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Issue Highlights

Damage control surgery & interventions

REBOA or retroperitoneal packing in pelvic injuries

CT guided placement of neuromonitoring in swine model

Clinical images of Endovascular resuscitation and Trauma Management

And more...

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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 Archives can be found on www.jevtm.com under journals and are there with no time or access limitations.

JEVTM is indexed in Scopus and Web Of Science.

Official publication of the Society of Endovascular Resuscitation and Trauma Management (EVTM)

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

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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/evtm-society.

The Membership fee is 50 USD biannually.

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/evtm-society

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.
- Authors: These should be listed in order for publication, with first name, initials and surname, along with highest academic degree.
- Affiliations: The institution(s) that the authors are affiliated with should be listed. A full address is not required, but enough to ensure identification.
- Corresponding Author: This individual should be clearly identified, along with full institutional address and e-mail address.
- Author Contributions: All authors are expected to have substantially contributed to the study and manuscript writing.
- Funding Declaration: Any grant funding should be listed.
- Presentation: The meeting where any of the submitted data was presented should be listed.

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
Sub-sub-heading Italicized

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.

Ethical & Legal Considerations

The journal is committed to maintaining the highest level of integrity in the content published. This journal has a Conflict of Interest policy in place and complies with international, national and/or institutional standards on research involving Human Participants and/or Animals and Informed Consent. The journal is follows the Committee on Publication Ethics (COPE) regulations and subscribes to its principles on how to deal with acts of misconduct thereby committing to investigate allegations of misconduct in order to ensure the integrity of research. The journal may use plagiarism detection software to screen the submissions. If plagiarism is identified, the COPE guidelines on plagiarism will be followed. Content published in this journal is peer reviewed (double blind review process). detailed information will follow in the text below in this section.

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. All authors are obliged to provide reractions or corrections of mistakes after review process. 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). Please follow the ethical guidlines as explaied also in the "intractuins for authors" section.

Detailed ethical guidelines

Maintaining integrity of the research and its presentation is helped by following the rules of good scientific practice, which is outlined here:

- The manuscript should not be submitted to more than one journal for simultaneous consideration.
- The submitted work should be original and should not have been published elsewhere in any form or language (partially or in full), unless the new work concerns an expansion of previous work. (Please provide transparency on the re-use of material to avoid the concerns about text-recycling ('self-plagiarism').
- A single study should not be split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time (i.e. 'salami-slicing/publishing').
- Concurrent or secondary publication is sometimes justifiable, provided certain conditions are met. Examples include: translations or a manuscript that is intended for a different group of readers.
- Results should be presented clearly, honestly, and without fabrication, falsification or inappropriate data manipulation (including image based manipulation). Authors should adhere to discipline-specific rules for acquiring, selecting and processing data.
- No data, text, or theories by others are presented as if they were the author's own ('plagiarism'). Proper acknowledgements to other works must be given (this includes material that is closely copied (near verbatim), summarized and/or paraphrased), quotation marks (to indicate words taken from another source) are used for verbatim copying of material, and permissions secured for material that is copyrighted.
- Authors should avoid untrue statements about an entity (who can be an individual person or a company) or descriptions of their behavior or actions that could potentially be seen as personal attacks or allegations about that person.
- Authors are strongly advised to ensure the author group, the Corresponding Author, and the order of authors are all correct at submission. Adding and/or deleting authors during the revision stages is generally not permitted, but in some cases may be warranted. Reasons for changes in authorship should be explained in detail. Please note that changes to authorship cannot be made after acceptance of a manuscript.
- In order to maintain the highest scientific standards, the journal follows strict quality standards.

Upon request authors should be prepared to send relevant documentation or data in order to verify the validity of the results presented. This could be in the form of raw data, samples, records, etc. Sensitive information in the form of confidential or proprietary data is excluded.

If there is suspicion of misbehavior or alleged fraud the Journal and/or Publisher will carry out an investigation following COPE guidelines. If, after investigation, there are valid concerns, the author(s) concerned will be contacted under their given e-mail address and given an opportunity to address the issue. Depending on the situation, this may result in the Journal's and/or Publisher's implementation of the following measures, including, but not limited to:

If the manuscript is still under consideration, it may be rejected and returned to the author.

Author Guidelines

(continued)

If the article has already been published online, depending on the nature and severity of the infraction:
– an erratum/correction may be placed with the article

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– or in severe cases retraction of the article may occur.

The reason will be given in the published erratum/correction, expression of concern or retraction note. Please note that retraction means that the article is maintained on the platform, watermarked "retracted" and the explanation for the retraction is provided in a note linked to the watermarked article.

Authors have an obligation to correct mistakes once they discover a significant error or inaccuracy in their published article. The author(s) is/are requested to contact the journal and explain in what sense the error is impacting the article. A decision on how to correct the literature will depend on the nature of the error. This may be a correction or retraction. The retraction note should provide transparency which parts of the article are impacted by the error.

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).

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Editorial

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JEVTM 10th Edition

Tal M Hörer

Editor in Chief JEVTM

Four years ago, a group of enthusiastic physicians established the Journal of Endovascular Resuscitation and Trauma Management, JEVTM [1,2] (www.jevtm.com). The need for a professional, peer-reviewed platform for endovascular and hybrid methods of resuscitation and trauma has increased over the last decade as new methods have become established in the field [3]. The development of multidisciplinary teamwork and new technologies in endovascular therapy and imaging has made it possible to treat patients using minimally invasive methods and potentially decrease the morbidity and mortality of both trauma and non-trauma patients [4,5].

In parallel, the Endovascular Resuscitation and Trauma Management (EVTM) platform has developed through scientific publications in high-impact journals, manuals, textbooks, workshops, symposia, and the EVTM society [3,6,7]. These developments have increased in recent years and are reflected in the submission rate (and also the rejection rate) of the JEVTM as well as interest in collaboration with other international established medical societies (trauma, vascular, radiology, intensive care, emergency medicine, and military).

The fact is that the surgical and non-surgical treatments of many patient groups have changed in recent decades, significantly in favor of the use of endovascular methods. Examples of some well-documented disorders are: ruptured abdominal aneurysm and the need for endovascular aortic repair, blunt thoracic aortic injuries, embolization in the spleen and other visceral organs, and bleeding or pelvic bleeding in trauma [8–10]. We believe that use of the EVTM concept, which covers all these conditions, methods and their applications, and even some others, can, in multidisciplinary efforts, save more patients. This concept can be used in both developed and less-developed countries, in highly sophisticated hybrid suites with state-of-the-art technology and in austere or military environments [11]. The potential of EVTM is huge and covers both bleeding and non-bleeding patients at the early phase of intervention and during resuscitation. This includes trauma-induced hemodynamically unstable patients ; non-trauma bleeders; patients with gastrointestinal, post-partum or other types of bleeding; potentially patients with cardiac arrest; and other patient groups. Considering the high mortality and morbidity of patients who go through resuscitation, there is a very important place for research and clinical development in the field of EVTM [3,12]. The JEVTM aims to share data and clinical experiences to spread this news.

In the last nine editions of the journal, more than 120 peer-reviewed papers presented scientific developments in the field of EVTM. In this forthcoming 10th edition, we hope to present more scientific and clinical data to encourage our readers to develop EVTM-related clinical and experimental research that might benefit our patients. A shift from a great interest in Resuscitative Balloon Occlusion of the Aorta (REBOA) previously to other diverse endovascular and hybrid methods for bleeding control and resuscitation becomes clear when reading the last nine editions of JEVTM. Over time, more high-quality articles have been submitted and the journal is developing with every issue. The editorial board and editors work clinically and are established researchers in the field. Trauma and vascular surgeons, interventional radiologists, intensive care and emergency doctors, and prehospital experts are all dedicated to developing the field of EVTM and making the JEVTM an established medical journal. JEVTM is indexed in Scopus and Web-of-Science, and we hope that it will be indexed soon in other well-established systems so it can well serve our readers. The JEVTM is free online and is the official journal of the EVTM Society.

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Lastly, we would like to thank our former editor, Jonathan Morrison; leading editors, Joe DuBose, Megan Brenner and Yosuke Matsumura; associate editor, Boris Kessel; senior advisor, Ernest E Moore; as well as the editorial technical team and the Örebro University Hospital research division. The work of our reviewers should also be acknowledged as well as their contributions to the critical revision of all articles published in the JEVTM.

We hope the next edition of the JEVTM will be of great value to our readers and that it will continue to grow as a true scientific platform for EVTM.

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Invited Editorial

Vol. 5, No. 1; 2021; pp 3–5
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REBOA or Preperitoneal Packing in Patients with Pelvic Fractures: Why Not Both?

Maya Paran[1], Boris Kessel[1] and Eyal Hashavia[2]

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[2]Trauma Unit, General Surgery Division, Tel Aviv Sourasky Medical Center, Israel

A non-Shakespearean scenario of a hemodynamically unstable patient with pelvic fractures is a challenge for any highly professional trauma team. The treatment paradigm of this life-threatening condition has changed multiple times during the past decades, depending on the institution's facilities and teams' availability. In the 1980s and early 1990s, the standard approach consisted of exploratory laparotomy and internal packing with or without bilateral internal iliac ligation [1]. With passing years, accumulated experience has demonstrated that such procedures are ineffective and should therefore be abandoned when treating patients with isolated pelvic fractures and no concomitant intra-abdominal injury requiring laparotomy. The accepted treatment shifted to other surgical procedures, such as different types of external pelvic ring fixation, which aim to decrease the pelvic volume and create local tamponade [2]. These techniques became considered as the standard care until several studies reported that hemodynamic instability, in an adequately resuscitated patient with pelvic fractures, is a marker of arterial injury. Hence, pelvic angioembolization has become the preferred approach [2]. However, safe invasive radiology techniques require adequate physiological parameters to allow a transfer to the angiography suite and, occasionally, time-consuming procedures [3].

During the late 1990s and early 2000s, pelvic preperitoneal packing (PPP) was introduced for primary stabilization of patients with pelvic fractures [4–6]. This relatively simple and quick technique, which can be performed in the emergency room, achieves a rapid blood pressure improvement in most cases [7,8] and has thus become favored worldwide [9]. Additionally, depending on the source of bleeding, some authors reported no need to follow up with angio-embolization after the packing [10,11]. Although angio-embolization is the treatment of choice for arterial bleeding, it does not address the more prevalent venous bleeding, for which PPP is an important treatment option [12]. For example, Burlew et al. [10] have reported arterial bleeding to be present in only 13% of patients with pelvic fractures, making the need for angio-embolization very limited. Nevertheless, despite gaining popularity, PPP has been reported to be associated with several disadvantages. The main concern is with regard to the next appropriate step when it does not work. To date, when treating an unstable blunt trauma patient with a positive FAST and an unstable pelvic ring, the question remains: Should explorative laparotomy or PPP be performed first? In the presence of an open abdomen, the efficacy of the packing markedly decreases. In addition, performing PPP prior to laparotomy possibly limits the necessary abdominal exposure. Other disadvantages of PPP include increased morbidity associated with essential de-packing, closure of wounds, increased infection rates [13], etc.

Surprisingly, although REBOA was first approved for hemorrhage control in patients with pelvic fractures [14–16] and is mentioned in various guidelines/recommendations for pelvic fracture management [17–19], only a few studies have compared REBOA with PPP in these patients. Mikdad et al. [20] have published a retrospective analysis of 204 blunt trauma patients, of which 102 were treated with PPP and 102 matched patients who were treated with REBOA placement. No significant differences in blood transfusion volume, length of hospital stay or rates of major complications were reported. Time to intervention was shorter in those patients treated with REBOA. However, REBOA was found to be associated with higher rates of 24-h mortality and in-hospital mortality.

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Another study by Duchesne et al. [21] that investigated the outcome of different methods for hemorrhage control included 24 patients who underwent PPP and 7 who were treated with REBOA. No differences between the two groups were found with regard to median injury severity score (ISS), rates of head abbreviated injury scale (AIS) ≥3, chest AIS ≥3, extremity AIS ≥3, median Glasgow coma scale, heart rate, and systolic blood pressure. The authors have found PPP to be associated with mortality rates of 58%, whereas REBOA was associated with a mortality rate of 86% ($P < 0.001$). Median length of hospital stay was 16 (1–33) days for PPP and 1 (1–2) days for REBOA ($P = 0.017$).

In the most recent published study, Asmar et al. [22] also compared these two techniques in the management of hemodynamically unstable patients with pelvic fractures. This study included 156 patients, of which 52 were treated with PPP, 52 with REBOA, and another group of 52 with both PPP and REBOA. The authors found that both 24-h mortality and in-hospital mortality were highest in the patients who underwent both PPP and REBOA. However, these mortality rates were lowest in the group of patients who were treated with REBOA alone, even when compared with the group treated with both REBOA and PPP. Moreover, time to laparotomy and/or angioembolization was also shorter in the REBOA-only group.

To the best of our knowledge, the above-mentioned study, was a pioneer evaluation of the feasibility of a combination of REBOA and PPP. Unfortunately, this article doesn't include the crucial details of such combined approach. When reading through this paper, two questions arise: Which was performed first, the PPP or REBOA? and Is it feasible to perform both procedures simultaneously? There are several aspects that we believe should be further discussed. From a technical point of view, simultaneous performance of these two procedures is feasible. Normally, the blood pressure in the iliac artery is nearly similar to the aortic blood pressure. Therefore, PPP, even when performed after zone-III balloon inflation, cannot occlude arterial blood flow. Furthermore, an arterial access achieved via the groin approach does not decrease the efficacy of PPP. Certainly, the ability to perform these techniques relies on the immediate availability of properly trained teams.

In summary, there is no single appropriate treatment for patients with unstable pelvic fractures. The choice of treatment must also rely on appropriate teams' availability and the specific medical center's resources. Most patients with unstable pelvic fractures respond adequately to PPP, allowing for follow-up investigation and pelvic angioembolization. In the small group of PPP non-responders, the mortality rates remain high. REBOA is a temporary bridging technique for blood pressure stabilization, which isn't always efficient. Simultaneous use of REBOA and PPP or preparedness for placement of REBOA with achievement of immediate access may provide safe patient transfer to a hybrid room where any endovascular treatment could be maximally utilized. In this editorial, we call for future animal and human studies to investigate and better define the indications, proper timing and feasibility of a truly hybrid approach, combining both PPP and REBOA.

Ethics Statement

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

All authors have contributed to the writing and editing of this manuscript.

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Original Article

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Vascular Access Training for Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) Placement: A Feasibility Study in Emergency Physicians

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Background: Training vascular access skills for Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) to emergency physicians (EPs) could contribute to better outcomes in patients with non-compressible truncal hemorrhage. This study aimed to determine whether a concise training program could train EPs to recognize anatomical structures and correctly visualize and identify the puncture site for percutaneous REBOA catheter placement.
Methods: Our training program included basic anatomy and training in access materials for REBOA. Participants underwent expert-guided practice on each other and were then tested on key skills: the identification of anatomical structures, anatomy knowledge, technical skills for vascular access imaging with a handheld ultrasound, and time to identify adequate puncture site of the common femoral artery (CFA). Consultant vascular surgeons functioned as expert controls.
Results: Eleven EPs participated. They had a median overall technical skills score of 32.5 (27.0–35.0) and median time to identify the CFA puncture site of 52.9 s (35.6–63.7), which improved to 34.0 s (21.2–44.7) at the post-test ($Z = -2.756$, $P = 0.006$). Consultant vascular surgeons were significantly faster ($P = 0.000$).
Conclusions: EPs are capable of visualizing the femoral artery and vein within 1 min. This speed improved rapidly after repetition. Our concise training program proved useful regardless of prior endovascular experience. This program, as a component of an expanded Endovascular Resuscitation and Trauma Management curriculum, in combination with realistic task training models (simulator, perfused cadaver, or live tissue) has the potential to provide effective training of the skills required to competently perform REBOA.

Keywords: *Vascular Access; Ultrasound; Training; Aortic Balloon Occlusion; Emergency Physicians; REBOA*

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INTRODUCTION

Although airway and breathing management are the first critical steps in the management of critically injured patients, controlling catastrophic bleeding is a major life-saving skill in trauma and vascular surgery. Recent experiences on the battlefields of Iraq and Afghanistan have validated the efficacy of tourniquets and massive transfusion protocols for managing extremity hemorrhage [1–3]. However, areas not amenable to tourniquet application, such as the neck, trunk and junctional regions, continue to represent challenges for prompt effective bleeding control. Given a number of recent mass casualty incidents from shootings and terrorist attacks, new concepts of truncal and junctional bleeding control need to be evaluated and possibly implemented.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is a technique in which a catheter with an occlusion balloon is advanced into the aorta and then inflated, thereby obstructing flow into the distal circulation as a temporary measure to control hemorrhage (Figure 1) [4,5]. The balloon can be inflated in either aorta zone 1, between the left subclavian artery and celiac trunk, or zone 3, between the distal renal artery and aortic bifurcation, depending on the level of injury. REBOA is an important component of the evolving hybrid practice of the Endovascular Resuscitation and Trauma Management (EVTM) of bleeding in trauma patients [6]. Previously, an EVTM workshop was developed as a training to introduce the principles of REBOA as an adjunct to the management of patients with massive hemorrhage from truncal or junctional injuries [7]. REBOA catheters have been used successfully in the hospital setting, combat environment, and even in the earliest phases of prehospital care [3]. However, there is an ongoing debate as to which professionals should obtain vascular access and perform REBOA. A recent joint statement by the American College of Surgeons Committee on Trauma (ACS COT) and the American College of Emergency Physicians (ACEP) states that emergency physicians (EPs) may perform REBOA after sufficient training [8].

