Furthermore, where article content would benefit from high-quality figures, artwork can be commissioned to support the publication.

References
References should follow the Vancouver Style and should be noted in the text numerically in sequence within the text using square brackets, eg: [1] or [1,2] or [1;3].

An example article:

Stannard W, Rutman A, Wallis C, O'Callaghan C. Central microtubular agenesis causing primary ciliary dyskinesia. Am J Respir Crit Care Med. 2004;169:634.
Where there are more than six authors, the first three should be included followed by et al .

Supplementary Digital Content
Where manuscripts would benefit from additional content (datasets, images, video), which does not necessarily need inclusion in the published article, supplementary digital content (SDC) can be hosted. This includes, but is not limited to, tables, figures or video. Authors should include in their cover letter a description of this content and its purpose.

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A submitted manuscript must be an original contribution not previously published (except as an abstract and should be indicated); Cannot be under consideration for publication in other journals; and, if accepted, must not be published or reproduced elsewhere. The final responsibility for the scientific accuracy and validity of published manuscripts rests with the authors, not with the Journal, its editors, or the publisher (Örebro University Hospital).

Patient Anonymity and Informed Consent
It is the authors's responsibility to ensure that a patient's anonymity is protected, to verify that any experimental investigation with human subjects reported in the manuscript was performed with informed consent and follows all the guidelines for experimental investigation with human subjects required by the institution(s) with which all the authors are affiliated and/or ethical committee processing. Authors are asked to comply with the general guidelines for integrity protection, as listed by the health ministries in the EU, the EU commission and US department of health. (example: https://www.hhs.gov/hipaa/forprofessionals/special-topics/research/index.html). Authors should mask patient's eyes and always remove patient names from figures as well as genital organs as possible.

Protection of Human Subjects & Animals in Research
For original articles in the Journal that report research involving animals, the corresponding author must confirm that all experiments were performed in accordance with relevant guidelines and regulations (i.e. IACUC guidelines and federal regulations, or EU guidelines for animal research). One recommended documenting animals studies, might be the ARRIVE reporting guidelines (PLoS Bio 8(6), e1000412,2010). We encourage to follow the RRR principles of animal studies in medicine: https://www.feam.eu/wp-content/uploads/FEAM-Forum_Round-table-animals_Report_Final.pdf)

All studies of human subjects must contain a statement within the Methods section indicating approval of the study by an institutional review body (i.e. Institutional Review Board or ethical committee), and, if appropriate, a statement confirming that informed consent was obtained from all subjects if possible. If no legally informed consent can be obtained, such as in research carried out with human subjects receiving emergency treatment, authors should indicate as possible if a waiver of regulatory requirements for obtaining and documenting informed consent applies.

All submissions are screened for inappropriate image manipulation, plagiarism, duplicate publication and other issues that violate research ethics. Depending on the outcome of these investigations, the Journal may decide to publish errata, or, in cases of serious scientific misconduct, ask authors to retract their paper or to impose retraction on them.

General statement
Patients have a right to privacy that should not be infringed without informed consent. Identifying information, including patients' names, initials, or hospital numbers, should not be published in written descriptions, photographs, and pedigrees unless the information is essential for scientific purposes and the patient (or parent or guardian) gives written informed consent for publication. Informed consent for this purpose requires that a patient who is identifiable be shown the manuscript to be published. Authors should identify Individuals who provide writing assistance and disclose the funding source for this assistance.

Identifying details should be omitted if they are not essential. Complete anonymity is difficult to achieve, however, and informed consent should be obtained if there is any doubt. For example, masking the eye region in photographs of patients is inadequate protection of anonymity. If identifying characteristics are altered to protect anonymity, such as in genetic pedigrees, authors should provide assurance that alterations do not distort scientific meaning and editors should so note.

The requirement for informed consent should be included in the journal's instructions for authors. When informed consent has been obtained it should be indicated in the published article.
- International Committee of Medical Journal Editors ("Uniform Requirements for Manuscripts Submitted to Biomedical Journals") -- February 2006

JEVTM follows guidelines and best practices published by professional organizations, including Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals by ICMJE, and Principles of Transparency and Best Practice in Scholarly Publishing (joint statement by COPE, DOAJ, WAME and OASPA).

Contents

Editorial

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JEVTM: Standing on the Shoulders of Giants

Charles J Fox MD, FACS

Chief of Vascular Surgery, Denver Health Medical Center, Associate Professor Surgery, Division of Vascular Surgery, University of Colorado School of Medicine, Denver, Colorado, USA

The concept of endovascular trauma management (EVTM) has evolved for over half a century, beginning with simple devices used for intraluminal hemorrhage control and reaching the modern-day development of aortic stent grafts used for emergent endovascular aneurysm repair (EVAR) for ruptured abdominal aortic aneurysms [1–4]. Additionally, lower profile and more compliant endovascular devices have advanced the management of blunt aortic injury from open repair to widespread thoracic endovascular aortic repair (TEVAR). Large multicenter trials have reported such persuasive survival benefits for these conditions that informing patients of the evidence has nearly extinguished many open surgical treatment options [5–7]. By 2001, for the first time since the Vietnam War, vascular surgeons were being deployed to conflicts to manage wartime vascular injuries, this time with substantial endovascular skills and training. The partnering with trauma surgeons, while positioned far forward in the battle area, has created a fertile ground for using hybrid approaches in managing severely injured patients with sophisticated endovascular techniques. For example, the success of selective transfemoral supra-celiac aortic balloon occlusion reported a decade ago by vascular surgeons [8] has given birth to resuscitative endovascular balloon occlusion of the aorta (REBOA) for trauma. As a result, the translational research on non-compressible torso hemorrhage has created widespread enthusiasm for endovascular strategies [9–11]. Innovation has resulted in the modification of older "predicate" devices to produce lower profile, wireless, fluoroscopic-free systems, designed for trauma patients, which are currently in use on battlefields around the world [12].

The historical lessons from the past now allow us to stand on the "shoulders of giants" as we harness worldwide enthusiasm and a growing international academic collaboration for preparing those at the bedside to care for the sick and injured around the world. The continued exchange of endovascular applications that originated with programs such as Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS) [13] and Basic Endovascular Skills for Trauma (BEST) is self-evident with the ongoing high caliber of submissions to the *Journal of Endovascular Resuscitation and Trauma Management* (JEVTM). The multispecialty editorial board has compiled numerous issues of outstanding peer-reviewed articles that feature the latest concepts and expert opinion on hemorrhage control, novel devices, REBOA, embolization, training, and hybrid imaging to improve survival. As the JEVTM moves toward PubMed index approval, the next issue is no exception as the reviewers and writers assemble informative hot topics in simulation training, endovascular management of post-partum hemorrhage, considerations in pediatric patients and crucial damage control concepts. The cover illustration serves as a tribute to the hosting city of Denver, Colorado for the next Pan-American EVTM meeting in November 2019. Abstracts from the Denver meeting that promote the latest endovascular advances, represent the diverse international composition, and stimulate global discussion on various provocative topics are selected to engage the readers.

The crosshairs of EVTM will now focus on formalizing a global multidisciplinary membership of professionals that can take the society to the next level of organization. Nominations of officers, establishing formal committees, and encouraging ideas for new directions from the membership are the future directions that will undoubtedly build the team. I encourage those with scientific and innovative endovascular academic pursuits

Corresponding author:

Charles J Fox MD, FACS, Chief of Vascular Surgery, Denver Health Medical Center, Associate Professor Surgery, Division of Vascular Surgery, University of Colorado School of Medicine, Denver, Colarado, USA.

Email: Charles.Fox@CUAnschutz.edu

to get involved: to attend the EVTM workshops and meetings, serve on committees, and prepare manuscripts for submission to the journal. To quote an African proverb, "If you want to go fast, go alone. If you want to go far, go together." We hope to see you all together at the Pan American EVTM meeting in November. Let's go far!

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Editorial

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The Trauma-Vascular Surgeon: A Global Necessity

Ernest E Moore MD

Ernest E Moore Shock Trauma Center at Denver Health, Denver, Colorado, USA

Trauma is the most common cause of death in the United States in the population under 45 years of age. Despite the National Academy of Medicine, Engineering, and Science (NAMES) white paper calling for "Zero Preventable Deaths following Injury" [1], mortality attributed to trauma has increased in the United States over the past decade [2]. Uncontrolled bleeding is the leading cause of preventable death following injury in both the civilian and military settings and, thus, is a conspicuous target to improve outcome. In recent multicenter studies the time to death from bleeding has been reported to be 1.6–2.3 hours, and a third of these fatalities occur within the first hour [3–9]. The Hybrid Operating Room construct provides a tremendous opportunity to accomplish prompt control of life and limb threatening bleeding [10]. However, a major challenge to optimize these resources for trauma is the immediately availability of surgeons in regional trauma centers capable of performing open and endovascular control of bleeding. Similarly, the military needs trauma surgeons with vascular capabilities. Currently there is an emerging crisis to ensure this timely surgical care, but the underlying forces are multifactorial [11]. While I am convinced this is a worldwide problem, my comments will be limited to the US experience where penetrating wounds remain common in urban settings.

One of the major factors in this evolving crisis is the decline in vascular skills of the trauma surgeon. This deterioration begins with general surgery training which is detailed in publicly available national reports. A recent review of the Accreditation Council for Graduate Medical Education (ACGME) case logs during the last 15 years has documented a 38% decrease in open arterial operations performed by general surgery residents [12]. The reduction in vascular care has been particularly conspicuous over the past decade, with current general surgery residents finishing with less than 2 vascular trauma procedures [13]. This decline has been attributed to the dramatic shift to endovascular therapy, increased vascular surgery trainees (5+2 fellowships and 0–5 vascular programs), as well as the increased number of general surgery training programs. The current Trauma and Acute Care Surgery (TACS) model in the United States has exacerbated this crisis. Somewhat ironically, the TACS concept was formalized to re-establish operative experience for trauma surgeons by integrating emergency general surgery (EGS). Unfortunately, in most trauma centers, this has primarily increased nocturnal experience with laparoscopic appendectomies and cholecystectomies with the virtual elimination of open vascular operations [14]. The TACS shift construct and extensive surgical intensive care unit (SICU) responsibilities have further limited the capacity of the modern TACS surgeon to participate in vascular work. Finally, the unbridled over-designation of trauma centers has reduced the trauma volume at many academic trauma centers, further diluting experience for training and maintaining vascular skills.

On the other side is maintaining trauma expertise in those formally trained in vascular surgery. Most vascular surgeons are understandably reluctant to participate in in-house calls for trauma surgery, and few are interested in maintaining expertise in non-vascular trauma procedures. The limited experience with open thoracic, abdominal, and pelvic procedures is a further dilemma for 5–0 trained vascular surgeons who have focused on endovascular work.

There are a number of potential solutions to the provision of timely vascular care in regional trauma centers, and I would like to focus on training the next generation of trauma-vascular surgeons (TVSs). Following completion of a general surgical residency, the current TACS

Corresponding author:
Ernest E Moore MD, Ernest E Moore Shock Trauma Center at Denver Health, Denver, Colorado, USA.
Email: Ernest.Moore@dhha.org

fellowship consists of a year-long ACGME surgical critical care (SCC) fellowship with EGS and on-call trauma duties, and a second year with minimal case criteria for thoracic, vascular, and hepatobiliary procedures as well as additional EGS and trauma calls [15]. Although a shift from rotation-based duties to minimal longitudinal cases is intuitively attractive, the conspicuous downside is ensuring technical competency. I acknowledge that one year focusing on SCC certification is fundamental, but submit that the second year should have the flexibility to enable the option of a year focusing on acquiring open and endovascular skills. This fellowship will be limited to relatively high-volume urban trauma centers in an academic environment supporting this new training paradigm. Currently the Adams Cowley Shock Trauma Center in Baltimore is the best example in the United States.

In summary, I strongly believe EndoVascular Resuscitation and Trauma Management (EVTM) is the optimal international forum to solve the existing international crisis of ensuring the immediate availability of a skilled TVS, 24 hours a day, 7 days a week, 365 days a year.

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Original Article

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Approximation of Pediatric Morphometry for Resuscitative Endovascular Balloon Occlusion of the Aorta

Erik S DeSoucy DO[1,2], A Francois Trappey MD[1,2], Andrew M Wishy DO[1,2], Meryl A Simon MD[1,2], Anders J Davidson MD MAS[1,2], Joseph J DuBose MD[1,2,3], Timothy K Williams MD[4], M Austin Johnson MD PhD[2] and Jacob T Stephenson MD[1,2,3]

[1]*David Grant USAF Medical Center, Department of Surgery, Travis AFB, California, USA*
[2]*University of California Davis Medical Center, Department of Surgery, Sacramento, California, USA*
[3]*Uniformed Services University of Health Sciences, Bethesda, Maryland, USA*
[4]*Wake Forest Baptist Health, Medical Center Blvd, Winston-Salem, North Carolina, USA*

Background: Resuscitative endovascular balloon occlusion of the aorta (REBOA) may be beneficial in the management of traumatic and iatrogenic vascular and solid organ injuries in children, but requires an understanding of vessel diameter at the access site and landing zones. We adapted the Broselow Tape method to estimate aortic and femoral artery diameters for this purpose.

Methods: Computed tomography scans from trauma and non-trauma pediatric patients at a level 1 trauma center were reviewed for vascular dimensions at aorta Zone I, Zone III, and the common femoral artery (CFA). Vessel size was measured by two providers using a vascular software suite with a 10% interobserver comparison. Height was used to create linear regression equations for each location and calculate ranges for each Broselow Tape category.

Results: We reviewed scans from 110 patients ages 2–14 years with less than 8% interobserver variability. Of these, 64% were male and 46% were trauma patients. Height-based regression equations were closely correlated with vessel diameter: Zone I (mm) = [0.093 ± 0.006 · height (cm)] + 0.589 ± 0.768; $R^2 = 0.714$, $p < 0.001$; Zone III (mm) = [0.083 ± 0.005 · height (cm)] – 0.703 ± 0.660; and $R^2 = 0.728$, $p < 0.001$; CFA (mm) = [0.043 ± 0.003 · height (cm)] + 0.644 ± 0.419; $R^2 = 0.642$, $p < 0.001$. These equations, along with the minimum and maximum length for each Broselow Tape color, were used to define color-coded normal ranges for each REBOA landing zone and access site.

Conclusion: Knowledge of the access vessel and occlusion zone diameters in pediatric patients is crucial for future research and application of REBOA in this population. Furthermore, an adapted Broselow Tape including these measurements would assist in appropriate sheath and balloon catheter selection in emergent settings.

Keywords: *Pediatric REBOA; aortic morphometry; trauma; balloon occlusion resuscitation; Broselow tape*

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Corresponding author:
Erik S DeSoucy, DO, 2335 Stockton Blvd, Room 5107, Sacramento, California, 95817, USA.
Email: erik.s.desoucy.mil@mail.mil

Author contributions: ESD, AFT, AMW, MAS AJD, JJD, MAJ, TKW, and JTS were responsible for conception and design. ESD, AFT, AMW, MAS, and JTS performed data acquisition. ESD performed data analysis and interpretation. ESD, AFT, and AMW drafted the manuscript. ESD, AFT, AMW, MAS, AJD, JJD, MAJ, TKW, and JTS were involved in critical revision of the manuscript. ESD takes responsibility for the content.

Conflicts of interest: MAJ and TKW are stakeholders and cofounders of Certus Critical Care Inc.

Funding: None

Presentation: This work was presented as a poster at the Clinical Congress of the American College of Surgeons in Boston, MA, USA, on October 22nd, 2018.

Disclosure: The views expressed in this material are those of the authors, and do not reflect the official policy or position of the US Government, the Department of Defense, the Department of the Air Force or the University of California.

INTRODUCTION

There is growing translational data and clinical support for the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) for the resuscitation of adult trauma patients with abdominal and pelvic hemorrhage [1–10]. While additional research is required to fully understand the utility of REBOA in different patient populations, REBOA may be beneficial in the management of traumatic and iatrogenic vascular and solid organ injuries in children. Using data from the Japan Trauma Data Bank, Norii et al. [11] published the first report on pediatric REBOA use, demonstrating equivalent survival rates to adults in 54 pediatric REBOA patients ranging from 5 to 17 years of age. Although clinical use has now begun, there remain no studies describing the morphometric variability between pediatric patients as applied to the selection of appropriate aortic occlusion catheters.

Ninety percent of pediatric trauma results from blunt traumatic mechanisms [12,13]. Solid organ injury is the most common abdominal injury following blunt trauma and requires operative intervention in 4% of cases while direct vascular injuries from penetrating mechanisms requiring intervention are even more rare, comprising only 1% of all trauma cases [14–16]. Both sources of hemorrhage in pediatric populations may be amenable to aortic occlusion to minimize blood loss and profound shock. Additionally, REBOA may have application in hazardous pediatric surgical cases such as large abdominal or sacral tumor excision, either for prophylactic use or following iatrogenic injury. However, broad anatomical differences exist across the pediatric age range, affecting vessel diameters, lengths, and locations of key branch vessels, negating the potential for a "one balloon fits all" approach.

The potential for iatrogenic vessel injury within the aorta or at the site of vascular access is a significant concern given changes in aortic and femoral size throughout childhood. Inherently, this represents a challenge for exploring REBOA use in this population. We sought to ameliorate these anatomical concerns by defining the typical balloon occlusion zone and access site vessel diameters in a representative pediatric population and adapting these values to the Broselow Tape method used commonly during pediatric resuscitations [17,18].

METHODS

Computed Tomography Imaging Analysis

Our cohort included any pediatric patient (age 2–14 years) evaluated with intravenous (IV) contrasted computed tomography (CT) imaging of the abdomen in the University of California Davis Medical Center (UCDMC) Emergency Department for abdominal pain or appendicitis between July 2015 and June 2017. A cohort of age and sex-matched patients who underwent IV contrasted CT scan of the abdomen for trauma from the same time period were then identified. The age, sex, height, weight, and systolic blood pressure (SBP) within 2 hours of CT imaging were included for analysis. Body mass index (BMI) and body surface area (BSA) were calculated [19]. Exclusion criteria included lack of height measurement and lack of adequate extent or clarity of imaging. Additionally, patients with systolic hypotension as determined by age-adjusted norms were excluded to avoid the effect of shock on compliant vessels. Hypotension was defined as SBP <70 mmHg plus age times 2 for children 2–9 years of age and SBP <90 mmHg for patients 10 and older [20].

CT scans were performed on one of four CT scanners (three 64-slice, one 16-slice) with IV contrast administered per standard UCDMC radiology protocols.

Each CT was analyzed using TeraRecon 3D (TeraRecon Inc., Foster City, CA). The recorded measurements included: aortic diameter at the superior endplate of the T10 vertebral body, immediately superior to the celiac artery origin, inferior to the lowest primary renal artery, and at the aortic bifurcation. Common femoral artery (CFA) diameter was obtained just proximal to the deep femoral artery. The imaging was analyzed by two senior vascular surgery residents (MS/AW). Ten percent of cases were interpreted by both residents to provide an interobserver comparison.

The collection of CT imaging and patient data was performed under UCDMC IRB # 935667-2.

Data Analysis

The data was collected and analyzed using Excel (Microsoft, Redmond, WA) spreadsheets. Descriptive statistics were used to define the cohort demographics including age, sex, height, weight, and trauma vs non-trauma. Zone I diameter was defined as the mean aortic diameter between the superior endplate of the T10 vertebral body and just superior to the celiac axis. Zone III measurement was defined as the mean aortic diameter between the lowest renal artery and the aortic bifurcation. Measured left and right CFA diameters were averaged for each patient. Height, weight, BMI, and BSA were individually plotted against Zone I, Zone III, and CFA diameters and analyzed using linear regression lines. Pearson's correlation coefficient (R^2) was calculated for each variable. Height was used to create simple linear regression equations and the standard error for slope and intercept was calculated. Residual plots were also examined.

Creation of Broselow Tape Ranges

A Broselow Tape (CareFusion, 2011 Version A) was used to measure the minimum and maximum lengths for each color. These values were entered into the linear regression equations to define the Broselow category minimum and maximum vessel diameter for each zone

and the CFA using one standard deviation. The calculation of sheath size recommendations was based on the recommended ratio of catheter outer diameter to arterial luminal diameter (OD/AD ratio) of ≤50% [21].

RESULTS

Cohort Description

We identified 227 trauma and non-trauma patients with CT scans of the abdomen and pelvis with contrast. Of these 107 were excluded due to lack of height data and 10 scans were excluded due to poor or inadequate image quality, leaving 110 scans for analysis. No patients were excluded for hypotension. There were 51 scans for trauma (46%) and 59 scans for non-trauma (54%) complaints. The patients were mostly male (64%) with a median age of 9 years (range 2–14 years).

Linear Regression Analysis

Vessel diameter data was plotted against the variables of height, weight, BMI, and BSA to produce scatter plots. A best-fit linear regression line was applied to each plot and the coefficients of determination were examined. The highest Pearson correlation coefficients for Zone I, Zone III, and CFA diameters were identified for the independent variables of height (R^2 = 0.7144, 0.7275, and 0.6420, respectively), BSA (R^2 = 0.7276, 0.7200, and 0.6335, respectively), and weight (R^2 = 0.6569, 0.6382, and 0.5676, respectively). BMI was poorly correlated (R^2 = 0.3175, 0.2979, and 0.2749, respectively). The scatter plots and regression lines for height are presented in Figure 1. The linear regression equations, their associated standard error, and correlation coefficients are as follows: Zone I (mm) = [0.093 ± 0.006 · height (cm)] + 0.589 ± 0.768; R^2 = 0.714, $p < 0.001$; Zone III (mm) = [0.083 ± 0.005 · height (cm)] – 0.703 ± 0.660; R^2 = 0.728, $p < 0.001$; CFA (mm) = [0.043 ± 0.003 · height (cm)] + 0.644 ± 0.419; R^2 = 0.642, $p < 0.001$.

The scatter plots and regression lines for weight, BMI and BSA are presented in Figure 2 for comparison.

Broselow Tape Adaptation

As height was among the highest correlating factors and the goal was to produce a representative vessel diameter range for each length range on the Broselow tape, the regression line equations for height were selected for extrapolation. The vessel diameter ranges for Zone I, Zone III, and CFA can be found in Figure 3 in a color-coded format to match the corresponding Broselow color. Included in section C of this figure is the suggested CFA access sheath sizes which would not result in a greater than 50% OD/AD ratio including a 1 French (Fr) buffer to account for the added thickness of the sheath material. These are represented as a range with the smaller sheaths being appropriate at the low end of the height range and larger diameter sheaths suggested for the upper end of the height range.

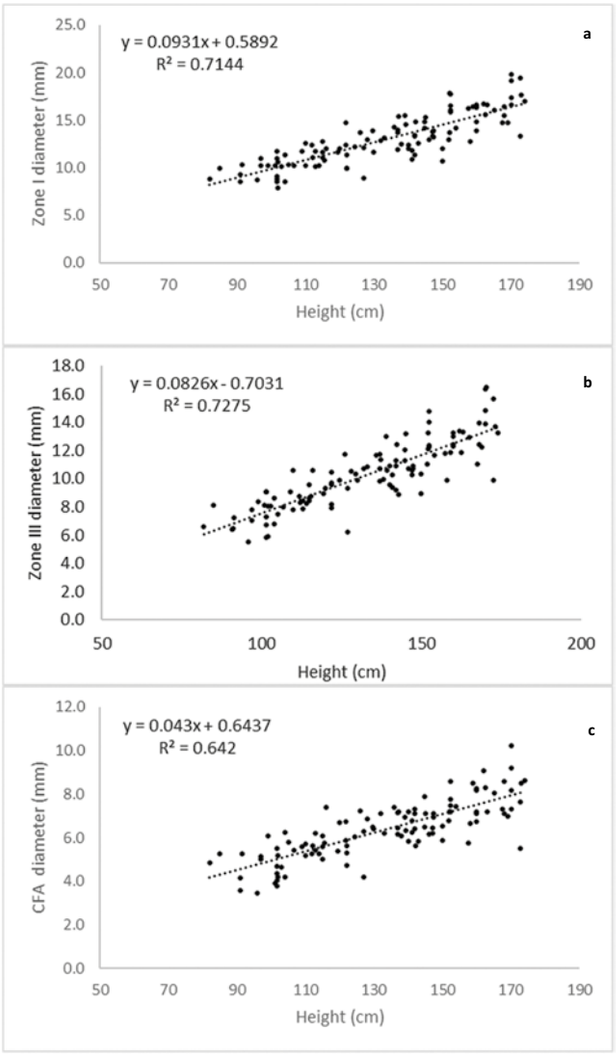

Figure 1 Scatter plots and linear regression lines comparing height with vessel diameter. (**a**) Zone I, (**b**) Zone III, (**c**) and CFA; $p < 0.001$ for all.

Interobserver Comparison

Thirteen patients (11.8%, 7 trauma, 6 non-trauma) were selected at random for dual interpretation. There was less than 8% variability between the readers for measurement of each diameter (Zone I 7%, Zone III 8%, and CFA 7%).

DISCUSSION

Broselow Adaptation

The Broselow Tape is a widely used tool to estimate weight, drug dosing, endotracheal tube diameter, and

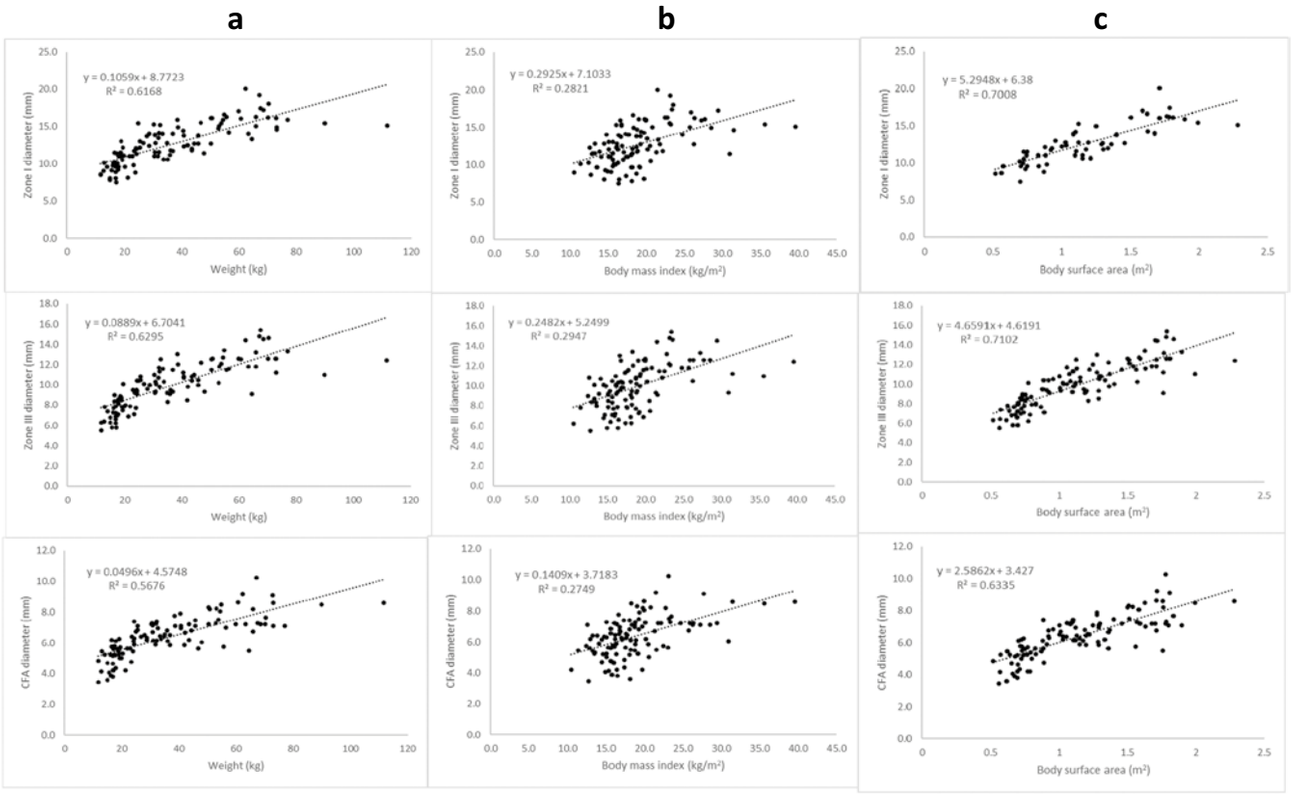

Figure 2 Scatter plots and linear regression lines comparing (**a**) weight, (**b**) body mass index, and (**c**) body surface area with vessel diameter at Zone I, Zone III, and CFA.

other emergent interventions based on the length of an injured child before an initial weight can be obtained [17,18,22]. Anatomical considerations for the use of REBOA in a pediatric patient include aortic and femoral artery diameters as well as distances between the femoral access point and occlusion zones. For the purposes of REBOA, the regions of greatest importance include the supraceliac aorta cephalad to the diaphragm (Zone I) and the infrarenal aorta (Zone III). Sandgren et al. [23] determined that CFA diameter and BSA parallel each other for both males and females up until 25 years of age. Although very accurate when height and weight measurements are readily available, BSA is inherently difficult to estimate in emergent settings, supporting the use of tools such as the Broselow Tape to guide rapid intervention. While the determination of BSA and BMI based on height and estimated weight will not be perfect for all patients, it can provide an estimate to select occlusion balloons in an emergency. In our regression analysis, height, weight, and BSA carried similar correlation to vessel diameter.

Common Femoral Artery Access Considerations

CFA access is frequently performed in children for cardiac catheterization or extracorporeal membrane oxygenation (ECMO). Cardiac catheterization utilizes smaller diameter access sheaths (3.3 Fr to 6 Fr) compared with ECMO which starts at 12 Fr and often requires additional distal perfusion access. In a series of 21 pediatric patients treated with femoral venous-arterial ECMO, 52% developed limb ischemia despite the use of distal perfusion catheters in a portion of patients, a figure in line with previous reports of 30–50% [24–26]. In contrast, cardiac catheterization via femoral artery access has much lower rates of ischemic complications (3.8%) suggesting that the smallest possible access sheaths will provide the lowest rate of arterial injury and thrombotic complication [27].

In infants and small children, CFA diameters are expected to be small resulting in a higher risk of adverse events such as arterial injury and limb ischemia. Alexander et al. [21] reviewed 486 catheterizations in children (median age 22 months) in which 33 patients experienced loss of pulse (LOP) in the ipsilateral extremity post-procedure. The only independent risk factor for LOP was CFA diameter <3 mm. Additionally, the ratio of catheter outer diameter to arterial luminal diameter (OD/AD ratio) was identified as a predictor for LOP with OD/AD ratio of >50% leading to LOP in 17.2% of patients compared with 5.2% of patients with OD/AD ratio of ≤50%. For 4, 5, and 6 Fr sheaths, ideal CFA

a

Broselow Color	Zone I Diameter (mm)	
	Min	Max
Pink	3.9	6.8
Red	4.6	7.5
Purple	5.2	8.4
Yellow	6.1	9.6
White	7.1	10.8
Blue	8.2	12.1
Orange	9.3	13.0
Green	10.2	14.3

b

Broselow Color	Zone III Diameter (mm)	
	Min	Max
Pink	2.3	4.7
Red	2.9	5.4
Purple	3.5	6.2
Yellow	4.2	7.2
White	5.1	8.4
Blue	6.1	9.5
Orange	7.1	10.3
Green	7.8	11.4

c

Broselow Color	CFA Diameter (mm)		Introducer Sheath (Fr)
	Min	Max	
Pink	2.1	3.6	2-5
Red	2.4	3.9	3-5
Purple	2.7	4.4	4-6
Yellow	3.1	4.9	4-7
White	3.5	5.5	5-8
Blue	4.1	6.1	6-9
Orange	4.6	6.5	6-9
Green	4.9	7.1	6-9

Figure 3 Broselow category vessel diameters. (**a**) Zone I, (**b**) Zone III, and (**c**) common femoral artery including recommended access sheath sizes. Range represents calculated diameter for minimum and maximum height for each Broselow color ± one standard deviation.

diameter would be greater than 2.67, 2.34, and 4 mm, respectively. The risk of partial or near-complete occlusion of the CFA for the duration of REBOA intervention must be weighed against the potential lifesaving benefits and, when possible, access sheaths and devices should be selected to optimize the OD/AD ratio. Low profile devices deployable through 4 Fr access sheaths hold the most promise for implementing REBOA in very young children while minimizing the risk of arterial injury and thrombotic complications.

Utilization in a Pediatric Population

Defining clinical criteria for REBOA placement in children will be challenging, yet crucial. While physiologic indications for pediatric REBOA may eventually differ from that of adults (i.e. presenting SBP <90 mmHg), injury pattern indications and contraindications will likely remain constant with some additional unique indications such as sacral or coccygeal tumor resection [28]. It is unknown when a patient will be old enough to meet adult indications for REBOA, however, we can estimate the height at which the femoral artery would be of adequate diameter to safely accept a 7 Fr access sheath and deployment of the standard ER-REBOA (Prytime Medical, Boerne, TX) platform. A CFA diameter of 5.9 mm allows for a standard 7 Fr sheath with an outer diameter of 2.95 mm to be placed while maintaining <50% OD/AD ratio. This CFA diameter is expected at a height of 122 cm or approximately 4 feet which lies

in the green Broselow Tape color group. The use of lower profile sheaths would allow for use in smaller patients. As of now, there are no trauma-specific devices which would serve the spectrum of pediatric sheath sizes needed. Future investigation will be required to identify acceptable off the shelf catheters for use in pediatric REBOA. In addition, it is yet to be seen whether intervention with REBOA in children is more beneficial as a prophylactic adjunct or whether it should be used after physiologic decline has manifested.

Limitations

A potential limitation of this study was the adaptation of height-based estimates to a population with accelerating obesity. Our analysis determined that height, weight, and BSA held comparatively close correlation with aortic and CFA diameters ($R^2 = 0.57–0.73$) as compared with BMI which was poorly correlated ($R^2 = 0.28–0.32$). These measurements were obtained from contrast imaging which was not necessarily protocolled for precise measurements of the vasculature. However, this modality is becoming commonplace for establishing normal vasculature morphometry [23,29–32]. There were no children under 2 years of age and CT scans for the Broselow colors below blue were either poorly powered or absent. It is possible that the vasculature growth curves below 2 years of age are markedly different, however previous work using angiograms and CT scans has come to similar conclusions that height, weight, and BSA correlate well with vasculature diameter, even in infants as young at 1 month of age [29]. Future studies may be able to further refine these estimates, but as CT imaging in the very young is generally avoided due to concerns for ionizing radiation, significant numbers of scans may be difficult to obtain.

CONCLUSION

Pediatric REBOA may be a useful adjunct in the management of life-threatening traumatic and iatrogenic bleeding. Height correlates closely with and can be used to estimate aortic zone and CFA diameters for use in emergent settings. By adapting a rapid system accounting for the anatomic differences associated with vascular development during childhood, this study provides a foundation for research, development, and execution of REBOA techniques in the pediatric population.

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Original Article

Is Time of the Essence: A Retrospective Analysis of Operating Room Procedure Length for First Phase Damage Control Trauma Surgery

Alison Smith MD PhD[1], Lynn Hakki BS[1], Jessica Friedman MD[1], Rebecca Schroll MD[1], Chrissy Guidry DO[1], Patrick McGrew MD[1], Danielle Tatum PhD[2] and Juan Duchesne MD[1]

[1]*Tulane School of Medicine, Department of Surgery, New Orleans, LA, USA*
[2]*Our Lady of the Lake Trauma Hospital, Baton Rouge, LA, USA*

Background: Damage control surgery (DCS) involves limiting operating room (OR) time for patients with multiple life-threatening injuries and coagulopathy who are reaching physiologic exhaustion. However, there is a paucity of current evidence to support a survival benefit with shorter OR times. The objective of this study was to determine if operation length affects mortality in trauma patients with abdominal injuries.
Methods: An 8-year retrospective review of adult patients with DCS for penetrating abdominal trauma at a Level I trauma center was conducted. Univariate and multivariate analyses were performed.
Results: Patients were stratified into short OR group (SHORT, $n = 95$) and long OR group (LORT, $n = 98$) based on the median operative time of 157 minutes. The SHORT group received more ICU blood transfusions (52.6% vs. 35.7%, $p = 0.02$). Average hospital length of stay (22.8 + 2.3 vs. 31.0 + 3.5 days, $p = 0.05$) and ICU length of stay (10.6 + 1.2 vs. 12.6 + 1.4 days, $p = 0.28$) were lower in the LORT group. The SHORT group had 22 patients with an unexpected return to the OR versus 3 in the LORT group ($p < 0.0001$). OR time was not an independent risk factor for mortality (odds ratio 1.0, 95% CI 0.98–1.0, $p = 0.48$).
Conclusions: Modern damage control practices should focus on early surgical control in combination with effective intra-op resuscitation efforts and not on the amount of time required to accomplish these resuscitative goals. These findings suggest that in the era of modern DCS, the old tenet of 60 minutes may not be as relevant.

Level of evidence: IV.

Keywords: *Damage Control; Resuscitation; Time*

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Corresponding author:
Alison A Smith MD PhD, Tulane School of Medicine, 1,430 Tulane Ave, Dept of Surgery, SL-22, New Orleans, LA 70112, USA.
Email: asmith7@tulane.edu

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INTRODUCTION

Damage control surgery (DCS) focuses on abbreviated surgical procedures to identify and treat life-threatening injuries as rapidly as possible to sustain patients until physiologic factors such as coagulopathy, hypothermia, and acidosis are corrected [1,2]. During DCS, the anesthesiologist and surgeon work in tandem to rapidly restore effective blood volume with damage control resuscitation (DCR) and effective hemorrhage control. The goal of the initial phase of DCS is to perform operative procedures as expeditiously as possible with effective hemorrhage and contamination control [3–7]. After this initial phase of DCS, the patient is transferred to the Intensive Care Unit (ICU) for continued correction of acidosis, coagulopathy, and re-warming. The patient subsequently returns to the OR for definitive repairs once clinically and physiologically stable. From previous studies by our research group we were able to demonstrate the survival benefit of DCR paired with DCS with a significant increase in 30-day survival rate [8].

While the importance of maintaining physiologic stability in the severely injured trauma patient is not under debate, questions have been raised as to the role of DCS with the advent of modern DCR practices and improved resuscitation protocols for trauma patients [9–16]. The brevity of the initial operation could, in theory, result in increased surgical errors, missed injuries, and difficulty with definitive abdominal closure. Based upon these concepts, the objective of this study was to determine if length of OR time affects outcomes in patients with DCS who received modern DCR following penetrating abdominal trauma at a Level 1 trauma center. Our hypothesis was that patients with shorter initial DCS would have an increased incidence of complications, including missed injuries.

METHODS

This study was a retrospective chart review from 2010–2018 of all consecutive adult trauma patients with penetrating abdominal injuries who underwent damage control laparotomy (DCL) at an American College of Surgeons Level 1 Trauma Center. Institutional Review Board approval was obtained from Tulane University and research approval was obtained from the University Medical Center.

DCL was defined as the patient leaving the initial surgery with a temporary abdominal wall closure. The decision for DCL was made by the attending surgeon based upon the components of the death triad in addition to the patient's condition, severity of injuries, and importance of "second look" surgery due to the nature of the injuries. Operating room (OR) time was calculated from the patient's arrival to the OR to departure from the OR to the ICU and operative time was calculated as incision time to placement of a temporary abdominal dressing. Exclusion criteria were: age less than 18 years, blunt trauma, patient death in the OR, severe traumatic brain injury, or incomplete operative reports. Data collected included: age, gender, mechanism of injury, and severity of injury as measured by abdominal abbreviated injury score (AIS), injury severity scale (ISS), and Penetrating Abdominal Trauma Index (PATI) scores [17]. Surgeon experience level was also recorded. Outcomes measured were: pre-op and post-op systolic blood pressure (SBP), heart rate (HR), shock index (SI), base deficit (BD), lactic acid, international normalized ratio of prothrombin time (INR), core body temperature, as well as hospital length of stay (HLOS) and mortality. Data recorded were the worst values for each phase of care (pre-op, intra-op, and ICU). Unplanned return to the OR was defined as the patient being brought from the ICU to the OR due to clinical decompensation or concern for missed injury after initial DCL. The death triad was identified by the conventional definition of hypothermia (body temperature < 35°C), acidosis (lactic acid >2.5, pH < 7.2, and/or BD >–14), and coagulopathy (INR>1.5) [18]. Massive transfusion protocol (MTP) initiation, total OR and ICU packed red blood cells, fresh frozen plasma, platelets, and cryoprecipitate were also recorded.

As only one patient was identified to have a DCL less than 60 minutes, it was decided to stratify patients by median total procedure time into two groups (short OR time <157 minutes and long OR ≥ 157 minutes) to create two comparison groups. Differences between the pre- and post-op SI, BD, INR, core body temperature, HLOS, and mortality were calculated using unpaired two-sample *t*-tests and Fisher's exact test. A multivariate binary logistic regression was performed to assess risk factors for mortality (age, ISS, OR time, PATI score, total PRBCs, pre-operative SI). Statistical analyses were performed with GraphPad Prism (version 5, La Jolla, CA) and SPSS (version 24, Armonk, NY). A p value of ≤ 0.05 was considered significant. Results are presented as average ± standard error of the mean unless noted otherwise.

RESULTS

Demographics

The majority of patients in the study were male (89.6%) and African American (82.9%), which was similar between the two cohorts stratified by OR time. The average age of patients was 30.9 ± 0.8 years. While patients in the SHORT group were significantly younger (29.3 ± 0.9 vs. 32.5 ± 1.2, $p = 0.04$), this probably had no clinical relevance given the similar average ages.

Initial DCL and OR Time

A total of 203 patient charts were fully reviewed for inclusion in the study. Ten patients were excluded due to missing intra-operative data. The median OR time for

Table 1 Demographics and injury mechanism for 193 patients with damage control laparotomy (DCL) included in the study.

	All *n = 193*	*SHORT* *n = 95*	*LORT* *n = 98*	*p value*
Demographics				
Age, years (SEM)	30.9 (0.8)	29.3 (0.9)	32.5 (1.2)	**0.04**
Male gender, *n* (%)	173 (89.6)	87 (91.6)	86 (87.8)	0.48
Caucasian, *n* (%)	26 (13.5)	14 (14.7)	12 (12.2)	0.68
African American, *n* (%)	160 (82.9)	78 (82.1)	82 (83.7)	0.85
Other race, *n* (%)	7 (3.6)	3 (3.2)	4 (4.1)	1.0
Mechanism of injury, n (%)				
Gunshot wound	182 (94.3)	90 (94.7)	92 (93.9)	1.0
Stab wound	8 (4.1)	3 (3.2)	5 (5.1)	0.72
Glass/sharp object	1 (0.5)	1 (1.1)	0	0.49
Unknown	2 (1.0)	1 (1.1)	1 (1.0)	1.0
Severity of injury, avg (SEM)				
Injury severity score,	24.6 (0.8)	31.6 (1.1)	21.8 (1.2)	<**0.0001**
Penetrating abdominal trauma index	30.1 (1.3)	32.8 (1.9)	22.5 (1.5)	<**0.0001**
Abdominal abbreviated injury score	3.2 (0.07)	3.3 (0.1)	3.1 (0.1)	0.16

Bold *p* values in all tables represent $p < 0.05$.

all patients was 157 minutes with a range of 59–573 minutes and median operative time was 133.5 minutes, range 41–551 minutes. Only one patient had an initial DCL of less than 60 minutes. Patients were then stratified into the short OR group (SHORT, $n = 95$) and the long OR group (LORT, $n = 98$) based on the median OR time of 157 minutes. The most commonly performed procedures were small bowel resection/repair (24.3%), vascular repair or bypass (19.5%), colon resection/repair (16.7%), and control of bleeding from a liver laceration (12.2%).

Mechanism and Patterns of Injury

Gunshot wounds were the most common mechanism of penetrating trauma (94.3%) followed by stab wounds (4.1%), and glass or sharp objects (0.5%). Two patients had unknown mechanisms of penetrating trauma. The average ISS was 24.6 ± 0.8 and the average PATI scores were 30.1 ± 1.3 for all patients. The SHORT group had significantly higher average ISS and PATI scores ($p < 0.0001$), however average abdominal AIS were similar between the SHORT and LORT groups (3.3 ± 0.1 vs. 3.1 ± 0.1, $p = 0.16$). The most common abdominal organs injured were small bowel (65.9%), liver (43.9%), colon (42.9%), and stomach (26.8%) (Table 1).

Pre-Operative Vital Signs

Table 2 shows pre-operative vital signs for entire cohort stratified by OR time. There was no significant difference between the two cohorts in terms of average pre-operative SBP, HR, SI, and admission acid-base status ($p > 0.05$). The LORT group had a lower average pre-operative INR (1.1 ± 0.02 vs. 1.2 ± 0.03, $p = 0.006$) and core body temperature (34.9 ± 0.2 vs. 35.5 ± 0.1, $p = 0.009$). Two patients (1.0%, $n = 2/193$) had all three components (hypothermia, acidosis, and coagulopathy) of the death triad pre-operatively.

Post-Operative Vital Signs

Post-operatively in the ICU, the LORT group had lower average SBP (128.8 ± 2.6 vs. 138.2 ± 1.9, $p = 0.01$) and higher SI (0.9 ± 0.03 vs. 0.8 ± 0.03, $p = 0.02$). There was no difference in average post-operative HR, core body temperature, acid-base status, and INR ($p > 0.05$). Three patients (1.6%, $n = 3/193$) had all three components (hypothermia, acidosis, and coagulopathy) of the death triad pre-operatively. One patient was in the LORT group and two were in the SHORT group (Table 2).

Outcomes by Surgeon Experience

Trauma surgeons had an average of 12.8 ± 0.6 years of experience. Surgeons in the SHORT had significantly more years of experience compared to the LORT group (16.5 ± 0.8 vs 9.0 ± 0.8, $p < 0.001$). However, there was no difference in surgeon experience for patients with missed injuries compared to those without missed injuries (12.3 ± 1.6 vs. 12.8 ± 0.7 years, $p = 0.80$) (Table 2).

Blood Products in the OR

A higher percentage of patients in the SHORT group required blood transfusions (87.4% vs. 66.3%, $p = 0.0006$).

Table 2 Vital signs, acid/base, and coagulation studies for exploratory laparotomies in 193 patients with penetrating abdominal trauma requiring damage control resuscitation stratified by SHORT and LORT.

	All *n = 193*	*SHORT* *n = 95*	*LORT* *n = 98*	*p value*
Pre-operative data, avg (SEM)				
Surgeon experience	12.8 (0.6)	16.5 (0.8)	9.0 (0.8)	**<0.001**
Systolic blood pressure	113.4 (2.3)	112.0 (2.7)	115.0 (3.7)	0.52
Heart rate	107.6 (1.8)	108.0 (2.3)	107.1 (2.8)	0.80
Shock index	1.1 (0.04)	1.0 (0.04)	1.1 (0.06)	0.17
Core body temperature °C	35.2 (0.1)	35.5 (0.1)	34.9 (0.2)	**0.009**
Lactic acid	6.3 (0.3)	6.0 (0.3)	6.5 (0.5)	0.10
Base deficit	−9.4 (0.5)	−9.5 (0.5)	−9.2 (0.8)	0.75
INR	1.2 (0.02)	1.2 (0.03)	1.1 (0.02)	**0.006**
ICU data, avg (SEM)				
Systolic blood pressure	133.9 (1.9)	138.2 (2.6)	128.8 (2.6)	**0.01**
Heart rate	105.3 (1.6)	104.3 (2.4)	106.5 (2.1)	0.49
Shock index	0.8 (0.02)	0.8 (0.03)	0.9 (0.03)	**0.02**
Core body temperature, °C	36.1 (0.1)	36.1 (0.1)	36.3 (0.1)	0.16
Lactic acid	4.4 (0.2)	4.8 (0.2)	4.1 (0.3)	0.06
Base deficit	−4.4 (0.2)	−4.3 (0.5)	−4.5 (0.5)	0.78
INR	1.2 (0.01)	1.2 (0.01)	1.2 (0.02)	1.00

Table 3 Blood products requirements for 193 patients with penetrating abdominal trauma requiring damage control resuscitation stratified by SHORT and LORT.

	All *n = 193*	*SHORT* *n = 95*	*LORT* *n = 98*	*p value*
Intra-operative data				
Blood transfusion required, *n* (%)	148 (76.7)	83 (87.4)	65 (66.3)	**0.0006**
Massive transfusion protocol, *n* (%)	84 (43.5)	47 (49.5)	37 (37.8)	0.11
PRBCs, avg (SEM)	8.3 (0.6)	10.2 (0.8)	6.3 (0.8)	**0.0007**
FFP, avg (SEM)	7.3 (0.5)	9.2 (0.8)	5.4 (0.7)	**0.0004**
Platelets, avg (SEM)	0.6 (0.1)	0.7 (0.1)	0.4 (0.1)	**0.04**
Cryoprecipitate, avg (SEM)	0.3 (0.1)	0.3 (0.1)	0.2 (0.1)	0.48
ICU data				
Blood transfusion required, *n* (%)	85 (44.0)	50 (52.6)	35 (35.7)	**0.02**
PRBCs, avg (SEM)	2.8 (0.4)	2.9 (0.5)	1.5 (0.2)	**0.009**
FFP, avg (SEM)	3.0 (0.4)	3.1 (0.5)	1.0 (0.2)	**0.0001**
Platelets, avg (SEM)	0.3 (0.1)	0.5 (0.1)	0.2 (0.1)	**0.01**
Cryoprecipitate, avg (SEM)	0.2 (0.1)	0.3 (0.1)	0.1 (0.04)	0.06

The SHORT group had higher amounts of PRBCs (10.2 ± 0.8 vs. 6.3 ± 0.8, $p = 0.0007$), FFP (9.2 ± 0.8 vs. 5.4 ± 0.7, $p = 0.0004$), and platelets (7 ± 1 vs. 4 ± 1, $p = 0.04$) transfused in the OR compared to the LORT group. Similar amounts of cryoprecipitate were given to both groups ($p = 0.48$). There was no difference in MTP activation between LORT and SHORT groups ($p = 0.11$) (Table 3).

Blood Products in the ICU

The SHORT group received more blood transfusions (52.6% vs. 35.7%, $p = 0.02$) in the ICU with higher amounts of PRBCs (2.9 ± 0.5 vs. 1.5 ± 0.2, $p = 0.009$), FFP (3.1 ± 0.5 vs. 1.0 ± 0.2, $p = 0.0001$), platelets (5 ± 1 vs. 2 ± 1, $p = 0.01$), and cryoprecipitate (3 ± 1 vs. 1 ± 0.4, $p = 0.06$) transfused (Table 3).

Outcomes by OR Time

Average operative room time was almost twice as long in the LORT group (214.6 ± 6.2 vs. 121.4 ± 2.6 minutes, $p < 0.0001$). The average HLOS (22.8 ± 2.3 vs. 31.0 ± 3.5 days, $p = 0.05$) and ICU length of stay (10.6 ± 1.2 vs. 12.6 ± 1.4 days, $p = 0.28$) were both lower in the LORT group compared to the SHORT group.

Table 4 Clinical outcomes and complications for 193 patients with damage control resuscitation for penetrating abdominal trauma stratified by operating room (OR) time.

	All *n = 193*	*SHORT* *n = 95*	*LORT* *n = 98*	*p value*
Outcomes, avg (SEM)				
Operative time	168.7 (4.8)	121.4 (2.6)	214.6 (6.2)	<**0.0001**
Hospital LOS, days	26.8 (1.2)	31.0 (3.5)	22.8 (2.3)	**0.05**
ICU LOS, days	11.6 (0.9)	12.6 (1.4)	10.6 (1.2)	0.28
Complications, n (%)				
Mortality	27 (14.0)	13 (13.7)	14 (14.3)	1.00
Unexpected early return to OR	25 (13.0)	22 (23.2)	3 (3.1)	<**0.0001**
Major missed injury	4 (2.1)	3 (3.2)	1 (1.0)	0.36
Post-operative hemorrhage	28 (14.5)	13 (13.7)	15 (15.3)	0.84
Superficial surgical site infection	76 (39.4)	46 (48.4)	30 (30.6)	**0.01**
Pneumonia	28 (14.5)	14 (14.7)	14 (14.2)	1.00
Acute respiratory distress syndrome	28 (14.5)	13 (13.7)	15 (15.3)	0.84
Sepsis	68 (35.2)	36 (37.9)	32 (32.7)	0.46
Deep vein thrombosis	10 (5.2)	7 (7.4)	3 (3.1)	0.21
Pulmonary embolism	7 (3.6)	1 (1.1)	6 (6.1)	0.12
Acute kidney injury	40 (20.7)	14 (14.7)	26 (26.5)	**0.05**

Table 5 Multivariate analysis of risk factors for mortality in patients with damage control resuscitation for penetrating abdominal trauma.

	Odds Ratio	*95% Confidence Interval*	*p value*
Risk factor			
Age	1.0	0.96–1.1	0.82
Pre-op shock index	3.5	1.3–9.0	**0.01**
PRBCs in OR	1.1	0.97–1.1	0.18
OR time	1.0	0.99–1.0	0.26
Injury severity score	0.97	0.92–1.0	0.37

Complications by OR Time

The SHORT group had 22 patients with unplanned return to the OR compared to three in the LORT group ($p < 0.0001$). A total of four missed major injuries were found, which included missed colon, diaphragm, rectal, and ureter injuries. Three of these injuries were found in the SHORT group ($p = 0.36$). The incidence of superficial surgical site infections was significantly higher in the SHORT group ($p = 0.01$). Of the patients with SSI, 55.2% ($n = 42/76$) had colon injuries. SSIs were managed with local wound care, including incision, and drainage at the bedside (Table 4).

In-Hospital Mortality

The in-hospital mortality rate was 14.0% ($n = 27/193$) with an average time to death of 12.0 days (range, 1–51 days). The in-hospital mortality rate was similar between the LORT and SHORT cohorts (14.3%, $n = 14/98$ vs. 13.7%, $n = 13/95$, $p = 1.0$). A multivariate analysis of risk factors for mortality showed that OR time was not an independent risk factor for mortality (odds ratio 1.0, 95% CI (0.99–1.0) $p = 0.26$) (Table 5).

Non-Abdominal Trauma

A total of 39 patients (20.2%) had additional procedures at the time of initial DCL. The most commonly performed non-abdominal procedures during the initial DCL were pulmonary (i.e. chest tube placement, thoracotomy, or lung resection), cardiac (pericardial drainage or cardiac repair), diaphragm repair, or extremity (fasciotomy, incision, and drainage). In addition, lumbar or genitourinary injuries were also some of the most commonly reported non-abdominal organs injured. There was no statistical difference in the number of additional procedures performed between the LORT and SHORT groups ($n = 25/98$, 25.5% vs. $n = 14/95$, 14.7%, $p = 0.07$).

DISCUSSION

The main strategic goal of DCS is to minimize mortality in patients with severe trauma [1,2]. DCS employs a staged operative plan starting with an initial abbreviated laparotomy for hemorrhage and contamination control, followed by ICU physiological resuscitation and stabilization with subsequent return to the surgical suite for definitive repair [3–7]. The goal of our study was to

evaluate if operative time was a significant factor in patients with penetrating abdominal trauma in the era of modern DCR. We observed that shorter operative times were not associated with improved overall survival or a shorter length of hospital stay in patients with severe penetrating abdominal trauma despite the patients who had the shortest initial operative intervention being more critical. Furthermore, we found that the overwhelming majority of DCLs performed at our institution did not adhere to the traditional rule of 60 minutes or less. This observation suggests that the "classic" DCS goal of minimizing the operative intervention has transformed into a different practice in modern trauma surgery.

Several previous studies have demonstrated the importance of DCR in modern trauma surgery [8,9]. The correction of coagulopathy with an effective and balanced hemostatic resuscitation allows surgeons to focus on identifying and repairing traumatic bleeding and careful assessment of any other injuries in the OR during the initial operation [18]. Practice management guidelines from the Eastern Association for the Surgery of Trauma support DCR for patients with severe traumatic hemorrhage [19]. However, there has been a lack of high-quality evidence to support the impact of time on DCL outcomes and to help define the role of additional parameters other than the "lethal triad" of acidosis, coagulopathy, and hypothermia. Given the small percentage of the patients in our study who had all the elements of the lethal triad, it is likely that other parameters such as rapid identification of life-threatening injuries, balanced resuscitation with a focus on the replacement of blood products, and continued resuscitation in the ICU are also imperative in DCL [1,2,16,19,20].

Despite the adequate initial resuscitation of our cohort, the patients' abdomens were left open with a plan for a "second look" either due to hemodynamic instability, need for further resuscitation and/or patient re-warming, or due to the anatomic nature of the injuries. Notably, 2.0% of patients in this cohort did have missed injuries which were identified in the second-look laparotomies. This observation can suggest the importance of this practice to re-evaluate a severely injured trauma patient even though the incidence of missed injuries was found to be low in our cohort.

Considering that only one patient had a DCL of less than 60 minutes, our approach highlights modern trauma surgeon practices in the era of modern DCR. In general, the SHORT group was more critical than the LORT group, which probably contributed to the shorter length of initial DCL. Despite this shorter DCL, the incidence of missed injuries remained low in the entire patient cohort and there was ultimately no difference between the two groups in terms of in-hospital mortality. Furthermore, an interesting observation was that more experienced trauma surgeons were more likely to have shorter OR times during the initial surgery. This observation could suggest that trauma surgeons with more experience were more likely to have an abbreviated laparotomy in favor of continuing resuscitation in the ICU before returning for a second look.

The results of our study demonstrate that long OR times do not negatively affect patient outcomes and surgeons can focus on delivering quality care and definitively repair injuries, thus minimizing the need for additional "definitive" surgeries or unplanned early return to the OR. In the near future, DCS and DCR will start as early as the first contact with the patient on the scene with effective pre-hospital resuscitation and hemorrhage control, followed by effective intra-operative resuscitation, and early hemorrhagic control regardless of time restrictions. Our findings suggest that OR time restrictions in the era of effective hemostatic resuscitation in combination with DCS does not impact mortality. Re-direction on strategies that focus on early patient contact hemorrhage control and not on truncated OR time could potentially change the phases and outcomes of DCS patients. However, we also stress the importance of second look laparotomy if clinically indicated in the immediate peri-operative period before definitive abdominal closure.

Our study has several important limitations to discuss. First, this study is limited by the retrospective design. It also represents the experience of a single institution with DCR and DCL. Our patient population is predominately penetrating trauma, which may limit the applicability of our conclusions to some trauma centers. In addition, the authors focused on patients requiring DCR for penetrating abdominal trauma, as these patients tend to represent the most severely injured cohort requiring immediate operative exploration. However, it remains important to determine if the conclusions from this study also apply to blunt trauma patients. Furthermore, the cutoff for long versus short OR time was based on the median operative time for DCLs at our institution. We chose to use OR time instead of operative time as we felt it was important to include other variables such as anesthesia induction time, airway placement, operative prep, and patient transfer time in the analysis. We did not find any literature to help guide what should be defined as long versus short OR time, as the majority of the DCLs performed at our institution were longer than 60 minutes. The authors acknowledge that the definition of long vs. short OR time might be different at other trauma centers. In future studies, it would be important to look at the role of operative time and the time to control hemostasis and/or contamination and the impact of these time periods on the patient outcomes. In summary, future multi-institutional studies are necessary to address the limitations of this current study.

CONCLUSION

Our findings demonstrate that longer OR times do not result in increased mortality for patients with abdominal

trauma undergoing DCL. Furthermore, shorter OR times even in the most critically ill patients were not associated with worst outcomes. A multivariate analysis controlling for severity of injury and patient age found that operating time did not correlate with increased mortality. Our results suggest that damage control practices should prioritize early surgical hemorrhage control in combination with effective intra-operative resuscitation efforts by both the surgeon and the anesthesia team without focusing on the procedure length. As these practices become refined, the role of the "60 minute" DCL becomes less of a focus.

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Original Article

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Comparison of Simulation Models for Training a Diverse Audience to Perform Resuscitative Endovascular Balloon Occlusion of the Aorta

Charity Evans MD[*,1], Lisa Schlitzkus MD[*,1], Alicia Schiller PhD[2], Alexey Kamenskiy PhD[3] and Jason MacTaggart MD[1]

[1]*Department of Surgery, University of Nebraska Medical Center, Omaha, USA*
[2]*Department of Anesthesiology, University of Nebraska Medical Center, Omaha, USA*
[3]*Department of Biomechanics, University of Nebraska, Omaha, USA*

Background: The use of resuscitative endovascular balloon occlusion of the aorta (REBOA) for hemorrhagic shock is increasing, but questions remain about who to train and how best to train them. We developed a REBOA training curriculum and performed a pilot course teaching the technique to surgeons and non-surgeons using four different simulation models.

Methods: A REBOA curriculum was created incorporating four simulation models: (1) virtual reality, (2) mannequin, (3) large animal live tissue, and (4) perfused cadaver. The course was taught to $n = 6$ military personnel, including two surgeons, two emergency medicine physicians, and two non-physicians, with no prior REBOA experience. Performance using each model was recorded, and pre and post-course tests and surveys were administered. Simulation models compared capabilities, learner preferences, and cost.

Results: Learners gained confidence and performed REBOA successfully in the perfused cadaver models. Higher-fidelity live tissue and cadaver models were preferred, and learners rated them as the most realistic. Virtual reality and mannequin simulation were rated the least realistic and most dispensable methods of learning. All simulation models required significant resource investment.

Conclusions: A simplified curriculum, focusing only on the skills necessary to perform REBOA, shows promise in providing medical personnel with the confidence and competence to perform the procedure. Higher-fidelity perfused cadaver and live tissue models are preferred by learners, and future work is required to improve the usefulness of mannequin and virtual reality simulation for training. Although REBOA simulation education is expensive, it has the potential to help revolutionize military and civilian prehospital hemorrhage control.

Keywords: *REBOA; Training; Simulation; Virtual Reality; Mannequin; Large Animal Model; Perfused Cadaver*

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INTRODUCTION

Percutaneous resuscitative endovascular balloon occlusion of the aorta (REBOA) is a minimally invasive technique capable of expeditiously stabilizing patients with hemorrhagic shock due to noncompressible hemorrhage originating from vessels and organs deep in the abdomen and pelvis. The basic procedure was described by

Corresponding author:

Jason MacTaggart MD**,** Department of Surgery**,** 987690 Nebraska Medical Center**,** Omaha, NE 68198-7690, USA.

Email: jmactaggart@unmc.edu

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*These authors contributed equally.

Table 1 Course schedule.

Day 1	
2:00–2:30 pm	Registration, meet, and greet
2:30–2:45 pm	Pre-Test
2:45–3:20 pm	Didactic 1 – Course Overview • Problem of non-compressible hemorrhage • Diagnosis, signs and symptoms, mechanisms of injury • Historical management of non-compressible hemorrhage • Indications and contraindications for REBOA • Intro to REBOA
3:20–3:30 pm	Break
3:30–4:20 pm	Didactic 2 – Basics of REBOA • Equipment and technique • REBOA mannequin demonstration
4:20–4:30 pm	Break
4:30–4:50 pm	Didactic 3 – Management of the REBOA patient • Resuscitation • Monitoring • Balloon manipulations • Immediate complications • Late complications
4:50–5:00 pm	Break
5:00–6:30 pm	Hands-on technique practice • Virtual reality simulations (Mentice) • Mannequin simulators
Day 2	
7:30–8:00 am	Questions and answers
8:00–9:00 am	Hands-on technique practice • Virtual reality simulation (Mentice) • Mannequin simulation
9:00–11:00 am	Live tissue model simulation
11:00–11:30 am	Lunch
11:30 am–1:00 pm	Cadaver model simulation and testing
1:00–1:15 pm	Break
1:15–1:45 pm	Feedback
1:45–2:00 pm	Post-test, end of course survey

Hughes more than half a century ago [1], but only recently have improvements in technology merged with advances in training to allow the increasing use of REBOA to control hemorrhagic shock in trauma units throughout the world [2,3]. Because the equipment required to perform REBOA is extremely portable, the potential exists to use the technique as a temporizing measure in austere prehospital environments, and case reports describing such uses in both civilian and military populations are emerging [4,5].