An International Collaborative Workgroup has been developed to evaluate the safety and efficacy of REBOA and EVTM as a potential standard for the emergency care of selective patients. An important research question is whether it is feasible to train medical personnel with limited or no prior endovascular or surgical experience, including EPs, to perform such endovascular procedures. There are formal training curricula designed for physicians to train the skills necessary to perform REBOA. These include the Basic Endovascular Skills for Trauma (BEST™), the Endovascular Skills for Trauma

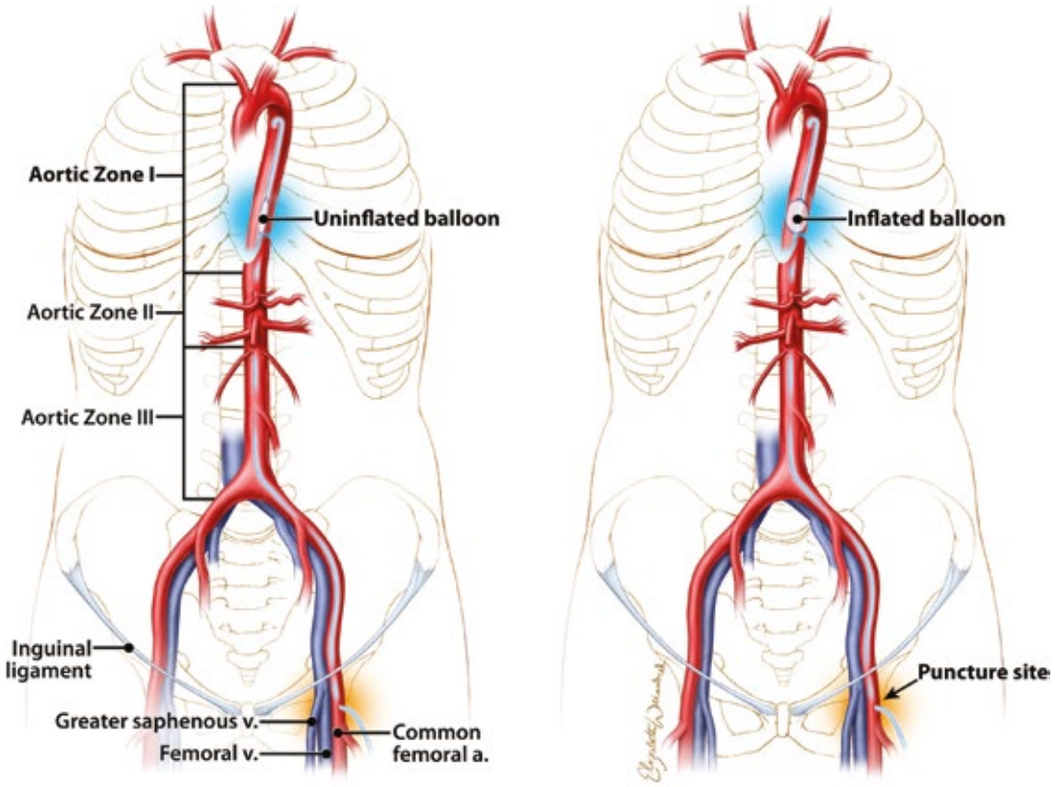

Figure 1 Schematic representation of REBOA balloon deployment in the aorta.

and Resuscitation (ESTARS), and the EVTM courses. The EVTM International Collaboration Workgroup has recently reported on a comprehensive vascular access training program using a live-tissue simulator hybrid porcine model that can be used for femoral access and REBOA placement training in medical personnel with different levels of prior training [7].

In the Netherlands, EPs are integrated in emergency departments in all major trauma centers and many trauma units. They are often the first physicians providing emergency care. Vascular access training and REBOA placement for EPs could thereby contribute to better outcomes in the hemorrhagic patients they receive. Currently, endovascular procedures and the use of ultrasound to obtain vascular access are not part of the standard Dutch Emergency Physician training curriculum.

The primary aim of this study was to determine whether our concise training program could train EPs with limited or no experience to recognize anatomical structures and correctly visualize and identify the puncture site for the percutaneous placement of a REBOA catheter.

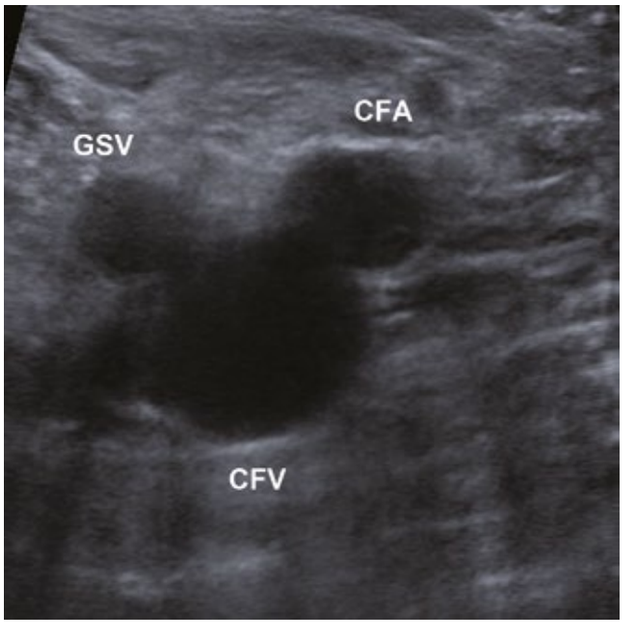

Figure 2 Transverse ultrasound image of the common femoral artery (CFA) and vein (CFV) and great saphenous vein (GSV), also known as Mickey Mouse sign.

METHODS

Participants

All EPs from a Dutch level-I trauma center were approached to engage in our training program, and 11 signed up to participate. The participating EPs had varying prior experience with ultrasound imaging of the femoral artery and vein, and none of them had experience with REBOA. At their institution, the EPs receive patients from all medical disciplines and are generally the first physicians to provide emergency care. They are usually in charge of the management of trauma patients.

In this study, the participants, who were all healthy, also served as anatomy subjects, so they could practice the skills on each other. Three consultant vascular surgeons with extensive endovascular experience performed the same procedure, serving as expert controls.

Curriculum

Participants were asked to score themselves on their pre-existent general ultrasound skills and vascular access ultrasound skills on a scale from one (worst) to ten (best). A formalized concise training curriculum (30 min) comprised of basic anatomy of the femoral region, and knowledge of the access materials (the guide wire and introducer sheath) was presented. The details and instructions for use of the ER-REBOA™ Catheter (Prytime Medical; Boerne, Texas USA) were explained and demonstrated via an animated video (15 min) covering the steps necessary for deployment of the balloon in aortic zone 1 [4]. Participants were subsequently separated into buddy pairs and one trio for the training and test. They practiced (on each other) identification of the anatomical landmarks and ultrasound identification of the femoral vessels, guided by an experienced vascular surgeon or ultrasound specialist.

Key skills were as follows: (1) identification of anatomical structures, (2) anatomy knowledge, (3) technical skills for vascular access imaging using a handheld ultrasound and (4) time to identify adequate puncture site of the common femoral artery (CFA) with "Mickey Mouse sign" as seen in Figure 2.

A point-of-view GoPro® camera placed on a helmet was used for all participants, as well as one additional GoPro® camera positioned to achieve a full view of the subject and participant. After verbalizing every step of the procedure, video recording was commenced, and the actual test was started with registration of procedure time. As a post-test, all EPs performed the identical procedure a second time 2 h after additional endovascular training during this EVTM workshop.

Scoring System

Participants were evaluated using a modified checklist that was developed as part of a validation study for the Advanced Surgical Skills Exposures for Trauma (ASSET™) course [9,10]. This included technical and nontechnical skills, Global Rating Scale scores, errors, and time to achieve visualization of the "Mickey Mouse sign" (time from hand on ultrasound gel bottle to "Mickey Mouse sign"). Two evaluators (RH and TD)

Table 1 **(a)** Self-rated pre-existent ultrasound skills of the emergency physicians and correlation with actual skills score. **(b)** Average results of the emergency physicians.

a. *Self-Rated Pre-Existent Ultrasound Skills*	*Score (n = 11) Median (IQR)*	*Correlation (Spearman's ρ)*
General ultrasound skills*	6.0 (3.0–7.0)	NA
Vascular access ultrasound skills*	5.0 (3.0–6.0)	$r_s = 0.620$, $P = 0.042$
b. *Technical Skill*	*Score (n = 11) Median (IQR)*	
01. Correctly identifies anatomical landmarks†	4.0 (3.0–4.0)	
02. Proceeds at appropriate pace with economy of movement†	3.0 (3.0–4.0)	
03. Communicates clearly and consistently†	3.0 (3.0–4.0)	
04. Follows a logical sequence for the procedure†	4.0 (3.0–4.0)	
05. Uses US probe in optimal orientation†	4.0 (3.0–4.0)	
06. Correctly identifies CFA‡	1.0 (1.0–1.0)	
07. Correctly identifies CFV‡	1.0 (1.0–1.0)	
08. Correctly identifies DFA‡	1.0 (1.0–1.0)	
09. Correctly identifies SFA‡	1.0 (1.0–1.0)	
10. Correctly identifies "Mickey Mouse"‡	1.0 (1.0–1.0)	
11. Identifies adequate puncture site CFA‡	1.0 (1.0–1.0)	
12. Overall technical skills for introducing imaging CFA / CFV / DFA†	3.5 (3.0–4.0)	
13. Overall understanding of the surgical anatomy of the femoral region†	4.0 (4.0–5.0)	
Overall technical skills score	32.5 (27.0–35.0)	

** Score ranging from 1 (worst)–10 (best).*

† Score ranging from 0–5.

‡ Score ranging from 0–1.

CFA: common femoral artery; CFV: common femoral vein; IQR: interquartile ranges; DFA: deep femoral artery; NA: not applicable; SFA: superficial femoral artery.

located in the same laboratory evaluated performance using a standardized script for data collection to ensure a reliable evaluation.

Statistical Analysis

Statistical analyses were performed in collaboration with an expert statistician, using the Statistical Package for the Social Sciences (SPSS®, Version 22, IBM Corporation, Armonk, New York). All baseline information from the subjects and subsequent follow-up data were registered in an electronic data file. The Wilcoxon signed rank test was used to analyze the procedure times. For all statistical analyses, a *P* value equal or less than 0.05 was considered significant.

Ethical Approval and Informed Consent

The study was conducted under a protocol reviewed and approved by the Dutch Ministry of Defense and both the Institutional Review Board and Medical Ethics Committee of Alrijne Hospital, the Netherlands (NWMO 17-15, 17.409rt.tk). All participants completed an informed consent to participate in this effort.

RESULTS

Eleven EPs with varying ultrasound experience and no experience with REBOA participated in this study. They had a median self-evaluated pre-existent ultrasound skills score of 6.0 (3.0–7.0) for general ultrasound skills and 5.0 (3.0–6.0) for vascular access ultrasound skills (Table 1*a*). The median overall technical skills score was 32.5 (27.0–35.0) (Table 1*b*). All EPs were able to identify the correct CFA puncture site, although two were unable to identify all appointed vascular structures correctly. The median global rating score for introducing imaging of the CFA, common femoral vein (CFV) and deep femoral artery (DFA) was 3.5 (3.0–4.0), and was 4.0 (4.0–5.0) for overall understanding of the surgical anatomy of the femoral region (Table 1*b*). The median time from the start of the procedure to adequately identifying the puncture site of the CFA with "Mickey Mouse sign" was 52.9 s (35.6–63.7) on the first attempt, which significantly improved to 34.0 s (21.2–44.7) by the post-test ($Z = -2.756$, $P = 0.006$) (Table 2). Of 11 EPs, 10 were able to improve their procedure times on the second attempt. There was a significant correlation between self-evaluated pre-existent vascular access ultrasound skills and actual technical skills ($r_s = 0.620$, $P = 0.042$)

Table 2 Time needed to identify adequate puncture site common femoral artery (CFA) with Mickey Mouse sign; emergency physicians ($n = 11$).

Procedure Time	*First Attempt (s)*	*Second Attempt (s)*	*Difference (s)*	*Significance (Wilcoxon Signed Rank)*
Time total Median (IQR)	52.9 (35.6–63.7)	34.0 (21.2–44.7)	–18.87	$Z = -2.756$, $P = 0.006$

IQR: interquartile ranges.

Table 3 Procedure time emergency physicians (post-test) versus consultant vascular surgeons.

Expert Level	*Emergency Physicians (n = 11) (s)*	*Vascular Surgeons (n = 3) (s)*	*Difference (s)*	*Significance (MWU-Test)*
Time total Mean (SD)	33.9 (12.6)	9.8 (5.2)	–24.13	$U = 1.000$, $r = 0.780$, $P = 0.000$

MWU-test Mann-Whitney U-test; SD: standard deviation.

(Table 1*a*). The post-test procedure times of the consultant vascular surgeons (the expert controls) were significantly faster than those of the EPs ($P = 0.000$) (Table 3).

DISCUSSION

This study provides evidence that it is feasible to train EPs with a concise training program in the use of ultrasound for femoral artery imaging to identify the correct puncture site for REBOA catheter placement, regardless of pre-existent endovascular experience and training. The EPs were able to identify the adequate puncture site of the CFA with satisfying procedure times after a curriculum of 30 min. Procedure times improved significantly at the post-test, indicating that repetition of training is effective in improving procedure times. This finding is supported by the result that experienced consultant vascular surgeons were significantly faster in visualizing the CFA. Our training program could be the foundation of a comprehensive REBOA procedure training curriculum for health care providers who have limited or no endovascular experience.

Since the primary medical specialists, such as EPs, who assess patients with hemorrhagic trauma are usually not experienced in vascular procedures, it is important to show that it is feasible to train these primary care providers in possible life-saving skills, such as REBOA. Achieving vascular access during an early stage in the treatment of trauma patients is important, not only to enable possible REBOA or interventional radiology procedures, but also for continuous blood pressure monitoring, blood sampling, and (fluid) resuscitation. Trauma patients who arrive hemodynamically stable might deteriorate quickly, and obtaining vascular access can then be challenging. Adding a second "A" for vascular access to the well-known "ABCDE" mnemonic ("AABCDE") has therefore been proposed for modern trauma care [11]. In obtaining arterial groin access, identifying the correct CFA puncture site is an important skill, considering that cannulation of the smaller superficial femoral artery is a common mistake and may be associated with a greater risk of leg ischemia [11].

To our knowledge, this is the first study assessing the feasibility of training EPs with limited endovascular experience in identifying femoral structures for REBOA placement in living humans. Previous studies have focused on the training of medical and non-medical personnel with no prior ultrasound or endovascular experience in obtaining ultrasound-guided vascular access and placement of a REBOA catheter in a REBOA Access Task Trainer (RATT). In those studies, participants were able to perform REBOA with ultrasound-guided vascular access with acceptable procedure times where repetition improved procedure times significantly [12,13]. Another study focused on the feasibility of training surgical residents, EPs and surgeons with no or limited endovascular experience in placement of a REBOA catheter in a live-tissue simulator hybrid porcine model [7]. This study showed that residents and medical consultants with no prior endovascular experience were able to perform REBOA placement within acceptable procedure times and, again, that higher levels of training are associated with faster procedure times. In a different study, REBOA was placed without ultrasound-guided vascular access in 24 patients in tertiary medical centers in Japan [14]. In 22 of 24 patients, introducer sheaths and REBOA catheters were placed by EPs. In a case report, successful REBOA catheter placement was performed by an EP with the use of ultrasound [15].

Although previous studies have demonstrated that EPs are capable of localizing the femoral vein with ultrasound to diagnose deep vein thrombosis (DVT) or

place a central venous line in the femoral vein [16,17], the ultrasound techniques for these procedures and for REBOA vascular access imaging are not fully comparable. While DVT examinations can be performed in a stress-free environment without time pressure, REBOA vascular access imaging has to be performed quickly and under stressful circumstances. Furthermore, an average time of almost 15 min has been reported for ultrasound-guided central venous catheter placement in the femoral vein by EPs [16], while a mean time of less than 7 min has been reported for REBOA procedures conducted by trauma or vascular surgeons [18]. It is therefore important to show that EPs can identify the correct CFA puncture site in a limited amount of time. It has been demonstrated that over 50% of REBOA procedural times are attributed to obtaining CFA access [19].

A Japanese study reports that the use of REBOA is easy and safe for trained EPs [20]. This is an important finding considering that, to date, only a minority of REBOA procedures have been conducted by EPs [21, 22]. Also, the current Dutch national training program of EPs does not cover endovascular procedures and the use of ultrasound to obtain vascular access, although some clinics choose to offer an internship that includes ultrasound-guided vascular access. It is desirable to proceed to an inguinal cut down when a physician fails to achieve percutaneous arterial access. This is challenging for providers with no sufficient training in vascular surgery and should be the focus of further training.

Obviously, there are limitations in this feasibility study. Some of the participants did have prior vascular ultrasound experience. Nevertheless, they also improved their procedure time after repetition. Furthermore, healthy EPs were used as a training model. This does not fully represent the reality of a bleeding hypotensive patient with possible obesity or peripheral vascular disease. However, it does provide standardization. Ideally, visualization and cannulation of the femoral artery using ultrasound would be trained on a hypotensive human (cadaver) model. It would be interesting to compare the EPs procedure times with procedure times of other consultants, such as vascular and trauma surgeons. Also, the training and testing environments were ideal and not stressful or austere, as would be expected in real-life situations. These variables can be added in a subsequent training phase and will be added in a prospective study with real trauma patients that is being planned. Further training is required using ultrasound in combination with a realistic moulage model and cadaver flow model. Such a setup is needed for percutaneous and open access training to achieve successful placement of REBOA in a hypotensive model with collapsed vessels.

CONCLUSION

This study shows that inexperienced EPs are, after training, capable of visualizing the femoral artery and vein within 1 min. The speed of correct visualization improved rapidly after repetition. Our concise theoretical and practical training program proved useful regardless of prior endovascular experience and training. This training program, as a component of an expanded EVTM curriculum and in combination with realistic task training models (simulator, perfused cadaver, or live tissue) has the potential to provide effective training of the skills required to competently perform REBOA.

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Ethics Statement

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

Conflicts of Interest

The authors (SV, RM, BBB, DE, TD, IB, MB, RH) declare that there are no conflicts of interest that could inappropriately influence (bias) their work. We confirm that this submission has not been published elsewhere and is not under consideration by another journal. All authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content and (3) final approval of the version to be submitted.

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Author contributions

SV, RM, BBB, DE, MB and RH prepared the study set-up. SV, RM, DE, TD, IB and RH included participants and performed the study during the EVTM training in The Hague and collected the data. SV and TD performed the statistical analyses. SV, RM, BBB, DE, IB, MB and RH prepared the manuscript. SV, RM, BBB, TD and MB prepared the tables and figures. SV, RM, BBB,

DE, TD, IB, MB and RH contributed to the final version of the paper.

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Narrative Review Article

Indications for the Appropriate Use of Damage Control Surgery and Damage Control Interventions in Civilian Trauma Patients

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In patients undergoing emergent operation for trauma, surgeons must decide whether to perform a definitive or damage control (DC) procedure. DC surgery (abbreviated initial surgery followed by planned reoperation after a period of resuscitation in the intensive care unit) has been suggested to most benefit those injured patients more likely to succumb to the "vicious cycle" of hypothermia, acidosis and coagulopathy, and/or postoperative abdominal compartment syndrome (ACS) than the failure to complete all organ repairs. However, currently there exists no unbiased evidence to support that DC surgery benefits injured patients. Further, the procedure is associated with substantial morbidity, long durations of intensive care unit and hospital stay, increased healthcare resource utilization, and possibly a reduced quality of life among survivors. Therefore, it is important to ensure that DC laparotomy is only utilized in situations where the expected procedural benefits are predicted to outweigh the expected procedural harms. In this manuscript, we review the comparative effectiveness and safety of DC surgery when used for different procedural indications. We also review recent studies suggesting variation in use of DC surgery between trauma centers and the potential harms associated with overuse of the procedure. We also review published consensus indications for the appropriate use of DC surgery and specific abdominal, pelvic, and vascular DC interventions in civilian trauma patients. We conclude by providing recommendations as to how the above list of published appropriateness indications may be used to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, and surgical practice.

Keywords: *Damage Control Surgery; Damage Control Interventions; Indications; Wounds and Injuries*

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INTRODUCTION

In patients undergoing emergent operation for trauma, surgeons must decide whether to perform a definitive or damage control (DC) procedure [1–4]. In contrast to definitive laparotomy, DC laparotomy includes an abbreviated initial operation that aims to rapidly control the "compelling source" of hemorrhage and/or contamination using what Feliciano originally termed "rapid conservative operative techniques" (now also referred to as DC interventions) [5–8]. The patient is subsequently admitted to the intensive care unit (ICU) after temporary abdominal closure (TAC) for ongoing resuscitation before returning to the operating room for additional surgery and/or primary abdominal fascial closure (i.e., fascia-to-fascia re-approximation within the index hospitalization) [1,5,6].