Although the knowledge and skills to perform REBOA are relatively simple and are considered to be basic fundamentals for surgical and interventional specialists that frequently perform catheter-based procedures, these basic endovascular skills are often lacking in first-line trauma and general surgical providers that were not trained during the endovascular era. Civilian and military courses for acquiring the basic endovascular skills needed to perform REBOA are proliferating, but teaching and testing methods differ, and the majority of these courses primarily target surgeons [6,7]. Furthermore, course content detailing and performing more complex endovascular therapies, such as iliac artery embolization, may not be required if the ultimate training goal is to educate front-line health-care providers, who are closest to the point of injury, how to perform fluoroscopy-free REBOA. With teaching model costs often exceeding tens of thousands of dollars, comparisons between simulation tools are warranted to maximize resource utilization.

With these issues in mind, the goal of this pilot study was to develop a course capable of training a diverse group of learners to confidently and competently perform fluoroscopy-free REBOA. To help determine the best teaching and simulation strategies suitable for both surgeons and non-surgeons, we created a basic curriculum with associated evaluation tools and then administered the pilot course to a group of military medical personnel. Learner performance, simulation preferences, and costs were compared between virtual reality, mannequin, live tissue, and perfused cadaver simulation models to help guide optimal teaching methods and determine rational investment for future educational efforts.

METHODS

The study was approved by the Institutional Review Board and Institutional Animal Care and Use Committee at the University of Nebraska Medical Center (UNMC). Additional human subject and animal model research approval was also obtained through the Department of Defense to study n = 6 military personnel enrolled in a two-day pilot endovascular skills for trauma course incorporating multiple endovascular surgery simulation models, including a swine model of hemorrhagic shock (Table 1). This work built upon prior work involving the research groups in San Antonio, Ann Arbor (ESTARS), and Baltimore (Basic Endovascular Skills for Trauma, BEST). Three subject matter experts in trauma and vascular surgery participated in multiple REBOA training courses, performed a task analysis, and discussed the project with military and civilian thought leaders on REBOA. The three subject matter experts then created a curriculum composed of five elements: (1) didactic lectures (DL), (2) mannequin simulation (MS), (3) virtual reality simulation (VRS), (4) large animal live tissue simulation (LTS), and (5) perfused cadaver simulation (PCS). Survey and examination questions were based upon key points stressed during the didactic and simulation sessions. Prior to administering the pilot course to military personnel, an afternoon trial run session using the MS models and some of the didactic material was performed with the help of UNMC trauma faculty, medical students, and nurses.

Didactic

The didactic portion of the curriculum contained three slide-based lectures focusing on (1) diagnosis of hemorrhagic shock and indications for REBOA, (2) endovascular equipment and techniques for REBOA, and (3) post-REBOA resuscitation and complication management. Although this portion of the curriculum focused primarily on the cognitive aspects of REBOA training, the learners were able to get their first hands-on exposure with endovascular equipment and observe an expert performing REBOA on a mannequin simulator as part of the initial didactic sessions.

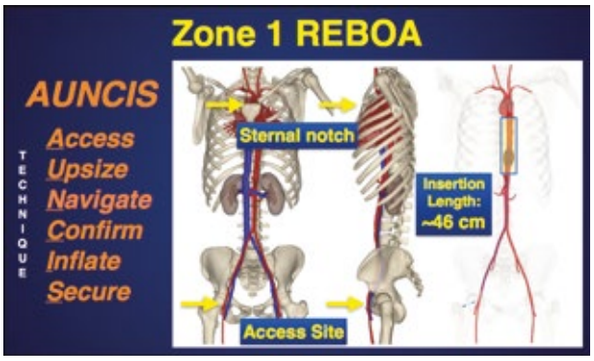

Figure 1 Procedural steps to REBOA and illustration of aortic occlusion Zone 1 balloon catheter placement.

Skills Simulation

For each of the four different modes of technical skills simulation, the REBOA procedure was deconstructed into a series of six successive steps and a checklist was created to record learner performance. For teaching purposes, the acronym *AUNCIS* (Figure 1) was used to help learners engrain the steps of performing REBOA into memory: (1) *Access* of the femoral artery; (2) *Upsizing* of the femoral artery sheath; (3) *Navigation* of the balloon catheter to the proper aortic occlusion zone; (4) *Confirmation* of proper balloon placement within the target aortic zone; (5) *Inflation* of the balloon; and (6) *Securing* of the balloon and sheath. Success or failure for each step, as well as time to completion, were recorded for each learner, during every trial, using each simulation model if applicable (VRS does not simulate femoral access). For the LTS and PCS simulations, failure to complete any of the steps was considered an unsuccessful attempt. Proper positioning of the balloon was determined by direct visualization in the MS and VRS models, palpation and blood pressure response in the LTS model, and fluoroscopy in the PCS. The volume of balloon inflation was not specifically assessed, although in the LTS model it was stressed to gently inflate only to the point of seeing a hemodynamic response on the arterial line tracing.

Mannequin Simulation (MS)

Two different mannequins were used for this pilot study. The Complete REBOA Task Trainer (CRTT) (Medalus, St. Louis, MO) is a partial torso mannequin trainer that allows simulation of the entire REBOA procedure from arterial access to balloon inflation. It contains pressurized arterial and venous systems that are represented by plastic tubes and an arterial access zone in an anatomically correct groin with soft tissue-like properties. The plastic artery and vein are visible using handheld ultrasonography and may be repeatedly accessed with needles, wires, sheaths, and catheters

during training sessions. In addition, the artery and vein can be exposed surgically for teaching femoral artery cutdown techniques.

The REBOA Access Task Trainer (RATT) Pulsatile Simulator (Prytime Medical, San Antonio, TX) is a partial torso mannequin trainer similar to CRTT that also allows simulation of the entire REBOA procedure. In addition, the RATT mannequin model provides a pulsatile fluid flow that can simulate the physiology of hemorrhagic shock demonstrating visible improvements in arterial pressure waveforms via a tablet display upon successful balloon occlusion of the plastic tube that represents the aorta. Each learner completed three trials on each mannequin trainer.

Virtual Reality Simulation (VRS)

For VRS, the VIST G5 Endovascular Simulator (Mentice, Gothenburg, Sweden) was used to simulate the passage of wires and catheters using the Vascular Trauma Management software module. This VR simulator is capable of producing variable resistances to the passage of endovascular devices providing the user with some degree of haptic feedback during the advancement of the virtual occlusion balloon. Due to hardware limitations, this electronic simulator does not incorporate the actual wires and catheters used for REBOA and cannot simulate femoral artery access. Each learner completed three trials on the VR simulator.

Live Tissue Simulation (LTS – Swine Model)

On the second day of the course, a non-survival, acute non-compressible hemorrhagic shock model using anesthetized 40–45 kg domestic swine were employed to train providers for the live tissue simulation component. For each animal, the surgeon facilitator exposed the distal aorta and the left iliac artery through a retroperitoneal incision. A 10 cm 8 French sheath (Terumo, NJ) was placed in the left iliac artery for the purpose of creating massive, but controlled hemorrhage. Upon creation of a systolic blood pressure less than 80 mmHg, each learner accessed a femoral artery using handheld ultrasound guidance (V Scan, GE Healthcare, Chicago, IL) with a 5 French micropuncture access kit (Cook Medical, Bloomington, IN), upsized the access to a 7 French sheath (Terumo Medical, Somerset, NJ), and then navigated a balloon occlusion catheter (Prytime Medical, Boerne, TX) into the descending thoracic aorta (aortic occlusion Zone 1). The balloon was inflated to control blood loss and raise proximal aortic pressure. This model provided accurate, high fidelity haptic feedback to each learner during endovascular navigation and manipulation, using equipment identical to that actually used in humans. Animal hemodynamic parameters, including blood pressure and heart rate, were monitored and displayed for real-time physiologic feedback during active hemorrhage and aortic balloon occlusion. Each participant had one attempt at performing the entire procedure, with success versus failure and procedure times recorded. Following the timed procedure, each learner was also given the opportunity to perform surgical cutdown on the common femoral artery.

Perfused Cadaver Simulation (PCS)

We used lightly embalmed cadavers because light embalming improves the preservation of natural tissue properties while reducing biohazard issues [8]. Each cadaver was assessed the day prior to the course to assure lack of prohibitive femoral, iliac or aortic occlusive disease by passing a wire from the distal superficial femoral artery proximally for at least 60 cm. Suitable cadavers were then prepared with open surgical exposure of the right common carotid artery and an 18 French cannula (Terumo Medical) placed in a retrograde fashion into the aorta. The distal carotid artery was ligated and the cannulae were secured to the artery and then attached to a large animal pulsatile blood pump (Harvard Apparatus, Holliston, MA) with a reservoir containing warm colored water. One pump was able to simultaneously drive two simulated cadaver circulations. Upon starting the pump, the arterial vasculature was pressurized and entrance into the femoral artery with a needle produced the characteristic flash and pulsatile fluid flow from the needle hub, realistically simulating femoral artery access. Though teaching emphasized placement of access into the common femoral artery, we did not specifically assess whether or not the access might have been in the superficial femoral artery or distal external iliac artery. Learners performed REBOA in its entirety using this model. For the purpose of assessing the capability of the learner to perform REBOA, the perfused cadaver model was considered the gold standard for testing purposes due to its realistic anatomy and pulsatile flow characteristics. As with the live tissue model, each learner was again given the additional opportunity to perform surgical cutdown on the common femoral artery and perform REBOA through direct arterial access.

Evaluation

Pre- and post-tests assessing cognitive knowledge, and pre- and post-course surveys assessing learner demographics, experience levels, preferences, and beliefs were created and administered immediately before and after the training course. There were no passing or failing scores determined for the examination, as this was our initial pilot study. Means and standard deviations were calculated where appropriate, however the small sample size considerably limited statistical power for most comparisons.

Table 2 Learner characteristics.

Occupation	*Clinical Experience, Years*	*Central Venous Catheter Placements per Year*	*Performed REBOA Clinically?*
Acute Care Surgeon	11–20	>10	No
	In training	>10	No
Emergency Medicine	0–5	0	No
	11–20	>10	No
Non-Clinical (PhD)	0	0	No
	0	0	No

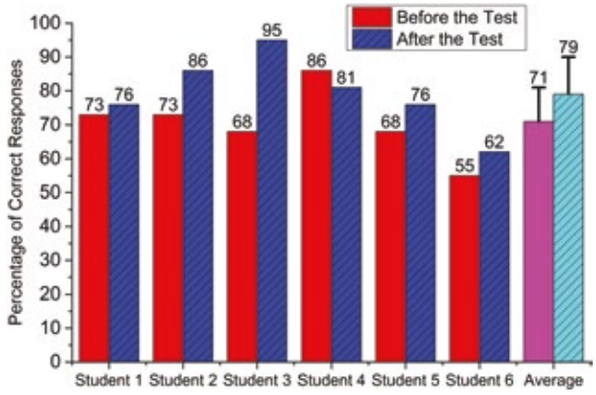

Figure 2 Pre- and post-test results.

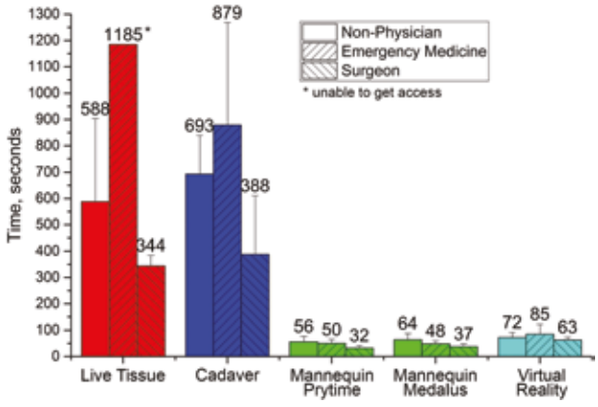

Figure 3 Times to complete the REBOA simulation for each model. Mannequin and virtual reality simulation did not include femoral access and upsizing of the sheath, resulting in greatly reduced times to completion.

RESULTS

We recruited six military personnel through an email announcement with the goal of having a mix of experienced clinician and non-clinician learners without prior training or experience performing REBOA. The characteristics of the trainees are listed in Table 2. All learners rated the didactic sessions highly and all but one learner demonstrated improved cognitive knowledge based on the pre- and post-test scores (Figure 2). All learners performed three trials on each of the VRS and MS models, while one trial was performed for each of the LTS and PCS models. Times to completion for the procedure were recorded for each trial (Figure 3).

Difficulties with the femoral access modules for each of the MS models severely limited the incorporation of this step into the simulation. As a result, for the MS and VRS trials, the learner began each trial with the upsized 7 French sheath already in place, with the times measuring the portion of the REBOA procedure that included navigation of the catheter, confirmation of balloon placement in Zone 1 of the aorta, inflation of the balloon, and verbalization of device securement. LTS and PCS model performance required significantly more time to completion for all learners due to the additional steps of percutaneous femoral access and sheath upsizing. One learner was unsuccessful at obtaining percutaneous femoral artery access in the LTS model due to hematoma and vasospasm of the artery following repeated attempts over the course of 15 minutes until the attempt was aborted. All learners were successful obtaining percutaneous access and navigating the balloon catheter to Zone 1 of the aorta in the PCS model. Learners gained confidence in their skills to deploy REBOA compared to their baseline (Table 3). Learners rated VRS as the least useful and least realistic of the simulation models (Figure 4). LTS and PCS were the preferred models and both MS and VRS were considered dispensable by the greatest number of learners (Figure 5).

Costs for all models were significant (Figure 6). Depending upon the presence of basic institutional simulation resources, like ultrasounds and reusable surgical instruments such as dissecting scissors, retractors, and arterial clamps, these costs can vary greatly. Costs may also be heavily influenced by the choice between purchase or rental of the necessary equipment. For VRS, initial outlays approaching or exceeding US$100,000 are often necessary to own the equipment and software, with several additional thousands of dollars in annual service contract fees for maintenance of optimal simulator function.

For our pilot course, we rented one simulator to use alongside the VIST G5 simulator owned by our institution. For purposes of cost comparison, we consider only

Table 3 Pre and post-course confidence in skills to deploy REBOA graded on a five-stage scale.

	Before the Course		*After the Course*	
Non-Physician	Not confident	Not confident	Slightly confident	Fairly confident
Emergency Medicine	Somewhat confident	Very confident	Fairly confident	Very confident
Surgeon	Not confident	Somewhat confident	Very confident	Very confident

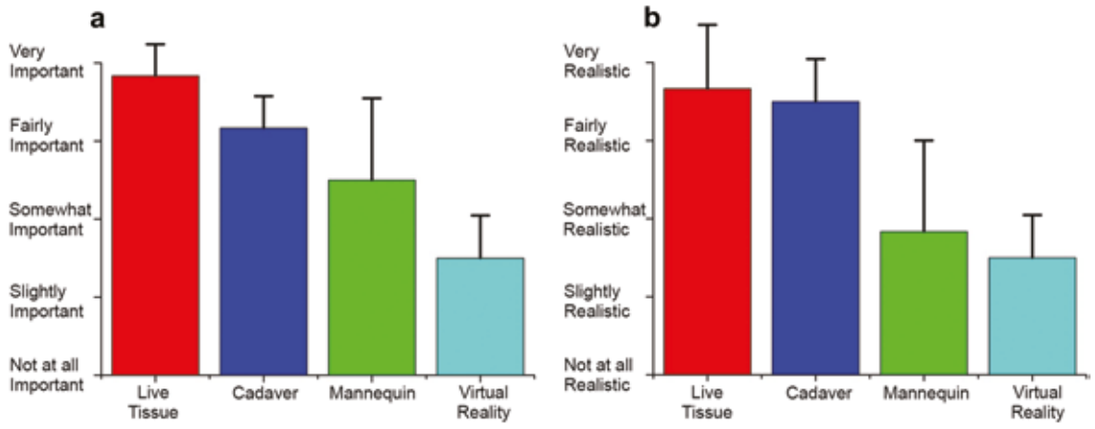

Figure 4 Learner ratings of simulation model utility (**a**) and realism (**b**).

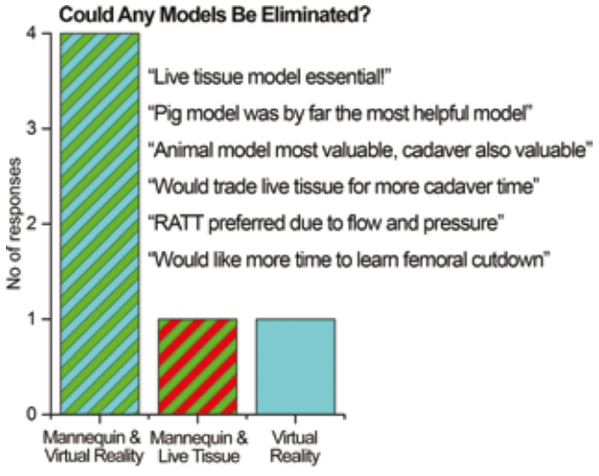

Figure 5 Learner comments and recommendations.

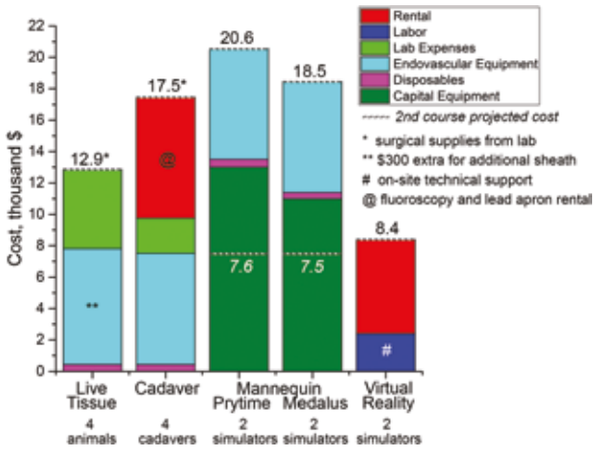

Figure 6 Cost comparison for the course with all models for six learners.

VRS rental, which also includes on-site technical support to help assure optimal function of the device and expert troubleshooting of any unforeseeable issues. MS models are the least expensive models to use over time once the upfront cost of purchasing the simulators is satisfied. The PCS model is significantly more expensive than the LTS model, primarily because of the high cost of fluoroscopy rental at our institution. Costs for the MS and LTS models over time would be primarily driven by endovascular equipment costs, most of which are related to purchase of the Prytime balloon occlusion catheters.

DISCUSSION

With the rapid adoption of REBOA as a viable means to rescue patients with exsanguinating non-compressible torso hemorrhage, data have begun to accumulate that support its utility for both civilian and military applications [4,9]. In addition to trauma, indications appear to be expanding to include other conditions that lead to circulatory collapse [10,11], spurring significant interest in the technique from non-surgical disciplines. Though REBOA theoretically is little more than an extended femoral arterial line [12], users must combine detailed

knowledge regarding the indications, complications, and technical performance of the much higher stakes procedure. The ability to know how hard and fast one can push endovascular devices through iliac arteries, or how to gain percutaneous access into a pulseless femoral artery under adverse conditions, may also require more tailored training and experience.

In analyzing the steps to perform successful REBOA, our team developed the pneumonic AUNCIS to simplify the memorization of the procedure in its entirety for novice learners. Other memorization aids have also been proposed, including the pneumonic "MEFIZZ" distributed by the manufacturer of the REBOA specific catheter. The AUNCIS pneumonic comprehensively encompasses all the steps of the procedure required to get the balloon safely inserted and functioning, including femoral access and the upsizing of the access sheath necessary to introduce the catheter, whereas MEFIZZ deals primarily with specific catheter-related preparation such as emptying the balloon and flushing the catheter.

Deciding how to optimally train the most impactful health-care providers to perform REBOA is critical to its safe and effective implementation. Multiple civilian and military training courses have used different simulation and testing models for teaching and assessing the knowledge and skills required to perform REBOA [6,7]. These methods most often include the use of mannequins, virtual reality simulators, human cadavers [13], and live tissue, usually swine. Each of these models has distinct advantages and disadvantages (Table 4).

Our data demonstrate that learners of various backgrounds preferred higher-fidelity live tissue models above all others, with the perfused cadaver also preferred over the mannequin and virtual reality simulators. Animal live tissue models offer several unarguable advantages. Real-time and reactive physiology in live tissue produces a feel similar to that of an actual REBOA procedure. Moreover, the emotional component that creates a sense of urgency and mental stress to perform the procedure correctly is difficult to replicate [14]. In a military or civilian trauma scenario, it is arguable that this experience could provide learners with a significant edge. However, ethical and cost concerns over the use of live animals are potentially prohibiting [15]. Additionally, the anatomy, although similar in the swine, is still not identical to that of a human. This makes the live tissue model viable as a training option, but not without significant limitations.

The perfused cadaver model provides a training environment in which anatomic differences are less of a concern. The model is perfused, which is most useful for confirmation of arterial access and for providing some degree of physiological feedback, but it does not appear to produce the same emotional training component that the live tissue model does. This perfused cadaver model is similar in cost and resource utilization to the live tissue model, but issues with cadaver availability and vasculature variability, often including arterial occlusive disease in more aged donors, can be limiting. The risk of communicable disease transmission is also more of a concern with fresh or frozen cadaver models. The American College of Surgeons BEST course currently employs a cadaver model as the gold standard teaching and testing method [16].

Virtual reality simulators are the newest modalities being used in medical/surgical education. There is the potential for these models to provide very real physiological feedback and allow multiple repetitions without the need to replace expensive disposable components. In our study, the virtual reality simulator was incapable of simulating the most critical portion of the procedure – percutaneous access of the femoral artery. This may not be critical for learners that have had the experience of performing hundreds of arterial or venous access procedures, but for novice learners, this weakness severely limits the utility of VRS. This was reflected in our results, with learners rating virtual reality the lowest for scales of realism and utility. The absence of access simulation, low user ratings, and relatively high cost require further examination to improve the use of this exciting and promising technology in teaching REBOA. One very promising use for VRS is in the assessment of learner technical proficiency in a standardized manner. Sensors and algorithms are capable of translating user device handling into automatically generated reports that may correlate with user competence and skill. Although the virtual reality simulators have distinct advantages that should be further pursued and refined, this technology requires significant improvement before it could fully replace existing training modalities.

In an effort to potentially alleviate many of the concerns of live tissue and cadaver models, many training and educational programs have incorporated the use of mannequins into their curriculum. Although upfront costs are not necessarily drastically reduced compared to the live tissue and cadaver models, the ongoing use of mannequin simulation versus all of the other modes of simulation is significantly less. Major purported advantages of the mannequin models are the ability to simulate the entire procedure from start to finish and the capability to withstand multiple repetitions by multiple learners. Both mannequins used in our study were completely reusable with the exception of a replaceable groin femoral access module. As we experienced in our pilot study, issues remain with the femoral access modules, and the learners rated the realism significantly less than live tissue and cadaver models. As with VRS, significant room for improvement exists for mannequin simulators that may also perform both automated teaching and assessment tasks.

For patients in hemorrhagic shock that are alive when they arrive at hospitals equipped with REBOA catheters, first-line trauma and general surgeons must be able to gain access into the femoral artery, deliver the

Table 4 Simulation model comparative matrix.

Simulation Modality		*Strengths*	*Weaknesses*
Live Tissue		Simulates the entire procedure using real equipment	Anatomical differences from human
		High fidelity physiologic and haptic feedback	One to two users for each animal
		Simulates femoral cutdown for access	Expensive – animal care and use staffing
			Vessels are smaller, more difficult to access
			Ethical issues
			More regulatory issues
Cadaver		High anatomical fidelity	5–6 uses for each cadaver
		Simulates the entire procedure using real equipment	Expensive
		High fidelity physiologic and haptic feedback	Tissues are stiffer
		Simulates femoral cutdown for access	More elderly donors with vascular occlusive disease
Mannequin	Prytime RATT	Simulates the entire procedure using real equipment	Cannot catheterize smaller branch vessels
		Fluid pressure provides enhanced haptic feedback	Groin access material stiff, prone to leaks
		Can be used with fluoroscopy	Seams in vasculature are frequent causes of obstruction
		Simulated physiological feedback	No femoral bifurcation
		Portable – can be used for deliberate practice	
	Medalus	Simulates the entire procedure using real equipment	Groin access material needs improvement
		Less expensive	No physiological feedback
		Haptic feedback	Seams in vasculature are frequent causes of obstruction
		Can be used with fluoroscopy	No femoral bifurcation
		Simulates femoral cutdown for access	
		Side branches present, though not anatomically correct	
		Portable – can be used for deliberate practice	
Virtual Reality		Can record data about learner technical skills	Does not simulate access portion of the procedure
		Simulates physiological feedback	Does not use identical equipment as real REBOA
		Simulates fluoroscopy without radiation	Expensive
		Simulates erroneous vessel catheterization	No haptic feedback to balloon inflation
		Some haptic feedback upon catheter movement	
		Portable – can be used for deliberate practice	

balloon catheter to the proper zone in the abdominal or thoracic aorta, and inflate the balloon without rupturing the balloon or the aorta. If this technology is to be pushed closer to the point of injury, where it would likely have the greatest impact on mortality, other non-surgeon or non-physician providers will need to be trained to decide when and how to perform the procedure. Our pilot data suggest alignment with previous publications that demonstrate the feasibility of accelerating the training of trauma surgeons, non-surgeon clinicians, and even non-physicians to perform REBOA [17]. Though the costs of this training may differ somewhat between institutions, the resources required to execute each of the models are significant. Although our pilot study sample size is small, insights gleaned from our data should help optimize additional studies that will help improve REBOA training for a diversity of learners. Furthermore, although follow up clinical data documenting successful performance of the procedure following course participation should be the gold standard to judge the success or failure of a curriculum, these data are sparse [18]. Further work focusing on assessing competency, skill decay, and methods to incorporate constant advances in new technology should be done to assure the safe dissemination of REBOA to those in the best position to save lives that previously were inevitable mortalities.

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Narrative Review Article

Embolization and its Limits: Tips and Tricks

Anna M Ierardi MD[1], Filippo Pesapane MD[2], Tal Hörer MD[3], Victor Reva MD[4] and Gianpaolo Carrafiello MD[5]

[1]Diagnostic and Interventional Radiology Department, University of Milan, Milan, Italy
[2]Postgraduate School of Radiology, University of Milan, Italy
[3]Faculty of Medicine and Health, Department of Cardiothoracic and Vascular Surgery, Örebro University, Örebro, Sweden
[4]Department of War Surgery, Kirov Military Medical Academy, Saint-Petersburg, Russian Federation
[5]Unità Operativa di Radiologia, Fondazione I.R.C.C.S. Cà Granda Ospedale Maggiore Policlinico, Milan, Italy

Nowadays, non-operative management is the preferred strategy, when possible. During recent years, an improvement in embolic techniques and agents, make non-operative management more feasible and effective. In the present paper, current indications, technical requirements, advantages and disadvantages, and contraindications are discussed. Moreover, particular attention is given to the limits of the embolization procedure, suggesting some tips documented by data in the literature to overcome these limits. The most feared limit or complication is the risk of non-target embolization, especially when target tissues are noble organs. Skilled interventional radiologists, embedded into an adequate multidisciplinary team, have the available tricks to limit risks, complications, and failures.

Keywords: *Interventional Radiology; Embolization; Non-operative Management; Embolization Agents*

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INTRODUCTION

Nowadays, non-operative management (NOM) is a strategy for most hemodynamically stable blunt trauma patients, whereas patients who are hemodynamically unstable despite initial resuscitation are directly transported to the operating room for exploration [1]. The mini-invasive approach and NOM certainly expedite patient recovery and minimize hospital management, which is attractive in the current era of requiring the cost-effective use of hospital facilities.

Embolization is an interventional radiology (IR) procedure involving the intentional endovascular occlusion of an artery or vein which is usually performed on patients who are hemodynamically stable, or whose hemodynamic status is stabilized with initial resuscitation [2].

Although embolization was initially employed to diminish vascular inflow in neoplastic lesions and/or to facilitate surgical excision, with the development of endovascular techniques, procedures in IR allow most of these patients to be treated effectively, sparing the need for surgery [3,4].

Since embolization should be as selective as possible, interventional radiologists can precisely identify the bleeding vessel (as well as the presence of collaterals or anatomical variants) thanks to imaging modalities such as ultrasound or contrast-enhanced computed tomography (CT) angiography, and effectively occlude it [5]. Signs of clinical improvement are often evident as soon as the procedure has been completed [1].

Although NOM is preferred if possible, many cases require damage control surgery or a combination of surgery and IR techniques [6]. In hemorrhage settings, IR and damage control surgery are indeed complementary techniques. Moreover, during NOM and mini-invasive procedures, some limits may be encountered [7] and relative contraindications should always be considered (for instance, pregnancy, renal failure, and contrast allergy) [6,8–11].

Corresponding author:
Anna M Ierardi, Diagnostic and Interventional Radiology Department, University of Milan, Via di Rudinì 8, 20142 Milan, Italy.
Email: amierardi@yahoo.it

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Table 1 Embolization key-points.

Main indications	– Treatment/stopping internal bleeding
	– Treatment of uterine fibroid tumors
	– Palliative treatment of some tumors
	– Treatment of aneurysms by blocking an artery supplying the aneurysm
	– Treatment of varicoceles
	– Administration of chemotherapy.
Limits	– Non-target embolization
	– Coagulopathy
	– Lack of time
Alternatives	– Open surgical repair
	– Correction of coagulopathy if any
Meds	– 1% Lidocaine
	– Moderate sedation
	– Antibiotics may be necessary (solid organ embolization)
Equipment	– Regular needle or micro-puncture kits
	– Guidewires/diagnostic and microcatheters
	– Embolization agents
How to perform	1. Prep and drape
	2. Local anesthesia and skin nick
	3. Seldinger technique - Guidewire, sheath, place catheter into
	4. Imaging (e.g. angiogram) to visualize target vessel
	5. Microcatheters may be used to access target vessel
	6. Deploy appropriate embolization agent
	7. Post-embolization imaging
	8. Remove catheter, obtain hemostasis
	9. Clean site and sterile bandages
Contraindications	– Hemodynamic instability
	– Pregnancy
	– Renal failure
	– Contrast allergy
	– Compartment syndrome, skin ischemia or necrosis
Adverse reactions	– Post-embolization syndrome (fever, pain, leukocytosis, nausea, vomiting)
Complications	– Puncture site: bleeding, hematoma, pseudoaneurysm, infection
	– Damage to healthy adjacent organs
	– Ischemia
	– Contrast allergy/nephropathy
Follow-up	– Bed rest per protocol
	– Evaluate puncture site
	– Keep clean and dry

In the present study, we discuss the indications, the main limits, and contraindications of embolization, with a focus on patients with hemorrhage in an emergency setting. Additionally, we analyze some challenging conditions in which embolization is required and feasible but the risk of non-target ischemia prevents execution. Finally, some tips to overcome ischemic damage will be reported.

The key-points of embolization are shown in Table 1.

INDICATIONS AND CONTRAINDICATIONS

Embolization has been used extensively in clinical practice because it may avoid the need for surgery, which has high mortality and morbidity rates in an emergency setting [6]. With technological improvements in the last decades, NOM has become the preferred first-line therapy for acutely injured patients [7, 12].

Although embolization was initially used to diminish vascular inflow in neoplastic lesions or to facilitate surgical excision, especially when the tumor is difficult or impossible to remove, this procedure can be applied to almost any part of the body to control or prevent abnormal bleeding [13].

In the acute setting, the workflow starts with a clinical evaluation. If the patient is hemodynamically stable, embolization should be promptly performed by interventional radiologists. On the contrary, if the patient is hemodynamically unstable, surgery is the gold standard and IR may have a role as embolization to reduce flow (such as in spleen or kidney hemorrhages) or as resuscitative endovascular balloon occlusion of the aorta in abdominal trauma patients [14].

Common indications include bleeding resulting from a traumatic injury, from gastrointestinal tract lesions (such as an ulcer or diverticular disease) or from vascular malformations [1]. Additionally, embolization is a technique used largely in IR to arrest small and medium-sized arteries of the peripheral system where preservation is not critical [15], whether due to penetrating or blunt injuries (for example, a patient with traumatic brain injury and pelvic trauma may require decompressive craniectomy prior to pelvic angiography and embolization; likewise, an unstable pelvic fracture may require external fixation or pre-peritoneal packing prior to embolization) [16].

Currently, NOM is the standard of care for most hemodynamically stable patients because it reduces the time of hospitalization, transfusion requirements, and costs while reducing the pain associated with tumor bleeding, preserving splenic function, and improving overall survival rates [8,17]. Furthermore, arterial embolization is also performed to treat aneurysms by either blocking an artery supplying the aneurysmal sac or closing the aneurysmal sac itself as an alternative to surgery [18–21].

Hemodynamic instability is the only absolute contraindication to NOM in traumatic patients with hemorrhage [6]. Provided that in an emergency setting there are no contraindications to carrying out embolization; pregnancy, renal insufficiency, and contrast allergy are relative contraindications in elective cases [1,5].

TECHNICAL REQUIREMENTS

Image-guided, minimally invasive procedures such as embolization should be performed by a specially trained interventional radiologist in an IR suite or occasionally in the operating room [6]. Moreover, effective integration of IR into the trauma management paradigm requires a multidisciplinary team composed of an interventional radiologist with an assistant, a nurse skilled in critical care, an interventional radiology technologist, and the availability of surgeons [22].

In an emergency setting, the primary goal of embolization is to arrest hemorrhage [12] and, hence, to minimize non-target embolization, thereby preserving organ function and limiting ischemic sequelae. Because procedures in IR can be time-consuming, it is crucial that life and limb threatening injuries are recognized and prioritized.

The multidisciplinary team decision to perform embolization rather than conventional surgical repair is typically made on the basis of imaging findings [23]. Prior to the procedure, ultrasound (US), CT, contrast-enhanced angiography, or magnetic resonance imaging (MRI) may be performed. Aside from their specialized training in the delivery of trans-catheter therapies, interventional radiologists receive broad-based multimodality imaging training, which renders them highly capable of correlating findings from pre-procedural imaging studies to speed diagnosis and the treatment of trauma patients [1,13]. The multidisciplinary team should also choose how to use the permanent or temporary (namely, resorbable) embolization material (Table 2). Resorbable in addition to permanent material may be used to aid the action of coils/plugs-occlusion [24]. Resorbable material should be the first choice in post-partum hemorrhages to spare the uterus, arresting acute bleeding while providing an early restoration of uterine artery flow, or in massive hepatic hemorrhage (when the portal vein is patent) to restore pressure and vital function of the patient with acute and massive abdominal (or even pelvic) bleeding [24–27].

A pre-procedural imaging evaluation must be complete, not only to identify injured vessels but also to document the presence of collaterals and variant anatomy [5]. Findings of vascular injury on angiography include contrast extravasation, occlusion, intimal irregularity, pseudoaneurysm (PSA), arteriovenous malformation, and dissection [12].

Currently, thanks to the rapid acquisition of CT imaging, angiography is no longer required for diagnosis and characterization of solid organ and major vascular injuries and contrast-enhanced CT (CECT) is routinely performed in most patients with blunt abdominal- and pelvic trauma, while angiography is now reserved essentially for therapeutic or problem-solving scenarios [1,6].

The length of an embolization procedure varies from 30 minutes to several hours depending on the complexity of the condition, but in the case of an emergency issue, the team response time should be within 60 minutes [13]. Moreover, the availability of contemporary angiographic equipment with digital subtraction capabilities and a complete array of IR instruments (angiographic catheters, microcatheters, guidewires, stents, stent-grafts, and embolic agents) are required [12].

The importance of rapid patient assessment and resuscitation prior to and during the embolization procedure is essential and, although CECT is highly sensitive and specific, this technique may be a time-consuming procedure that involves a considerable risk of deterioration during CT scanning itself and/or patient transfer to

Table 2 Embolization agents.

Embolic Agent	*Indications*	*Advantages*	*Disadvantages*
Permanent			
Coils	blush, PSA, AVF	super-selective, rapid effective	effectiveness in coagulopathy
Standard coils			
Detachable coils			
Active coils			
Particles	injury terminal vessel	permanent	non-target embolization, reflux
Gelfoam			
Polyvinyl alcohol particles			
Spherical particles			
NBCA (N-butyl-2-cyanoacrylate)	alternative to coil/ +++rebleeding	rapid; alternative in rebleeding	non-target embolization, microcatheter entrapment
Plugs	large vessel	1 device (vs multiple coils)	proximal embolization; angiographic catheter
Detachable balloon			
Vascular plug (AVP)			
EVOH (Onyx)	conform to complicated network of vessels	not influenced by vasospasm; not adhesive	cost
Temporary			
Gelatin sponge	rapid non-selective control of hemorrhage	cheap	poor effectiveness (+++ in impaired hemostasis)
Autologous clot		rapid	non-target embolization
Starch/swine skin gelatin particles		effective	
		uniform distribution	

AVP: Amplatzer vascular plug; EVOH: Ethylene vinyl alcohol copolymer.

CT suites. In this scenario, the hybrid emergency room is a novel trauma management system that is potentially suitable for the evaluation and care of patients with severe multiple injuries [28]. The key component of this system is a trauma resuscitation room that is designed for the completion of all the examinations and treatments in a single place and includes angio-CT equipment, anesthesiologic equipment and surgical, neurosurgical, and IR instruments.

Innovations in microcatheters, embolic agents, and stent graft technology have broadened the scope and improved the efficiency and efficacy of NOM for traumatic hemorrhage.

Procedural Consideration

Standard arterial access using the Seldinger technique should be achieved through a common femoral artery approach preferably using the side opposite any unilateral pelvic or lower extremity injury [29]. Given the extent and location of these injuries, as well as the presence of orthopedic fixation devices, axillary or brachial arterial access might be required [1]. Although sheaths are not absolutely required, many angiographers use them because multiple catheter changes are often needed. In addition, if a catheter becomes occluded or if an embolic agent deployment is compromised, arterial access can still be maintained if a sheath is used [5].

A careful selection of microcatheters is required, and end-hole catheters should be used to overcome the main limitation of this procedure, namely, non-target embolization, as discussed above. Selection of a catheter or coaxial system with an inner diameter and taper large enough to prevent occlusion by the embolic material is also crucial [6] (Table 2). Coaxial systems and microcatheters allow a more accurate selection of injured vessels and hence a more selective embolization [30]. Accordingly, a super-selective embolization technique allows rapid hemostasis in an injured vessel while preserving as much tissue as possible.

The choice of embolic agents will vary based on the site and nature of the injury, the desire to preserve collateral flow, and operator reference, as well as the inherent properties and behavior of the agent [22]. Although modern embolic agents may be either temporary or permanent, permanent agents are more common, and there are many applicable subsets including liquid agents, particulates, coils, and detachable plugs and balloons [4]. Some liquid agents, such as ethylene vinyl alcohol copolymer (EVOH), have been used in several indications (e.g., the embolization of selected traumatic injuries, renal arteriovenous malformations, renal aneurysms, and

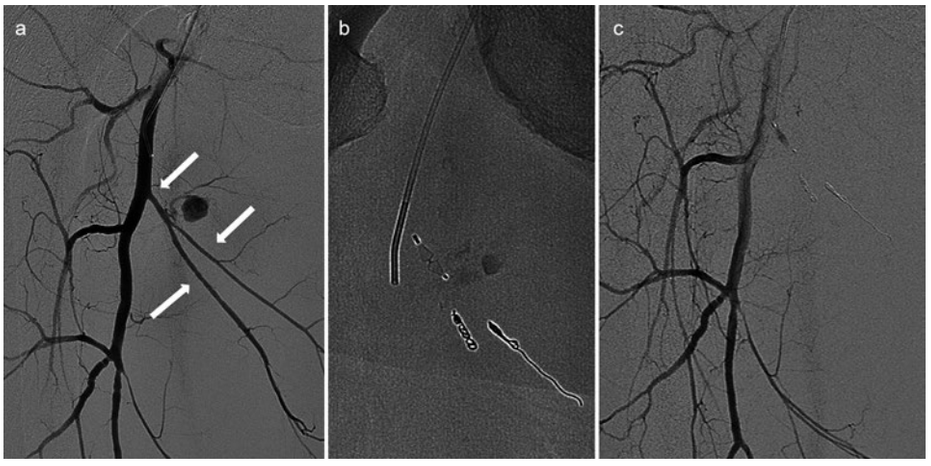

Figure 1 (**a**) Pseudoaneurysm of profunda femoral artery; (**b**) embolization performed with sandwich technique to prevent retrograde flow; (**c**) final angiogram documented complete embolization.

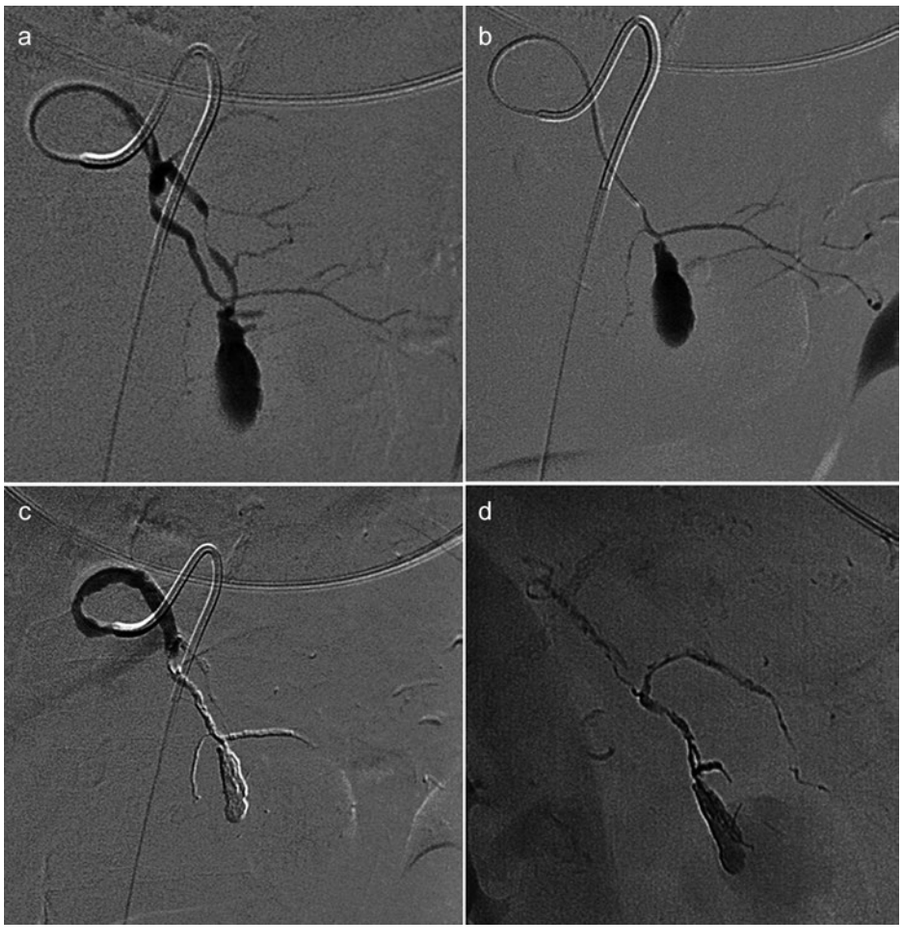

Figure 2 (**a**) Pseudoaneurysm (PSA) of left gastric artery; (**b**) selective arteriogram; (**c,d**) embolization was performed with Onyx that reached a distal vessel, filled the PSA and embolized the feeder.

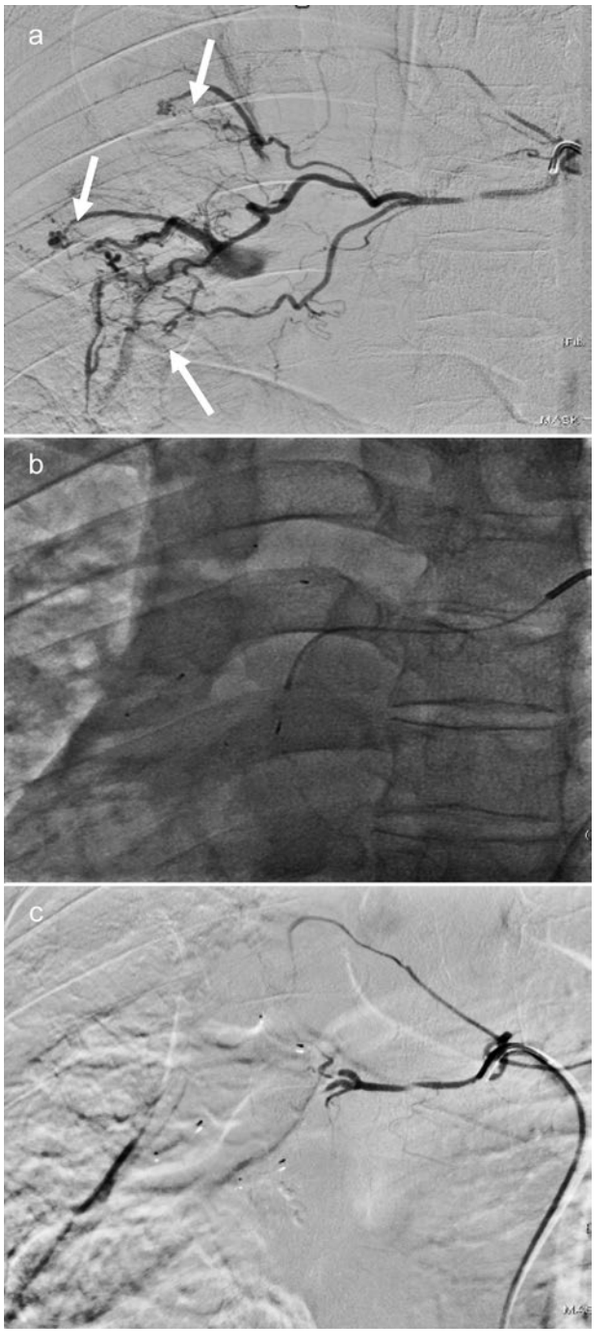

Figure 3 (**a**) Selective angiogram of the right bronchial artery reveals communication with pulmonary arteries (white arrows); (**b**) selective embolization of fistulas with micro-plugs (white arrows); (**c**) final angiogram following embolization of bronchial artery with particles.

PSAs) [3,31–35], especially in patients with coagulopathy [3]. Accordingly, Onyx (Covidien, Plymouth, MN) is the embolic agent of choice to overcome the problems of endovascular navigation and to first obtain a distal occlusion, and then a proximal occlusion [31, 36].

Clearly, the clinical condition of the patient also determines how selective a distal embolization is performed. In the stable patient, a more super-selective technique is usually undertaken, whereas in a patient who is more unstable or has massive bleeding a more non-selective proximal embolization technique is used as the main aim is the cessation of hemorrhage in a more timely manner [37].

LIMITS

Prompt, effective, and safe embolization requires good knowledge of the available equipment, arterial anatomy, role of collateral arterial flow, and possible risks. A clear understanding of the target vessel is critical, especially if it contains extensive collateral supply (e.g., via muscular branches) as these can provide distal flow and supply to the bleeding vessel and therefore result in continued bleeding if they are not also embolized. Accordingly, both the proximal and distal segments of the artery, in relation to the site of injury, are routinely embolized to prevent this complication [37].

Broadly speaking, the non-target embolization and the ischemia caused by embolization of the vital area may be considered the main limits of the embolization [1]. A technically successful embolization requires the (micro)-catheter be placed in a precise position to prevent injuring normal tissue. In a small percentage of cases, the procedure is not technically possible because the (micro)-catheter cannot be positioned to appropriately deposit embolic material in the target blood vessels [30].

The risk of non-targeted embolization should be reduced by EVOH with good radio-opacity and its injection under continuous fluoroscopy [4,31,36]. Nevertheless, symptomatic EVOH migration in pulmonary arteries has been described after embolization of cerebral vascular malformations, in the graft limb during embolization of type I endoleak, and during gastrointestinal bleeding causing non-target embolization [38,39]. Accordingly, considering its ability to penetrate, it is essential to pay extreme attention to the progression of EVOH when potentially dangerous anastomoses and/or fistulas are present [40].

The intraprocedural impossibility to reach the distal branch during an endovascular exclusion of a PSA represents an example of a condition that is a common challenge [6]. As opposed to actively bleeding vessels, PSAs require slightly different considerations. Firstly, if the vessel is non-vital, it might be sacrificed. Secondly, many vessels cannot be completely embolized [19]. When considering embolization of PSA, an interventional radiologist needs to prevent retrograde flow in the embolized vessel from collaterals, occluding vessels both distal and proximal to the injury [5] (Figure 1*a–c*). If the proximal embolization is inadequate, the PSA is revascularized by collateral vessels. If the distal embolization is inadequate, bleeding may occur in retrograde fashion via collateral blood flow. Should retrograde bleeding occur, re-embolization usually cannot be performed

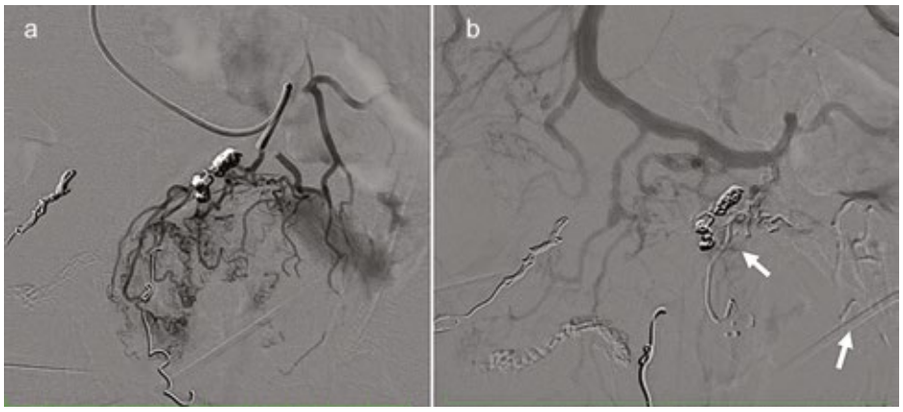

Figure 4 (**a**) Voluminous colic angiodysplasia first embolized with coils; (**b**) rebleeding after one week, embolized with Onyx (white arrows).

through the same vessel because of the more proximal embolization. Therefore, it is necessary to consider the achievable percutaneous puncture of the PSA or the use of embolizing agents (such as Onyx) which can transit into the vessels going into terminal vessels [19,41] (Figure 2*a–d*) A major limitation is the embolization of bleeding vessels that supply noble organs, such as embolization of the following vessels: medullary arteries (during embolization of intercostal arteries or bronchial arteries) (Figure 3*a–c*), mesenteric artery branches that supply parts of the intestine, hepatic artery proper when the door is thrombosed, dorsal pancreatic arteries (during splenic embolization) that would revascularize the spleen [30]. In order to facilitate distal super-selective catheterization of a microcatheter for embolization, it is preferable to place a guiding catheter as distal as possible, which may, however, increase the risk of vessel injury by manipulation of the guiding catheter [31,36].

Gentle manipulation of a guiding catheter or a microcatheter as well as a guidewire is essential to avoid vessel injuries during catheterization. Once an injury occurs, early recognition and appropriate management minimize the clinical sequelae. It is noteworthy that many dissections heal spontaneously with only conservative management [42]. For the treatment of simple vasospasm, the use of intraarterial injection of nitroglycerin is commonly performed [42]. The use of inappropriate (namely, liquid) agents into the gastrointestinal arteries may not be sufficient (e.g., the embolization of angiodysplasias coils are often not sufficient and Onyx is necessary) (Figure 4*a*,*b*) or may involve the risk of pancreatitis [1,12,43–45].

Notably, most of the embolization agents requiring a relatively intact coagulation cascade with embolization are ideally performed before severe coagulopathy develops [37]. This is noteworthy since trauma patients have frequently altered coagulation profiles [5,7,30]: one-third of patients with hypothermia and major hemorrhage require multiple blood transfusions [2,7,12,30]. Accordingly, embolization should be performed before the onset of coagulopathy [2,7,12]. Although EVOH is a notable exception—because it is effective even in the setting of coagulopathy—costs, availability, time-consuming preparation, and a technical learning curve preclude the widespread use of these embolic agents in the trauma setting [3, 39].

Finally, time is another possible limit to consider. Embolization requires skilled operators and should be available within a short time. However, no matter how quickly the procedure is conducted, it must be understood that embolization requires a significant amount of time [5].

ADVANTAGES AND DISADVANTAGES

Prospective randomized trials, which show advantages and disadvantages of embolization are difficult to perform because the trauma patient population varies widely with respect to the extent and type of injuries, clinical status on presentation, presence of comorbidities, and patient demographics. Moreover, the hyper-acute treatment scenario creates an additional obstacle to randomization [46].

In Table 3 the main benefits and risks of the embolization procedure are shown.

Pregnancy

The radiation exposure of an unborn child should be principally avoided, whenever it is medically reasonably possible. However, in cases of emergency saving the life of the patient has a higher priority than the radiation protection of the unborn child [47]. The effects of fetal radiation are highly dependent on both the administered dose and developmental stage at the time of exposure. Beyond 25 weeks, the risks of physical deformity and mental retardation are believed to be minimal unless exposure levels exceed 500 mGy [48]. The other concern is regarding the administration of contrast media as

Table 3 Main benefits and risks of embolization.

Benefits	*Risks*
It is a highly effective way of controlling bleeding, especially in an emergency situation.	Slight risk of an allergic reaction if contrast material is injected.
It can be used to treat tumors and vascular malformations that either cannot be removed surgically or would involve great risk if surgery was attempted.	Any procedure that involves placement of a catheter carries certain risks, including damage to the blood vessel, bruising or bleeding at the puncture site, and infection. However, precautions (such as antibiotic prescription) are taken to mitigate these risks.
It is less invasive than conventional open surgery. As a result, there are fewer complications and the hospital stay is relatively brief.	There is always a chance that an embolic agent can lodge in the wrong place and deprive normal tissue of its oxygen supply.
Blood loss is less than with traditional surgical treatment, and no surgical incision is needed.	The risk of kidney damage due to the contrast material, particularly in patients with diabetes or pre-existing kidney disease, is reported.

iodinated contrast agent crosses the human placenta and enters the fetus [49]. However, the intravascular administration of non-ionic iodinated contrast agent has been reported to have no effect on neonatal thyroid function unlike that administered intravenously [8].

The above considerations have no sense if the patient is a pregnant woman with a life-treating hemorrhagic condition without any other indication for alternative treatments. Moreover, embolization minimizes morbidity related to surgery. Close relatives and the patient (when it is possible) have to be informed and radiation to the fetus must be limited as much as possible. Intraprocedural radiation monitoring and dose documentation are important, particularly when a future review of fetal exposures will be performed by the patient and multidisciplinary team [9].

Renal Failure

The post-contrast–acute kidney injury (PC-AKI) incidence following direct intraarterial contrast media administration with first-pass renal exposure is frequently reported to be higher than after intravenous administration, but this remains controversial [50]. Currently, the identification of high-risk patients, appropriate hydration regimens with either isotonic sodium chloride or sodium bicarbonate, withdrawal of nephrotoxic drugs, and the use of the minimum contrast medium volume represent the preventive measures which can be suggested for daily clinical practice [51].

In life threatening hemorrhages, renal insufficiency is not a contraindication to the administration of non-ionic iodinated contrast agent; when possible the appropriate precautions described above may be adopted. Morbidities related to a surgical approach in renal failure patients should be compared with PC-AKI and its sequelae. To the best of our knowledge, no randomized studies are available, and they appear difficult to organize in this cohort of patients, as discussed above.

However, when trans-arterial procedures may be life-saving, all the other concerns should be considered secondary.

Contrast Allergy

Adverse reactions to contrast media are not uncommon, but they are usually mild and caused by toxicity or hypersensitivity [52]. Common minor adverse reactions include rash, pain at the injection site, nausea, vomiting, and minor hemodynamic changes, which are all usually self-limiting. Acute severe reactions are likely anaphylactoid in nature, and patients with asthma, atopy, or a history of an acute reaction to a contrast media are at greatest risk [53].

Known hypersensitivity to non-iodinated contrast media must alert the entire staff of the operating theater (angiographic suite or hybrid room). Pretreatment with corticosteroids can reduce the risk of, but not prevent, severe reactions. If a reaction occurs, the airway, breathing, and circulation should be managed. Administration of epinephrine and intravenous fluids is critical [53]. In the most severe cases, anaphylactic shock and acute coronary syndrome (Kounis Syndrome) can occur [52]. First-line drugs for the treatment of anaphylaxis must always be available, as should the equipment and trained personnel required for its management.

COMPLICATIONS

The inadvertent distal infarction of nonexpendable vessels and the continued bleeding distal to the point of embolization secondary to collateral flow [16,54] are the complications that may follow the embolization procedure. Occlusion of a normal territory may occur during embolization due to misinterpretation of vascular anatomy, distal migration of the embolic material during an "en passage feeder embolization," reflux of embolic material or migration of the embolic material through the artery-to-artery anastomosis. To protect a normal territory for embolization, liquid coils may be placed in the vessel, which is distal to the malformation [42].

Figure 5 and Figure 6 show the migration of glue as a complication of embolization in two different patients, probably due to an incorrect dilution of the embolization

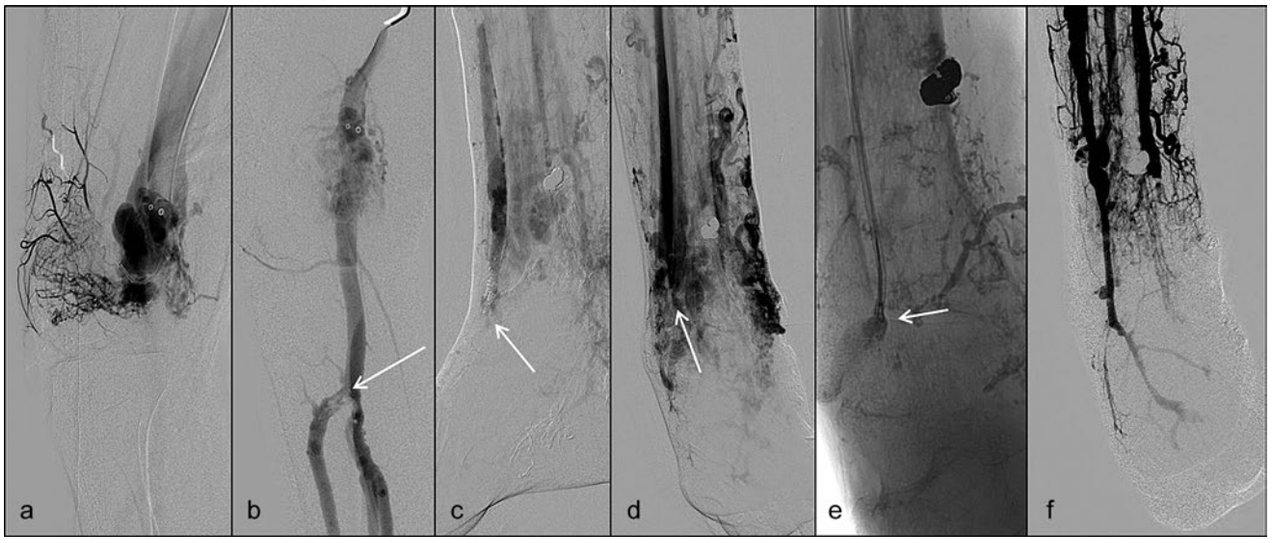

Figure 5 (**a**) Arteriovenous malformation; (**b–d**) migration of glue in anterior tibial artery and dorsal pedis artery; (**e**) recovery with snare of the migrated glue; (**f**) final angiogram.

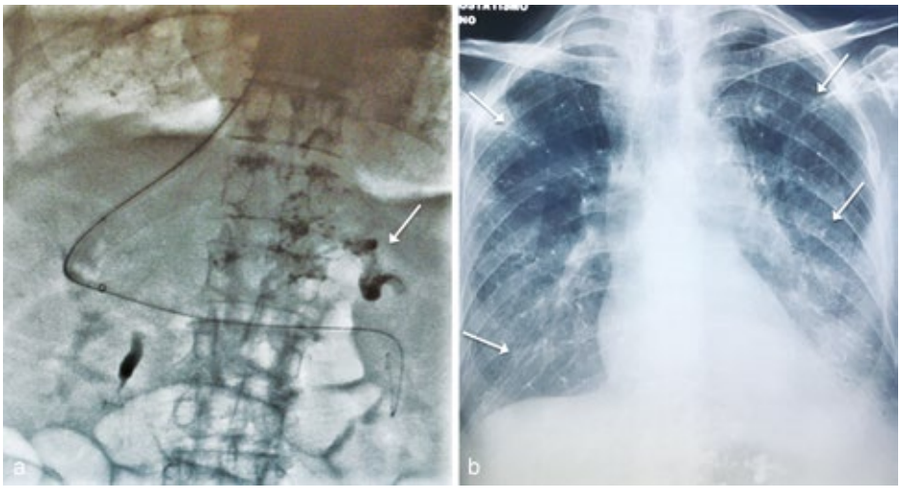

Figure 6 (**a**) Previous embolization of gastric varices with glue (white arrow). (**b**) Thorax radiograph shows diffuse migration of glue in both lungs (white arrows).

glue material. Among major complications, damage in adjacent organs has been reported [11,54,55]. Minor complications occur in approximately 10–20% of cases and include fever, pain, injuries in the puncture site (bleeding, hematoma, infection or, rarely, PSA).

Prevention is the best solution for any kind of complication [42]. Once a technical complication occurs, however, its early recognition and proper management are critical to minimize the clinical sequela. Knowledge of the disease, vascular anatomy, potential complications (and their management), the skill of interventional radiologists to handle catheters, guidewires, and embolic materials safely, and adequate equipment are the most important elements in preventing and managing technical complications that may occur during such procedures [1,30,54,56].

CONCLUSIONS

As a safe and effective first-line therapeutic approach for the majority of hemodynamically stable patients, NOM improves the clinical outcomes with acceptable low post-procedural complication rates.

Interventional radiologists have a central role in modern trauma management protocols, and their integration of intervention requires adequate and available staffing and equipment, and importantly, rapid multidisciplinary assessment and direct communication.

Limits and adverse events, among which the most feared is non-target embolization, may often be overcome using techniques and materials or a combination of them by skilled operators.

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Case Report

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Successful Control of Massive Vaginal Bleeding With Resuscitative Endovascular Balloon Occlusion of the Aorta and Pelvic Packing

Yunus E Özlüer MD, Çağaç Yetiş MD, Evrim Sayın MD and Mücahit Avcil MD

Department of Emergency Medicine, Adnan Menderes University Hospital, Aydın, Turkey

Gynecological malignancies may present as life-threatening vaginal bleeding. Pelvic packing and resuscitative endovascular balloon occlusion of the aorta (REBOA) may be useful along with conventional vaginal packing in terms of hemorrhage control. Emergency physicians should be able to perform these interventions promptly in order to save patients from exsanguination.

Keywords: *REBOA; pelvic packing; emergency department; vaginal bleeding; cervical cancer*

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CASE REPORT

A 41-year-old female with a known history of inoperable cervical malignancy presented with massive vaginal bleeding for one hour prior to her presentation to the ER. Initial vital signs upon her presentation were as follows, blood pressure of 60/40 mmHg, heart rate of 120 beats per minute and SpO2 of 99 in room air representing a Class III hemorrhagic shock with an estimated 30–40% loss of circulating blood volume [1]. She was fully alert with a Glasgow Coma Scale of 15. Her physical examination was normal except a diffuse tenderness of the abdomen with palpation. She was on low molecule weight heparin therapy due to recently diagnosed deep vein thrombosis in her right leg.

Initial laboratory workup revealed a lactic acidosis with a lactate level of 5.1 mmol/L and pH of 7.27, complete blood count of hemoglobin of 5.3 gr/dL, hematocrit of 16.7%, mean corpuscular volume of 90.3 fL and a platelet count of 427 × 10^3/μL. Coagulation tests included: international normalized ratio (INR) of 1.07, prothrombin time of 13.3 seconds (normal values: 10–14 seconds), and activated partial thromboplastin time of 43.5 seconds (normal values 22.8–31 seconds).