DC surgery has been suggested to most benefit injured patients more likely to die from physiological exhaustion secondary to the "vicious cycle" of hypothermia, acidosis and coagulopathy, and/or postoperative abdominal compartment syndrome (ACS) than the failure to complete all organ repairs [6,9,10]. However, currently there exists no unbiased, randomized evidence to support that DC surgery significantly benefits injured patients [1,5]. Further, the procedure is associated with substantial morbidity, long lengths of ICU and hospital stay, increased healthcare resource utilization, and possibly a reduced quality of life among survivors [11–15].

Therefore, it is important to ensure that DC surgery is only utilized in situations where the expected procedural benefits are predicted to outweigh the expected procedural harms [2,3]. However, several studies have reported that the procedure may presently be overused [3,16,17], which is concerning as overuse of DC laparotomy has increasingly been reported to be associated with increased morbidity and mortality [18,19]. Our group has therefore suggested that injured patient outcomes may improve with more selective use of DC laparotomy [2–4].

In this article, we review the comparative effectiveness and safety of DC versus definitive trauma surgery when used for different procedural indications. We also review studies that suggest significant variation in use of DC laparotomy among trauma centers and the potential harm associated with overuse of the procedure. Finally, we review results of recent studies conducted by the Indications for Trauma Damage Control Surgery International Study Group. Their work created a list of pre- and intraoperative clinical scenarios that nine experts in trauma surgery and a large cohort of surgeons who regularly operate on injured patients in level-1 to -3 trauma centers agreed appropriately indicated use of DC surgery in civilian trauma patients [1–4,6]. We conclude by providing recommendations on how to use the above list of published appropriateness indications to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, future research, and surgical practice.

COMPARATIVE EFFECTIVENESS AND SAFETY OF TRAUMA DC SURGERY

Although one study began enrolling patients as early as 2016, to date no randomized controlled trial (RCT) that compares DC and definitive surgery in trauma patients has been completed [1,20,21]. A Cochrane systematic review of DC laparotomy for abdominal trauma conducted in 2012 identified a small number of observational studies and no RCTs [1,21]. In June 2016, Harvin et al. began enrolling patients aged 16 years or older undergoing emergent laparotomy (defined as admission directly to the operating room from the emergency department within 90 min of arrival) into a pragmatic, single-center, parallel group, pilot RCT comparing DC and definitive laparotomy [20]. Inclusion criteria require that the attending surgeon must believe that one or more predefined potential indications for DC laparotomy exist [20]. Results of this RCT were originally expected in 2020.

Another systematic review conducted by our group in 2018 identified two cohort studies [22,23] that evaluated outcomes associated with implementation or utilization of indications for DC surgery [24]. Rice et al. reported that, when compared with minor deviations, moderate or major deviations from a protocol that suggested using DC surgery for patients with a temperature <35°C, lactate >4 mmol/L (or greater than twice the upper limit of normal), or corrected pH <7.3 were independently associated with a significantly reduced survival at 90 days [22,24]. Asensio et al. developed a guideline that suggested use of DC surgery in patients who received more than 4 L of packed red blood cells (PRBCs), more than 5 L of PRBCs and whole blood combined, or a total operating room fluid (PRBCs and whole blood, other blood products, and crystalloid) volume replacement of more than 12 L; had a temperature <34°C, serum [HCO3-] ≤15 mEq/L, or arterial pH ≤7.2 during operation; were found to have a thoracic or abdominal vascular injury or complex hepatic injury requiring packing; required emergency department or operating room thoracotomy; or developed intraoperative coagulopathy or dysrhythmias [23,24]. In this study, use of this guideline was associated with a significantly decreased unadjusted odds of intra-abdominal abscesses, extra-abdominal infections, and abdominal fistulae; a significantly increased unadjusted odds of abdominal closure; and significantly reduced unadjusted lengths of ICU and hospital stay [23,24].

We also identified 14 other cohort studies [18,19, 25–36] that compared outcomes of patients treated with DC versus definitive laparotomy in different clinical situations [24]. Stone et al., Rotondo et al., and Chinnery et al. reported a significant improvement in unadjusted survival with use of DC or staged laparotomy instead of definitive laparotomy for those that developed a coagulopathy during operation, received

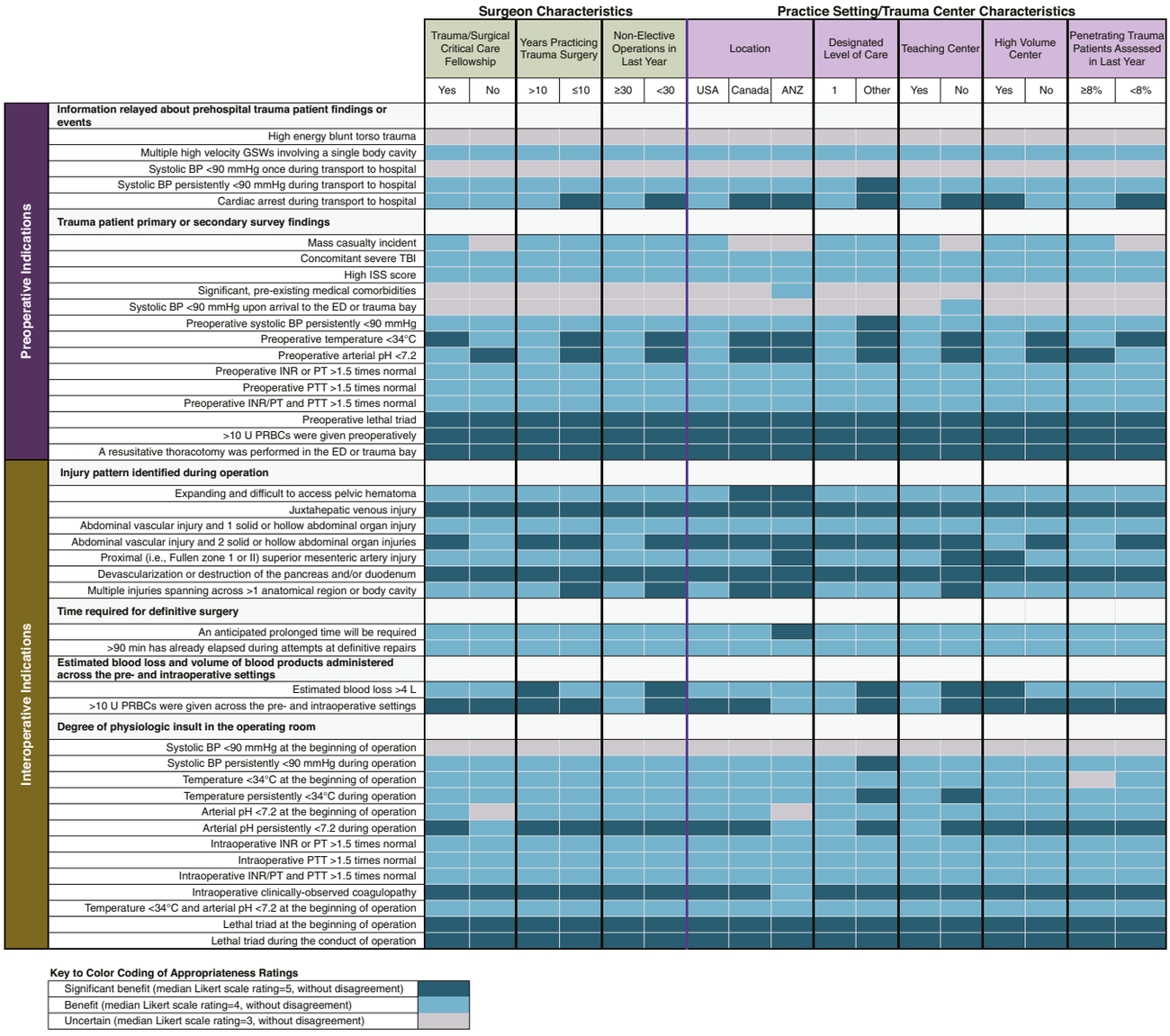

Figure 1 Color map of respondents' appropriateness ratings of published candidate pre- and intraoperative indications for use of damage control surgery stratified by surgeon- and trauma center-level characteristics. ANZ indicates Australia and New Zealand (i.e., Australasia); BP, blood pressure; ED, emergency department; GSWs, gunshot wounds; INR, international normalized ratio; ISS, injury severity scale; PT, prothrombin time; PTT, partial thromboplastin time. Interpolated median values halfway between two integers were rounded up. Disagreement was defined as at least 33% of respondents rating the indication as 1–2 (significant harm–harm) on the Likert Scale and at least another 33% rating it 4–5 (benefit–significant benefit). Figure and Figure legend reprinted from reference [4], copyright (2016), with permission from Elsevier. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the publisher, Elsevier.

more than 10 U PRBCs and had one or more major abdominal vascular and two or more abdominal visceral injuries, or had combined abdominal vascular and pancreas gunshot injuries, respectively [25–27]. However, because the type of surgery (DC or definitive laparotomy) for the patients enrolled in these and the other 11 cohort studies identified by the systematic review mentioned above were not randomly assigned, these studies are likely confounded by indication [6]. This confounding occurs because surgeons choose to perform DC laparotomy based on patient, provider, and hospital characteristics, and these characteristics likely influence outcomes [37].

Therefore, very little valid or unbiased observational studies exist to support use of DC over definitive surgery in different clinical situations.

VARIATION IN AND POTENTIAL OVERUSE OF TRAUMA DC LAPAROTOMY BETWEEN CENTERS

Several authors have recently reported data suggesting that a variation in use of DC laparotomy may exist

Table 1 Reported descriptions of thoracic, abdominal/pelvic, and vascular interventions identified as constituting damage control [44].

Intervention	*Description*
Abdominal/pelvic damage control interventions	
Therapeutic perihepatic packing*	Compressive gauze packing is placed around the liver to tamponade venous and/or coagulopathic hemorrhage from the hepatic parenchyma or surrounding juxtahepatic veins at least until the first reoperation (which frequently occurs within <24–48 h).
Staged pancreaticoduodenectomy [46–49]	During the index laparotomy, major vascular hemorrhage is controlled; where necessary (sometimes this has already been done by the inciting trauma), the duodenum distal to the pylorus, common bile duct, pancreas distal to the injury, and distal duodenum or jejunum are transected; and the right upper quadrant and peripancreatic space are widely drained (some authors also report use of T- or biliary drainage tubes at this time). Reconstruction (pancreaticojejunostomy, hepaticojejunostomy, and duodenojejunostomy) is delayed until reoperation.
Therapeutic renal fossa packing [50]*	Compressive gauze packing is applied to the renal fossa to tamponade venous and/or coagulopathic hemorrhage from the kidney at least until the first reoperation (which frequently occurs within <24–48 h).
Bilateral externalized ureteral stenting and diversion [50]	When neither transurethral nor suprapubic drainage effectively evacuates urine from the injured bladder, J-stents are passed up each ureteral orifice and then externalized to divert the urinary output of both kidneys until definitive repair of the bladder is possible.
Temporary abdominal closure/open abdominal management	The abdomen is temporarily closed using a Barker's vacuum pack, commercial negative pressure peritoneal therapy device, silo/Bogotá bag, mesh or sheet, or another technique.
Extraperitoneal pelvic packing [51–53]	After a 6- to 8-cm midline incision is made extending from the pubic symphysis cephalad (dividing the midline abdominal fascia) and the preperitoneal space is opened using digital dissection (where necessary), laparotomy pads are placed on either side of the bladder, the fascia is closed with a heavy suture, and the skin is closed with staples.
Bilateral internal iliac artery ligation [54]	Both internal iliac arteries are ligated using heavy, permanent sutures during laparotomy.
Vascular damage control interventions	
Balloon catheter tamponade [55–59]	A Foley, Fogarty, Sengstaken-Blakemore, or improvised balloon catheter (created using a red rubber catheter and Penrose drain) is inserted into a bleeding wound tract. The balloon of the catheter is then inflated with sterile water and repositioned until adequate hemostasis is achieved.
Temporary intravascular shunting [60, 61]	After an embolectomy and administration of local intravascular heparinized saline, the defect in the injured artery and/or vein is bridged with a Pruit-Inahara, Argyle, Javid, or Sundt vascular shunt or with a piece of an intravenous line or nasogastric/chest tube (cut to length such that it overlaps within the vessel by approximately 2 cm and secured into place with a heavy silk tie on either end). The shunt is left in place until at least the first reoperation (which frequently occurs within <24–48 h).

*GIA, gastrointestinal anastomosis; TA, thoracoabdominal. *In contrast to resuscitative packing (where packs are used to check intraoperative bleeding for a short period of time), therapeutic packing refers to prolonged (intra- and postoperative) use of packs to tamponade hemorrhage [5]. Table and Table legend reproduced from reference [44], with permission from Wolters Kluwer Health, Inc. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the Publisher, Wolters Kluwer Health, Inc. Please contact permissions@lww.com for further information.*

Table 2 Highest rated candidate indications for use of damage control surgery in civilian trauma patients.

Indications
Injury pattern identified during operation
A difficult to access major venous (intrahepatic, retrohepatic, retroperitoneal, or pelvic) injury
A major liver or combined pancreaticoduodenal injury with hemodynamic instability in the OR
A combined pancreaticoduodenal injury with massive hemorrhage from the head of the pancreas
Devascularization or massive disruption of the duodenum, pancreas, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD
Inability to control bleeding by conventional methods
Amount of resuscitation provided
A large volume of PRBCs (median >10 U) or PRBCs, other blood products, and crystalloids combined (median >12 L) were administered preoperatively or across the pre- and intraoperative settings
Degree of physiological insult
Hypothermia, acidosis, and/or clinical or laboratory coagulopathy in the pre- or intraoperative settings*
Persistent intraoperative cellular shock†
Development of intraoperative ventricular arrhythmias
Need for staged abdominal or thoracic wall reconstruction
Inability to close the abdominal or thoracic wall without tension because of visceral edema‡
Signs of an abdominal or thoracic compartment syndrome developed during attempted abdominal or thoracic wall closure
Need to reassess the extent of bowel viability after a period of further resuscitation in the ICU

*CBD, common bile duct; ED, emergency department; ICU, intensive care unit; OR, operating room; PRBCs, packed red blood cells. *Hypothermia, acidosis, and clinical and laboratory coagulopathy were most commonly defined in the literature and the appropriateness rating study as a temperature <34°C, pH <7.2, a PT and PTT >1.5 times normal, and the absence of visible blood clots during operation/diffuse oozing from all injured tissues. †Cellular shock is defined as an oxygen consumption index <100 mL/min/m^2, lactate >5 mmol/L, pH <7.2, base deficit >15 mmol/L, and core temperature <34°C. ‡Surgeons may also not be able to close the thoracic wall without tension because of the presence of resuscitative intrathoracic packing.*

among trauma centers or that the procedure may currently be overused [3,4,6]. In a recently reported post-hoc analysis of the PROPPR randomized trial, DC surgery was used for 33% to 83% of patients requiring urgent laparotomy across 12 of the participating institutions [38]. Interestingly, although there was no significant adjusted mortality difference among these centers, the unadjusted risk of sepsis and ventilator-associated pneumonia was higher among those treated with DC laparotomy [38]. Therefore, some have suggested that decreasing use of DC among individual trauma centers may not necessarily influence injured patient mortality but may decrease their morbidity [38].

Variation in use of DC across trauma centers could relate to increasing use of the procedure for indications other than those previously suggested to be appropriate or validated in the literature [1,6,24]. In support of this, one retrospective cohort study by Hatch et al. reported that one in five patients who received DC laparotomy at a level-1 trauma center between 2004 and 2008 failed to have at least one traditional indication for use of the procedure [1,6,39]. In this study, only 33% of the patients who underwent DC laparotomy were acidotic, 43% hypothermic, and 48% coagulopathic on arrival at the ICU after operation [1,6,24,39]. Although the ideal rate of use of DC during emergent laparotomy is presently unknown, it was estimated in one cohort study to range between 19% and 27% across six American, level-1 trauma centers [40].

Some evidence suggests that overuse of DC laparotomy may be associated with increased morbidity and mortality [3,4,18,19,39,41]. Martin et al. reported that, when compared with patients with a severe abdominal injury who underwent therapeutic definitive laparotomy, use of DC laparotomy in patients with an arrival systolic blood pressure (BP) >90 mmHg, no severe traumatic brain injury (TBI) (head Abbreviated Injury Scale score <3), and no combined abdominal injuries was independently associated with significantly increased odds of major postoperative complications and a significantly increased adjusted length of hospital stay [18]. In another propensity-matched cohort study, Harvin et al. reported that use of DC instead of definitive laparotomy [for intra-abdominal packing (68%), second-look laparotomy (6%), hemodynamic instability (15%), to expedite postoperative care or intervention (8%), abdominal compartment syndrome prophylaxis (1%), contamination (1%), or other/unclear reasons (1%)] was associated with a significantly increased incidence of gastrointestinal (GI) ileus and bleeding, abdominal fascial dehiscence, superficial surgical site infection (SSI), and death [19]. Finally, in a follow-up study by Harvin et al. in 2019, injured patients who underwent DC laparotomy across six American, level-1 trauma centers and were judged by majority faculty vote to have been candidates for definitive laparotomy were matched 1:1 with those who underwent definitive trauma laparotomy at these centers using propensity scores [42]. In this study, for those whom surgeons had equipoise

Table 3 Indications for use of thoracic, abdominal/pelvic, and vascular damage control interventions that were rated to be appropriate by a panel of experts.*

Indication(s) For
Abdominal/pelvic DC interventions in patients undergoing laparotomy
Therapeutic perihepatic packing†
An expanding or ruptured extensive subcapsular hematoma
An extensive bilobar hepatic parenchymal injury
A juxtahepatic venous injury
An AAST grade III-V liver injury and a concomitant severe traumatic brain injury or multiple other concomitant solid and/or hollow abdominal organ injuries
Administration of a large volume of PRBCs preoperatively or across the pre- and intraoperative settings in a patient with a liver injury‡
A liver injury with hemodynamic instability, hypothermia, acidosis, and/or coagulopathy in the OR
Inability to control hepatic bleeding by conventional methods
To facilitate transfer of a patient from a hospital with little experience with (or resources for) management of major liver injury to a level-1 trauma center
Staged pancreaticoduodenectomy
Devascularization or massive disruption of the pancreas, duodenum, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD (especially when there is an associated massive hemorrhage from the head of the pancreas/pancreaticoduodenal complex)
Temporary abdominal closure/open abdominal management
Coagulopathy (especially when combined with hypothermia and acidosis) in the OR
Administration of a large volume of crystalloids or PRBCs preoperatively or across the pre- and intraoperative settings
Inability to close the abdominal fascia without tension
Signs of abdominal compartment syndrome develop during attempted abdominal wall closure
Need for a planned relaparotomy to remove intra-abdominal packs or reassess the extent of bowel viability
Extraperitoneal pelvic packing
Significant hemodynamic instability in the ED in patients with a pelvic fracture where IR is not immediately available
Severe pelvic trauma with massive, ongoing hemorrhage in the OR
Evidence on ongoing massive hemorrhage in patients with a pelvic fracture despite pelvic angioembolization
Vascular DC interventions
Balloon catheter tamponade
Significant, ongoing bleeding from a difficult to access anatomical location or vessel in the OR§
Significant, ongoing bleeding from a deep or transfixing hepatic parenchymal wound in the OR
Temporary intravascular shunting
An abdominal vascular injury requiring operation and an anticipated prolonged operative time with a suboptimal response to resuscitation
An extremity or abdominal vascular injury requiring operation and hypothermia, acidosis, and coagulopathy in the OR
Presentation of a patient with an abdominal vascular injury requiring operation during a mass casualty incident or to a hospital with little experience with surgical management of vascular trauma

*CBD, common bile duct; DC, damage control; ED, emergency department; IR, interventional radiology; OR, operating room; PRBCs, packed red blood cells. *Hypothermia, acidosis, and coagulopathy have most commonly been defined in the peer-reviewed literature as a temperature <34, pH <7.2, and a PT or PTT >1.5 times normal and the absence of visible blood clots during operation/diffuse oozing from all injured tissues [3]. †In contrast to resuscitative packing (where packs are used to check intraoperative bleeding for a short period of time), therapeutic packing refers to prolonged (intra- and postoperative) use of packs to tamponade hemorrhage [5]. ‡A large volume of PRBCs was most often defined in the literature as >10 or >12.5 units. §Difficult-to-access anatomical locations have been reported to include the head, zone III of the neck, the angle of the mandible, and the trunk; while difficult-to-access vessels have been reported to include the carotid artery behind the pharynx, the carotid artery or internal jugular vein at the base of the skull, the internal maxillary artery, the second, third, and fourth portions of the vertebral artery, and the distal branches of the internal iliac artery in the pelvis. Reproduced with permission from reference [44], with permission from Wolters Kluwer Health, Inc. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the Publisher, Wolters Kluwer Health, Inc. Please contact permissions@lww.com for further information.*

regarding use of DC or definitive laparotomy, definitive laparotomy was associated with a significantly higher probability of fewer hospital-free, ventilator-free, and ICU-free days, suggesting that use of definitive laparotomy in this setting may decrease hospital resource utilization [42]. However, the two groups demonstrated a similar probability of major abdominal complications [42].