The patient was considered to be in Class III hemorrhagic shock and prompt resuscitation with two packs of red blood cells without a cross-match was initiated in the ER and maintained through the ICU admission process. A vaginal pack soaked in Monsel's solution (ferric sulfate) was applied to the cervix. An intravenous infusion of tranexamic acid (1 g in 8 hours) was also initiated following an intravenous bolus dose of 1 g. Despite these resuscitative measures and blood transfusions, the hemoglobin and hematocrit levels increased only to 6.7 gr/dL and 16.7%, respectively. Also, the hypotension and the vaginal bleeding persisted. We then decided to place a zone III intermittent resuscitative endovascular balloon occlusion of the aorta (iREBOA) with a 7 Fr Edwards Fogarty® occlusion catheter (Edwards Lifesciences, Irvine, CA, USA) through a 7 Fr sheath introducer (Shunmei Medical Co., Ltd., Guangdong, China), which was placed under ultrasound guidance in the patient's left common femoral artery. The occlusion catheter balloon was deflated for 15 minutes every 2 hours to perform hemorrhage control and avoid possible reperfusion injury. Total iREBOA time including the duration of the

Corresponding author:
Yunus Emre Özlüer MD, Department of Emergency Medicine, Adnan Menderes University Hospital, Aytepe Mevkii, 09100, Aydın, Turkey.
Email: yeozluer@adu.edu.tr

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Table 1 Changes in vitals and the laboratory profile after each intervention.

	Admission	*Two packs of O Rh (-) RBCs*	*iREBOA*	*iREBOA+PPP*	*PPP Alone*	*After Unpacking*
			4:4:4 Packs of RBC:FFP:Plt			
BP (mmHg)	61/52	93/66	125/66	140/90	110/80	110/70
Pulse/min	136	83	116	90	90	105
Hb (g/dL)	5.3	6.7	8.7	10.1	10.0	9.1
Htc (%)	16.7	21.3	26.1	29.9	29.3	27.2
Plt (10^3/μL)	427	275	80	95	131	124
INR	1.07	1.36	0.80	0.99	0.79	0.89
PT	13.3	17.2	10.9	13.1	10.7	12
APTT	43.5	48.7	25.1	28.3	20.3	27.6

BP, blood pressure; Hb, hemoglobin; Htc, hematocrit; Plt, platelets; INR, international normalized ratio; PT, prothrombin time; APTT, activated partial thromboplastin time.

deflation was 20 hours Although the bleeding was slowed with iREBOA, hemorrhage persisted as continuous oozing, so we decided to perform preperitoneal pelvic packing in combination with the balloon occlusion via a midline suprapubic vertical incision. Three packs were placed in each lower abdominal quadrant and hemorrhage control was achieved. iREBOA was then stopped on the next day and the patient was unpacked on the third day. During iREBOA and packing the patient received four packs of RBCs with a cross-match, four units of fresh frozen plasma and four units of platelets (Table 1). The patient was discharged on the 7th day of her ICU admission with a Modified Rankin Scale of 0.

DISCUSSION

One of the main indications for REBOA is the management of bleeding originating from non-compressible regions of the body such as the pelvis. According to the literature, REBOA seems an effective method for the management of postpartum major vaginal bleeding [2]. However, we did not come across a publication that considered the use of REBOA for major bleeding from cervical cancer.

Vaginal bleeding is a common symptom and may vary from low-grade oozing to life-threatening bleeds especially in advanced cervical cancer [3]. Local measures such as vaginal packs soaked with Moh's paste or Monsel's solution are recommended in the literature [4]. However, these measures were not able to control the bleeding in our patient. Thus, we need more advanced interventions, which we are able to perform in an emergency setting. Preperitoneal pelvic packing is primarily considered in hemodynamically unstable patients with a pelvic fracture who require a transfusion of more than two units of blood products [5]. In our patient, we sought to increase the intrapelvic pressure by packing to restrict the blood supply of the cervix. With all these interventions we achieved bleeding control in several ways: transvaginal, pelvic, and intraaortic. This led us to believe that in patients with uncontrolled hemorrhage, from a cervical malignancy, pelvic packing may be considered at an early stage of the hemorrhage as an adjunct to REBOA to achieve bleeding control.

Pelvic packing and REBOA are quick, simple and effective interventions which can be performed by emergency physicians to save their patients from exsanguination. Our patient had a Stage IVB cervical malignancy which was considered incurable with a median duration of survival under one year [6]. She had had several sessions of chemotherapy combined with radiotherapy but the efforts to cure the disease had been terminated for 6 months. With our intervention, the patient was discharged without any neurologic sequelae and we were informed via a phone call with the patient's relatives that the patient lived for 3 months after the discharge and that she was ambulatory until one month before she died. We believe that this short period of time may be important for the patient considering the situation she was in. Above all, we also suggest that even with an incurable health condition, such as end-stage malignancies, a patient should not bleed to death.

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Case Report

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Successful Fluoroscopy-Free Extremity Endovascular Revascularization in an Austere Environment

Viktor A Reva MD PhD[1], Jonathan J Morrison MD PhD[2] and Igor M Samokhvalov MD PhD[1]

[1]Department of War Surgery, Kirov Military Medical Academy, Saint-Petersburg, Russian Federation
[2]R. Adams Cowley Shock Trauma Center, University of Maryland Medical System, Baltimore, USA

Background: The use of endovascular techniques in military trauma has increased over time. We present a case of stent-graft placement in a far-forward medical treatment facility (MTF).
Methods: A 27-year-old male sustained a blast injury to his upper extremities. He was admitted to a Role 2 MTF 7 hours post-injury. On presentation, he was hemodynamically stable, with multiple closed fractures of both hands, a partial amputation of the right forearm, and the absence of right upper-extremity pulses. Plain radiographs revealed two metallic fragments overlying the right humerus head.
The patient underwent a completion below-elbow amputation and right brachial artery exploration. Following the insertion of an arterial sheath, a multipurpose 5-Fr catheter was used to obtain a single-shot angiogram, which demonstrated a traumatic sub-total occlusion of the axillary artery.
Using a combination of gentle catheter-wire manipulation and serial radiography, the lesion was traversed and access to normal subclavian artery obtained. A Fluency® Stent-Graft (6 × 100 mm) was then deployed, followed by a completion angiogram, which demonstrated the restoration of extremity perfusion.
Results: The patient was evacuated to the next echelon of care on day 5 with good perfusion of the extremity. Computed tomography angiography on day 30 demonstrated thrombotic occlusion of the stent-graft; however, the extremity was viable and further revascularization was not clinically indicated. He was discharged on day 78 following conversion to internal osteosynthesis.
Conclusion: Endovascular revascularization of extremity trauma is possible in an austere environment, although techniques need to be refined to support a reduced logistical footprint.

Keywords: *Arterial Trauma; Military Trauma; Stent-Graft; Endovascular; Vascular Trauma; Endovascular Trauma Management*

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INTRODUCTION

Combat casualty care has dramatically improved over the last decades. Alongside the military medical revolution, a paradigm shift in war surgery is taking place [1–4]. One of the most important achievements of modern military surgery lies in the implementation of endovascular techniques that have been primarily applied by civilian surgeons. Having been shown to be effective in trauma care, endovascular capabilities in a combat zone

Corresponding author:
Viktor A Reva MD PhD, Department of War Surgery, Kirov Military Medical Academy, 6 Lebedeva str., Saint-Petersburg, Russian Federation 194044.
Email: vreva@mail.ru

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have significantly improved over time, and many advanced endovascular procedures are now being performed by military surgeons on the frontline.

Resuscitative endovascular balloon occlusion of the aorta (REBOA), embolization, and stent or stent-graft implantation are among the most effective endovascular procedures for trauma care. REBOA is now being effectively used in far-forward medical treatment facilities (MTFs) and even at Role I by Special Operations Surgical Teams and in prehospital settings [5–8]. More sophisticated techniques—embolization and stenting—have been widely used in Combat Support Hospitals during the recent conflicts in Iraq and Afghanistan [9–12]. However, advanced endovascular procedures typically require fluoroscopy imaging and a wide spectrum of endovascular devices: wires, catheters, coils, stents, etc.; hence, there is still no opportunity to push forward these life-saving interventions to Role 1 and Role 2 MTFs where only basic open-damage control surgery can currently be provided.

Herewith, we present a case of successful fluoroscopy-free upper-extremity endovascular revascularization using very limited endovascular equipment and poor X-ray imaging at a Role 2 MTF.

CASE DESCRIPTION

A 27-year-old male sustained a blast injury to his upper extremities while holding the handrail of a track and was injured by small fragments during an explosion. Due to the patient's remote location, he was admitted to a Role 2 MTF 7 hours post-injury with splints applied over both his hands in tactical field care. On presentation, he was hemodynamically stable, with a Glasgow Coma Scale score of 13, and with multiple closed fractures of both hands, a partial amputation of the right forearm, and the absence of right upper-extremity pulses. Plain extremity radiographs confirmed multiple hand fractures, and two metallic fragments were observed on top of the right humerus head; however, no obvious entry wounds were ascertained. Primary laboratory testing revealed a hemoglobin level of 7.8 g/dl, platelets of 143×10^9/l, a pH of 7.39 and base excess of –2 mmol/l.

The patient was taken into the operation room, intubated and—along with resuscitation with three units of red packed blood cells and three units of fresh frozen plasma—underwent simultaneous surgery on both hands (severe bilateral triple fractures) (Figure 1). On the right arm, completion below-the-elbow debridement-amputation and a right brachial artery exploration were performed, revealing a diminished pulse (Figure 2*a*). An attempt to advance a Fogarty catheter in a proximal direction failed as the catheter met resistance at a distance of 40 cm. Following the insertion of an arterial 6-Fr sheath, a standard J-tip guidewire failed to pass through the zone of resistance at the subclavian-axillary level (Figure 2*b*). A multipurpose 5-Fr catheter

Figure 1 Simultaneous surgery is undertaken to the patient at a Role 2 medical treatment facility. External fixation of the left upper arm and debridement and vascular surgery on the right upper arm are performed.

was advanced over the wire to obtain a single-shot angiogram, which demonstrated traumatic sub-total occlusion of the axillary artery at the level of two metallic fragments (Figure 3*a*,*b*). Additional patient examination revealed two small holes (2–3 mm in diameter) in the right part of neck zone II under the patient's beard.

To restore arterial patency, the sheath was upsized to the only 11-Fr sheath available. Using a combination of gentle catheter-wire manipulation and serial radiography (a portable X-ray machine), the lesion was traversed and access to the normal subclavian artery (a middle portion) obtained (Figure 3*c*). A Fluency® Stent-Graft (6×100 mm) was then deployed, followed by a completion angiogram, which demonstrated the restoration of extremity perfusion (Figure 3*d*). No post-dilatation was performed. During the whole 80-min endovascular procedure, more than 50 radiographs were taken in total and 80 cc of contrast media was injected. At the end of the operation, the sheath was removed followed by lateral arterial suture (Prolene 6/0). The bilateral upper extremities fractures were then immobilized with external fixators. The endovascular procedure was performed by a military trauma surgeon trained in vascular and endovascular surgery who had completed several Endovascular Trauma Management workshops and who had personal, albeit limited, expertise in stent-grafting.

The patient was not treated with either anticoagulation or antiplatelet therapy, as there was an ongoing risk of traumatic brain injury. On post-injury day 1, the amputated extremity was found pale and pulseless (at the elbow) with collateral flow on Doppler examination. The patient was transported to the nearest hospital for computed tomography (CT) scanning of the head and CT angiography of the right upper extremity. CT revealed in-stent thrombotic occlusion but no significant brain injury. The first necessitated additional

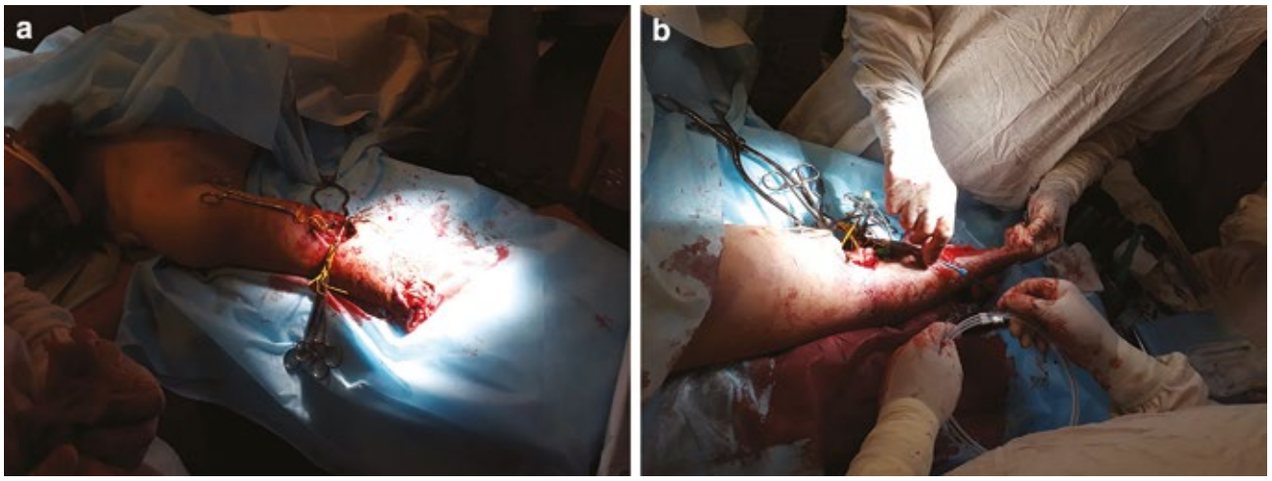

Figure 2 A below-elbow amputation and exploration of the right brachial bifurcation. (**a**) A diminished pulse is noted upon examination, which necessitates urgent surgery. (**b**) The brachial artery is cannulated with a 6-Fr sheath and a wire is advanced to perform retrograde angiography.

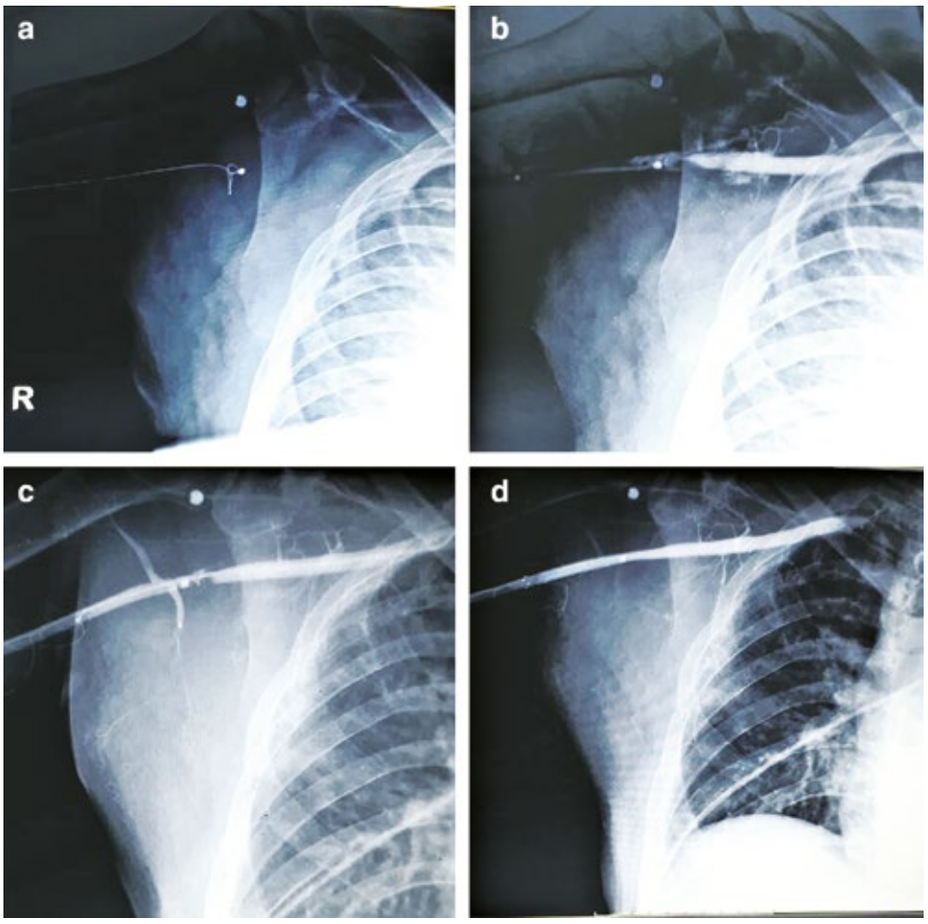

Figure 3 Fluoroscopy-free angiography and stent-graft implantation (a series of plain radiographs). (**a**) A guidewire meets resistance at the level of the axillary artery injury (two small metallic fragments are seen). (**b**) Retrograde angiography is performed to visualize the injury pattern. (**c**) An arterial lesion is traversed by a catheter, and angiography demonstrates sub-total occlusion of the axillary artery. (**d**) A completion angiogram demonstrating blood flow after stent-graft implantation.

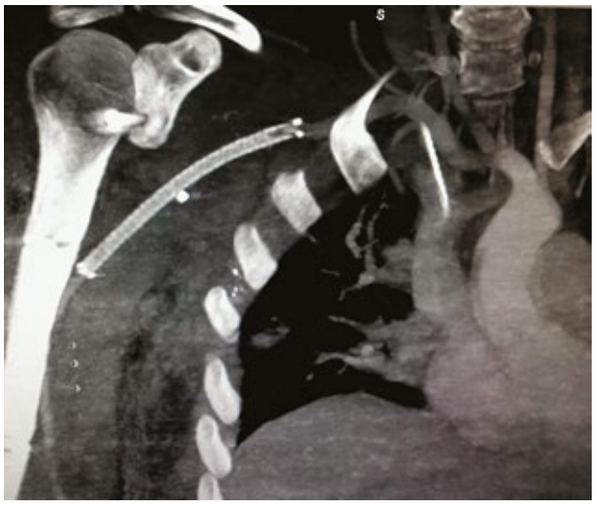

Figure 4 Day 3 CT-angiography demonstrates patency of the stent-graft and a metallic fragment lying over the vessel wall.

elbow-sparing surgical debridement of the right lower arm and re-exploration of the brachial artery bifurcation. A Fogarty catheter thrombectomy allowed extremity perfusion to reoccur, and low-molecular weight heparin (daily 10,000 IU of dalteparin), and dual anti-platelet therapy (daily 75 mg of clopidogrel and 100 mg of aspirin) were administered intra- and post-operatively. Regular Doppler examinations and day 3 CT angiography confirmed stent-graft patency and good right upper-extremity perfusion (Figure 4). On post-operative day 5, the patient was evacuated to the next echelon of care with good perfusion of the extremity. His clinical course was uneventful, the amputation stump healed completely, and no additional interventions were required. CT angiography on day 30 demonstrated thrombotic occlusion of the stent-graft; however, the extremity was viable and further revascularization was not clinically indicated. No anticoagulation was administered afterwards. The patient was discharged on day 78 following conversion to internal osteosynthesis. Two years post-injury, the patient wears a cosmetic terminal prosthesis but experiences neither phantom limb nor residual limb pain in its use.

DISCUSSION

This is the first case report to demonstrate the possibility of implementation of a sophisticated endovascular procedure—stent-graft implantation—in a far-forward (Role 2) medical facility. The Role 2 MTF is typically deployed in tents aimed to provide basic resuscitative and damage control surgery [13,14]. Surgery is usually performed by a forward surgical team consisting of a few surgeons and nurses, but not including either a vascular surgeon or an interventional radiologist [13]. At this level of care, no mobile fluoroscopy unit (C-arm) is available and only limited equipment and diagnostic tools, such as portable X-ray and ultrasound machines, are used.

A portable X-ray device was the only tool available to localize the zone of arterial injury. A single-shot angiography permitted the understanding of the mechanism and the type of arterial injury, as a pulseless arm in blunt trauma is usually caused by either concomitant bone fracture or (neuro)vascular traction injury. In this case, a careful secondary survey in addition to angiography ruled out both these potential injuries and revealed that the injury mechanism was penetrating rather than blunt, and also that two small fragments had caused the axillary arterial wall injury and concomitant occlusive thrombosis.

Recognized limb-threatening ischemia requires urgent intervention to restore perfusion and to avoid major amputation. It can be performed in one of the following ways: open surgery, endovascular stent-grafting (permanent or temporary), or as a hybrid procedure. An open approach to vascular injuries is regarded as the gold standard in civilian and military trauma care. A review of PROOVIT Registry data has demonstrated that penetrating wounds are predominantly treated with open surgery [15]; however, this results in additional trauma and blood loss. On the other hand, covered stent deployment is now a feasible alternative for patients with an axillo-subclavian injury as it leads to shorter procedure time and less blood loss, and is less technically challenging [16–19]. Stent-graft implantation, however, necessitates dual anti-platelet therapy that may theoretically worsen traumatic brain injury, which we had no possibility of excluding upon admission. In addition, endovascular devices of different sizes and lengths are required for the precise healing of an arterial lesion and adequate blood flow restoration. In our case, only two 100-mm long stent-grafts were available at the time of surgery. Our 6-mm stent seemed to fit the lesion since it covered the axillary artery and crossed to the first portion of the brachial artery, which was 4–5 mm in diameter; however, it turned out to be inadequate even for short-term patency, and reluctant inappropriate sizing was likely to be a reason for early in-stent thrombotic occlusion. Apparently, in our setting, if limb ischemia had progressively deteriorated, then open surgery would have been the method of choice to restore perfusion by either replacement or bypass of the implanted stent-graft.

Temporary stent-graft placement, as part of an "endovascular damage control" strategy, is regarded as an alternative option. Rohlffs and co-authors reported a case in which a through-and-through wire technique followed by three stent-graft deployments were successfully used as a temporary bridging tool for a completely transected axillary artery [20]. The stent-graft, implanted in our patient for temporary limb perfusion, could also be used as a "temporary endovascular shunt." Thus, by reaching Role 5 MTF, the patient could undergo the next stage of surgery—either open reconstruction or the

endovascular correction of a possible stenosis according to CT or standard transfemoral angiography.

The latest option for healing such a lesion is to establish endovascular proximal control for open vascular repair—a method described as early as in the 1990s [21]. Gilani and co-authors [19] proposed temporary balloon occlusion of the subclavian artery to allow through-and-through recanalization of a lesion via the brachial artery followed by stent deployment. Hörer and Reva described another hybrid technique (endovascular and open) to control bleeding with minimal blood loss, where a balloon catheter was temporarily placed from below or from above (crossing the aortic bifurcation) to control iatrogenic inguinal or retro-peritoneal bleeding [22]. Proximal control of the right subclavian artery followed by open repair could have been an option in our case to avoid the necessity of prolonged anti-platelet therapy; however, subclavian artery catheterization requires fluoroscopy imaging, which was unavailable.

In the given austere setting, where diagnostic and treatment options are limited, personnel and the surgical/endovascular inventory play important roles. According to the Joint Trauma System Clinical Practice Guideline, the following broad spectrum trauma-specific endovascular armamentarium is recommended for in-theater capability in the treatment of wartime vascular injuries: wires, sheaths, catheters, angioplasty and occlusion balloons, bare-metal and covered self-expandable stents of different sizes, inferior vena cava filters, embolization materials, snares, dilators, and other accessories [23]. It is, however, also applicable in a Role 3 MTF, where advanced surgical techniques can be used by a team of professionals in a stable setting. At our Role 2 MTF, there were only a few sheaths, wires, catheters, balloons and coils, and a pair of stent-grafts available during deployment. This limited endovascular inventory was mostly used for angiography and REBOA. While the latter is now a prehospital damage control option and included in Advanced Resuscitative Care [24], "direct" stent implantation can become a Role 1 or even pre-hospital intervention—as part of a "temporary endovascular shunting" strategy—in the near future.

Since the role of endovascular surgery in wartime injuries is increasing over time, personnel have to be ready to confront the new frontiers. This kind of advanced endovascular intervention, as well as the previously described REBOA cases [25], were performed by military vascular surgeons with personal experience in interventional radiology. While vascular cases are the most challenging during deployment, basic and specific endovascular training is required for military surgeons, austere surgical teams, and medics.

CONCLUSION

Our case has demonstrated the feasibility of an advanced intervention—endovascular revascularization of extremity trauma—in a far-forward Role 2 MTF with limited equipment and imaging capabilities, although techniques need to be refined to support a reduced logistical footprint. Successful fluoroscopy-free axillary artery stenting was effective in restoring the perfusion of a severely injured limb. Further evaluation of endovascular surgery in a theater of war, and the role of basic and advanced interventions on the frontline is certainly needed.

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Case Report

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Endovascular Resuscitation with Aortic Balloon Occlusion in Pediatric Trauma

Mitra Sadeghi MD[1], David T McGreevy MD[1], Rickard Lindgren MD PhD[2], Kjell Ågren MD[2] and Tal M Hörer MD PhD[1]

[1]Department of Cardiothoracic and Vascular Surgery, Faculty of Medicine and Health, Örebro University Hospital and Örebro University, Örebro, Sweden
[2]Department of Surgery, Örebro University Hospital, Örebro, Sweden

Background: The use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in resuscitation and trauma management in adults is increasing. However, there is limited data published concerning its use in pediatric patients.
Methods: We describe a case using REBOA for traumatic hemorrhagic shock in a pediatric patient according to the concept of EndoVascular resuscitation and Trauma Management (EVTM) at Örebro University Hospital in April 2019. Informed consent has been received.
Results: An 11-year-old boy arrived at the emergency room (ER) after a motor vehicle accident. Due to total hemodynamic collapse, cardiopulmonary resuscitation was initiated with return of spontaneous circulation. Zone 1 total REBOA was successfully performed for 7 minutes while damage control surgery was performed and massive transfusion was initiated to stabilize the patient. The patient survived and returned to almost normal daily activity.
Conclusion: REBOA for endovascular resuscitation and trauma management may be an additional method for temporary hemodynamic stabilization in pediatric patients and, in this specific patient, was used instead of resuscitative thoracotomy.

Keywords: *REBOA; Hemorrhage; Hemorrhagic shock; Endovascular Resuscitation; Pediatric Trauma*

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INTRODUCTION

In the pediatric population, blunt polytrauma is a major cause of mortality and morbidity, and abdominal injuries are the third leading cause of death [1]. The anatomy of children differs from that of adult patients making them more exposed to severe internal organ injuries [1]. Immediate aggressive management to control hemorrhagic shock is the key to reducing mortality [2,3]. Aortic occlusion in adolescent and pediatric patients has previously shown dismal outcomes, especially in those presenting after blunt trauma with cardiac arrest [4]. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is an endovascular device used for hemorrhage control in adults [5,6]. REBOA has primarily been used in the adult population but there is a lack of long-term prospective data. The evidence in the pediatric population is even more limited with only one retrospective observational cohort publication from the Japanese Trauma Data Bank. This includes 54 severely injured children and suggests REBOA as a reasonable option in the pediatric population [7].

To the best of our knowledge, this article presents the first published case of pediatric REBOA used in trauma performed outside Japan and the youngest trauma REBOA survivor known, as well as the youngest survivor after pediatric blunt trauma who presented in cardiac arrest.

Corresponding author:
Dr. Mitra Sadeghi, Department of Cardiothoracic and Vascular Surgery, Faculty of Medicine and Health, Örebro University Hospital and Örebro University, Örebro, Sweden.
Email: mitra.sadeghi@regionoreborlan.se

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METHODS

The case data was analyzed using the hospital medical chart. Informed consent was received from the patient's family before writing this article. The Regional Ethics Committee of Uppsala approved the study as part of the ABOTrauma Registry (Study number: 2014/210; EPN Uppsala, Sweden).

Case Presentation

An 11-year-old boy was brought by air ambulance to Örebro University Hospital after a high-speed motor vehicle collision. He had initially been conscious with stable vital signs, but during helicopter transportation he quickly decompensated with loss of vital signs. He became unconscious with no palpable pulse or measurable blood pressure and with an arrhythmic heart rate of 45 beats per minute. Impending cardiac arrest led to intubation and the initiation of cardiopulmonary resuscitation and the administration of 1 unit of packed red blood cells (PRBC) and 1 unit of fresh frozen plasma (FFP). Helicopter transportation time was 17 minutes. On arrival to the emergency department (ED), he continued to be pulseless and was noted to have a massive seat belt sign on the abdomen and chest (Figure 1). Signs of cardiac arrhythmic activity were confirmed during the initial FAST (focused assessment with sonography for trauma) assessment as well as detection of hypovolemia and free intraperitoneal fluid.

The patient received an 8 Fr sheath in both the right common femoral artery (CFA) and left common femoral vein using ultrasound guidance. REBOA (ER-REBOA) was inserted and placed uninflated in Zone 1 using landmark guidance while he was being rapidly transported to the operating theater. Total ED time was around 12 minutes. A damage control laparotomy was performed on arrival to the operation room. During laparotomy, the balloon was inflated for 5–7 minutes with 4 ml of saline as invasive systolic blood pressure (SBP) was measured at 40 mmHg; it was then used as a bridge to massive transfusion and definitive treatment with a return of spontaneous circulation. As the patient's only other access was intraosseous, the femoral venous access was used for massive transfusion since further peripheral vascular access could not be established due to his hypovolemic state. The balloon was gradually deflated while massive transfusion with 4 units of PRBC, 3 units of FFP and 1 unit of platelets was given as well as fibrinogen and tranexamic acid. The SBP was stabilized at 110 mmHg. The injuries consisted of laceration of the abdominal wall and major parts of the intestinal mesentery causing massive hemorrhage from the ileocolic artery and branches, which were ligated. A small retroperitoneal hematoma was also detected. Due to extensive devascularization of the distal parts of the small bowel, 2 meters of the small bowel, including the cecum, was resected

Figure 1 Patient on arrival to the emergency department. Bilateral vascular access and REBOA in situ (Zone I, deflated at this point).

with stapled ends leaving only 1 meter of small bowel remaining. Both introducers were initially removed by manual compression and a femo-stop compression device was placed on the right groin after the surgery was completed. The patient was hemodynamically stable but was kept sedated with an open abdomen. He was subsequently transported for a CT scan which showed a subdural hematoma and subarachnoidal hemorrhage, a craniocervical dissociation, a contrast defect from a vertebral artery, bilateral hemopneumothorax and lung contusions, a right clavicular fracture and costa 3-4 fractures, a thin layer of retroperitoneal hematoma, an unstable L3 chance fracture and a grade 2 aortic injury with intimal laceration at the same level (Figure 2).

The patient was later transported to the intensive care unit (ICU) for continued monitoring and bilateral chest drains were inserted. During second-look surgery, a left diaphragmatic rupture was observed and sutured. Subsequently, an ileocolic anastomosis to the ascending colon was performed, however abdominal wall reconstruction was not possible and the abdomen was closed with a remaining hernia. Regarding the orthopedic damage, fusion of C0-C2 and L2-L4 was performed. The grade 2 aortic injury was treated conservatively with multiple follow-up computed tomography angiography and duplex ultrasound examinations demonstrating a

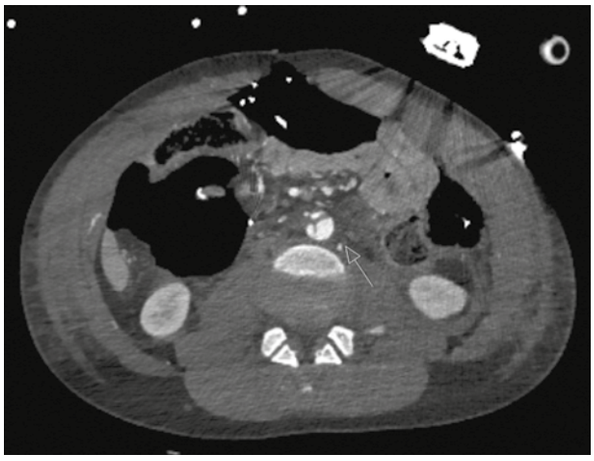

Figure 2 Abdominal CT scan after laparotomy showing a short intimal laceration of the abdominal aorta at the L3 level.

minor aortic dilation of 15 mm without progression. As the patient was experiencing neurologic symptoms corresponding to the left brachialis muscle, an MRI was performed showing signs of brachial plexus injury as well as diffuse axonal injury; both were treated conservatively. The patient remained in the ICU for 16 days and was discharged after 48 days. At 90-day follow-up, the patient had only minor paresis remaining in the left arm and has gradually returned to normal activity. Ultrasound did not show further progression of the aortic injury. Abdominal reconstructive surgery is planned.

DISCUSSION

To the best of our knowledge, this is the first case of pediatric REBOA in trauma performed outside Japan and the youngest trauma REBOA survivor known. This is also the first reported survivor to discharge after pediatric blunt trauma under the age of 14 who presented in cardiac arrest. REBOA was successfully used as a bridge to transfusion and damage control surgery. No complications were reported regarding the femoral accesses.

During the past decade, endovascular trauma management has rapidly evolved. The use of REBOA as an endovascular tool for resuscitating trauma patients with exsanguinating hemorrhage as a bridge to intervention and definitive treatment is increasing worldwide [8–10]. There are still conflicting reports regarding the benefits and dangers of REBOA and randomized studies are lacking [11–14]. The use of REBOA in the pediatric population is even more controversial since only isolated reports are available. Apart from a couple of case reports, there is only one study that has evaluated the efficacy of REBOA in pediatric trauma patients [7,15,16]. Previous requirements for using large sheaths (12 Fr) has probably been the reason that REBOA has not been considered in young patients. The alternative, resuscitative thoracotomy (RT) with aortic cross clamping, primarily recommended for penetrating trauma, is rarely performed in this group due to its high mortality rate [17]. In pediatric blunt trauma, there have only been two documented survivors who presented in cardiac arrest and no survivors documented under the age of 14 [4,18]. The introduction of smaller 7 Fr REBOA catheters has now made it technically possible for REBOA to be performed in some of these patients and therefore might be an alternative to RT. However, the question remains regarding if and for whom REBOA may be beneficial.

In this case, REBOA was performed due to traumatic impending cardiac arrest caused by exsanguinating hemorrhage and cardiac arrhythmia according to the EndoVascular Resuscitation and Trauma Management (EVTM) concept [8,19,20]. The placement of vascular access in pediatric patients should, however, be carried out with caution as the diameter of the CFA is related to age, body size, and gender. REBOA was placed in Zone 1 to allow control of the life-threatening hemorrhage, as needed, to facilitate rapid transport to the operating theater for definitive treatment. The inflation of the balloon allowed the anesthesiologists to "catch up" on blood transfusion to stabilize the patient and the limited inflation time of 5–7 minutes minimized the risk of visceral and renal ischemia. The amount of saline used for inflation of the REBOA was based on experience using targeted blood pressure level as well as the sensation of resistance when the aorta is totally occluded. It is noteworthy to discuss the cause of the grade 2 aortic injury. In this case, the aortic injury was detected on the CT scan postoperatively and, most probably, was caused by the L3 chance fracture at the same level. However, iatrogenic injury from the REBOA cannot completely be excluded and caution must be taken when inserting the device blindly.

CONCLUSION

This is the first described pediatric blunt trauma patient presenting in cardiac arrest with no signs of life that survived to discharge under the age of 14. This landmark patient and description of their care demonstrates that REBOA is a feasible option for the management of pediatric trauma patients presenting in severe hemorrhagic shock. Its use should be considered in the right patient and in the right clinical setting, however further prospective long-term studies in the pediatric patient population are needed.

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Commentary

Pediatric Blunt Trauma and REBOA

Alexis D Smith MD

Children's Healthcare of Atlanta, Emory University, USA

This is a landmark case report in that it is the first described pediatric blunt trauma patient presenting in cardiac arrest with no signs of life that survived to discharge under the age of 14. Aortic occlusion in adolescents and children has long been debated due to dismal outcomes, especially in pediatric blunt trauma in which only two survivors who presented in cardiac arrest have ever been described and no survivors documented under the age of 14 [1,2]. Current recommendations for aortic occlusion in children are extrapolated from adult data and are still highly debated. Some trauma surgeons support its utilization in only traumatically injured children that present with signs of life while others advocate for its removal altogether from the trauma treatment algorithm [1].

This paper now demonstrates that a severely injured child due to blunt injury could benefit from endovascular occlusion of the aorta as an adjunct in resuscitation for temporization of hemorrhage. The use of REBOA in the pediatric population was first described in 2010 in an acute care surgical patient by vascular surgeons at Emory with deployment to control a ruptured aortoesophageal fistula in a 10-year-old child [3]. They utilized a 7F sheath and 14 mm angioplasty balloon and were able to successfully temporize hemorrhage and bridge the patient to endovascular stent placement. A survey of Japanese experience with REBOA in pediatric trauma patients was recently published, which reviewed 54 cases of the use of REBOA in trauma patients under the age of 18 [4]. However, the Japanese database failed to capture any REBOA-specific details such as hemodynamic status, timing of AO, size of catheters or complications.

During a recent Pediatric Trauma Society meeting, the US series on pediatric and adolescent REBOA (youngest age of 14, mean age of 17) described REBOA-specific details in 7 patients that underwent endovascular aortic occlusion. While their overall in-hospital mortality was 71%; all of those patients were in arrest at the time of REBOA with ongoing CPR, had return of spontaneous circulation (ROSC), and survived to the operating room. The primary critique of the study was on the lack of change in paradigm as there was no survivor to discharge of pediatric blunt trauma due to utilization of the REBOA. Therefore, this case report of the first survivor of blunt pediatric trauma under the age of 14 with the use of aortic occlusion may have the potential to have a large impact on the consideration of REBOA in the pediatric and adolescent trauma population.

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Corresponding author:
Alexis D Smith MD, Pediatric Surgeon, Children's Healthcare of Atlanta, Emory University, USA.
Email: alexisdeanasmith@gmail.com

3005-A-1930

Two cases of extracorporeal cardio-pulmonary resuscitation (veno-arterial ECMO) in traumatic cardiac arrest caused by penetrating thoracic injuries

Yosuke Matsumura[1], Igor Samokhvalov[2], Daniil Shelukhin[3], Alexander Rud'[2], Alexander Petrov[2], Gennady Khubulava[2], Natalya Rodina[2], Marat Vasil'ev[2], Grigory Lysenko[2], Alexander Emel'yanov[2], Evgeny Ershov[2], Vasiliy Suvorov[2], Viktor Reva[2]

[1] 1) Chiba University Graduate School of Medicine, Chiba, Japan
[2] 2) Kirov Military Medical Academy, Saint-Petersburg, Russia
[3] 3) Nikiforov Russian Center of Emergency and Radiation Medicine, Saint-Petersburg, Russia

Background. We demonstrate two cases of penetrating thoracic injuries necessitated extracorporeal CPR.

Materials and methods. Two male patients were admitted to our hospital within 20-25 minutes after a chest stab and gunshot injury, respectively. With ongoing CPR, patient #1 underwent resuscitative sternotomy/left thoracotomy. Bleeding from a through-and-through right ventricle injury was controlled, but cardiac arrest (CA) re-occurred. Patient #2 underwent immediate surgery due to multiple rib fractures, massive hemopneumothorax; experienced multiple CAs (defibrillated 19 times). Due to refractory asystole with ongoing CPR, ECMO was initiated in 100 and 135 minutes in both cases, respectively.

Results. In both cases, femoral artery (17-19Fr) and vein (25-27Fr) were cannulated and connected to the Maquet ECMO circuit with a flow rate of 4-5 L/min. Intraoperatively collected shed blood was reinfused to maintain blood volume. In both cases, the ROSC was achieved within 20 minutes after ECMO initiation with relative stabilization of mean arterial pressure: 50-60 and >80 mmHg, respectively.

In patient #1, postoperative bleeding necessitated re-thoracotomy and hemorrhage control. In patient #2, left pulmonectomy, ligation of intercostal arteries, and pleural cavity packing were performed. Twelve and 30 units of red blood cells, 16 and 45 units of fresh frozen plasma, and 2 and 8 units of platelets were given in case #1 and #2, respectively. Additionally, 7160 mL of blood were reinfused in case #1. Lactate level increased from 8 to 25 mmol/L and decreased from 20 to 8 mmol/L in 5 hours in case #1 and #2, respectively. Both patients died in the ICU within 9 and 13 hours after admission, respectively, due to bleeding.

Conclusion. Extracorporeal-CPR allows vital function protection even in traumatic CA, but necessitates appropriate resuscitation. If no bleeding control is achieved, then E-CPR is futile.

This study was supported by a grant #MK-5676.2018.7.

3006-A-1930

Ninety minutes of aortic occlusion – Is there a chance for survival? A comparative study of occlusive and non-occlusive REBOA techniques in a hemorrhagic ovine model

Yosuke Matsumura[1], Viktor Reva[2], Alexey Denisov[2], Artem Nosov[2], Konstantin Demchenko[2], Mikhail Sokhranov[2], Margarita Sokolova[2], Natalya Zhirnova[2], Igor Samokhvalov[2]

[1] 1) Chiba University Graduate School of Medicine, Chiba, Japan
[2] 2) Kirov Military Medical Academy, Saint-Petersburg, Russia

Introduction. The aim of this study is to evaluate the early (24 hour) survival and organ damage following total [tREBOA], partial [pREBOA] and intermittent [iREBOA] 90-minutes REBOA in an ovine model of severe hemorrhagic shock.

Materials and methods. Eighteen sheep were induced into shock by undergoing a 35% controlled exsanguination followed by sheath removal and uncontrolled hemorrhage. Animals were randomized into three groups: tREBOA, pREBOA (defined by proximal to distal systolic blood pressure [sBP] ratio 2-3:1 and/or proximal sBP of 90-100 mmHg) and iREBOA (15-min occlusion/non-occlusion intervals). Resuscitation with crystalloids and whole blood was initiated 10 and 75 mins after the induction of shock. Animals were monitored in an animal ICU for 24 hours. Autopsy was performed to evaluate organ damage. This study was supported by a grant RSF#17-73-20318.

Results. Additional blood loss was higher in the pREBOA group: 158 [15-169] mL compared to the iREBOA (60 [37.5-150.5] mL) and tREBOA group (27 [10.5-64.7]) mL (p=0.285). No animals died within shock induction and during hemorrhage. Twenty-four hour survival for the t-, p-, and iREBOA groups was 0/6, 4/6, and 2/6. Mean survival time was lower in the tREBOA group (8.8h) versus pREBOA (21.0h) and iREBOA (17.7h) group (p=0.0008, log-rank test).

No significant changes in pH-level was found among non-occlusive groups. After balloon deflation in the tREBOA, pH-level sequentially decreased from 7.28±0.10 to 6.81±0.01 (p=0.049). Lung weight/body mass index was higher in the tREBOA group 15.63±3.42 compared to the pREBOA (11.69±2.14) and iREBOA (13.19±1.47) groups (p=0.044). Autopsy revealed necrotic damage of small intestines and severe acute tubular necrosis in the t- and iREBOA groups only.

Conclusion. Ninety-minutes total aortic occlusion is highly lethal. Non-occlusive techniques should be used to avoid severe metabolic insult, organ damage and early death. Partial-REBOA is better tolerated compared to other REBOA techniques.

3049-A-1930

REBOA as resuscitative tool for postpartum hemorrhagic shock due to ruptured renal artery aneurysm

Simone Fajer[1], Moanis Ajaj, Maysam Shehab

[1] EVTM

Severe postpartum hemorrhage occurs in 1/1000 in women giving births. Fluoroscopy free REBOA has been presented for controlling life threatening postpartum hemorrhage. We present a case with ruptured renal artery aneurysm after childbirth in a 35 year old woman.

Methods:

Fluoroscopy- free REBOA was used to treat postpartum hemorrhagic shock in a woman without vaginal bleeding. Blood pressure decreased to 50mmHg despite aggressive resuscitative measures. The REBOA was inserted by a vascular surgeon into Zone II after a femoral artery cut down was performed. Full inflation aided in stabilization of blood pressure to 70-80mmHg. Simultaneously, the abdomen was opened midline and control was obtained of the aorta, vena cava and right renal vessels. Hemorrhage from lacerations of the vena cava below the right renal vein were sutured, as were the right renal vessels. A right nephrectomy was performed. The REBOA remained inflated fully for 15 minutes; thereafter partial inflation was required. After definitive treatment , the balloon and sheath were removed with no complication. She was discharged one week later.

Results:

REBOA successfully aided in the treatment of severe shock in a postpartum patient and bought time for the anesthesiology team to resuscitate the patient. Partial inflation also greatly aided in maintaining systemic blood perfusion.

The pathology report of the kidney demonstrated a ruptured renal artery aneurysm with evidence of fibromuscular dysplasia.

Conclusions:

Severe abdominal hemorrhage after normal childbirth occurs in a small percentage of women. Rupture of renal artery aneurysms are even more rare, with an incidence of renal artery aneurysms less than 1.5 %. The event is usually acute and life threatening.

We suggest the use of REBOA as resuscitative tool, possibly inserted fluoroscopy free in well trained hands. Partial inflation of the REBOA plays an important role in stabilizing the patient after initial full inflation

3071-A-1930

Utilization of the Compass pressure transducer for resuscitative endovascular balloon oclusion of the aorta guided resuscitation

Daniel Lammers[1], Christopher Marenco[1], Jessica Weiss[1], Kaitlin Morte[1], Dominic Forte[1], Woo Do[1], Rowan Sheldon[1], Jason Bingham[1], Matthew Martin[2], Matthew Eckert[1]

[1] Madigan Army Medical Center
[2] Scripps Mercy Hospital

Introduction: Resuscitative endovascular balloon occlusion of the aorta (REBOA) and partial REBOA (pREBOA) are becoming increasing popular adjuncts for noncompressible truncal hemorrhage. Continuous blood pressure monitoring remains logistically intensive during REBOA and pREBOA and may prove difficult within military or austere environments. This study aims to assess blood pressure monitoring through a comparison of standard arterial line measurements to the Compass, a handheld pressure transducer, during REBOA- and pREBA-guided resuscitation practices.

Methods: Twenty adult swine (35-55kg) were randomized to normal physiologic conditions with Zone 1 ER-REBOA (nER, n=5) vs prototype pREBOA (nP, n=5) or a combined 20% controlled hemorrhage and iliofemoral vascular injury with zone 1 ER-REBOA (iER, n=5) vs prototype pREBOA (iP, n=5). Continuous blood pressure readings were obtained using both standard arterial line (AL) and Compass device (CD) readings proximal and distal to the occlusive balloon while aortic occlusion was sequentially deflated in a flow targeting fashion from complete occlusion (0L/min) to full aortic flow of 1L/min.

Results: AL and CD readings proximal to the REBOA balloon failed to demonstrate any significant differences overall ($p>0.05$ for all) and was further confirmed when stratified by hemorrhage versus no hemorrhage, ER-REBOA versus prototype pREBOA, and at each targeted distal aortic flow rate ($p>0.05$ for all). Blood pressure measurements distal to the occlusion demonstrated no difference between AL and CD for all flow rates except 0.3 ($p=0.017$), however reliably differed significantly when stratified by hemorrhage and REBOA type.

Conclusion: The Compass device demonstrated equivalent blood pressure readings proximal to the REBOA catheter when compared to standard arterial line monitoring. This device represents a less demanding approach to proximal blood pressure monitoring during REBOA and pREBOA resuscitation strategies with immediate translatable use in the far forward military and austere environment.

3072-A-1930

Endovascular treatment of concomitant innominate and subclavian artery injury from gun-shot wound with pseudoaneurysms in a polytrauma patient

TONGPORN WANNATOOP, WORAWONG SLISATKORN, PICHEJ LERDPUNNAPONGSE

Background: The study demonstrates the outcome of endovascular treatment in a patient with gun-shot wound at neck and concomitant innominate and right subclavian artery injury with pseudoaneurysms.

Materials and methods: A case report

A 34-year-old female who suffered from gun-shot wound penetrating to the anterior neck and chest, presented with cardiac arrest and tension pneumothorax. She was recovered after a successful resuscitation at the primary hospital. Three days later, she developed alteration of conscious and left hemiparesis. CT scan showed acute infarction involved right cerebral hemisphere and left cerebellar region and a large (7.1x8.6 cm.) pseudoaneurysm at anterior neck which was originated from innominate artery and a small (1.5x2.2 cm.) pseudoaneurysm from proximal right subclavian artery.

She was transferred to our University hospital. Repeated CT scan showed unchange in size of pseudoaneurysms and impending right uncal and tonsillar herniation. Emergency right craniectomy was immediately performed. Due to a complex vascular injury and unstable neurological condition, the endovascular intervention was planned to manage the complicated neck vessel injury. The innominate artery was repaired with a self-expandable stent graft (Viabahn , 8mmx10cm) landed into right carotid artery via left common femoral artery access and the right subclavian artery stent graft (Viabahn , 9mmx10cm) was deployed respectively via right brachial artery access.

After operation, her hemodynamic status was stable and neurological condition was gradually improved. She was discharged to home 3 weeks after operation. Two months postoperatively, her neck hematoma was completely resolved. CT scan showed good patency of both carotid and subclavian artery stent grafts without endoleakage nor pseudoaneurysm.

Conclusion:

Endovascular treatment showed an excellent short-term outcome in a complex neck vascular injury in polytrauma patient. Following concept of Endovascular Resuscitation and Trauma Management with prioritized approach, the best plan for patient is set with the great result.

3073-A-1930

Overinflation in aortic balloon occlusion- An ex vivo study.

Marta Madurska [1], Michael Richmond[1], Sakib Adnan [2], Curtis Franklin[3], Jonathan Morrison [1]

[1] R Adams Cowley Shock Trauma Center
[2] Einstein Medical Center, Philadelphia
[3] Prytime Medical

Background

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is as an effective alternative to resuscitative thoracotomy in noncompressible torso hemorrhage (NCTH). Despite improvements in catheter profile there are fears of overinflation and aortic damage. However, technology continues to evolve with improved devices. The aims of this study are to compare inflation properties of a standard REBOA balloon, and a novel catheter with an added pressure pop-off valve.

Methods

12 porcine aortic segments of varying sizes were harvested post euthanasia.

The study consisted of two phases. In the first phase, 6 semicompliant balloons with a pop-off valve set at 6.5 psi were inflated in the aortas until the valve release, followed by injection with additional 30ml. The second study involved intermittent inflation of 6 standard compliant balloons (SCO) and 6 semicompliant (CO) balloons, without the pop-off valve, until balloon or aortic rupture. Data including pressure, volume, balloon working length, diameter and circumferential stretch ratio were collected.

Results

At failure, mean balloon volume was almost double in CO group vs SCO group (p=0.004), with 36% increase in working length in the CO group (p=0.023). When plotted, the relationship pattern between volume and pressured differed between the groups. Following attempted overinflation with the pressure valve, there was no change in parameters before and after attempted overinflation.

Conclusions

During inflation, a compliant balloon changes shape to accommodate increasing volume with little change in pressure, in contrast to the semicompliant balloon. A pressure valve can successfully prevent overinflation but can only be used with a semicompliant balloon where incremental inflation brings on a sustained raise in pressure. With the addition of a pressure valve, a novel semi-compliant aortic occlusion catheter may effectively prevent overinflation and reduce the risks of aortic injury.

3074-A-1930

Partial vs Complete resuscitative endovascular balloon occlusion of the aorta (REBOA): early results from a single trauma center.

Marta J Madurska[1], Ashley McLenithan[2], Jonathan J Morrsion[1], Thomas M Scalea[1], Joseph J DuBose[1]

[1] R Adams Cowley Shock Trauma Center
[2] Philadelphia College of Osteopathic Medicine

Introduction

Since its introduction into clinical practice as a practical alternative to resuscitative thoracotomy in patients with noncompressible truncal hemorrhage (NCTH), REBOA technique has been evolving. The concept of partial REBOA (P-REBOA) has emerged in recent years with the aim of mitigating potential complications associated with aortic occlusion. However up to date, limited outcomes have been published with regards to P-REBOA. The aim of this study is to present our single center pilot data of trauma patients who were managed with P-REBOA and compare it with a cohort who had complete occlusion (C-REBOA).

Methods

Prospectively led REBOA registry at R Adams Cowley Shock Trauma Center has been analyzed. Patients included those who had zone I REBOA for NCTH between January 2013 and May 2019 and survived to operating theatre. Outcomes were compared between two groups: <30 min and <60min occlusion.

Results

A total of n=59 patients were treated with REBOA. N=14 had P-REBOA. In the <60min cohort, patients who had P-REBOA (n=3) had a shorter ICU stay (3 vs 14 days, p=.046), and overall hospital stay (7 vs 24 days, p=.042). There was also a difference in discharge disposition where P=REBOA patients were discharged home rather than to a rehab facility (p=.002). There was no difference between groups in overall survival, complications or resuscitation requirements.

Discussion

This is a preliminary report from a single center describing safety and efficacy of P-REBOA. In the <60min group, patients treated with P-REBOA had a significantly shorter ICU and hospital stay. No differences have been observed in survival and complications, but more data is required. Importantly, this study demonstrates that partial occlusion is not associated with significant complications or death compared with C-REBOA.

3077-A-1930

Infra-renal REBOA for pelvic bleeding control in animal model for prolonged evacuation time

Matan Golan[1], David Planer, Yaacov Samet

[1] Soroka Medical Center, Beer Sheva, Israel

Background: Resuscitative endovascular balloon occlusion of the aorta (REBOA), is gaining worldwide attention as a minimally invasive technique for initial control of acute intra-abdominal and pelvic hemorrhage. While most studies have shown effectiveness and safety for short term bleeding control, data is lacking regarding prolonged aortic occlusion.

Aim: The aim of this study is to investigate the safety and effectiveness of a six hour infra-renal REBOA for stabilizing a non-compressible pelvic hemorrhage in the pre hospital setting.

Methods: Pelvic bleeding was induced in swine through a 7F arterial introducer sheath inserted via the femoral artery. Basic bleeding rate was measured. After 5 min of bleeding, a high compliant aortic balloon (CODA, Cook Medical), was introduced via the contralateral groin, and inflated below the renal arteries. Treatment time was 6 hours, followed by 30 minutes of reperfusion. Continuous blood pressure was measured above and below the balloon. Survival and reduction in bleeding rate vs. baseline were the primary safety and effectiveness outcomes, respectively.

Results: Eleven animals were studied. All animals survived six hours of bleeding followed by 30 min of reperfusion.

Bleeding rate was significantly reduced by 84.9% from 105.9 ml/min pre-intervention to 16 ml/min with REBOA [p-value <0.001]. Mean potassium levels raised from a baseline of 3.65 mmol/l to 6.38 mmol/l at the end of the reperfusion phase. Respectively, lactate levels raised from 1.4 mmol/l to 4.3 mmol/l and pH decreased from 7.42 to 7.35.

Discussion and Conclusions: Prolonged pelvic bleeding control with infra-renal REBOA is safe and effective. The method can be applied in the pre-hospital setting with prolonged evacuation time.

3086-A-1930

Hate to Burst Your Balloon: Successful REBOA Use Takes More Than a Course

Christina Theodorou[1], Edgardo Salcedo[1], Joseph Dubose[2], Joseph Galante[1]

[1] University of California Davis Medical Center
[2] University of Maryland Medical Center

Introduction:

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is emerging as a viable intervention for hemorrhagic shock. Training surgeons to place the device is only part of the process. We hypothesize that implementation challenges extend beyond surgical skills training and initial REBOA use should not be expected to mirror published success.

Methods:

All REBOA placements from January 2016-February 2017 at a level 1 trauma center were reviewed for opportunities for improvement (OFI). From September 2016-February 2017 all patients meeting highest trauma activation criteria were reviewed against our REBOA algorithm for OFI to identify patients meeting criteria for REBOA placement but not undergoing the procedure.

Results:

REBOA was introduced at our institution in September 2015, with first placement in January 2016. Trauma surgery, Emergency Department, and Operating Room staff underwent training. Nine patients had REBOA placed with six survivors. One patient underwent unsuccessful REBOA attempt and died. Four patients had complications from REBOA. Eight additional patients met indications but did not undergo REBOA. Five major OFIs were identified (Table 1).

Conclusion:

Successful REBOA use requires more than teaching surgeons indications and techniques. For a successful REBOA program, systems factors must be addressed. Systems processes must ensure equipment and procedures are standardized and familiar to all involved. Complications should be expected.

3101-A-1930

Endovascular Skills Training and a Cost-Effective Toolkit for Trauma Surgeons

Anastasia Plotkin, Gregory Magee, Charles Fox[1]

[1] University of Colorado, Denver Health

Introduction:

There is increased interest from trauma surgeons to use endovascular techniques, enabling timely control of bleeding and minimizing collateral damage especially when interventional radiology access is limited. The resuscitative endovascular balloon occlusion of the aorta (REBOA) procedure is advocated by some as an alternative to thoracic aortic cross-clamping for unstable patients with abdominopelvic hemorrhage. However, as with the introduction of any new technology, there is substantial confusion as to what skills and training are necessary for adequate competency in these procedures, what equipment should be stocked, and the cost. The authors' hypothesis is that these factors have impeded the adoption of these techniques. The goal of this paper is to propose a strategy to enable greater adoption of endovascular techniques by trauma surgeons.

Methods:

Our institutional trauma database was reviewed to determine the most commonly performed endovascular interventions and supplies necessary to effectively perform them. Cost of commercially available devices was analyzed to determine a recommended basic starter inventory. Various endovascular training courses specifically for trauma surgeons were reviewed to determine their cost, availability, and skills taught.

Results:

We have identified a set of basic endovascular procedures that are of particular interest to trauma surgeons and developed a list of catheter-based skills for training to establish competency and maintain proficiency for the endovascular novice. We have also compiled an example cost effective inventory of supplies to enable timely availability for endovascular interventions that we now use at our institution.

Conclusions:

Trauma surgeons can rapidly gain catheter-based skills using industry-sponsored simulators and performing elective endovascular procedures on stable patients. A small cost effective versatile inventory maintained in the operating theater will allow better familiarity with endovascular items. Increasing efficiency with percutaneous arterial access and use of the proper nomenclature will promote a culture change in favor of endovascular trauma surgery.

3124-A-1930

Endovascular Resuscitation with Aortic Balloon Occlusion in pediatric trauma - a case report

Mitra Sadeghi, David T McGreevy, Rickard Lindgren, Kjell Ågren, Tal M. Hörer

Abstract

Background

The use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in resuscitation and trauma management in adults is increasing. However, there is limited data published concerning its use in pediatric patients.

Methods

We describe a case using REBOA for traumatic hemorrhagic shock in a pediatric patient according to the concept of EndoVascular resuscitation and Trauma Management (EVTM) at Örebro University Hospital in April 2019. Informed consent has been received.

Results

An 11-year-old boy arrived to the emergency room (ER) after a motor vehicle accident. Due to total hemodynamic collapse, cardiopulmonary resuscitation was initiated with return of spontaneous circulation. Zone 1 total REBOA was successfully performed for 7 minutes while damage control surgery was performed and massive transfusion was initiated to stabilize the patient. The patient survived and returned to almost normal daily activity.

Conclusion

REBOA for endovascular resuscitation and trauma management may be an additional method for temporary hemodynamic stabilization in pediatric patients and, in this specific patient, was used instead of resuscitative thoracotomy.

3139-A-1930

Compartment Syndrome of the Leg After Intraosseous (IO) Needle Insertion.

Pavel Kibrik[1], Ahmad Alsheekh[1], Sareh Rajaee[1], Natalie Marks[1], Anil Hingorani[1], Enrico Ascher[1]

[1] Vascular Institute of New York

Background:

Intraosseous(IO)needles are used in patients who are critically ill when it is not possible to obtain venous access.While IO allows for immediate access,complications can include fractures,infections and compartment syndrome.

Methods:

An 87 y/o male was admitted for sinus bradycardia and acute renal failure.Cardiology found the patient had paroxysmal atrial fibrillation(p-Afib)and placed the patient on apixaban.On hospital day 14,the patient had an episode of coffee ground emesis with a drop in hemoglobin.Rapid response team(RRT)was called,and placement of a peripheral IV was unsuccessful.RRT nurse placed intraosseous(IO)access into the right lower extremity(RLE)directly underneath the anterior tuberosity.Patient was transferred to Medical Intensive Care Unit,and Gastroenterology was consulted for upper gastrointestinal bleeding(UGIB).Anticoagulation for p-Afib was held due to UGIB.Patient underwent bedside EGD and a non-bleeding cratered duodenal ulcer with a large adherent clot was identified in the duodenal bulb.Area was successfully injected with 5ml of 1:10,000 solution of epinephrine.For hemostasis,five hemostatic clips were placed.IO needle was noted to be patent,flushed without resistance and without swelling.IO was used for administration of IV fluids and one unit of red blood cells.Several hours after EGD was completed,RLE was noted to be tense and pale,and the patient was taken to the operating room by Vascular Surgery and underwent four-compartment fasciotomies of the right calf.The muscle was found to be bulging with hemorrhage in all four compartments.

Results:

After the procedure,the foot began to regain color and the patient was taken to the MICU.Three days later,patient underwent closure of the fasciotomy incisions.Two days after fasciotomy incisions,patient was downgraded to the medical floor and was subsequently discharged home.

Conclusion:

Although compartment syndrome is a rare complication of IO placement,physicians should be on lookout for clinical symptoms. We are using IO placement more commonly throughout various fields of medicine,and it is important to have proper technique and monitoring of the involved extremity.

3160-A-1930

Hepatic Angioembolization increases complications with minimal benefit.

Jason Samuels[1], Catherine Velopulos[1], Shane Urban[1], Heather Carmichael[1], Robert McIntyre[1]

[1] University of Colorado Denver

Introduction:

Angioembolization(AE) is recommended to treat liver injuries, but data are limited to small series showing AE is associated with low mortality and frequent complications. We aim to evaluate hepatic AE associated morbidity and hypothesize that it is associated with increased complications without improving mortality in stable trauma patients.

Methods:

Part 1: Data were collected from registries of three level II and one level I trauma centers from 2010-2017. Inclusion criteria were an Abbreviated Injury Score(AIS) hepatic injury and an ICD9/10 code for hepatic angiography(HA).

Part 2: The 2016 Trauma Quality Improvement Project(TQIP) was queried for patients with grade≥III blunt liver injuries. Stable patients with systolic blood pressure(SBP)≥90, and heart rate(HR) 50-110 were included. Patients with intraabdominal or pelvic injuries(AIS≥3), laparotomy within six hours, and AE≥ 24 hours after arrival were excluded. Patients were matched 2:1 using a nearest neighbor method on age, sex, injury severity score(ISS), liver AIS, SBP and HR, and ≤ four-hour blood products.

Results:

Part 1: Median age was 38, 56% Male, median ISS 26, and median liver AIS 4. Of 1319 liver injuries, 32 subjects (2.4%) underwent HA with 23 undergoing AE. 75% had isolated liver injuries. 83% AE subjects had extravasation on CT. 39% subjects had AE-related complications (table 1), 30-day readmission following AE was 35%, and 0% 30-day mortality.

Part 2: 1939 met criteria with 116 (6%) undergoing hepatic AE. After matching, there was no difference in mortality (5.4% vs. 3.2%, p=0.5). There were no differences in hepatic resection or endoscopic interventions, but AE required a higher rate of IR drainage (13.3% vs. 2.2%, p<0.01). The AE group had longer LOS (10 vs. 6 days, p<0.01) and greater number of ICU days (4 vs. 3, p<0.01).

Conclusion:

Hepatic AE does not improve mortality but is associated with increased health care utilization and need for hepatic drainage.

3167-A-1930

Delta Systolic Blood Pressure Can be a Stronger Predictor of Mortality Compared to Pre-aortic Occlusion Systolic Blood Pressure in Non-compressible Torso Hemorrhage Patients; An ABOTrauma Registry and AORTA Database Analysis

Michelle Moe[1], Juan Duchesne[1]

[1] Tulane University School of Medicine

Background

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is becoming a standardized adjunct for management in patients with severe non-compressible torso hemorrhage (NCTH). Although guidelines have been developed to help with the best indications for REBOA utilization, no studies have addressed the significance of change in systolic blood pressure (ΔSBP) after REBOA insufflation. We hypothesized that in patients with NCTH, ΔSBP can be a quick surrogate marker for hemorrhage status and mortality.

Methods

This was an international, multicenter retrospective review of all patients managed with REBOA from the ABOTrauma Registry and the AORTA database. ΔSBP was defined as the difference between pre- and post-REBOA insertion SBP. Based on ΔSBP, patient's hemorrhage status was categorized as responders or non-responders. A non-responder was defined as a hypotensive patient with systolic blood pressure (SBP) < 90 mmHg after REBOA placement with full aortic occlusion. Significance was set at $P < 0.05$.