PUBLISHED APPROPRIATENESS INDICATIONS FOR USE OF DC SURGERY AND DC INTERVENTIONS IN CIVILIAN TRAUMA PATIENTS

We previously hypothesized that variation in use of DC surgery among trauma centers may occur when surgeons are uncertain which operative profile is best across the large number of varying clinical situations encountered

in practice [4,6,43,44]. This uncertainty is likely exacerbated by the limited available data evaluating the effectiveness and safety of DC surgery and DC interventions and the risks of bias associated with existing evidence on the topic [4,6,43,44]. Further, conducting RCTs evaluating DC laparotomy is difficult for many reasons, most importantly the lack of equipoise among surgeons regarding its likely superior outcomes when used instead of definitive laparotomy in certain clinical situations (e.g., a juxtahepatic venous injury) [45]. Despite this, however, surgeons must decide when to use DC (or specific DC interventions) over definitive surgery (or specific definitive surgical interventions) in their practices [6,44].

In 2013, Roberts et al. and the Indications for Trauma Damage Control Surgery International Study Group began a program of research to develop evidence-informed indications for the appropriate use of DC surgery and DC interventions in civilian trauma patients [1–5,44]. We first conducted a scoping review that aimed to identify a comprehensive list of the reported indications for use of DC surgery and DC interventions and examine the content and evidence on which these indications were based [2,24,44]. An indication was defined as "a clinical finding/scenario that advised use of DC surgery (or a DC intervention) over definitive surgery (or a definitive surgical intervention)" [3]. This study identified 270 peer-reviewed articles that reported 1,107 indications for DC surgery and 424 indications for 16 different DC interventions (see Table 1 for our previously published definitions of abdominal, pelvic, and vascular DC interventions) [2,24,46–61]. Of note, bilateral internal iliac artery ligation should only be performed in carefully selected patients, given the risk of pelvic ischemia associated with this intervention (which may lead to bilateral buttock claudication or necrosis, vasculogenic impotence, colorectal ischemia or necrosis, and spinal cord injury).

We subsequently conducted a qualitative content analysis to synthesize the above published indications into 123 codes representing uniquely reported indications for DC surgery and 101 codes representing uniquely reported indications for 16 different DC interventions [3, 44]. An international panel of nine different trauma surgery experts located in the United States ($n = 3$), Canada ($n = 1$), the United Kingdom ($n = 1$), Finland ($n = 1$), Australia ($n = 1$), and South Africa ($n = 2$) then rated 101 (82%) of the unique indications for DC surgery and 78 (77%) of the unique indications for DC interventions to be appropriate for use in surgical practice [3,44]. The highest rated indications for DC surgery and those rated to be appropriate for the individual DC interventions are listed in Table 2 and Table 3, respectively [3,44].

We then surveyed the opinions of 366 surgeons who regularly treat injured patients in the United States, Canada, Australia, and New Zealand on the appropriateness of many of the indications for DC surgery rated in the previous expert appropriateness rating study [4]. Of the 366 surveyed surgeons, 201 (56%) responded and rated 15 (78.9%) preoperative and 23 (95.8%) intraoperative indications to be appropriate for use in their practices [4]. Ratings of appropriateness were consistent across subgroups of surgeons with different training, experience, and practice settings, suggesting that practicing surgeons have relatively consistent opinions regarding use of DC surgery in certain clinical scenarios (see Figure 1 for a color map of respondents' appropriateness ratings reported in this study stratified by surgeon- and trauma center-level characteristics) [4]. Nearly 90% of the respondents also agreed that injured patients who present with physiological derangements that significantly improve or reverse during operation were candidates for definitive instead of DC laparotomy [4].

As the above studies did not measure how surgeons actually practiced, their assessments of appropriateness may have reflected idealized practices [4,62]. We therefore recently reported the results of a study that sought to determine the accuracy of the above-published appropriateness indications for predicting use of DC surgery among patients undergoing emergent laparotomy at a large, level-1 trauma center in the United States [62]. In this study, two published preoperative indications (a systolic BP persistently <90 mmHg or core body temperature <34°C) produced moderate changes in the pre-test probability of patients undergoing DC laparotomy [62]. Five published intraoperative indications produced large and often conclusive changes in the pre-test probability of conducting DC during emergent laparotomy, including the finding of a devascularized or completely disrupted pancreas, duodenum, or pancreaticoduodenal complex during operation; an estimated intraoperative blood loss greater than 4 L; administration of more than 10 U PRBCs in the pre- and/or intraoperative period; and a systolic BP persistently <90 mmHg or arterial pH persistently <7.2 during operation [62]. Many of the indications that produced large shifts in the pre-test probability of conducting DC laparotomy were uncommonly encountered in practice (i.e., their incidence was <2%) [62]. Finally, a small number of published appropriateness indications were independently associated with the conduct of DC laparotomy even after adjusting for the simultaneous presence of other indications, suggesting that some surgeons may choose to conduct the procedure when they encounter certain *single* clinical findings [62].

IMPLICATIONS OF RECENT RESEARCH AND RECOMMENDATIONS

In recent years, wide variation has been reported in the rates of use of DC laparotomy among North American trauma centers [3,16,17]. This variation may be explained by several factors, including differences in surgeon equipoise regarding the benefit of the procedure

Table 4 Unadjusted and adjusted odds of performing damage control laparotomy by published pre- and intraoperative appropriateness indications.

Published Appropriateness Indication	*OR for Performing DC Over Definitive Laparotomy (95% CI)*	
	Unadjusted	*Adjusted**
Preoperative indications		
Information relayed about prehospital trauma patient findings or events		
The patient suffered a successfully resuscitated cardiac arrest during transport to hospital	2.13 (0.13–34.11)	0.60 (0.036–10.17)
Trauma patient primary or secondary survey findings		
The patient presented with a concomitant severe TBI	5.51 (3.69–8.22)	1.99 (1.11–3.57)
The calculated ISS score of the patient was >25	4.57 (3.49–5.97)	3.14 (2.06–4.79)
The patient's preoperative systolic BP was persistently <90 mmHg	7.12 (4.32–11.71)	4.31 (2.09–8.88)
The patient's preoperative core body temperature was <34°C	5.45 (1.35–21.94)	1.31 (0.19–8.89)
The patient's preoperative BD was >15 mmol/L or lactate was >5 mmol/L	3.82 (2.89–5.06)	2.90 (1.93–4.35)
The patient presented with a coagulopathy on rTEG†	1.35 (1.05–1.75)	0.97 (0.66–1.43)
>10 U of PRBCs were given to the patient preoperatively	1.40 (0.95–2.07)	1.11 (0.49–2.53)
Intraoperative indications		
Injury pattern identified during operation		
The patient is found to have an abdominal vascular injury and a major associated abdominal solid or hollow organ injury	3.77 (2.62–5.41)	2.78 (1.61–4.82)
The patient is found to have devascularization or disruption of the pancreas, duodenum, or pancreaticoduodenal complex requiring a pancreaticoduodenectomy	Perfectly predicted use of DC	Perfectly predicted use of DC
Multiple blunt or penetrating injuries spanning across more than one anatomic region or body cavity that each require surgery	4.21 (2.57–6.91)	1.53 (0.73–3.22)
Time required for surgery		
>90 min has already elapsed during the index operation	0.56 (0.43–0.74)	0.37 (0.26–0.53)
Estimated blood loss and volume of blood products administered across the pre- and intraoperative settings		
The patient's estimated blood loss is >4 L	20.07 (10.21–39.46)	4.16 (1.60–10.83)
>10 U of PRBCs have been given to the patient across the pre- and intraoperative settings	18.95 (12.46–28.80)	7.84 (4.78–12.86)
Degree of physiological insult in the operating room		
The patient's systolic BP was <90 mmHg at the beginning of the operation	4.36 (3.11–6.13)	1.16 (0.71–1.91)
The patient's systolic BP was persistently <90 mmHg during the operation	35.64 (4.69–270.89)	5.01 (0.42–59.72)
The patient's core body temperature was <34°C at the beginning of the operation	3.30 (1.67–6.53)	2.46 (0.50–12.20)
The patient's core body temperature was persistently <34°C during the operation	3.34 (1.33–8.39)	0.43 (0.065–2.85)
The patient's arterial pH was <7.2 at the beginning of the operation	7.03 (5.03–9.83)	2.27 (1.42–3.63)
The patient's arterial pH was persistently <7.2 during the operation	32.28 (9.89–105.34)	3.26 (0.73–14.50)
The patient's core body temperature was <34°C and arterial pH <7.2 at the beginning of the operation	7.40 (2.37–23.12)	0.86 (0.11–6.54)

*BD, base deficit; BP, blood pressure; DC, damage control; ISS, injury severity scale; OR, odds ratio; PRBC, packed red blood cell; rTEG, rapid thromboelastography; TBI, traumatic brain injury; U, units. *Adjusted for the simultaneous presence of other pre- or intraoperative indications in order to determine the independent influence of that individual indication on the decision to conduct DC over definitive laparotomy. †Defined as an activated clotting time ≥128 s, K-time ≥2.5 min, α-angle ≤56°, maximal amplitude ≤55 mm, or lysis at 30 min ≥3% [64]. Table and Table legend reproduced from [62], copyright (2020), with permission from Elsevier. The Creative Commons license does not apply to this content. Use of the material is prohibited without written permission from the publisher, Elsevier.*

in different clinical situations and the lack of valid data supporting that DC laparotomy improves survival in severely injured patients. The possible overuse of DC laparotomy across these trauma centers is concerning as some recent data suggest that when DC is used instead of definitive laparotomy in patients in whom surgeons have equipoise between the two, use of DC laparotomy is associated with increased resource utilization [42]. Other studies have also suggested that use of DC instead of definitive laparotomy when DC laparotomy is not indicated may be associated not only with increased resource utilization, but with higher morbidity and possibly mortality [18,19].

Table 4 summarizes those published indications that have been rated to be appropriate for use in practice by experts and practicing surgeons [62]. We also provide estimates of the unadjusted and adjusted (i.e., adjusted for the simultaneous presence of the other indications listed in the table) odds of undergoing DC laparotomy for each of these different indications [62]. Although the intraoperative findings of an expanding or difficult-to-access pelvic hematoma or juxtahepatic venous injury were previously rated to be appropriate indications for use of DC laparotomy in our expert appropriateness rating study [3] and cross-sectional survey of practicing surgeons [4], we do not yet have data on their ability to predict use of the procedure in practice [62]. Despite this, experts and practicing surgeons strongly suggest using DC surgery in these situations.

The indications listed in Table 4 may be used to educate surgical trainees on the appropriate, yet limited use of DC laparotomy and guide trauma center quality improvement practices aimed at reducing inappropriate use of the procedure. The group at the Red Duke Trauma Institute at Memorial Hermann Hospital-Texas Medical Center recently reported a decrease in the rate of use of DC laparotomy from 39% between 2011 and 2013 to 23% between 2013 and 2015 using a multifaceted quality improvement initiative that included audit and feedback for every DC laparotomy case [63]. The indications listed in Table 4 may also be used to guide the development of prospective observational and randomized studies aimed at understanding in which clinical situations DC laparotomy may offer a survival benefit over definitive laparotomy in injured patients. In our opinion, it is now time for these studies to be conducted.

CONCLUSIONS

Although DC surgery may benefit select, critically injured patients, it may currently be overused in some trauma centers. This is concerning as some studies have reported that overuse of this technique may be associated with increased healthcare utilization, morbidity, and potentially mortality. The published DC surgery appropriateness indications outlined in this manuscript may be used to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, future research, and surgical practice.

Ethics Statement

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

All authors have contributed to the writing and editing of this manuscript.

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Tips and Techniques

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CT-Guided Placement of a Neuromonitoring Suite in Swine for Trauma and Resuscitation Research

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Background: In this manuscript, we aim to describe a standardized method for placement of a neuromonitoring suite into the brain of a porcine model using computed tomography (CT) guidance for use in trauma and resuscitation research.
Methods: A baseline CT allowed for precise planning of the placement of the neuromonitoring suite including measurement of skull thickness at the location of the intended burr hole. After the burr hole was drilled, three neuromonitoring probes (pressure catheter, temperature probe, and laser doppler flow probe) were advanced into the brain parenchyma of the swine. A subsequent CT confirmed appropriate placement of the neuromonitoring suite.
Results: Effective placement of the neuromonitoring suite was accomplished successfully and without complication in six Yorkshire swine. Mean duration of the procedure was 49.6±6.3 min. Representative data from one animal include the following presented as mean ± standard deviation: intracranial pressure of 10±0 mmHg, cerebral perfusion pressure of 61±1 mmHg, intracranial temperature of 34.8±0 °C, and brain perfusion of 704±13 relative perfusion units.
Conclusions: This CT-guided method facilitates placement of a neuromonitoring suite in a safe and reliable manner. The use of a neuromonitoring suite using CT may offer valuable insight into cerebral perfusion in the context of endovascular resuscitation.

Keywords: *Neuromonitoring; Computed Tomography; Swine Research; Resuscitation Research*

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INTRODUCTION

After major hemorrhage from trauma, approximately 40% of patients die before bleeding can be controlled [1]. Endovascular techniques such as Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) and Selective Aortic Arch Perfusion (SAAP) utilize a balloon catheter to obtain hemorrhage control and manipulate central blood pressure and perfusion in an effort to resuscitate patients [2]. Although these methods can be effective in preventing further hemorrhage, it remains unclear how these interventions affect brain perfusion. It is understood from cardiac arrest patients that both hypoperfusion and reperfusion of brain tissue can cause irreversible neuronal damage [3]. It is critical to develop reliable methods of neuromonitoring in order to assess neurological indices in the setting of novel endovascular resuscitation techniques.

Placement of neuromonitoring probes into the porcine model has traditionally been performed using anatomical landmarks such as the bregma [4]. Measuring the distance from certain bony landmarks, such as the distance from the lateral to frontal suture and anterior to the coronal suture, allow approximate triangulation for selection of probe location [5]. However, these measurements only offer an estimate of intraparenchymal probe location. Precise and consistent placement of the

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probe into the intended brain region is critical due to the interlobar and even intralobar variation in porcine cerebral blood flow [6]. Consistent probe placement across subjects would assure true comparison between the same brain regions.

Neuromonitoring probe placement can now be directed using imaging techniques such as computed tomography (CT) [7]. Imaging allows for improved precision and confirmation of appropriate probe placement. This method is becoming increasingly practical with improving technology and the availability of portable CT scanners. The aim of this manuscript is to describe a standardized method of CT-guided placement of a neuromonitoring suite in a porcine model.

METHODS

Overview

Procedures were approved by the University of Maryland, Baltimore Institutional Animal Care and Use Committee (Approval #0320017) and conformed to National Institutes of Health guidelines for ethical animal research. Six adult male Yorkshire swine weighing between 60 kg and 80 kg were enrolled in the study, which utilized ADInstruments devices, including pressure catheters, temperature probes, and laser doppler flow (LDF) probes (ADInstruments, Sydney, Australia). Insertion consisted of the following steps: preparation, burr hole creation, and insertion of neuromonitoring probes.

Preparation

The evening before the procedure, animals had free access to water but were fasted from food. Animals were sedated using intramuscular injection of Telazol (5 mg/kg) and Xylazine (2 mg/kg), then placed in ventral recumbency on the operating table. Endotracheal intubation was attained, and anesthesia was maintained with isoflurane (1–3%). Hair was removed from the scalp, and the site was scrubbed with povidone-iodine; after drying, the operative site was draped in a sterile fashion.

Burr Hole Creation

Creation of a burr hole was performed under CT guidance using an OmniTom portable CT scanner (Neurologica, Danvers, USA) and a drill (Ryobi, Hiroshima, Japan). CT images were acquired with 1.25-mm axial slices, 120 kV, and 40 mA. The protocol was designed to maximize the power of the machine to optimize images in the setting of the thick skull of swine. Images were transferred to a picture archiving and communication system (PACS) (Purview, Annapolis, USA) for burr hole planning.

A baseline non-contrasted CT was obtained, and images transferred to PACS. Skull thickness was measured 1 cm posterior and lateral to the bregma, where the creation of a burr hole was intended. A drill bit depth stopper was placed onto the drill bit (9/32 in) at this level to prevent drilling beyond the skull. A scalpel was used to make a cruciate incision at the site of intended burr hole creation. The drill, with depth-limiting stopper in place, was used to create a burr hole.

Insertion of Neuromonitoring Probes

An 18-gauge needle was inserted through the burr hole into the brain parenchyma, and a 1.8-Fr pressure catheter was advanced through the needle into the brain. The needle was slowly retracted to expose the catheter's pressure sensor. A 20-gauge needle was placed through the burr hole for placement of the temperature probe following the same procedure as for the pressure catheter. The LDF probe was directly advanced into the brain parenchyma. Figure 1*a* exhibits all neuromonitoring probes in place. A CT scan was performed to confirm the location of the probes in the brain parenchyma (Figure 1*b*).

Vitals were monitored throughout the experiment. At the conclusion, animals were euthanized using potassium chloride while under inhalant anesthesia. All data were captured continuously in LabChart (ADInstruments, Sydney, Australia). Data were averaged over a period of 7 min and is presented as mean ± standard deviation.

RESULTS

The neuromonitoring suite was placed successfully and without complication in all six animals. The mean weight was 67.1±4.9 kg. The mean duration from procedure start to start of data collection was 49.6±6.3 min. Intracranial and relevant hemodynamic indices for a representative animal are presented in Figure 1*c* and Table 1.

DISCUSSION

This study outlines a standardized method for CT-guided placement of a neuromonitoring suite in the porcine model. This method was demonstrated to be a reliable and safe procedure in all animals and enables laboratories to collect several intracranial indices in a dependable manner. CT can be used to confirm that intracranial probes are situated appropriately and allows for adjustment as needed for precise placement of probes as desired. No complications were encountered using the described method.

Neuromonitoring probe placement has typically been performed using anatomical landmarks, but the natural variance among individuals presents a potential

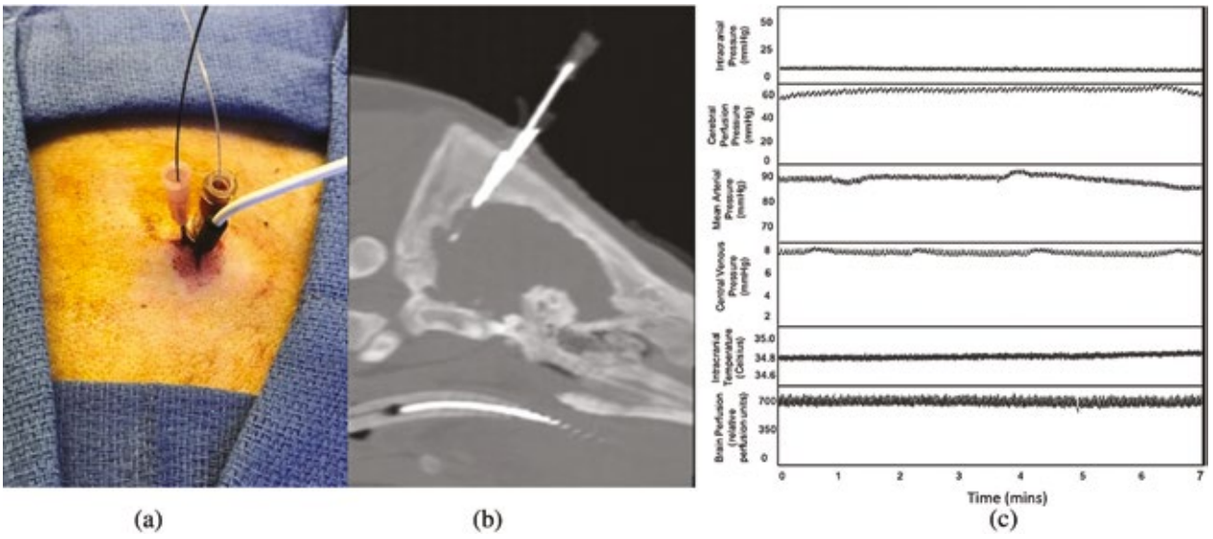

Figure 1 Neuromonitoring suite in place and representative data captured. (**a**) Image of burr hole with neuromonitoring probes in place. (**b**) Example of CT confirming placement of neuromonitoring suite. (**c**) Graph of representative neuromonitoring data.

Table 1 Representative data collected using this neuromonitoring suite.

	Mean ± SD
Intracranial pressure (mmHg)	9.93±0.13
Cerebral perfusion pressure (mmHg)	61.02±1.11
Mean arterial pressure (mmHg)	90.7±0.10
Central venous pressure (mmHg)	7.79±0.13
Intracranial temperature (°C)	34.80±0.01
Brain perfusion (relative perfusion units)	703.50±13.20

SD: standard deviation.

confounder. The increased availability of advanced imaging technology offers an opportunity to improve precision of instrumentation in order to gather more consistent data.

This method of placing a neuromonitoring suite can be a valuable adjunct in trauma and resuscitation research to evaluate neurological parameters such as brain perfusion during and following resuscitative maneuvers. The concept of endovascular resuscitation has grown over the last several years with the emergence of multiple novel techniques, some of which have demonstrated promising results in achieving return of spontaneous circulation. However, data are lacking with regard to brain perfusion and neurological recovery in the setting of these techniques. The method outlined in this manuscript offers a reliable procedure for instrumenting the porcine brain that allows future researchers to effectively evaluate brain perfusion in the setting of resuscitation. This information will prove critical as we continue to assess novel techniques and how to best utilize them to serve our patients in order to attain not only hemodynamic recovery but also meaningful neurological recovery.

CONCLUSIONS

CT-guided placement of a neuromonitoring suite is a safe and reliable procedure in the swine model. This technique enables researchers to further explore crucial neurological parameters, which will be especially useful in trauma and resuscitation research, particularly in evaluating novel endovascular resuscitation techniques in their ability to provide adequate brain perfusion to allow for meaningful neurological recovery.

Ethics Statement

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Conflicts of Interest

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Author Contributions

All authors have substantially contributed to the study and manuscript writing.

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Introduction

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Challenging Cases Managed by Interventional Radiology

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With recent advancements in imaging modalities and endovascular techniques, interventional radiology (IR) has become an increasingly popular and often less invasive option for treatment of a number of common emergencies.

The emergency interventional radiology services often require the need for quick decision-making given the clinical status of the patient, availability of resources for early intervention, and availability of alternative therapeutic options.

Interventional radiologists are able to easily interpret the CT scans and thus to optimize the management of patients; furthermore, the IR techniques of embolization and stent-grafting are extremely effective at stemming active haemorrhage.

In some cases, IR proposes itself as the first therapeutical choice over surgery; high chance of post-surgical complications, higher overall mortality rate, and unfitness of some patients for more complex procedures are just few of the many scenarios where IR outshines surgery thanks to the minimal invasiveness of its operations.

Nevertheless, IR requires highly trained specialists to perform efficient and safe procedures and, of course, hi-tech devices that are not currently available in every medical facility. It needs to be said, though, that the promising results and rising effectiveness of IR are encouraging hospitals and radiologists to implement this discipline in their medical routine more and more frequently.

The relative novelty of this branch means that often interventional treatments are not standardized or are not yet backed up by an extensive scientific literature; therefore, the interventional radiologist needs to think outside of the box and find solutions that often require a multi-thematical approach (mastery in the medical imaging techniques, different imaging-guided approaches, extensive knowledge of the functioning and usage of devices at their disposal, etc.).

The following series we are proud to present is a collection of challenging cases that were successfully resolved by interventional radiologists. They required multi-disciplinarian choices, often involving different clinicians, but were mostly made possible thanks to the wide knowledge of our specialty, which allowed a fitting solution to be found in the shortest possible time.

Ethics Statement

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Images of interest

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Post-traumatic Lung Embolization as a Bridge to Surgery in a Jockey Injured by a Fall from a Horse

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Keywords: *Lung; Endovascular Embolization; Bleeding; Intervention Radiology; Trauma*

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BACKGROUND

The mortality of trauma with severe chest injury showing greater than 3 on the Abbreviated Injury Scale (AIS) is very high—15.1% in all age groups and 28.4% in those 65 years or older [1]. Quick hemostasis and treatments with appropriate prioritization for injured organs are essential to rescue patients with polytrauma, especially severe truncal trauma with pulmonary contusion and massive hemorrhage.

Severe lung contusion can lead to massive hemothorax and severe tracheobronchial bleeding. Respiratory dysfunction can also be caused by blood flowing into the uninjured area from the pulmonary contusion.

CASE PRESENTATION

A 35-year-old woman with no past medical history was admitted to our emergency department following a fall from a horse during a show-jumping competition. An initial evaluation of the site highlighted a severe non-penetrating thorax trauma due to direct compression by the animal.

Heli transported her to the emergency block, at which time her respiratory rate was 35 breaths/min, hemoglobin level was 12.6 g/dL with a low blood oxygen saturation (90%) and an acceptable blood pressure of 110/70 mmHg. A focused assessment sonography for trauma (FAST) revealed a hemothorax in the left side of the chest.

The contrast enhanced computed tomography (CT; Revolution Evo, General Electric, USA) performed in the emergency block demonstrated a massive left lung contusion of about 10 × 6 × 16 cm^3, with important active contrast media extravasation in the lower lobe; multiple ribs fractures; and numerous fractures of transverse processes and dorsal vertebrae (Figure 1*a–c*).

After a multidisciplinary council, the trauma leader asked for a percutaneous embolization to achieve hemodynamic stability and to take time to possibly perform a lobectomy under better clinical conditions. The patient was thus moved to the angio-suite and a percutaneous right 5-F right common femoral vein sheath was managed, and digital subtraction angiography (DSA) confirmed active bleeding from the tributary arterial branch of the apical segment of the lower left lobe.

To confirm presence in the branch of the bleeding tributary pulmonary artery, a cone-beam CT was performed. Using a 2.7-F microcatheter (Progreat, Terumo,

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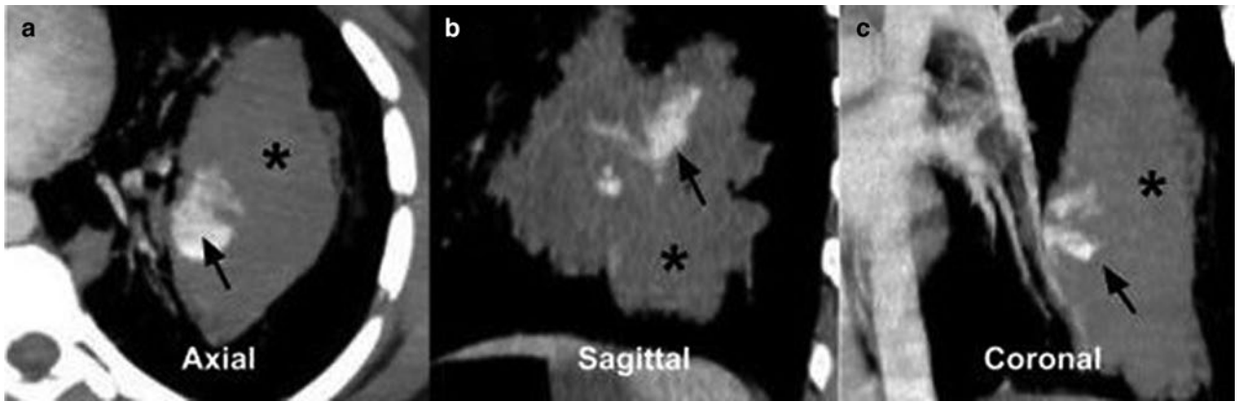

Figure 1 **(a–c)** A multiplanar maximum intensity projection shows the presence of active bleeding with massive left lung contusion (*black asterisk*) and contrast media extravasation in the lower lobe (*black arrow*).

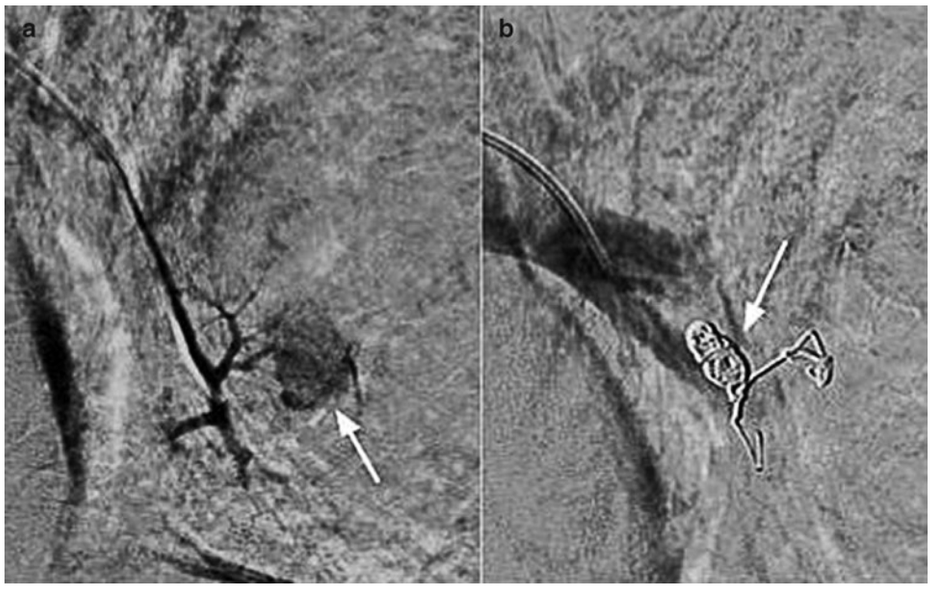

Figure 2 **(a)** Digital subtraction angiography (DSA) of the right pulmonary artery confirms massive active bleeding from the tributary arterial branch of the apical segment of the lower left lobe (*white arrow*). **(b)** A super-selective cannulation of the target arterial branch allows the deployment of micro-coils with endovascular hemostasis and complete resolution of bleeding.

Japan), the bleeding site was reached and three vascular occlusive micro-coils were deployed (Rubycoil soft, Penumbra Inc. Crossmed, USA).

A final DSA shows complete resolution of the bleeding (Figure 2*a*,*b*).

The patient had a regular post-procedure course with hemodynamic stability; however, after 48 h, symptoms and signs of superinfection of the treated lobe appeared. It was therefore decided to perform a lobectomy in order to minimize the risks of septic shock.

On the third day after the endovascular procedure, the patient underwent thoracotomy with left lower lobectomy, experienced no further blood losses and was hemodynamically stable (Figure 3*a*,*b*).

DISCUSSION

This case encapsulates the strategy and workflow in treating closed thoracic trauma with major active bleeding in young patients. The first point to keep in mind concerns the fact that a young patient compensates very well immediately post-trauma and then falls abruptly if not treated. Due to the high-energy trauma, this young patient's spine was immediately immobilized and she was transported by helicopter to the nearest trauma center. The second point concerns the execution of a total body CT with contrast (three phases: basal, angio-arterial and venous) which allowed identification and quantification of pulmonary bleeding. The third

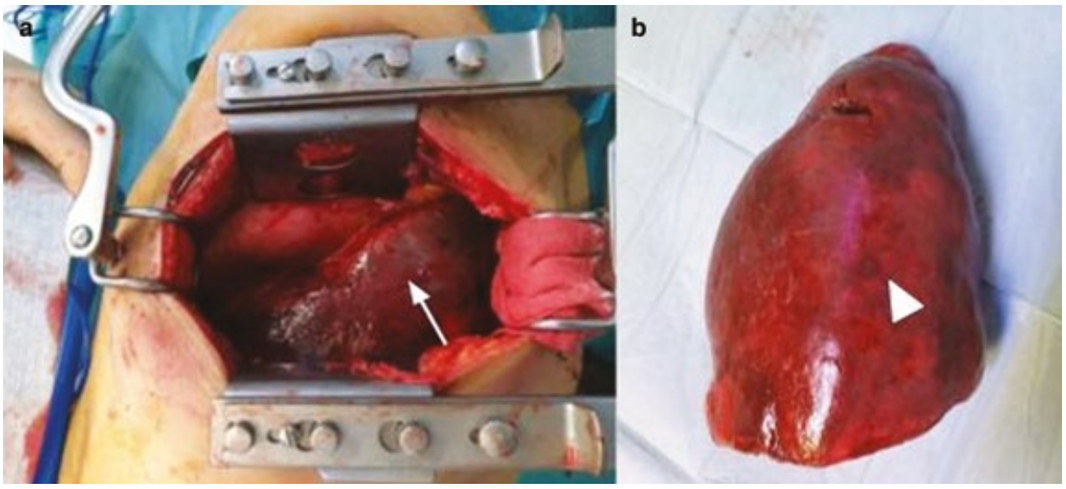

Figure 3 The findings during damage-control thoracotomy and views of the surgical site and operation room just before planned reoperation. **(a)** The lower lobe of the left lung is remarkably swollen due to intrapulmonary hemorrhage and hematoma (*white arrow*). **(b)** The removed lower lobe of the left lung is shown (*white arrow head*).

point concerns the multidisciplinary decision. Performing an embolization had a double objective: (1) to quickly stabilize the patient who was about to experience hemorrhagic shock, and (2) to try to avoid a lobectomy in such a young patient.

In the literature there are very few reports of embolization of traumatic pulmonary artery bleeding [2], although there are many examples of arteriovenous malformation and pseudoaneurysm embolization. The use of different types of embolizing agents, spirals, glue, non-adhesive liquid embolizing agents (such as ONYX, SQUID, etc.) is described [3]. In our case, the patient showed no alterations in the coagulation profile and, therefore, we opted for the use of metal coils which are easy to use and have a relatively low cost. Unfortunately, the possible superinfection of the treated lobe or lung segment is an expected complication that redirects the patient toward lobectomy. In trauma, this complication is greater in relation to communication between hematoma and airways.

CONCLUSION

The use of percutaneous embolization can be considered a valid attempt to avoid lobectomy in young patients; however, superinfection is to be considered a frequent complication.

During the current Covid-19 pandemic, the scarce availability of operating theaters can further lead to the use of interventional radiology as a first approach to trauma.

Ethics Statement

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

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Images of interest

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Emergency Embolization of Ruptured Giant Renal Angiomyolipoma in a Young Patient with Tuberous Sclerosis

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We present a case report of a young patient with tuberous sclerosis and massive retroperitoneal bleeding from giant renal angiomyolipoma following a car accident. We treated this patient with emergency embolization procedures.

Keywords: *Emergency; Endovascular; Renal Angiomyolipoma*

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Renal angiomyolipoma (AML) is an uncommon benign renal neoplasm (incidence 0.3–3%), often found incidentally during diagnostic imaging [1]. Due to the tumor-vessel architecture featured by dysplastic and abnormal arteries [2], management of renal AML bleeding is challenging. Radical partial nephrectomy and transcatheter arterial embolization (TAE) are considered treatment options [3].

A 24-year-old female patient affected by tuberous sclerosis was transferred to our trauma center because of acute distress with tenderness on palpation of the left flank following a car accident. She had a pulse rate of 105 beats/min, blood pressure of 96/56 mmHg, hemoglobin of 9.2 g/dL, platelet count of 280.000/μL, and normal coagulation parameters (INR: 1.02).

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Once hemodynamic stability was obtained, a contrast-enhanced computed tomography (c.e. CT) was performed and a giant bilateral renal AML was revealed with a massive retroperitoneal hematoma and active bleeding from the left renal tumor (Figure 1). After multidisciplinary consultation, and considering her young age, the tumor size and the cause of bleeding, the patient was referred to our interventional radiology department for TAE.

Under local anesthesia, a 5-Fr sheath introducer was placed into the right common femoral artery. A preliminary aortogram with 5-Fr pigtail catheter was performed to exclude polar renal artery or proximal renal capsular artery bleeding. Then, a left renal artery angiography was carried out using a 5-Fr catheter in order to detect bleeding feeder vessels (BFVs) (Figure 2). A super selective approach to BFVs was obtained using a 2.4-Fr microcatheter. Embolization of subcapsular bleeding was performed using microsphere 100–300 μm (Bead Block, Boston Scientific) and then a BFV ligation was obtained with coils (Axium™ MicroFX™, Medtronic) with complete occlusion of bleeding spots.