Results

A total of 524 patients with NCTH were included. Most (74 %) were male, 77% blunt injury with a median (IQR) age of 40 (27 – 58) and ISS 34 (25 – 45). Overall cohort mortality was 51%. After calculating ΔSBP, 20% of patients were classified as non-responders. Demographic and injury descriptors did not differ between responders and non-responders. Mortality was significantly higher in non-responders versus responders (64% vs 46%, respectively; $P = 0.001$). Non-responders had lower median pre-insertion SBP (50mmHg vs 67mmHg; $P < 0.001$) and lower ΔSBP (20mmHg vs 48mmHg; $P<0.001$).

Conclusions

REBOA non-responders present and remain persistently hypotensive and are more likely to die than responders, indicating a potential direct correlation between ΔSBP as a surrogate marker of hemorrhage volume status and mortality. Future prospective studies will need to further elucidate the impact of damage control resuscitation efforts on ΔSBP and mortality.

3168-A-1930

Strategies for Successful Implementation of REBOA in a Level 1 Trauma Center

Jamie Hadley[1], Alexis Cralley[2], Ernest E. Moore[1], Angela Sauaia[2], Ryan Lawless[2], Barry Platnick[2], Fredric Pieracci[2], Eric Campion[2], Clay Cothren Burlew[2], Mitchell Cohen[2], Charles Fox[2]

[1] University of Colorado Department of Surgery
[2] Denver Health Medical Center Department of Surgery

OBJECTIVES: The rationale for Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) to control life-threatening sub-diaphragmatic bleeding has been established, however, insinuating this into a trauma service 24/7 remains challenging. The objective of this study is to describe the process of successful implementation of REBOA use in a level I trauma center.

Methods: All REBOA procedures at a single level I trauma center from April 2014 through November 2018 were evaluated; REBOA was implemented after the faculty attended a required and internally developed Advanced Endovascular Strategies for Trauma Surgeons course (AESTS) by the vascular and senior trauma surgeon in the group. Success was defined by sustained early adoption.

Results: An institutional protocol was published, and a special cart was placed in the emergency department with posters on technical and procedural steps. REBOA was performed in 80 patients by 7 trauma surgeons. A focused professional practice evaluation was completed after the first two procedures which led to credentialing. Of the 80 REBOAs placed over this period, 27 were placed by surgeons with <10 years attending experience, 22 placed by surgeons with 10-20 years' experience, and 31 by surgeons with >20 years. Surgeons performed an average of 3.2 REBOAs per surgeon per year. Blunt abdominopelvic injuries (63/80, 78.8%) or penetrating injuries (12/80, 15%), comprised the main indications. Overall survival was 72.5% (58/80) with a steady early adoption trend (graph) that allowed for leading participation in a multicenter trial.

Conclusions: Strategies for how departments adopt new procedures require clinical guidelines, a training program focused on competence, and a hospital education and privileging process for those acquiring new skills. This is a protype for how to introduce new technology. Future studies should investigate the role of the learning curve as good outcome favors early adoption.

3169-A-1930

RADIOLOGIC DIAGNOSIS AND INTERVENTIONAL MANAGEMENT OF TRAUMA TO CHILDREN: FROM THE TOP OF THE HEAD TO THE BOTTOM OF THE FEET

Jaime Tisnado[1], Marco Leyva Vásquez Caicedo[2]

[1] Virginia Commonwealth University, Richmond, VA, USA
[2] Hospital Universitario Clínico San Carlos

Trauma is the leading cause (No. 1) of morbidity and mortality (M&M) in children and young adults (younger than 45-years-old).Yet there are very little, if any, discussions and presentations of the topic in radiologic and interventional radiologic meetings, congresses and conferences in USA, Europe, and worldwide as well.

This absence of exposure to trauma management indicates that serious gaps exist (as most "adult" interventional radiologists are not trained or involved directly in the radiologic diagnosis and management of trauma in children). It is well known that children are not "small adults" and their anatomic and physiologic features predispose them to certain injuries patterns. On the other hand, older and teen aged children can be and are, small adults.

Although great efforts have been made lately, in recent years, to educate the general population on many safety issues, and protection against injuries at home, car accidents, sports, unintentional injuries, and other situations M&M rates in children still remain prohibitively high.

Some of the social factors and/or causes for these situations are the lack of protection of children in motor vehicles in some countries and places, the continuous increase in speed and power of the motor vehicles, the increased incidence of impaired driving by alcohol and drug abuse persons, the violence and decay of the society, and the exorbitant existence of firearms in most homes in certain "advanced" countries (USA).

Therefore, all interventional radiologists, trauma physicians, pediatricians, and others must be prepared, educated, made aware and instructed on the need to be involved in the care of traumatized children. There are no enough pediatric interventional radiologists in any institution, around the world, to manage traumatized children, therefore, the care of these children is usually delegated to "adult" interventional radiologists, who do not have the special expertise or knowledge or desire for providing such a specialized and sophisticated care.

Moreover, the care of traumatized children usually is associated with emotional and personal issues, so the "adult" interventional radiologists are uncomfortable in dealing with this special group of patients and specially their parents and families. Obviously the "adult" interventional radiologists have to deal with the parents, families and guardians and special expertise (not usually acquired or learned) is needed to manage these social issues.

We have been involved in the care of traumatized children of all age ranges, from newborns to teen-agers (18 year-old and sometimes older than that)), involving all anatomic regions, organs and systems, from the top of the head to the bottom of the feet for about half a century, so we have developed some special expertise, therefore, we present here a review, as complete as possible, and as illustrative as feasible, considering the time and space allowed to us, to review this important topic, heretofore not well understood, as we see now many more children involved in traumatic events, due to some of the factors above mentioned.

We believe that with the continued and constant improvements in interventional radiologic methods and techniques, the availability of special pediatric equipment and materials, and with better and more availability of imaging methods (US is of prime importance in children, CT, MRI, etc.), the interventional radiologists will continue and improve in their important role in the team managing children with traumatic injuries.

Therefore, we propose that "adult" interventional radiologists, must strive for understanding the unique challenges presented to them and be prepared to intervene in children as needed. The time has arrived for the "adult" interventional radiologists to manage children as there are no enough "experts" for such management anywhere in the world.

3170-A-1930

REBOA Use in Non-trauma Emergency General Surgery: A Multi-Institutional Experience

Justin Hatchimonji[1], Amanda Chipman[2], Jose Diaz[2], David McGreevy[3], Tal Hörer [3], Sigrid Burruss[4], Stephanie Han[4], Chance Spalding[5], Charles Fox[6], Ernest Moore[6], Jeremy Cannon[1]

[1] Hospital of the University of Pennsylvania
[2] University of Maryland Medical Center
[3] Örebro University Hospital
[4] Loma Linda University Medical Center
[5] OhioHealth Grant Medical Center
[6] Denver Health Medical Center

Background: Resuscitative Endovascular Balloon Occlusion of Aorta (REBOA) may benefit trauma patients with severe non-compressible torso hemorrhage. Less is known about REBOA use in non-trauma emergency general surgery (EGS). The aim of this study was to determine timing and utilization of REBOA for hemorrhage control in non-trauma patients.

Methods: Data on REBOA use in non-trauma EGS patients from six centers, 2014-2019, was pooled for analysis. We performed descriptive analyses using Fisher's exact, t-test, or Mann-Whitney U tests as appropriate.

Results: A total of 32 patients with acute hemorrhage from non-trauma sources were identified. REBOA placement was primarily performed by trauma (16/32, 50%) and vascular (13/32, 41%) attendings. In 7 patients (22%), balloons were positioned prophylactically but never inflated. In 23/32 (72%) patients, REBOA was placed in the operating room (OR). 24/32 balloons (75%) were placed in zone 1, 7/32 (22%) were placed in zone 3, and there was one REBOA use in the inferior vena cava (IVC). Patient characteristics and indications are shown in the Table. 10/32 patients (31%) died prior to discharge. Of the 25 cases in which REBOA was deployed, 21/25 (84%) resulted in improved hemodynamics. Median time to definitive hemorrhage control among survivors was 20 minutes (interquartile range [IQR]: 0-60.5), whereas median time was 62.5 minutes (IQR: 25-90) among non-survivors (p=0.20, 7 patients missing data). There was one case (4%) of distal embolism and no other local/access-related complications. Of the 16 survivors, 10/16 (63%) were discharged to home. Median length of stay among survivors was 18 days (range 5-72).

Conclusion: REBOA has been used in a range of acutely hemorrhaging EGS patients with low rates of access-related complications. Mortality is high in this patient population; however, appropriate patient selection and early use may result in unexpected survivors. Further prospective study in this patient population is warranted.

3171-A-1930

A Bioengineered Human Acellular Vessel for Torso Arterial Reconstruction: A Role for Open Repair in the Endovascular Era

Alexis Cralley[1], Mitchell Cohen [1,2], Charles Fox[1,2]

[1] Denver Health
[2] University of Colorado

Background: Penetrating injuries to the left subclavian artery are associated with 40% mortality. Traditional open surgical approaches have high post-operative morbidity, such as longer recovery and risk of neuropraxia. With the advancement of endovascular repair options, many cases may be amendable to minimally invasive repair using covered stent grafts.

Materials and Methods: A 44 year old male presented to the ER with a gunshot wound to the left shoulder and an expanding chest hematoma. CT angiography showed occluded left axillary artery with distal flow. Initial exam revealed a pulseless left hand, but a monophasic doppler signal of the left brachial artery. Patient was taken to interventional radiology for attempted covered stent repair. Angiogram showed abrupt cutoff of the subclavian artery 3-4 cm distal to the take off of the vertebral artery, with 10-12 cm of absent subclavian and axillary artery. Antegrade stent advancement was unsuccessful, and open repair was undertaken using an 8cm infraclavicular approach. The thrombosed artery with extensive intimal disruption was identified along with an intact brachial plexus. 6cm of the injured artery was resected and replaced with a 6mm biologic graft.

Results: Post-operatively patient was extubated and transferred to the surgical ICU for hourly neurovascular checks. He was placed on daily aspirin indefinitely, and on hospital day 4 he was discharged home. He had an early thrombosis that was successfully restored with catheter directed thrombolytic therapy. Post procedure ultrasound confirmed patency with normal velocity measurements. The patient has a persistent neuropraxia and is followed by Physical Medicine.

Conclusion: Endovascular repair for axillosubclavian penetrating injuries may ideal for for large intimal flaps, pseudoaneurysms and arteriovenous fistulae. Transections may require retrograde approach for stent delivery. Hemodynamically unstable patients and those with long (> 2 cm) damaged segments or transections, or complete occlusion may benefit from expeditious open repair.

3173-A-1930

INJURIES TO THE ABDOMINAL AORTA – DIAGNOSIS, MANAGEMENT, AND OUTCOME: DATA FROM THE PROOVIT REGISTRY

Barak Raguan Schneidman[1], Simone Fajer[1], Joseph DuBose[2]

[1] Meir Medical Center
[2] University of Maryland Medical Center

Introduction: Traumatic injuries to the abdominal aorta (AAI) are rare and entail significant risk of morbidity and mortality.

Methods: Data on AAI was collected from the AAST PROspective Observational Vascular Injury Treatment (PROOVIT) registry

Results: Of 3,598 cases in the registry, 73 (0.02%) cases involved injury to the abdominal aorta. The injury was blunt in 48 cases (65.8%) and penetrating in 19 cases (26%). Motor vehicle accident was the most common mechanism of injury – 38 cases (65.8%).

Diagnosis was made by contrast enhanced computed tomography (CTA) in 34 (46.6%) cases, by operative exploration in 21 (28.8%) cases, and by conventional angiography in 2 cases (2.7%). The injury to the abdominal aorta was transection in 12 cases (16.4%), partial transection or flow-limiting defect in 34 cases (46.6%), and pseudoaneurysm in 8 cases (11%). Initial operative management was performed in 22 cases (30.1%). Damage control techniques were used in 9 of those cases. The most common method was primary repair, used in 11 cases, synthetic graft interposition or bypass was used in 4 cases, autologous vein interposition or bypass in 1 case, and other types of vascular repair in 2 cases. There were 10 cases of endovascular repair of the abdominal aortic injury (13.7%).

10 patients in the cohort died (13.7%). When comparing survivors with mortalities, the following factors were of statistical significance: AIS abdomen (3.3 vs 4.75, p=0.003), GCS (12.7 vs 5.8, p=0.000), hemoglobin (12.91 vs 10.57, p=0.018), hemorrhage as a hard sign of injury (12% vs 50%, 0.005). Diagnosis in operative exploration was associated with mortality (26% vs 70%, p=0.012), whereas diagnosis on CTA was associated with survival (62% vs 20%, p=0.033). The association of mortality with type of injury and mode of treatment were not of statistical significance.

Conclusions: AAI is a rare injury, and injury patterns, diagnosis and management remains highly variable. To our knowledge, this is the largest series on AAI, particularly in the era of endovascular treatment.

3175-A-1930

Embolization of decubitus ulcer-related pseudoaneurysm causing refractory bleeding

Naif Alsaikhan[1], Rachel Morris[1], Alexandra Fairchild[1], Parag Patel[1]

[1] Medical College of Wisconsin

A 29 years old male with history of gunshot wound injury to the right shoulder and chest resulting in T7 paraplegia. Patient developed stage 4 bilateral ischial decubitus ulcers which were complicated by osteomyelitis/bacteremia for which he underwent debridement and creation of diverting transverse colostomy. On post-operative day 10, he re-presented with continuous bleeding from his left decubitus ulcer wound refractory to medical therapy. Pelvic angiography was performed and showed a pseudoaneurysm involving a branch vessel of the posterior division of the left internal iliac artery, which was embolized with coils. Further wound debridement during the same admission was complicated by accidental removal of one coil pack. Repeat angiography after recurrent bleeding showed no source of bleeding. Eventually, patient's bleeding resolved with local wound care and medical therapy and was discharged in stable condition.

3176-A-1930

Aorto-Aortic Conduit for the Treatment of Traumatic Thoracic Pseudoaneurysm With Unfavorable Iliac Arteries

Matthew Bartley[1], Navin Vigneshwar[1], Christian Ghincea[1], Jamie Hadley[1], Andrew Eitel[1], Charles Fox[2], Michal Radomski[2], Mitchell Cohen[2], Barry Platnick[2]

[1] University of Coloardo
[2] Denver Health

Introduction:

Transfemoral access is ideal for thoracic endovascular aneurysm repair (TEVAR), when anatomy is unfavorable or there are inadequate distal and proximal seal zones endovascular procedures become limited. The use of an endoconduit to bridge stenotic or tortuous vessels has been described as an alternative for vascular access.

Methods: We present a 23-year old female who suffered multiple traumatic injuries after being T-boned by a dump truck. Her most serious injures included a 1.3 x 2.2 cm aortic arch pseudoaneurysm, liver, renal and splenic lacerations and a fractured pelvis. She was hypotensive upon arrival requiring endovascular occlusion of her aorta, exploratory laparotomy and external fixation of her pelvis with preperitoneal pelvic packing. Following stabilization in the OR she was taken to the ICU for resuscitation.

Results:

Interventional radiology (IR) determined that the diameter of her iliac vessels were inadequate for TEVAR. The decision was made to place an aortic conduit during her planned return to the OR for abdominal washout and removal of pelvic packing. In the OR the aorta was exposed just proximal to the bifurcation where a longitudinal arteriotomy was made allowing for end-to-side anastomosis with an 8mm PTFE graft (W.L. Gore & Associates, Flagstaff, AZ). The abdomen was temporarily closed, and the graft was tunneled through a groin incision. She was taken to the IR suite where she underwent successful placement of a 22 x 22 x 100 mm Medtronic Valiant (Medtronic, Dublin, Ireland) stent graft. She was transported back to the OR where the conduit was removed without incident and abdomen closed.

Conclusions: Completion aortogram showed exclusion of the pseudoaneurysm with proper placement of the stent graft. There were no complications following removal of the conduit and she recovered as expected. She was discharged home with rivaroxaban anticoagulation for a subsequent pulmonary embolism and iliac thrombus.

3177-A-1930

Morphometric analysis of torso arterial anatomy in pregnant women for Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) Deployment.

Michaela Gaffley[1], Talla Widelock[1], Andrea Fernandez[1], Robert P. Heine[1], Lucas Neff[1], Timothy Williams[1]

[1] Wake Forest, School of Medicine

Background: Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) has been implemented for non-compressible abdominopelvic hemorrhage and described in cases of obstetrical hemorrhage emergencies. However, detailed morphometry of the pregnant patient's aorta is lacking. This is especially pertinent given the adverse sequelae if endovascular balloons are unknowingly mispositioned. The objective of this study was to characterize aortic morphometry in pregnant trauma patients including zone lengths and aortic diameters at the recommended locations of catheter placement.

Methods: Center line measurements were made (TeraRecon) from contrasted computed tomography (CT) scans of pregnant trauma patients at various stages of pregnancy. Aortic zones were defined by accepted criteria: Zone I from left subclavian artery to celiac artery; Zone II from celiac to distal renal artery takeoff; Zone III from renal artery to aortic bifurcation.

Results: Twenty-one pregnant patients were identified for the study. The median (interquartile range) length (mm) of Zone I, II and III were 205 (192-210), 30 (26-35), and 83 (78-87) respectively. Median aortic diameters were 19 mm (17-21) at the left subclavian, 15mm (15-18mm) at the celiac, 12mm (12-13mm) at lowest renal arteries, and 12mm (12-13) at the aortic bifurcation. Distance from celiac artery and aortic bifurcation to right common femoral artery (CFA) was 315mm (302-329) and 201mm (190-208mm) respectively. These measurements were lower than those reported in males. The abdominal aorta measurements were similar to prior studies as stated for women.

Conclusions: This study provides a morphometric analysis of the aorta in pregnant trauma patients and is the first study describing aortic length to the REBOA zones and aortic diameter measurements in pregnant female patients to our knowledge. Our study informs use of REBOA in females and points to the need for a multicenter effort to capture these data in a larger cohort of women in the late 3rd trimester.

3178-A-1930

Unintentional Zone 2 balloon inflation is not infrequent: a call to re-evaluate the practice of REBOA insertion and position confirmation

Julia Coleman[1], Ernest Moore[1,2], Andrew Byars[2], Charles Fox[1,2]

[1] University of Colorado-Denver
[2] Denver Health Medical Center

Background

The Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) catheter is designed to be inserted to a known distance in Zone 1 or 3, yet despite morphometric analysis, the exact distance is difficult to predict using anatomic surface landmarks. We hypothesize that unintentional zones of placement are not infrequent and understanding how they occur may reveal knowledge gaps in REBOA use.

Materials and Methods

This is a retrospective analysis of all trauma activation patients at a level-1 trauma center in whom a REBOA was inserted from 2014-2019. Trauma registry records and radiographs (including radiography, computed tomography, intraoperative fluoroscopy) were reviewed to determine REBOA position. Zone 2 was defined as balloon position between T12 and L2 on imaging, with Zone 1 proximal to T12 and Zone 3 distal to L2.

Results

Overall, 78 patients were included: 81% (63) male, median age of 39.5. years, median initial systolic blood pressure of 100 mm Hg (range 48-160), majority (78%) with blunt injury, and median new injury severity score of 40. The mortality rate was 27%. Among the 78 patients, the majority were Zone 3 insertions (62%, n=48), with one Zone 1 insertion. The rate of unintentional Zone 2 insertion was 11% (n=9), and in this cohort, complications (n=5) included one case of femoral artery thrombosis leading to above the knee amputation and one case of renal infarcts leading to acute renal failure. Moreover, 25% (n=20) of patients had no radiologic confirmation of the balloon position although among these 20 patients, the median inserted distance was 27 cm, range 25-45 cm.

Conclusion

This study finds that REBOA malpositioning is not uncommon and can result in major adverse events. Surface landmarks may be misleading and radiologic confirmation of contrast-filled balloon position with subsequent adjustments should be performed immediately after balloon inflation.

3179-A-1930

Percutaneous Access for Extracorporeal Cardiac Bypass Rewarming in Severe Accidental Hypothermia

Navin Vigneshwar[1], Mahmood Kabeil[1], Matthew Bartley[1], Julia Coleman[1], Charles Fox[2]

[1] University of Colorado Department of Surgery
[2] Denver Health Medical Center, Department of Surgery

Introduction:

Extracorporeal cardiac bypass rewarming is reserved for patients with severe accidental hypothermia who present without life sustaining rhythms. The most common method of extracorporeal perfusion catheter placement requires a femoral cut-down and direct visualization of the vessels. Given the successful use of ultrasound guided, percutaneous placement of large bore catheters in an elective vascular surgery setting, we have conveyed this technique for use in bypass rewarming.

Methods:

We present three cases of severe accidental hypothermia requiring extracorporeal rewarming with bypass catheters placed using percutaneous techniques. Our patients ages ranged from 31 y.o to 55 y.o with presenting core temperatures of 17, 22 and 24 degrees Celsius. All patients presented in cardiac arrest and were taken directly to the operating room for extracorporeal cardiac bypass rewarming.

Results:

Upon arrival into the operating room all patients had a 5Fr sheath inserted into the common femoral vein by use of a micropuncture needle and guidewire. A 260cm glidewire was inserted through the sheath into the inferior vena cava without the use of fluoroscopy. The sheath was removed and a 17Fr venous perfusion catheter was inserted over the wire. One patient had a similar percutaneous placement of a 21Fr arterial cannula, while the other two patients had arterial cannulas placed by a femoral cut-down approach. All patients were rewarmed to 32C with return of spontaneous circulation. After weaning from the bypass circuit, all patients required femoral cut-downs to repair their respective venotomies and arteriotomies. While all three patients survived to transfer to the intensive care unit only one patient survived to hospital discharge.

Conclusions: Ultrasound guided, percutaneous access is a viable option for extracorporeal rewarming in the setting of severe accidental hypothermia. Adoption of this technique may increase the speed of large bore bypass catheter placement.

3181-A-1930

Feasibility of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in thoracic trauma: the experience of a Level I Trauma Center in Latin-America

Juan Jose Melendez[1], Fernando Rodríguez[2], Edinson Angamarca[1], Alberto García[2], Mónica Guzmán[2], Carlos Ordonez[2]

[1] Universidad del Valle, Division of Trauma and Acute Care Surgery
[2] Fundacion Valle del Lili, Division of Trauma and Acute Care Surgery, Cali, Colombia

Background: Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is an emerging treatment for Non-Compressible Torso hemorrhage control, indicated in abdominal and pelvis trauma, but its use in thorax trauma is limited. The aim of this study was to characterize the largest experience of trauma patients undergoing REBOA in Latin-America, and to evaluate its use and outcomes of patients with chest trauma.

Materials and Methods: This was a prospective, observational and single-center study. We included all adult patients with severe trauma who underwent REBOA from January, 2015 and December, 2018. Demographics, clinical and outcome variables were recorded, as well as parameters associated to REBOA.

Results: 50 patients underwent REBOA. All patients were hemodynamically unstable upon arrival. The median ISS was 25 (IQR: 25-41). Thoracic injury was the most common indication for REBOA (46%) followed by abdominal injuries (24%) and multiple cavity injuries (30%). 68% had penetrating trauma. Most of the REBOA catheters were inserted in the Operating Room (OR). In-hospital mortality was 32%, there were no differences in mortality between patients with injuries in thorax, abdomen or multiple cavities [35%; 33%; 27%, p=0.92)], neither with the calculated survival rate.

Conclusion: In this case series, the main indication for REBOA placement was thoracic injuries and most of the catheters were placed in the OR, even though REBOA is indicated in abdominal and pelvis trauma, and the most common place for REBOA placement is the ED. Moreover, there were no differences in mortality between patients with thoracic, abdominal or multiple cavities injuries. In our experience, REBOA can be used safely in penetrating and blunt thoracic trauma as in abdominal and pelvic trauma.

3182-A-1930

Common Femoral Artery Transection Following Penetrating Trauma

Linda Wang[1], Anahita Dua[1]

[1] Massachusetts General Hospital

History

The patient is a 20-year-old male who presented in Class IV hemorrhagic shock following a stab to the left groin with an admission BP of 60/40 mmHg. Due to ongoing pulsatile bleeding, continuous manual groin pressure was maintained for control. Rapid transfusion protocol was initiated. Remainder of exam was negative and the patient was taken emergently to the hybrid operating suite for exploration.

Plan

A longitudinal incision was made over the left groin and dissection down to the common femoral artery (CFA) was undertaken. A CFA transection was noted with a 6cm defect. Once proximal and distal control were obtained, poor back-bleeding from the distal CFA was noted. Fogarty balloon catheters were passed distally and a moderate amount of thrombus removed. A shunt was placed, however, the patient did not have distal pedal signals. Repeat labs had shown the patient's clinical condition had improved significantly with near resolution of his acidosis. The decision was thus made to heparinize and perform an angiogram (Figure). Angiography revealed vasospasm with good distal perfusion. It was felt the patient was stable enough for definitive revascularization at this point. The CFA was reconstructed with contralateral greater saphenous vein in end-to-end fashion. He was ambulatory on discharge with mild weakness in the femoral nerve distribution.

Discussion

The incidence of femoral artery injuries is high and represents 26% of all vascular trauma. We present a 20-year-old male with penetrating trauma to the left groin resulting in CFA transection with large defect, successfully reconstructed with vein interposition graft. Access to a hybrid suite provided a minimally invasive way to assess runoff, as differentiating between thrombus and vasospasm in young patients can be challenging. In stable patients, an aggressive approach towards early definitive arterial reconstruction is encouraged as the use of temporary shunts is a significant risk factor for amputation.

3183-A-1930

Aortic Transection Following Blunt Aortic Trauma

Linda Wang[1], Samuel Schwartz[1], Anahita Dua[1]

[1] Massachusetts General Hospital

History

The patient is a 33-year-old male who was skateboarding when struck by a car. He was hemodynamically stable on exam with chest wall and left flank tenderness. Imaging revealed thoracic aortic transection with associated mediastinal and esophageal hematoma. Figure 1a. A left pneumothorax and a grade 2 left renal laceration were also noted. A chest tube was placed and the patient was taken emergently to the hybrid operating suite.

Plan

The plan was for thoracic endograft stent placement (TEVAR). Given the short distance (<2cm) from the injury to the origin of the left subclavian artery (SCA), coverage of the left SCA was planned. The patient was placed supine and prepped from the chin to the knees. Percutaneous bilateral groin access was obtained under ultrasound guidance. Perclose Proglide closure devices were deployed on the left. The patient was systemically heparinized. A low profile thoracic stent graft system was introduced via the left femoral artery while a pigtail catheter was inserted on the right. A 40 degree LAO projection aortogram was performed and the left common carotid artery (CCA) location marked. The patient's systolic blood pressure was dropped to 70mmHg and the stent graft was deployed just distal to the left CCA with successful left SCA origin coverage. Figure 1b. The Proglide sutures were locked and a closure device deployed on the right. He was discharged on post-operative day 6.

Discussion

Blunt aortic injury (BAI) carries a high mortality rate. We present the case of a young gentleman with a Grade IV BAI, successfully treated with TEVAR with left SCA coverage. Given the high morbidity and mortality associated with open repair, TEVAR has increasingly become the preferred treatment modality for thoracic BAI. Emergent coverage of the left SCA can be performed safely, often without sequelae, in order to obtain an adequate proximal landing zone.

3187-A-1930

Discrepancies in Results Using REBOA: Potential Causes

Ryo Yamamoto[1], Ramon Cestero[2], Tomohiro Funabiki[3], Junichi Sasaki[1]

[1] Trauma Service/Department of Emergency and Critical Care Medicine, Keio University School of Medicine, Sinjuku, Tokyo, JAPAN
[2] Department of Surgery, UT Health San Antonio, San Antonio, TX, USA
[3] Department of Trauma and Emergency Surgery, Saiseikai Yokohamashi Tobu Hospital, Yokohama, Kanagawa, JAPAN

Background: While there is considerable debate regarding clinical outcomes associated with resuscitative endovascular balloon occlusion of the aorta (REBOA) in trauma patients, a recent retrospective observational study investigating REBOA outcomes reported lower in-hospital mortality among strictly selected severely injured patients. We aimed to elucidate potential reasons for this particular study's beneficial results, comparing the study's methods with previous similar studies which reported non-beneficial findings.

Methods: A narrative review was performed with a MEDLINE search for published studies using large databases evaluating the use of REBOA. Study design, patient population, and statistical methods were compared.

Results: Five studies were identified between 2015 and 2018. In 2015, a prospective study using the American Association for the Surgery of Trauma Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery (AAST AORTA) database revealed no difference in survival between REBOA and resuscitative thoracotomy (RT). However, two retrospective analyses in 2015 and 2016 using the Japanese Trauma Data Bank (JTDB) demonstrated that REBOA was associated with a higher in-hospital mortality compared with non-REBOA treatment. Conversely, a more recent study in 2018 using the AAST AORTA database reported a survival benefit using REBOA compared with RT among hypotensive patients who did not require cardiopulmonary resuscitation. Similarly, a 2019 study using the JTDB reported lower in-hospital mortality using REBOA in patients who were more strictly selected by propensity score matching. This particular study utilized more covariates, including hemoperitoneum, hemostatic procedures, and urgent transfusion, to define severely injured patients, and successfully matched similarly injured population from REBOA and non-REBOA groups by a narrower match-caliper, compared with the earlier JTDB studies using propensity score model.

Conclusions: Published studies reporting beneficial outcomes following the use of REBOA are associated with statistical methodology which utilizes more stringent criteria in the propensity scoring model to identify severely injured patients.

3189-A-1930

Percutaneous Access for Extracorporeal Cardiac Bypass Rewarming in Severe Accidental Hypothermia

Navin Vigneshwar[1], Mahmood Kabeil[1], Ian Brailler[1], Matthew Bartley[1], Charles Fox[2]

[1] University of Colorado Department of Surgery
[2] Denver Health Medical Center

Introduction:

Extracorporeal cardiac bypass rewarming is reserved for patients with severe accidental hypothermia who present without life sustaining rhythms. The most common method of extracorporeal perfusion catheter placement requires a femoral cut-down and direct visualization of the vessels. Successful use of ultrasound guided, percutaneous placement of large bore sheaths during elective vascular procedures, prompted a review of this technique for use in emergent bypass rewarming.

Methods:

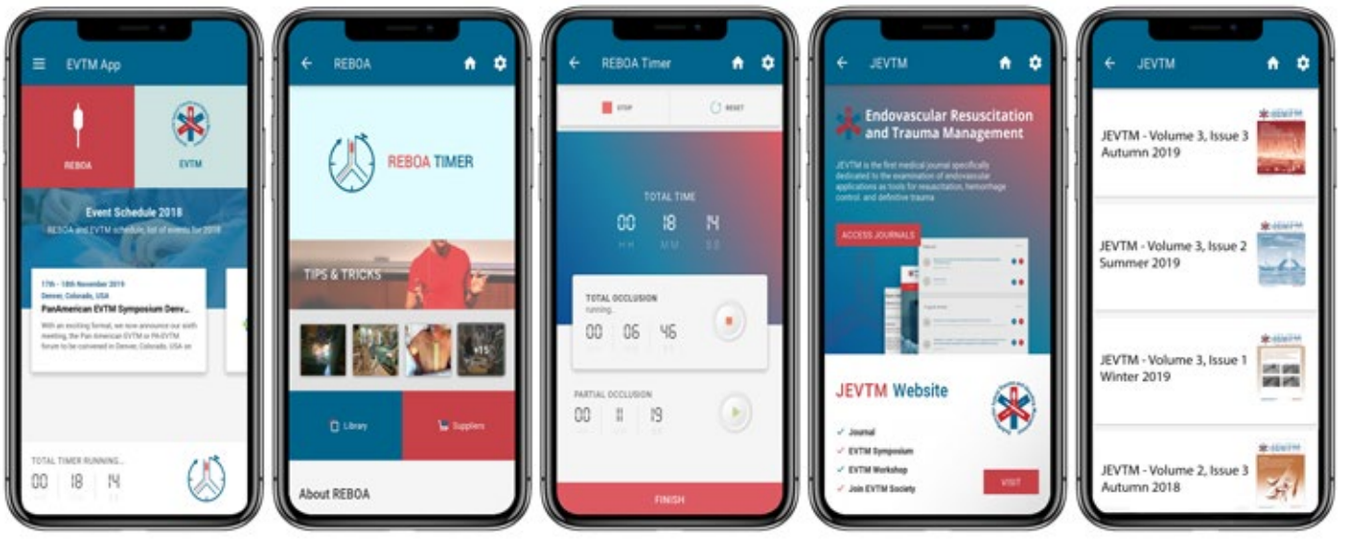
We present three cases of severe accidental hypothermia requiring extracorporeal rewarming using 19-24 French cannulas using percutaneous techniques. Our patients ages ranged from 31 y.o to 55 y.o with presenting core temperatures of 17, 22 and 24 degrees Celsius. All patients presented in cardiac arrest and were taken directly to the operating room for extracorporeal cardiac bypass rewarming.