After 48 h, c.e. CT showed the absence of bleeding, with initial resorption of the retroperitoneal hematoma

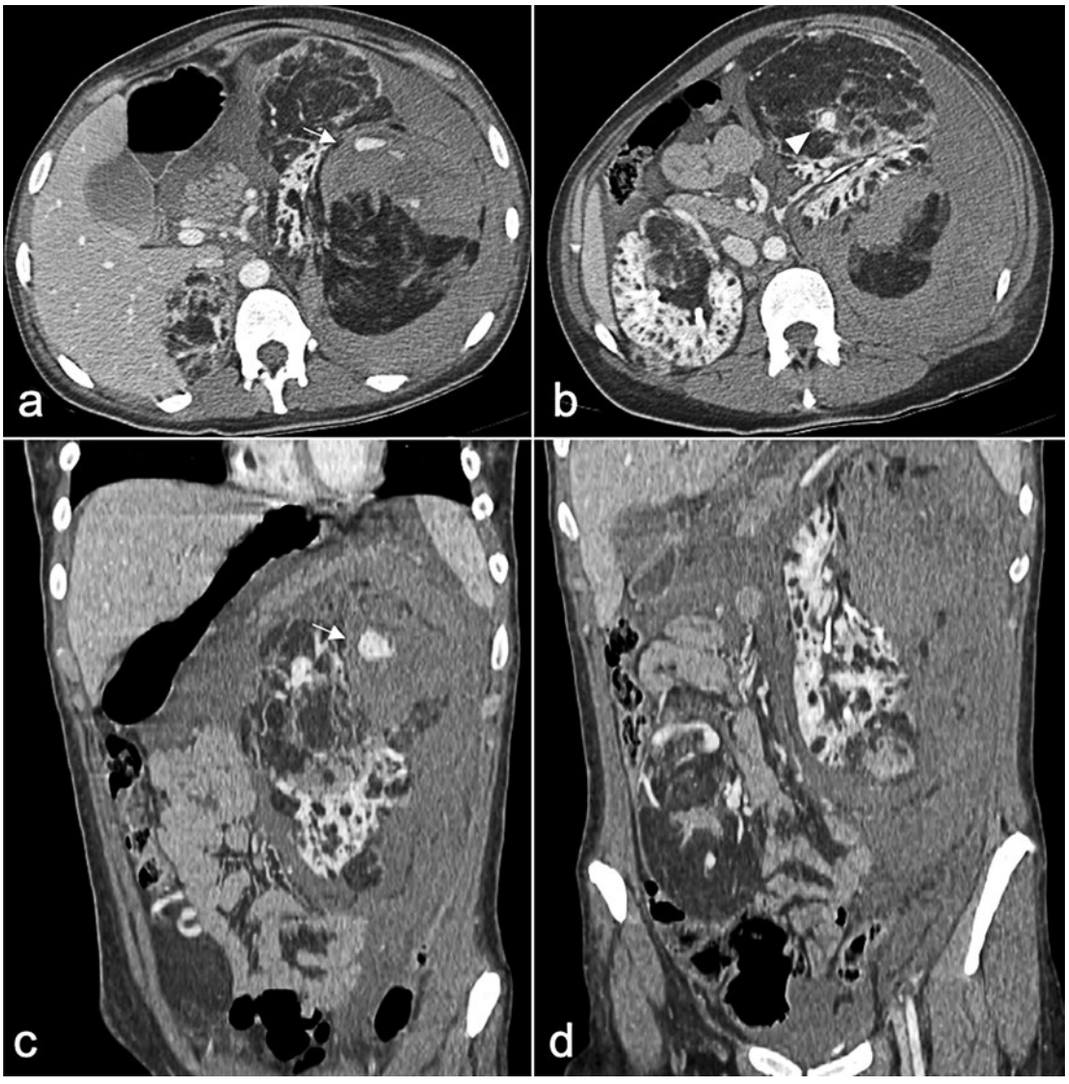

Figure 1 Contrast-enhanced computed tomography (CT) shows an exophytic superior renal pole, well-enhanced giant angiomyolipoma (AML) characterized by 18 cm of longitudinal diameter, with massive retroperitoneal hematoma and active bleeding (*arrows*; **a,c**) from left renal tumor. (**b**) The tumor, in the ventral lateral position in the left kidney, also contains microaneurysms (*arrowhead*). (**d**) Coronal reconstruction better defines longitudinal extension of AML.

and no sign of tumor necrosis or immediate changes in AML size (Figure 3). The patient was dismissed after 1 week.

Ethics Statement

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Author Contributions

All authors contributed substantially to the study and writing of the manuscript.

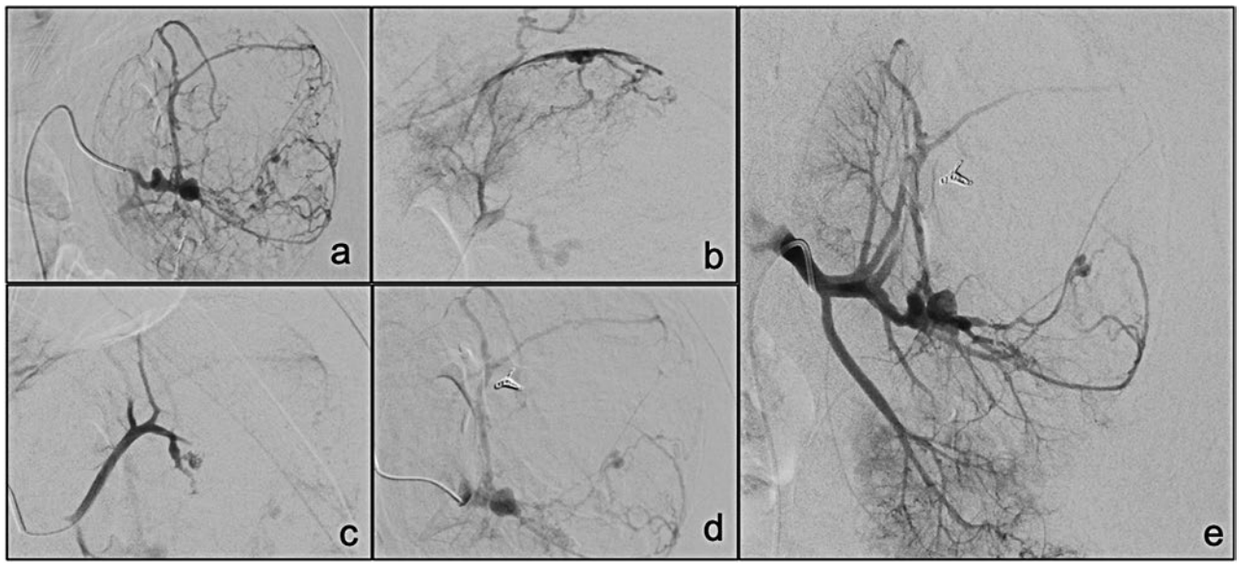

Figure 2 (**a**) Left renal angiography before embolization shows tumor staining and tortuous feeding arteries with a microaneurysm. (**b**) Subcapsular bleeding was detected after super-selective catheterization with subsequent embolization with particles and coils . (**c**) Angiography control after embolization with particles. (**d**,**e**) Postembolization angiogram shows occlusion of blood flow to the upper-pole angiomyolipoma. Note the preservation of flow to more normal-appearing interpole renal parenchyma.

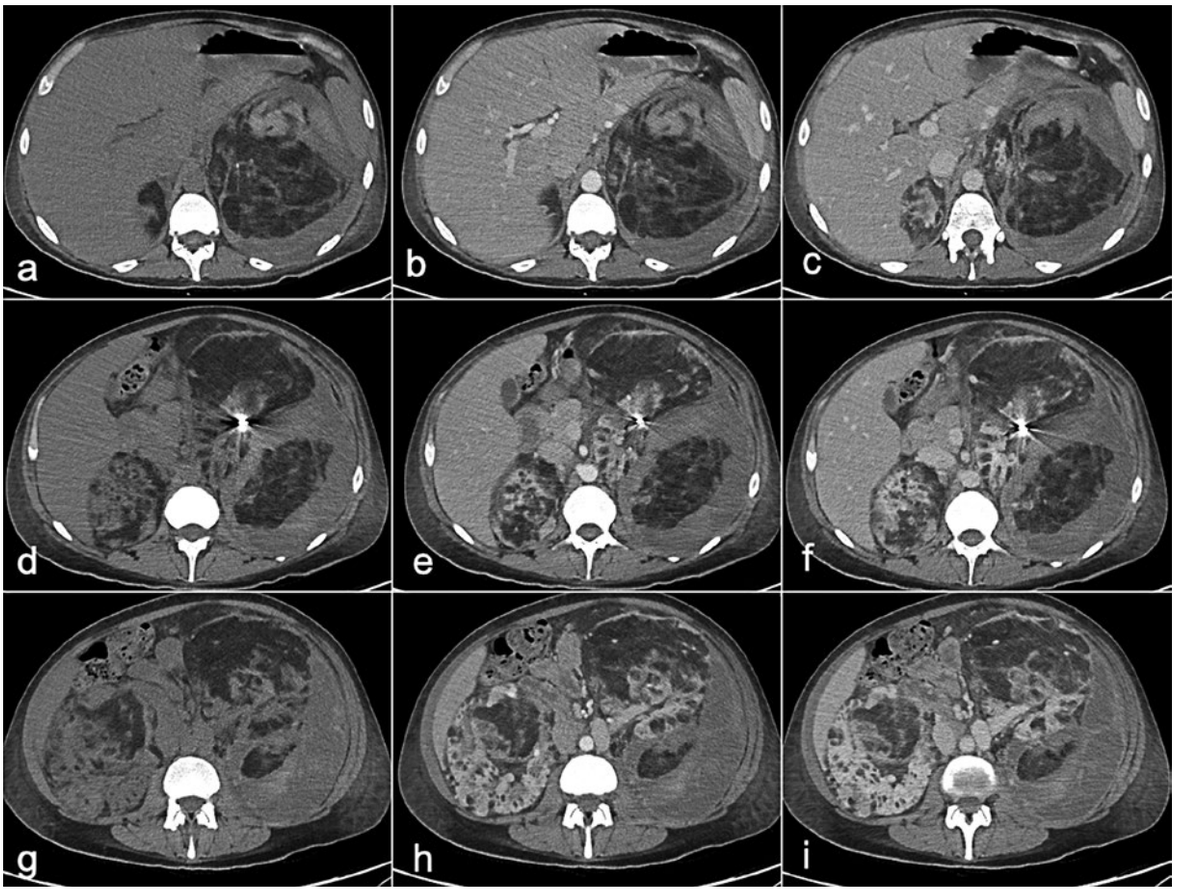

Figure 3 Embolized tumor stain and bleeding signs disappear after embolization using microspheres and microcoils. Normal renal parenchyma is retained, and a residual untreated tumor is shown. Moreover, initial resorption of the retroperitoneal hematoma without signs of tumor necrosis was observed.

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Images of interest

An Emergency Solution When Your Hybrid Suite Goes Dark: Use of a C-arm

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Keywords: *Aorta, Hybrid suite, TEVAR*

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Images of TEVAR (thoracic endovascular aortic repair) for an aortic aneurysm rupture carried out in a Phillips hybrid suite after a sudden technical failure with total system shut-down. A Zeihm mobile C-arm brought in from a nearby semi-hybrid suite was used to continue the TEVAR, with subclavian embolization with PHIL embolization agent and coils for complete seal and ongoing bleeding. Figure 1 shows the C-arm beside the hybrid suite arm that was moved manually cranially. Figure 2 shows the embolization with PHIL and coils on the mobile C-arm screen. The procedure was successfully completed as planned and the patient recovered.

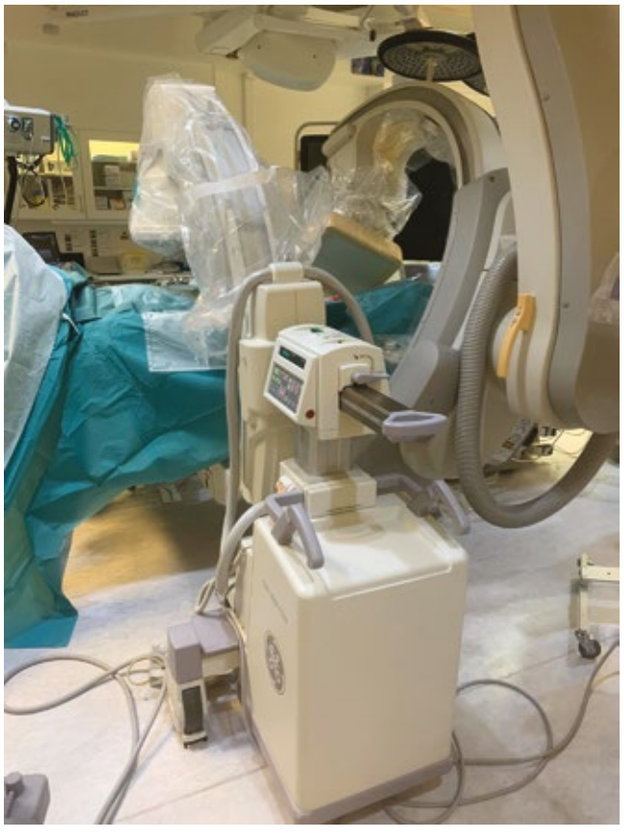

Figure 1

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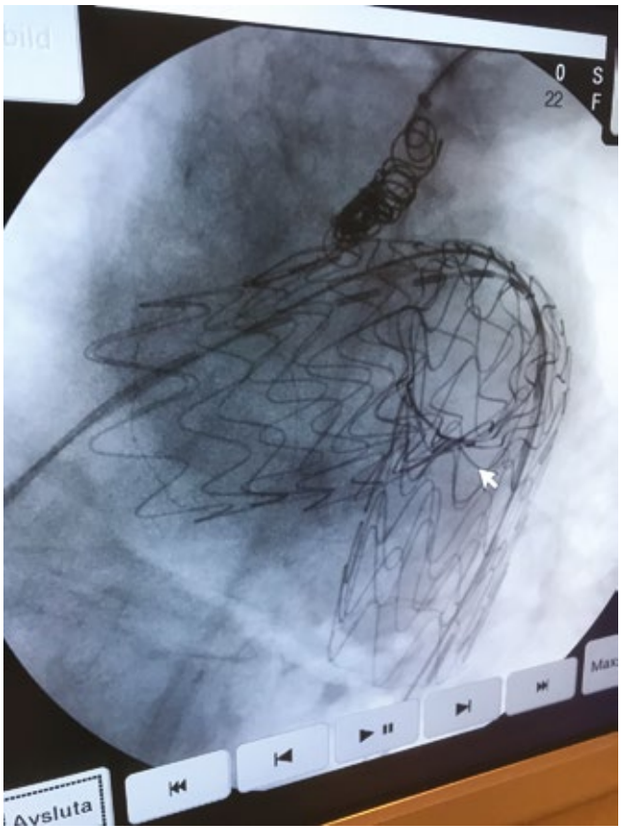

Figure 2

Ethics Statement

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Conflicts of Interest

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An Uncommon Thoracic Aortic Rupture after an Uncommon Motorcycle Accident with a Deer

Filippo Piacentino MD[1,2], Christian Ossola MD[1,2], Federico Fontana MD[1,2], Marco Curti MD[1,2], Marta Duvia MD[1,2], Giada Zorzetto MD[1,2] and Massimo Venturini MD[1,2]

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Keywords: *Trauma; Endovascular Management; Aortic Rupture*

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A 46-year-old male presented to our Trauma Center with a blunt thoracic aortic injury after a motor vehicle crash with a deer. At presentation in the emergency room, he scored 9 on the Glasgow Coma Scale and was hypotensive with a peripheral oxygen saturation of 85% at room air. Once his blood pressure was stable, he underwent full-body, triphase computed tomography angiography (CTA), which showed: a mediastinal hematoma with a posterior descending aortic pseudoaneurysm (PDAP) distal to the aortic isthmus in the presence of bovine aortic arch; bilateral pulmonary contusions; third-cervical body fracture; LeFort type-II, left facial fracture; and multiple bilateral rib and sternal fractures (Figure 1*a,b*).

Under general anesthesia, a percutaneous 5-Fr right common femoral artery and a 5-Fr left brachial artery sheath were managed. Via the brachial access, a pigtail was placed in the aortic arch and subtraction angiography confirmed the PDAP. Subsequently, through the femoral access, a thoracic endovascular aortic repair procedure was managed. Final subtraction angiography demonstrated successful exclusion of the PDAP (Figure 2*a,b*). A 1-year follow-up CTA was done with a stable aortic arch stent, and the pseudoaneurysm was no longer evident (Figure 3*a,b*).

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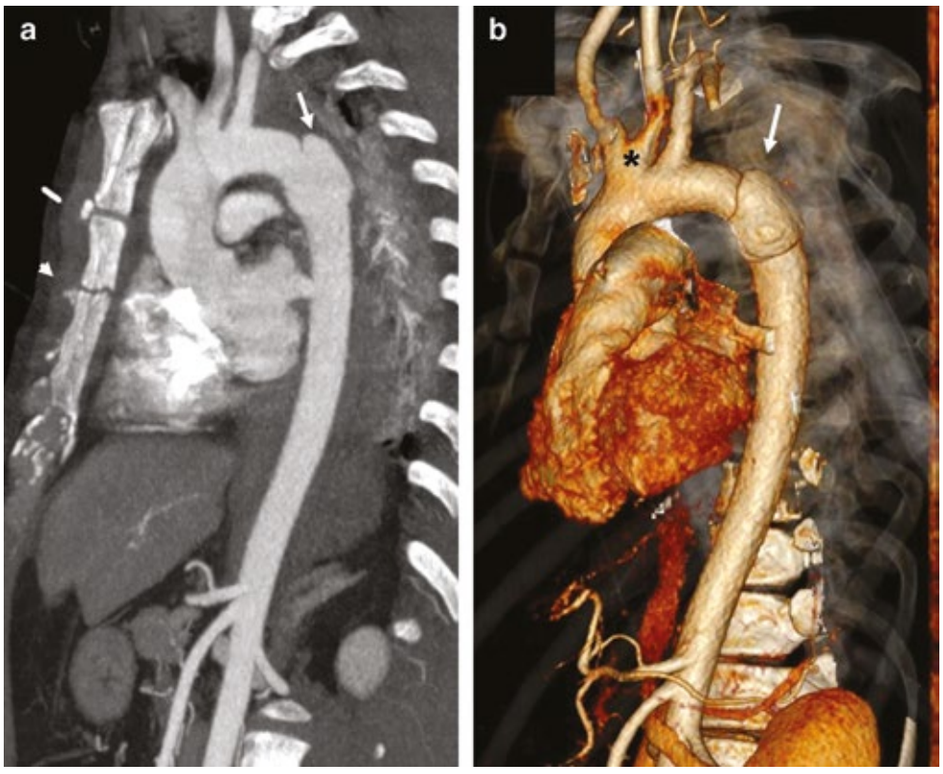

Figure 1 **(a)** Parasagittal maximum intensity projection (MIP) shows the presence of a posterior descending aortic pseudoaneurysm (PDAP) distal to the aortic isthmus (white arrow). Multifocal sternal fractures are indicated by white arrowheads. (**b**) CT 3DVR highlights the PDAP (white arrow) and bovine aortic arch (asterisk).