Results:

Upon arrival into the operating room all patients had a 5Fr sheath inserted into the common femoral vein and artery by use of a micropuncture needle and guidewire. A 260cm Glidewire was carefully inserted through the sheath into the inferior vena cava or the abdominal aorta without the use of fluoroscopy after taking surface landmarks. The sheath was removed and a 17Fr venous perfusion catheter was inserted over the wire after serial dilation. One patient had a similar percutaneous placement of a 21Fr arterial cannula, while the other two patients had arterial cannulas placed by a femoral arterial exposure and then direct micropuncture. All patients were rewarmed to 32C with return of spontaneous circulation. After weaning from the bypass circuit, all patients underwent femoral arterial and venous exposure to repair the vessels. While all three patients survived to transfer to the intensive care unit only one patient survived to hospital discharge.

Conclusions: Ultrasound guided, percutaneous femoral arterial and venous access is an effective option that avoids the exposure needed for direct insertion during extracorporeal rewarming in the setting of severe accidental hypothermia. Adoption of this technique may increase the speed of large sheaths and bypass cannulas during emergencies.

The EVTM App



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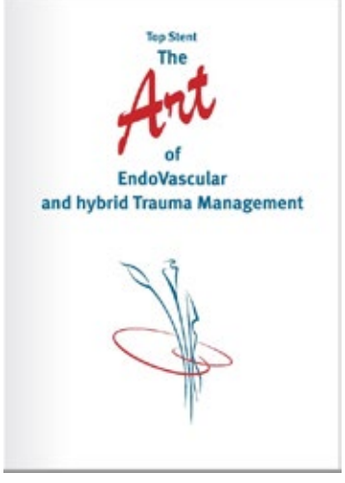

The Top Stent project is a multidisciplinary work manual for EVTM. 28 experts from around the world give tips and tricks for EVTM and REBOA.

The manual was released during the EVTM 2017 Symposium and is now distributed as a non-profit project at production costs of 302 SEK with addition to delivery by post.

If interested, send an e-mail to: asa.strandberg@regionorebrolan.se and state: number of books, address of shipment and address for invoice.

Pan-American EVTM

Endovascular Resuscitation & Trauma Management
17-18 November 2019

Denver•Colorado•USA

SUNDAY November 17th	
07.30-07.45	**Introduction** - *Chuck Fox, Ernest Moore, Joe DuBose*
07.45-09.10	**Trauma Applications of EVTM - REBOA.** 8 min talk - 5 minute discussion Moderators: Chuck Fox (Denver, CO, USA), Todd Rasmussen (Bethesda, MD, USA)
07.45-07.58	Endovascular resuscitation and trauma management in 2019 - A trauma leaders perspective - *Ernest Moore (Denver, CO, USA)*
07.58-08.11	Who are the caretakers of vascular injury for the future? - *Michael Sise (San Diego, CA, USA)*
08.11-08.24	The Endovascular Resuscitation and Trauma Management Society - Mission and future - *Tal Hörer (Orebro, Sweden)*
08.24-08.37	Pre-hospital EVTM applications in the civilian realm - Challenges and opportunities - *Laura Moore (Houston, Texas, USA)*
08.37-08.50	The role of the Emergency Medicine provider in EVTM - *Zaf Qasim (Philadelphia, PA, USA)*
08.50-08.58	REBOA as a transfer adjunct? - *Joe Galante (Sacramento, CA, USA)*
08.58-09.10	**Panel Discussion and Audience Questions**
09.10-09.40	**Breakfast/mingle in the exhibition area**
09.40-10.57	**Beyond trauma: Endovascular Adjuncts in Post-partum hemorrhage and medical arrest** 8 min talk - 5 minute discussion Moderators: Jonathan Morrison (Baltimore, MD, USA), Rishi Kundi (Baltimore, MD, USA)
09.40-09.53	Post-partum hemorrhage and EVTM: the problem defined - *Karin Fox (Houston, Texas, USA)*
09.53-10.06	The Cali mal-positioned placenta registry - an update - *Dr. Albaro Nieto (Cali, Columbia)*
10.06-10.19	High risk OB and REBOA in the US: present status and future studies - *Karin Fox (Houston, Texas, USA)*
10.19-10.32	REBOA capabilities and embolization in high risk obstetrics - current and future state - *JR Taylor (Little Rock, Arkansas, USA)*
10.32-10.40	REBOA use in medical arrest - an update - *Jim Manning (Chapel Hill, North Carolina, USA)*
10.40-10.57	**Panel Discussion and Audience Questions**
10.57-12.15	**Endografts and hybrid environments** 8 min talk - 5 minute discussion Moderators: Jerry Fortuna (St Louis, Missiouri, USA), Omid Jazaeri (Denver, Colorado)
10.57-11.10	Endovascular stent graft repair of blunt thoracic aortic injuries - an update - *Pedro Teixeira (Austin, TX, USA)*
11.10-11.23	Stent graft repair of non-aortic arterial injuries - who, when, where - *Ravi Rajani (Atlanta, GA, USA)*
11.23-11.36	Utilization of Intravascular Ultrasound for Blunt Aortic Injury - *Donald Jacobs (Denver, CO, USA)*
11.36-11.49	Single side branched thoracic stents for repair of blunt thoracic aortic injury - *Greg Magee (Los Angeles, CA)*
11.49-11.57	The Relay Pro for the Treatment of Thoracic Aortic Dissections and transections - *Jaime Benarroch-Gampel (Atlanta, GA, USA)*
11.57-12.15	**Panel Discussion and Audience Questions**
12.15-13.15	**Lunch/mingle in the exhibition area/ Resident/Fellow Lunch/ EVTM society meeting & Concurrent Resident Symposium** Moderators: Ryan Lawless (Denver, CO, USA), David McGreevy, (Orebro, Sweden), Stacy Plotkin (Los Angeles, CA, USA)
13.15-13.41	**Keynote address: Disruptive medical technology and the saga of innovation diffusion: a framework for navigating valleys and chasms on the road to product delivery** - Todd Rasmussen (Bethesda, MD, USA)
13.41-14.40	**Shunts and embolization for hemorrhagic control** 8 min talk - 5 minute discussion Moderators: Mike Sise (San Diego, CA, USA), Fernando Joglar (San Juan, Puerto Rico)
13.41-13.54	Endovascular management of Subclavian Artery Trauma - *Anahita Dua (Boston, MA, USA)*
13.54-14.07	Splenic embolization: Who, when, how - *Ben Zarzaur (Indianapolis, Indiana, USA)*
14.07-14.20	Endografts as shunts and in hybrid approaches - *AJ Davidson (Sacramento, CA, USA)*
14.20-14.28	The Rescue Stent: A Comprehensive Solution to Non-compressible Hemorrhage - *Bryan Tillman (Pittsburgh, PA, USA)*
14.28-14.40	**Panel Discussion and Audience Questions**
14.40-15.45	**Endovascular resuscitation and ECMO** 8 min talk - 5 minute discussion Moderators: Jim O'Connor (Baltimore, Maryland, USA), Jeremy Cannon (Philadelphia, PA, USA)
14.40-14.53	Early ECMO for trauma in 2019 - *William Teeter (Chapel Hill, North Carolina, USA)*
14.53-15.06	ECMO and transport - Why and how - *Phil Mason (San Antonio, Texas, USA)*
15.06-15.19	Establishing a regional Acute Lung Unit with ECMO capabiliy = challenges and opportunities - *Jay Menaker (Baltimore, Maryland, USA)*
15.19-15.32	ECMO - Who should own the technology and how should they be trained? - *Lena Napolitano (Ann Arbor, Michigan, USA)*
15.32-15.45	**Panel Discussion and Audience Questions**
15.45-16.15	**Coffee in the exhibition area**
16.15-17.30	**EVTM emerging technologies** 8 min talk - 5 minute discussion Moderators: Jim Manning (Chapel Hill, North Carolina, USA), Mike Dubick (San Antonio, Texas, USA)
16.15-16.28	Selective aortic arch perfusion - who and how? - *James Ross (Portland, Oregon, USA)*
16.28-16.41	It's not just about aortic occlusion: aortic flow regulation for traumatic injury - *Tim Williams (Winston-Salem, NC USA)*
16.41-16.54	4D-CT Evaluation of Organ Ischemia: Is There a role for Partial REBOA to Extend Aortic Occlusion Time? - *Yosuke Matsumura (Chiba, Japan)*
16.54-17.07	Intermittent vs. partial occlusion: which is the feasible answer? - *Matt Martin (San Diego, CA, USA)*
17.07-17.20	IVC filters: New technologies, new opportunities - *Fernando Joglar (San Juan, Puerto Rico)*
17.20-17.33	Catheter-Based TherOx Supersaturated Oxygen in Patients with ST Elevation Myocardial Infarction - *Graham Nichol (Seattle, WA, USA)*
17.33-17.41	Basic Endovacular Skills for Trauma Course: an update - *Laura Moore (Houston, Texas, USA)*
17.41-17.55	**Panel Discussion and Audience Questions**
19.00	**Dinner in the Grand Foyer**

Pan-American EVTM Symposium 2019

MONDAY November 18th	
07.35-07.45	**Introduction** - *Joe DuBose (Baltimore, Maryland, USA)*
07.45-09.10	**REGISTRY DATA and REBOA Study design - updates** 8 min talk - 5 min discussion Moderator: Ernest Moore (Denver, Colorado), Joao Sahagoff (Brazil)
07.45-07.58	AAST AORTA REGISTRY - Update 2019 - *Joe DuBose (Baltimore, Maryland, USA)*
07.58-08.11	The European ABO Trauma Registry - *David McGreevy (Orebro, Sweden)*
08.11-08.24	The UK REBOA study - an update - *Jan Jansen (Birmingham, AL, USA)*
08.24-08.37	What the literature tells us: Scoping out REBOA - *Andrew Beckett (Toronto, Ontario, CA)*
08.37-08.45	Minimizing the bias in observational studies - *Yosuke Matsumura MD (Chiba, Japan)*
08.45-09.10	**Panel Discussion and Audience Questions**
09.10-09.40	**Breakfast/mingle in the exhibition area**
09.40-11.05	**EVTM challenges: reperfusion and refining patient selection** 8 min talk - 5 minute discussion Moderators: Sheldon Teperman (Bronx, New York, USA), Lena Napolitaono (Ann Arbor, Michigan, USA)
09.40-09.53	Resuscitation and REBOA - an anesthesiology perspective - *Mark Chandler (Denver, CO, USA)*
09.53-10.06	Endovascular temperature modulation of re-perfusion injury - *Graham Nichol (Seattle, Washington, USA)*
10.06-10.19	Does REBOA Improve Survival? A Propensity Score Matching Analysis - *Ryo Yamamoto (Tokyo, Japan)*
10.19-10.32	Proximal physiology of the heart, lungs and brain during aortic occlusion - *Luke Neff (Winston-Salem, NC, USA)*
10.32-10.40	The Denver REBOA Algorithm - *Ryan Lawless (Denver, CO USA)*
10.40-11.05	**Panel Discussion and Audience Questions**
11.05-12.20	**Endovascular training issues** 8 min talk - 5 minute discussion Moderators: Michael Sise (San Diego, CA, USA), Melanie Hoehn (Denver, CO, USA)
11.05-11.18	REBOA as a Resuscitative Tool for Post-Partum Hemorrhagic Shock: A Case Report - *Simone Fajer (Kfar Saba, Israel)*
11.18-11.31	Training for high quality ultrasound guided femoral arterial access: Are we doing enough? - *Juan Duchesne (New Orleans, LA, USA)*
11.31-11.44	Building the optimal training platform for the EM members of the EVTM team - *Austin Johnson (Sacramento, CA, USA)*
11.44-11.57	Integrated DOD training and ESTARS - *Jason MacTaggart (Lincoln, Nebraska, USA)*
11.57-12.05	Integrating military/civilian training - advanced resuscitative care - *Zaf Qasim (Philadelphia, PA, USA)*
12.05-12.20	**Panel Discussion and Audience Questions**
12.20-12.50	**Lunch/mingle in the exhibition area**
12.50-15.00	**Miscellaneous Provocative Topics** 7 min talk - 5 minute discussion Moderators: Shahram Aarabi (San Francisco, CA, USA), Juan Duchesne (New Orleans, LA, USA)
12.50-13.02	Complications of REBOA: why vascular surgeons need to stay involved in this technology - *Greg Magee (Los Angeles, CA)*
13.02-13.14	A Hybrid Emergency Room: Has EVTM Influenced a Novel Concept? - *Takahiro Kinoshita (Boston MA, USA)*
13.14-13.26	How to build a hybrid OR when the institution cannot afford it - *Omid Jazaeri (Denver, Colorado)*
13.26-13.38	Prehospital transport of patients with REBOA at high altitude - *Becky Vogel (Denver, Colorado)*
13.38-13.50	Hybrid operating environments - The Canadian experience - *Chad Ball (Calgary, Alberta, Canada)*
13.50-14.02	Hybrid OR utilization - The Shock Trauma experience - *Jonathan Morrison (Baltimore, Maryland, USA)*
14.02-14.14	Embolization for pelvic hemorrhage, where does it fit in the algorithm? - *Melanie Hoehn (Denver, CO, USA)*
14.14-14.26	How Far Forward Should REBOA Go? Lessons from a Special Operations Surgical Team - *MAJ Regan Lyon, MD USAF*
14.26-14.38	EVTM in elective surgical interventions - potential oncologic and orthopedic indications - *Anna Romagnoli (Baltimore, Maryland, USA)*
14.38-14:53	Coffee in the exhibition area
14.53-15.58	**Rapid Fire Poster Session** - *David McGreevy (Orebro, Sweden), Stacy Plotkin (Los Angeles, CA, USA), Ernest E. Moore (Denver, CO, USA)*
16.00-16.30	**Humanitarian Assistance:** "Hemorrhage control during terrorist attacks: How will EVTM help civilian surgeons caught in a war zone? - *Mohammed Al-Musawi (Denver CO, USA).* Panelists: *Sabah Noori, Abdulameer Hussein, & Laith Abood (Baghdad, Iraq)*
16.30-16.45	**Conclusion and final words: EVTM Society, JEVTM, and the next Pan American Meeting** - Chuck Fox, Tal Hörer, Joe DuBose

The **JEVTM Society** and **Denver University Hospital** welcome you to participate in the 2nd Pan-American EVTM meeting at **The Westin Denver International Airport**

Pan-American EVTM Symposium 2019

Endovascular Resuscitation and Trauma Management

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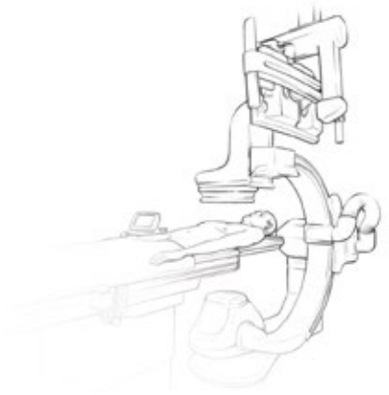

Program for Rapid Fire Poster Session

The order of presentations will be as follows

14:53-14:58	Maria	Wikström	Hemodynamic effects of arterial and venous endovascular balloon occlusion and Pringle maneuver in normovolemic pigs
14:58-15:03	Barak	Raguan Schneidman	Injuries to the abdominal aorta – Diagnosis, management, and outcome: Data from the PROOVIT registry
15:03-15:08	Matthew	Bartley	Aorto-Aortic Conduit for the Treatment of Traumatic Thoracic Pseudoaneurysm With Unfavorable Iliac Arteries
15:08-15:13	Linda	Wang	Aortic Transection Following Blunt Aortic Trauma
15:13-15:18	Tongporn	Wannatoop	Endovascular treatment of concomitant innominate and subclavian artery injury from gun-shot wound with pseudoaneurysms in a polytrauma patient
15:18-15:23	Navin	Vigneshwar	Percutaneous Access for Extracorporeal Cardiac Bypass Rewarming in Severe Accidental Hypothermia
15:23-15:28	Pavel	Kibrik	Compartment Syndrome of the Leg After Intraosseous (IO) Needle Insertion.
15:28-15:33	Christina	Theodorou	Hate to Burst Your Balloon: Successful REBOA Use Takes More Than a Course
15:33-15:38	Justin	Hatchimonji	REBOA Use in Non-trauma Emergency General Surgery: A Multi-Institutional Experience
15:38-15:43	Jamie	Hadley	Strategies for Successful Implementation of REBOA in a Level 1 Trauma Center
15:43-15:48	Marta	Madurska	Partial vs Complete resuscitative endovascular balloon occlusion of the aorta (REBOA): early results from a single trauma center.
15:48-15:53	Daniel	Lammers	Utilization of the Compass pressure transducer for resuscitative endovascular balloon occlusion of the aorta guided resuscitation
15:53-15:58	Julia	Coleman	Unintentional Zone 2 balloon inflation is not infrequent: a call to re-evaluate the practice of REBOA insertion and position confirmation

Following presentations, scores will be tallied and the winner of the competition will be announced.

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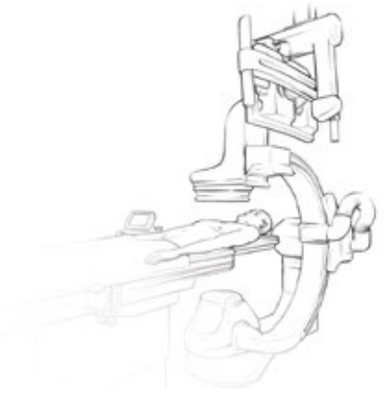

Program for Resident/Fellow Lunch Session

The order of presentations will be as follows:

12:20-12:25	Alley	Ronaldi	Next-generation partial resuscitative endovascular balloon occlusion of the aorta (PREBOA) catheter: Characterization of balloon volume and distal aortic flow in a porcine model (Sus scrofa domesticus) of hemorrhagic shock.
12:25-12:30	Anastasia	Plotkin	Endovascular Skills Training and a Cost-Effective Toolkit for Trauma Surgeons.
12:30-12:35	Mitra	Sadeghi	Endovascular Resuscitation with Aortic Balloon Occlusion in pediatric trauma - a case report.
12:35-12:40	Jason	Samuels	Hepatic Angioembolization increases complications with minimal benefit.
12:40-12:45	Michelle	Moe	Delta Systolic Blood Pressure Can be a Stronger Predictor of Mortality Compared to Pre-aortic Occlusion Systolic Blood Pressure in Non-compressible Torso Hemorrhage Patients; An ABOTrauma Registry and AORTA Database Analysis.
12:45-12:50	Alexis	Cralley	A Bioengineered Human Acellular Vessel for Torso Arterial Reconstruction: A Role for Open Repair in the Endovascular Era.
12:50-12:55	Anna	Stene Hurtsen	End-tidal carbon dioxide as an indicator of partial REBOA and distal organ metabolism in normovolemia and hemorrhagic shock in anesthetized pigs.
12:55-13:00	Juan Jose	Melendez	Feasibility of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in thoracic trauma: the experience of a Level I Trauma Center in Latin-America.
13:00-13:15			Audience questions and comments

EVTM Workshop
Örebro, Sweden 16-17 January 2020

- EVTM Society
- EVTM Workshop
- EVTM App
- EVTM Journal

Endovascular Resuscitation and Trauma Management

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REBOA Registries
- ABOTrauma
- REBOAGYN
- PreHospital

Next EVTM/REBOA Workshop 16-17 January 2020

EVTM Workshop
Örebro, Sweden 16-17 January 2020

EndoVascular resuscitation, bleeding and Trauma Management (EVTM)

Hands-on Workshop

Örebro, Sweden 16-17 January 2020

Endovascular and hybrid solutions for the bleeding patient; Aortic balloon occlusion (*REBOA*) usage, Vascular Access, Embolization, Imaging, Endografts, ECMO and other modern techniques in Resuscitation

Local EVTM instructors:
Artai Pirouzram MD; Asko Toivola MD; David McGreevy MD;
Rickard Lindgren MD, PhD; Per Skoog MD, PhD; Kristofer Nilsson MD, PhD;
Thomas Larzon MD, PhD and Tal Hörer MD, PhD

Dept. of Cardiothoracic and Vascular Surgery, Dept. of General Surgery,
Dept. of Anesthesia and Intensive Care, Örebro University Hospital, Sweden

Guest international EVTM instructors:
Viktor Reva (Trauma, Vascular, RU), Anna Maria Ierardi (IR, IT), Filippo Piacentino (IR, IT), Ofer Gallili (Vascular, IL), Frank Plani (Trauma, Surgery, ZA), Zoran Rancic (Vascular, Sz) Paul Rees (Resuscitation, Military, UK), Mansoor Khan (Trauma, UK), Melanie Hoehn (Vascular, Trauma, US), TBA

Local assisting group:
Maria Wikström MD, Mitra Sadeghi MD, Monica Clomen RN, Nina Adolfsson RN,
Jonas Berlin RN, Johan Josefsson RN.

In cooperation with the Japanese society of
Diagnostic and Interventional Radiology in Emergency, Critical care and Trauma (DIRECT). TBA

EVTM Workshop
Örebro, Sweden 16-17 January 2020

Target: Surgeons, IR, ED, Vascular and Intensivists with interest in trauma/bleeding/resuscitation, Emergency/pre-hospital teams, Military trauma teams

Date: 16-17 January 2020 at Örebro University Hospital Training Center and Animal Lab

Workshop Director: Dr. Tal Hörer MD, PhD, Associate Professor of Surgery

Workshop Secretary / Registration: Åsa Strandberg (asa.strandberg@regionorebrolan.se)

Cost (cover expenses only): 600€, 500€ for EVTM society members

Partners: Tokai Medical Products, REBOA Medical, Secma Medical Innovations, Ziehm Imaging, GE Healthcare, STILLE, Vingmed, COOK, Limedic, Örebro University Hospital. **TBA**

The aim of this WS is to stimulate discussion and practice EndoVascular resuscitation, bleeding and Trauma Management (EVTM) using a multidisciplinary team approach. "No ego, just good science and cooperation" is the main motion of the workshop. We will together explore different methods for resuscitation, bleeding control and trauma management, some with great experience and some that have never been practiced before anywhere.

- Vascular access:
  - Different methods (blind, Doppler, ultrasound, fluoroscopy and cut down)
  - Its use in hemodynamic unstable patients
- Aortic Balloon Occlusion (REBOA) basic and advanced methods
- Basic and advanced endograft and embolization methods
- Damage control EVTM and Bailout methods
- Basic and advanced postoperative considerations
- Up-to-date research and clinical experience
- ABOTrauma Registry cases; Own cases and participants cases
- Knowledge of basic material and new technologies on the market
- Intensive training on both dry models as well as live tissue.
- Basics for building a "REBOA / EVTM service"
- Advanced experimental methods in resuscitation

The workshop is designed for experienced physicians but is individually tailored during the practical parts. Participants will get basic training and knowledge of REBOA placement as part of the EVTM concept. The workshop has been certificated by the EUCME and acknowledged by the European Society for Trauma and Acute Care Surgery and in cooperation with other relevant societies.

EVTM Workshop
Örebro, Sweden 16-17 January 2020

Day 1 (16 January): Clinical Training Center (KTC), USÖ

- EVTM algorithm and up-to-date world experience
- Theory and methods for vascular access; Basic and advanced
- Practical physiology of REBOA/pREBOA/iREBOA and literature
- Use of access, aortic/arterial balloon occlusion, endografts, embolization and other tools for the bleeding and unstable patients
- Dry model training and simulator training
- Group discussion of participant cases and ABOTrauma Registry cases
- Building an EVTM service and initiating REBOA use per center
- Discussions/cases
- Current data updates
- New technologies in endo tools and imaging; what's hot, what's next?

11:45 Gathering at the Clinical Training Center (2nd floor)

12:00-12:30 Lunch, welcome and general information (Tal H)

12:40-16:30 **8-minute presentations** and short discussions (coffee served during sessions) Minor changes may follow. TBA

Ca 16:45-19:00 Practical discussions/exchange of information and training in stations and cases with scenario training on model.

Practical scenarios on training models

- Aorta 3D models
- C-arm usage; Angiography table
- Endo-simulator
- Access and REBOA stations
- Practical training and discussion with instructors in groups; individual level
- Material for endo-trauma and hybrid management
- The "EVTM REBOA trolley"
- Over the wire methods (Seldinger) on dry model
- Blind and ultrasound guided access
- Introducers and upgrading; endo-shunts

Around 19:00 Departure to dinner (TBA; walk together from the hospital)

Day 2 (17 January): Animal lab training & research center, USÖ

07:00 Gathering/changing at the Clinical Training Center (2nd floor)

07:15-08:40 "EVTM anatomical review - what can we do?" REBOA practice (Cadaver)
(Preliminary - if available, to be announced the day before)

08:40-09:15 Breakfast with the industry (Clinical Training Center); Clinical Cases

09:20-14:30 Hands-on animal lab including:

Every station is led by a highly experienced instructor with one-to-one training on live tissue as well as group scenario discussions. (Lunch and coffee will be served in the lab) Changing stations according to interest is encouraged.

Practical training points in the animal lab:

1. Material usage in bleeding patients, general considerations. The trauma-bay kit.
2. Vascular Access
    - Basic principles
    - Cut down techniques
    - Endoshunts (and shunts)
    - Hybrid procedures
    - Puncture methods
    - Seldinger technique
    - The failing access - alternatives
    - Venous access
3. Upgrading/introducers/guide wires
4. REBOA
    - Material and REBOA kit
    - Practical deployment
    - Deflation and re-positioning
    - Intermittent/Partial inflation with MAP as target (iREBOA/pREBOA)
    - Ongoing bleeding practice
    - CPR procedures and pending arrest

As times allows and based on individual level:

5. Balloon in alternate locations (Iliac, Subclavian, Brachiocephalic trunk/Zone 1 neck)
6. Aortography and Angiography considerations (type, volume etc.)
7. Embolization of target vessels: Material, Access, Coils, Onyx/Phil. Endograft deployment (basic/advanced issues), Pelvic bleeding
8. Bleeding management scenarios on live tissue will be incorporated.

14:30 -15:00 End of workshop and evaluation
The workshop is designed for mutual learning and sharing of experiences! It is built on individual professional level and experience.

"No ego, just good science and cooperation"

EVTM Society

Join the Endovascular Resuscitation Platform

The EVTM society is a non profit organization that aims to share information on advanced methods for bleeding control and endovascular resuscitation, exchange of data, and cooperation and education. It is also designed to serve as a professional platform for the multidisciplinary approach.

By joining the EVTM Society you will be part of this global development.

To join, please visit jevtm.com and click on "Join EVTM Society" in the menu.

Membership is free at this stage.

Vision and Mission:
Our mission is to promote optimal treatment and new methods for bleeding control in trauma and non-trauma patients, and state-of-the-art endovascular resuscitation. This will be achieved by a joint international body that will support the following:

- A web-based free platform for EVTM issues (jevtm.com).
- JEVTM – the Journal of Endoascular Resuscitation and Trauma Management, an open access peer-reviewed journal.
- The EVTM round table symposium, a platform for continuous debate and data exchange.
- Educational opportunities in the form of manuals (Top Stent), courses, workshops, and web seminars.
- Promoting open dialogue and cooperation between societies, organizations and the industry.
- Promoting new guidelines and recommendations for EVTM-related issues and protocols.
- Promoting research in EVTM-related areas, both human and animal.
- Promoting PR for EVTM issues, grants, and collaboration with industry.
- Encouraging residents and young colleagues to carry out research on EVTM issues.
- Promoting cooperation and data exchange with other medical instances.

Structure:
The EVTM council, led by the society chair will change membership periodically (i.e., after two years). The council aims to have one or two representatives from each participating country and discipline.

The EVTM society is supported at this stage by Örebro University Hospital in all financial respects (as part of EVTM research group support). This support has been granted for the forthcoming two years.

The main task of the council is to pave the way for the EVTM venture, and promote the JEVTM/EVTM symposium, EVTM-related courses, cooperation, and free exchange of information.

Members will obtain free access to all JEVTM information and discussions as well as regular updates on EVTM-related activities, education, and developments. Members will also be offered a reduced fee for the EVTM round table symposium.

EVTM Society is registered in Sweden, and is managed in collaboration with the EVTM program at Örebro University Hospital, the JEVTM journal and web platform, and other institutes.

Since the society is registered in Sweden, it will follow the rules and guidelines of the Swedish government and the EU. Expansion to other countries is welcome, but should follow our ethical guidelines and the EVTM society should be named in all documents appropriately.

Call for collaboration: We call out to physicians with an interest in endovascular resuscitation, trauma and bleeding management. We need the contributions of the medical professionals who want to be a part of our venture.

Please consider joining by filling out the form at:
http://www.jevtm.com/join-the-evtm-society

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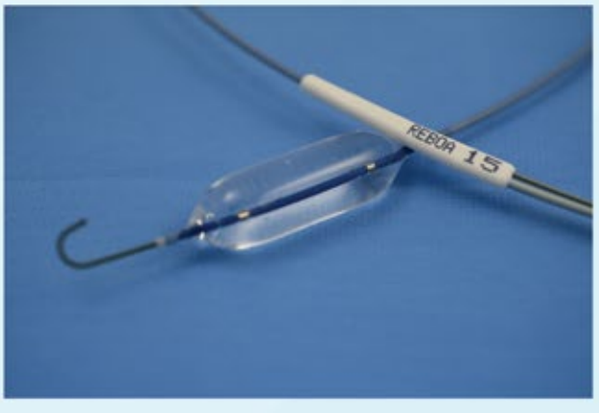
RBK20305007	20/30 (mm)	15,0 mL	7F

*both kits are delivered with a 23 cm long introducer

The REBOA balloon is inserted using standard Seldinger technique.



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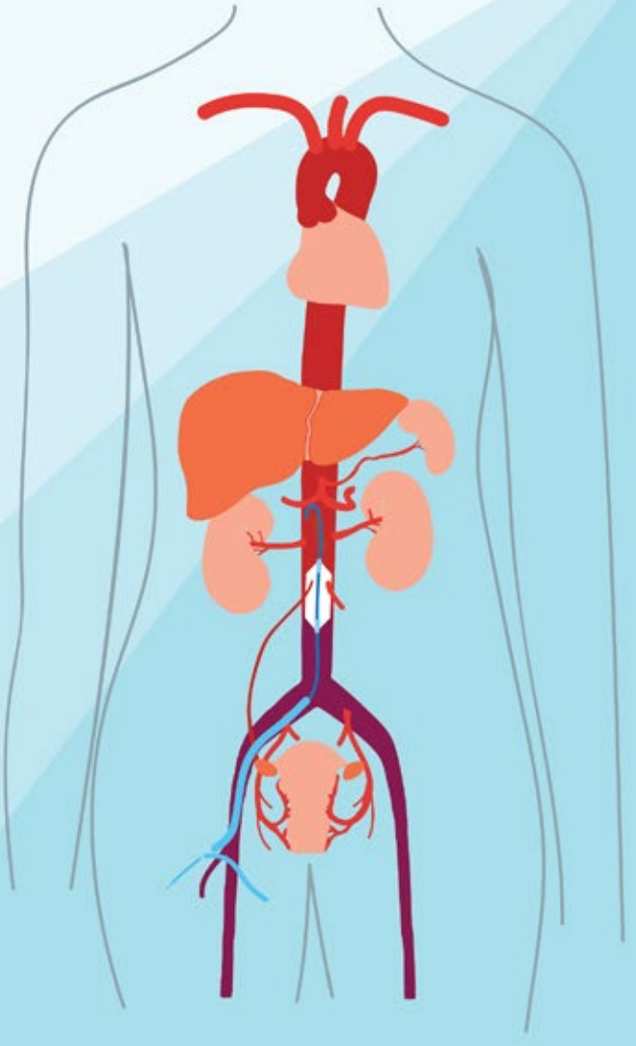

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