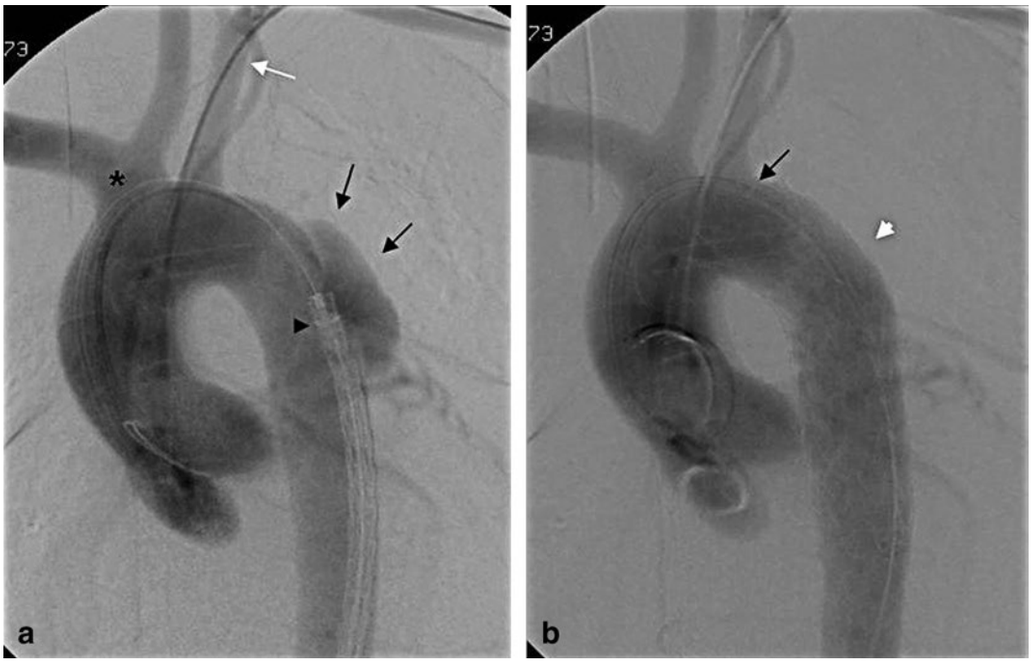

Figure 2 **(a)** Digital subtraction angiography (DSA) of thoracic aorta shows the back-sided large post-traumatic pseudoaneurysm (black arrows). The first DSA control was performed using a 5-Fr pigtail catheter inserted via the left subclavian artery (white arrow) with an aortic endograft already in the thoracic aorta to avoid an extra DSA control. The image confirms the presence of bovine aortic arch (asterisk). Use of left brachial access worked as an anatomical marker to be as aggressive as possible for the proximal landing zone. (**b**) DSA demonstrates successful exclusion of PDAP (white head arrow) with regular patency of left subclavian artery (black arrow).

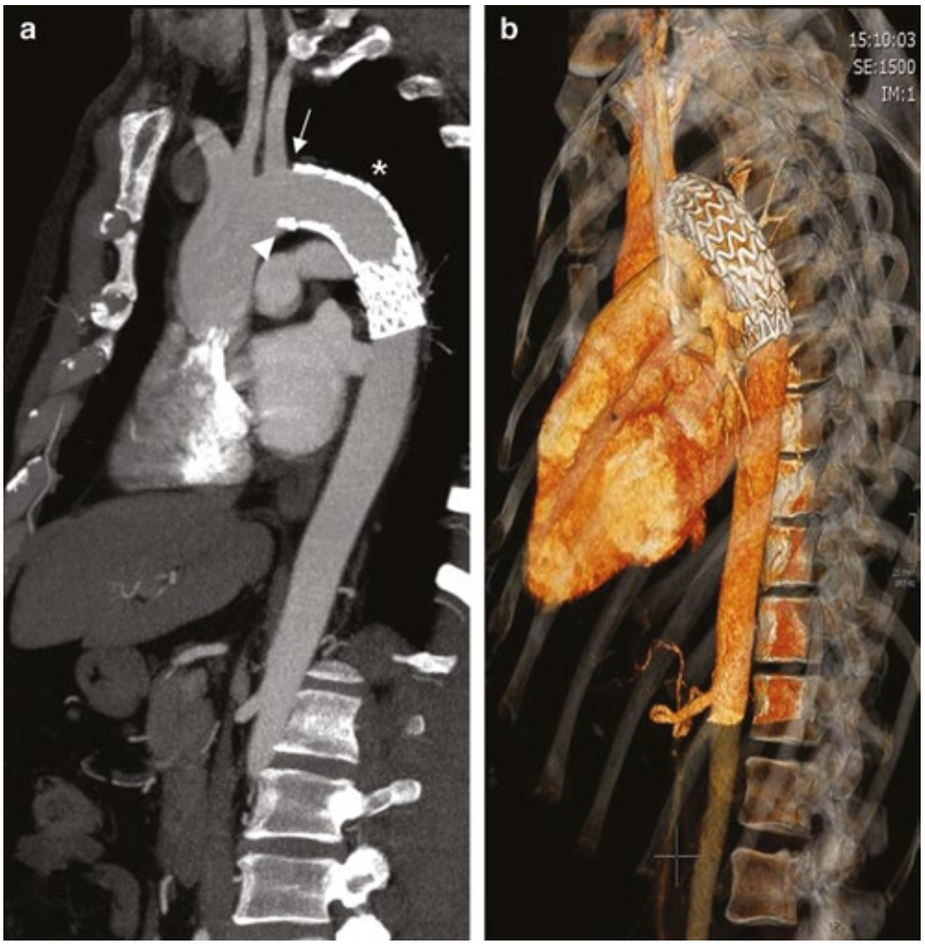

Figure 3 **(a)** Parasagittal MIP shows the exclusion of posterior descending aortic pseudoaneurysm (PDAP) with the correct positioning of the endograft (asterisk). The image demonstrates the graft at the ostium of the left subclavian artery (white arrow) with minimum "bird beak sign" (white arrowhead). (**b**) CT 3DVR highlights the endograft treating the PDAP.

Images of interest

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Embolization of Pancreaticoduodenal Artery Pseudoaneurysm Using Glubran in a Patient with SARS CoV-2

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Keywords: *Embolization; Pseudoaneurysm; Endovascular Procedure; Bleeding*

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Gastroduodenal arterial pseudoaneurysms could potentially evolve into life-threatening vascular complications. Urgent treatment is mandatory in symptomatic patients but might also be indicated even in those with asymptomatic pseudoaneurysms detected incidentally on imaging because of the high risk of rupture [1–3]. During recent years, endovascular methods for treatment of these pathologies has been preferred because of their minimal invasiveness, great efficacy, and larger applicability in patients unfit for surgical procedures [1–4].

On 10th of January 2021, a 72-year-old woman presented at our hospital's emergency department with mild respiratory symptoms characterized by asthenia, mild fever associated with pallor, and generalized pain in the upper abdomen. The blood count performed at that time indicated severe anemia with 7.7 g/l of hemoglobin and 12 × 10^3 leukocytosis; in addition, the patient tested positive for SARS CoV-2. A computed tomography was performed, which showed a 13-mm pseudoaneurysm of the pancreaticoduodenal artery with a sign of rupture (voluminous blood peritoneal collection) (Figure 1). Owing to the poor clinical condition, it was decided to proceed immediately with endovascular treatment. The pseudoaneurysm was typically alimented by vessels deriving from the gastroduodenal and inferior pancreatoduodenal arteries. Distally, these arteries were tiny and, therefore, it was decided to embolize by injecting Glubran (Figure 2); this embolizing agent corresponds chemically to N-butyl-2-cyanoacrylate and is a permanent liquid embolic material that shows several advantages when compared with other embolic agents in gastrointestinal hemorrhage. It has low viscosity and polymerizes at a low temperature, thus allowing rapid and permanent embolization. Moreover, it can be injected through a microcatheter into small arteries, which is often too difficult to do. N-butyl-2-cyanoacrylate can also allow simultaneous embolization of collateral vessels connected to the hemorrhagic focus, which can prevent recurrent bleeding from retrograde collateral flow; moreover, it acts independently from the coagulation cascade and, therefore, this material is successfully employed even in patients suffering from severe coagulation issues [4]. A CT performed at 36 h after the procedure confirmed the treatment's efficacy, with no signs of intestinal/pancreatic ischemia and with hematoma reduction (Figure 3). The origin of this pseudoaneurysm was not related to the presence of acute pancreatitis (from clinical, radiological and laboratory points of view), and we were aware of no previous endovascular treatments. Moreover, several vascular anomalies were noted during the procedure that could be

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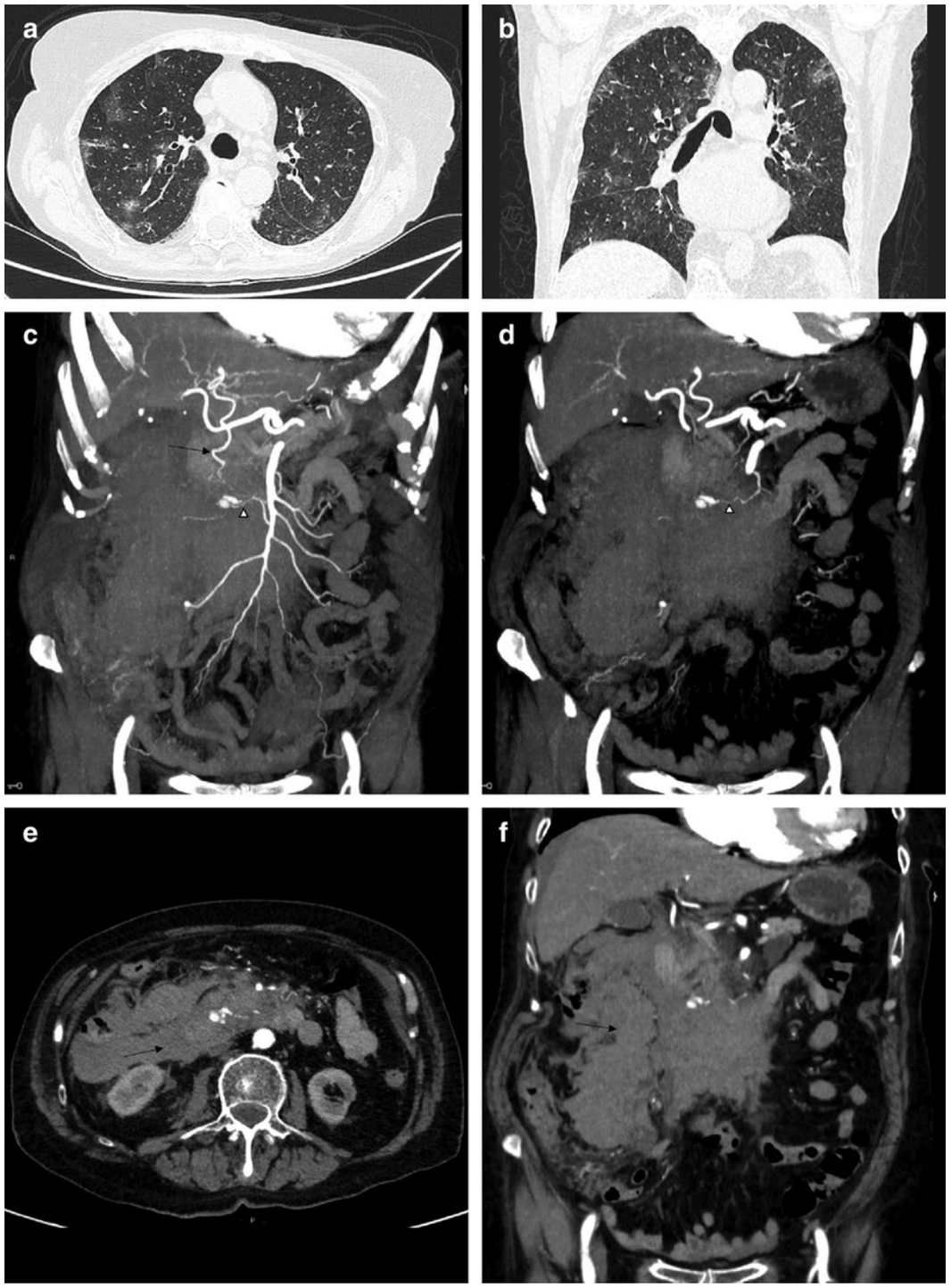

Figure 1 Chest computed tomography (CT) in axial (**a**) and coronal (**b**) planes showing bilateral, multifocal rounded subpleural "ground-glass" opacities compatible with SARS-CoV-2 infection. CT of the abdomen in coronal plane demonstrating the ruptured pseudoaneurysm of the pancreatoduodenal artery, fed by the gastroduodenal artery (black arrow; **c**) and the lower branch of pancreatoduodenal artery (arrowheads; **c**, **d**). CT of the abdomen in axial (**e**) and coronal (**f**) planes highlighting a voluminous intra-abdominal hematoma (black arrows) due to the pseudoaneurysm rupture.

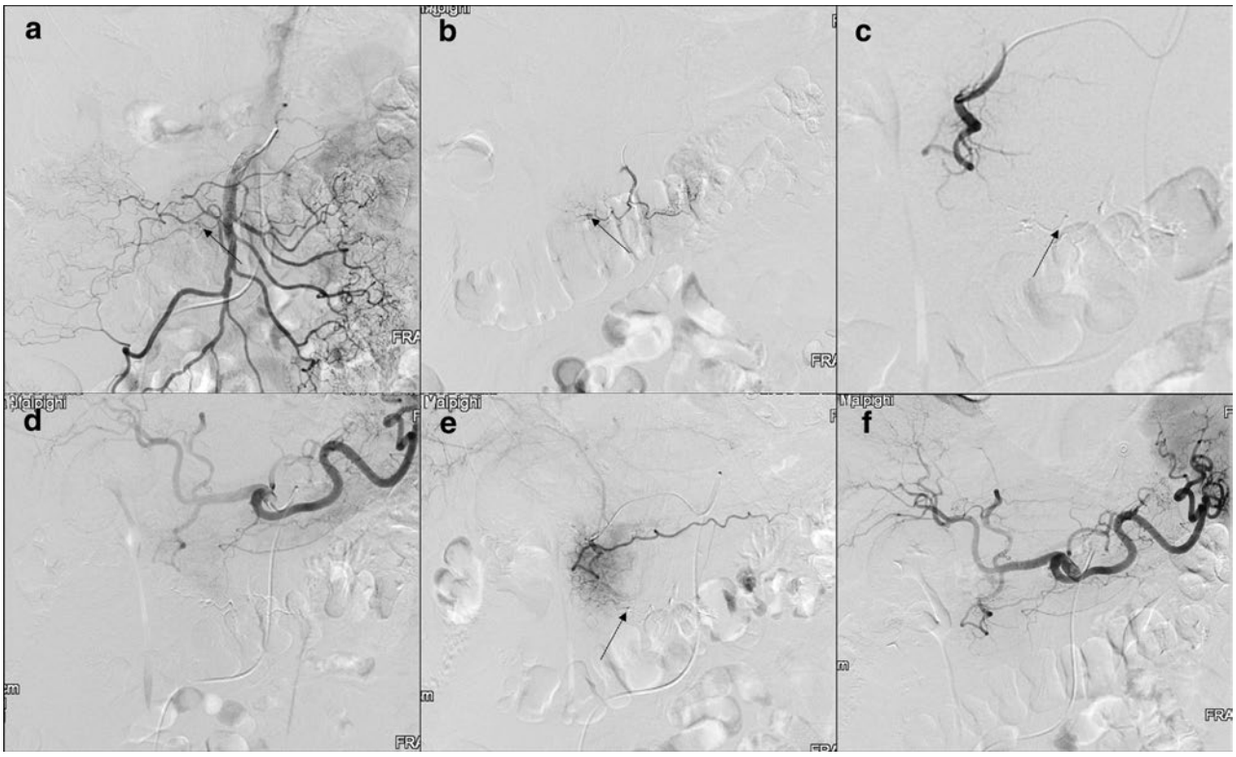

Figure 2 Angiographic study of the superior mesenteric artery (**a**) revealing the pseudoaneurysm of the pancreaticoduodenal artery (black arrow), more evident after selective catheterization of the inferior pancreatoduodenal artery (black arrow; **b**). The Glubran utilized to embolize the pseudoaneurysm is well detectable (black arrow). The proximal angiographic study of the celiac trunk does not show a feeding vessel of the pseudoaneurysm (**d**), well detectable after distal catheterization of the gastroduodenal artery (black arrow; **e**). This small vessel was also embolized finally excluding all pseudoaneurysm feedings (**f**).

attributable to a vasculitis related to SARS CoV-2 infection. The hospitalization was prolonged due to viral infection, with no signs of anemia.

Ethics Statement

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

Conflicts of Interest

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Idea conception: MR, DS. Data acquisition: MR, DS, NB. Manuscript preparation: MR, DS. Manuscript editing and reviewing: all authors. Quality control of

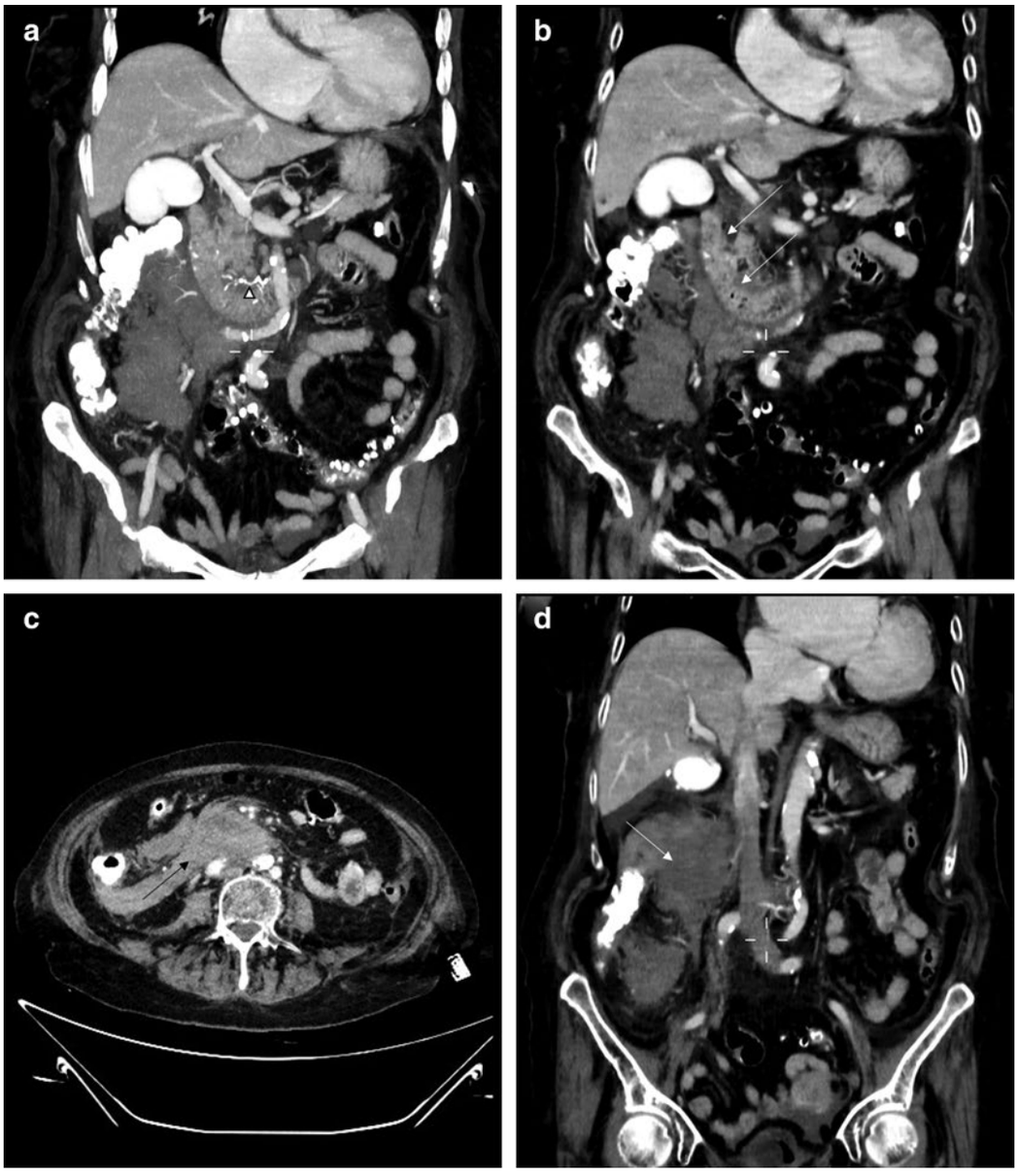

Figure 3 Coronal computed tomography (CT) of the abdomen showing the Glubran used for the pseudoaneurysm embolization (arrowhead; **a**), with no signs of ischemia of the duodenal walls (arrows; **b**). CT of the abdomen showing a huge reduction of the peritoneal hematoma in axial (arrow in **c**) and coronal (arrow in **d**) planes when compared with those in images in Figure 1*e, f*.

data: all authors. All authors read and approved the final manuscript.

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Images of interest

Endovascular Management of Unintentional Thoracic Aorta Injury

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Keywords: *TEVAR; Emergency; Endovascular; Thoracic Aorta; Penetrating Trauma; Iatrogenic; Complication; Ablation; Bleeding*

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We report on a case of a major complication following a microwave (MW) ablation of a hepatic lesion, which was successfully managed using an endovascular approach.

Bleeding is one of the most common major complications of hepatic tumor ablation, although direct injury of the thoracic aorta is extremely rare [1]. Immediately after the procedure, the patient presented with pain, tachycardia and hypotension. Ultrasonic intraprocedural control of the Morison's pouch was negative, but the patient didn't recover after medical therapy. Thus, an angio-computed tomography (CT) was performed.

The coronal maximum intensity projection (MIP) images of the CT were very impressive, showing a voluminous blush from the thoracic aorta feeding a massive hematoma (Figure 1). Wasting no time is crucial in these cases, and as soon as the complex injury was appreciated, the patient was immediately transferred to the Angio-Suite. An endovascular approach is a well-established treatment for thoracic aortic lesions [2].

Interventional radiologists and vascular surgeons worked together to solve this complex case. After bilateral femoral access, an angiography of the aorta was performed using a pig-tail catheter. The angiography showed the active blush from the aorta (Figure 2). A "Gore® TAG®" stent graft was immediately placed above the celiac trunk, excluding the thoracic injury. The final angiography showed a perfect placement of the stent graft, with no more vascular blush (Figure 3).

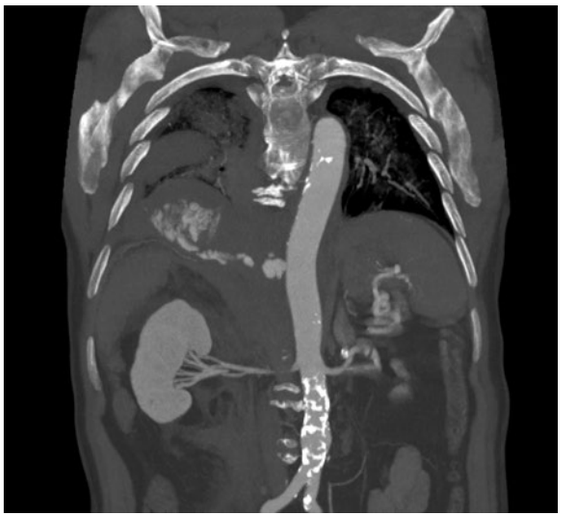

Figure 1 Coronal MIP image of the thoracic aorta showing a massive blush and hemothorax.

The patient was dismissed after 2 weeks, in good condition. A follow-up CT after a month showed perfect placement of the prothesis and quite total resolution of the hematoma (Figure 4). In a life-risk situation, nerve, haste and a multidisciplinary approach are crucial to save the patient's life.

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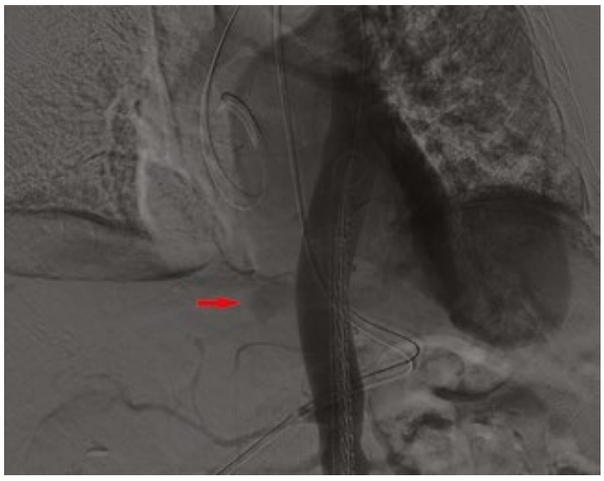

Figure 2 Aortography showing the massive blush (red arrow).

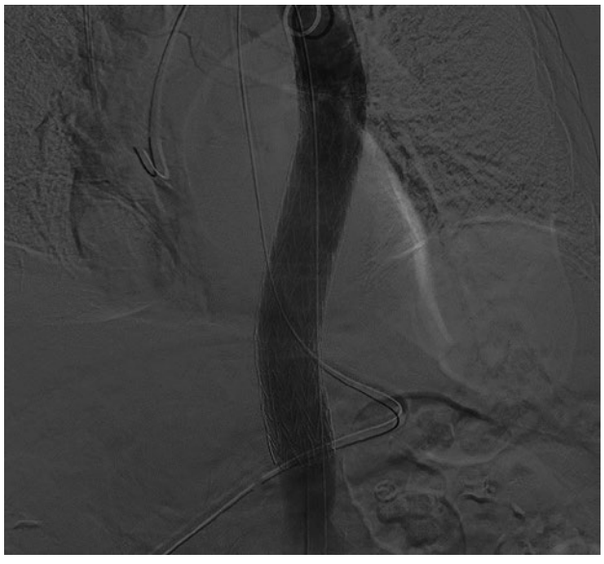

Figure 3 Post-procedure aortography, confirming the right placement of the stent graft.

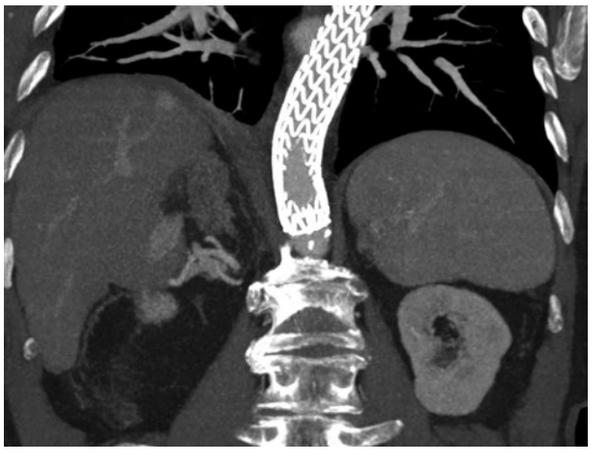

Figure 4 Coronal MIP image of the follow-up angio-computed tomography after 1 month.

Ethical Approval and Informed Consent

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent to the CT and procedure was obtained from all subjects in this study.

Ethics Statement

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

Conflicts of Interest

The authors declare that they have no conflicts of interest and have no financial relationship with any sponsoring organization.

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Author Contributions

All the authors contributed to the selection of the images and the production of the manuscript.

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Images of interest

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Post-Traumatic Pudendal Bleeding: Beyond the Satisfaction of Search

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Keywords: *Embolization; Pelvic Trauma; Diagnostic Angiography*

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Vascular injury is a common (up to 40%) finding in patients with pelvic trauma [1] and is frequently associated with multiple vessel involvement [2]. Endovascular embolization is usually the treatment of choice [3]; but, in patients with low hemoglobin levels, the vasoconstriction can obscure possible sources of bleeding by increasing procedural time or requiring re-treatments [4]. Apparent concordance between computed tomography (CT) and angiographic findings is a potential risk factor for preventing the interventional radiologist from performing a complete angiographic examination, such as selective cannulation and/or pressure injection, of the affected vascular district.

We report about a 46-year-old man with pelvic trauma following a motorcycle accident. The patient presented with signs of hemodynamic instability, low hemoglobin levels (5.7 g/dl) and clear evidence of left pudendal artery bleeding at the CT examination performed after admission to the emergency department (Figure 1*a–c*).

Right common femoral artery access was performed using a 5-French vascular sheath placement. Selective and super-selective catheterization of the left hypogastric and pudendal arteries was performed, respectively (Figure 1*d,e*). Angiographic findings were in accordance with those reported in the previous CT, but evaluation of the contralateral pudendal artery demonstrated massive bleeding (Figure 1*f,g*), probably covered up by vasoconstriction, spasm or cross-circulation via anastomosis of the bilateral pudendal arteries, and immediately controlled with a combination of coils and sponge particle embolization (Figure 1*h–k*).

In conclusion, bilateral selective angiographic examination using a power injector should be performed in pelvic post-traumatic vascular injuries in order to reduce the lack of identification and treatment of vascular injuries.

Ethics Statement

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Author Contributions

AC was responsible for writing and reviewing; ARS and EP were responsible for images and clinical data research; and RM was responsible for reviewing and supervising.

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Figure 1 Motorcycle accident in a 46-year-old man with pelvic trauma. (**a–c**) CT axial images show an important left hematocele (asterisk) supplied by two small spots of active bleeding (thin arrows) which increase during the post-contrast venous (**b**) and late (**c**) phases. (**d**) Left pudendal artery angiography confirms the presence of the small vascular lesions which are effectively controlled by absorbable particle embolization (**e**). Contralateral angiography (**f**) reveals a massive bleeding (thick arrows) due to an important vascular injury of the main trunk of the right pudendal artery which is managed with selective catheterization (**g**) and embolization (**h**) with 5 mm and 6 mm coils. Angiographic run after coil deployment (**i**) shows persistent bleeding (dot) from small collateral vessels (arrowheads) which is successfully managed (**j,k**) with absorbable particle embolization.

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Images of interest

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Aortoenteric Fistula: Endovascular Treatment

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Keywords: *Aorta; Fistula; Endovascular; Balloon; Endoprosthesis*

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A 67-year-old male patient arrived at our emergency department with abdominal pain and near syncope status: blood pressure 90/50 mmHg and heart rate 80 beats/min. His past medical history revealed an aorto-biliac surgical graft for abdominal aortic aneurysm (3 years ago), hypertension and left lower-leg claudication. Abdominal examination revealed no palpable mass. He underwent urgent, abdominal multi-detector computed tomography (MD-CT), with axial (Figure 1*a*) and coronal (Figure 1*b*) VRT reconstruction, which demonstrated, in the arterial unenhanced phase, a direct contrast extravasation (arrowhead) from the middle-distal third of the abdominal aorta to a small bowel loop (*) due to a fissured anastomotic pseudoaneurysm. Occlusion of the left common iliac artery (#) was also noted (Figure 1*b*).

The patient, who had already received and been maintained for 1 month on empiric antibiotic therapy (vancomycin, piperacillin, and tazobactam), was transferred immediately to an angiography room. From the left brachial and right femoral arteries, a 10-Fr and 20-Fr introducer, respectively, was inserted. From the left brachial access, an occlusion balloon was positioned and inflated in the abdominal aorta in front of the renal artery origins (arrowhead; Figure 2*a*). With the occlusion balloon still inflated (as a shadow image - arrowhead), an endovascular aorta–aortic endoprosthesis (Medtronic, Minneapolis, MN, USA) was deployed from the right femoral access in the middle-distal third of the abdominal aorta (markers – arrows; Figure 2*b*), with the aim of covering the fissured anastomotic pseudoaneurysm. Final abdominal aorta angiographic control (Figure 2*c*) demonstrated the correct positioning of the endoprosthesis and exclusion of the fissured aortic pseudoaneurysm. In this case, endovascular aorta–aortic endoprosthesis was a definitive treatment with observed clinical and technical successes on a 2-year follow-up.

Ethics Statement

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Conflicts of Interest

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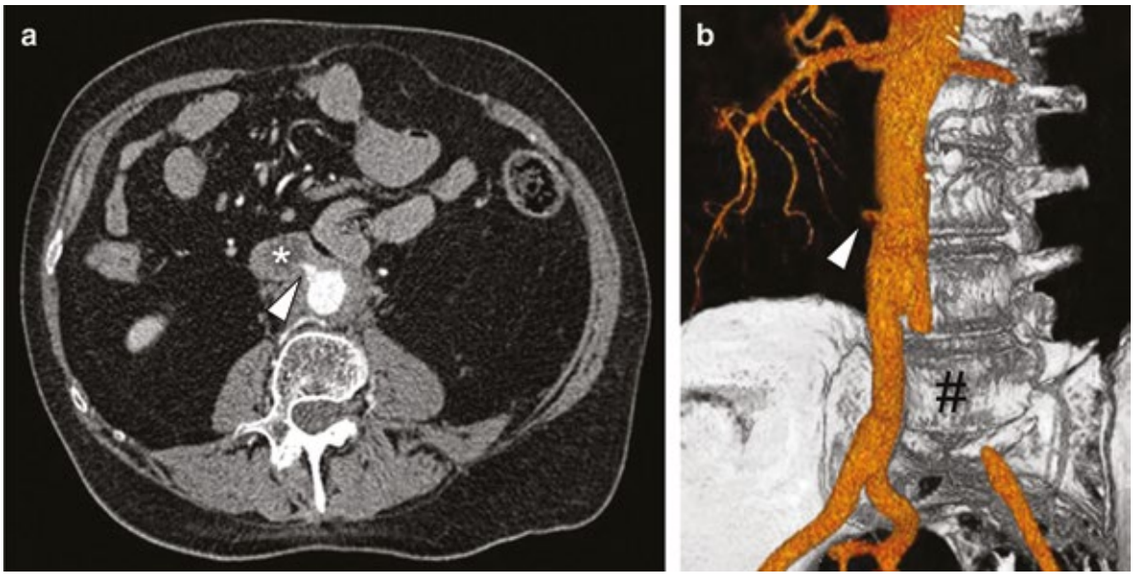

Figure 1

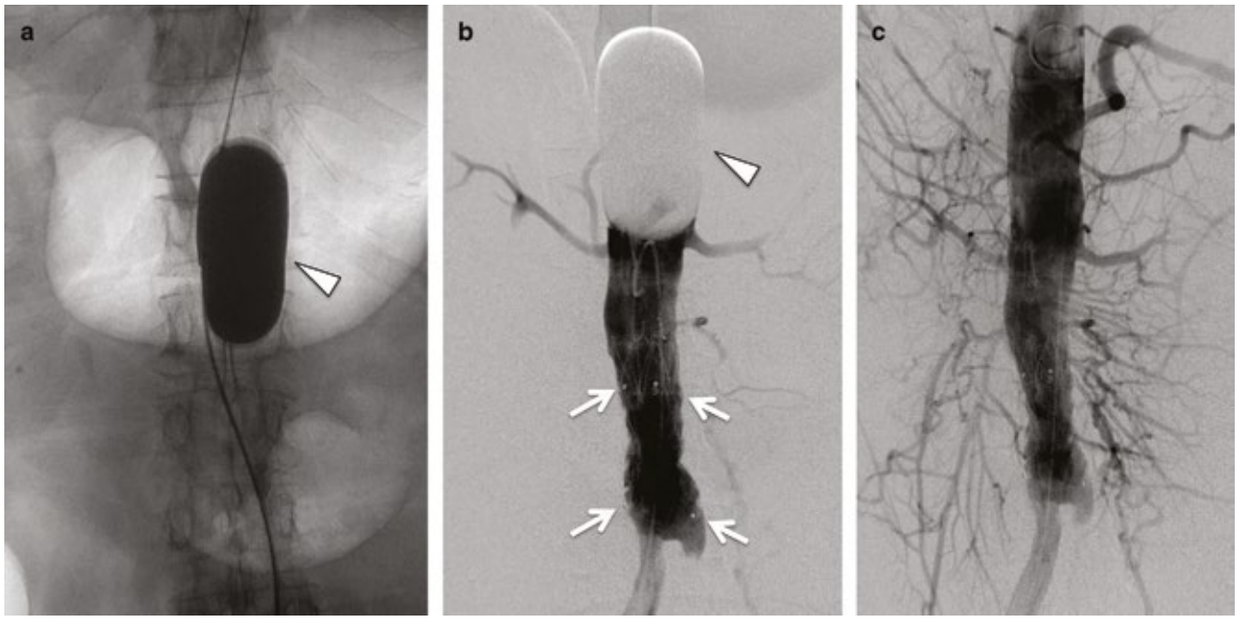

Figure 2

Case Report

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Segmental Artery Injury During Anterior Column Realignment: A Case Report and Review of the Literature

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Background: Anterior column realignment (ACR) is a minimally invasive technique used to restore lumbar lordosis and improve sagittal balance. The most feared complication from ACR includes injury to the great vessels. Segmental artery injuries are also a possible complication, although sparsely reported. We report such a case.
Case Description: During anterior longitudinal ligament release at L3–4, the L3 segmental artery was injured. Intraoperative angiogram and coiling were performed. Our patient remained hemodynamically stable, with the exception of during the postoperative period when his hemoglobin level fell five points.
Discussion: This patient was at risk for this complication due to the tortuosity of his vessels and his osteophytes. This injury can be treated concurrently with endovascular embolization if equipment and personnel are readily available. Ultimately, segmental artery injury does not appear to be as morbid as great vessel injury, if addressed emergently.

Keywords: *Anterior Column Realignment; Lateral Lumbar Interbody Fusion; Radicular Artery; Segmental Artery; Vascular System Injuries; Endovascular Hemostasis*

Received: 1 February 2021; Accepted: 12 March 2021

BACKGROUND

Adult spinal deformity is a wide-ranging, nebulously classified disease that plagues a significant number of people. In patients with adult spinal deformity, poor sagittal balance has been found to be a reliable predictor of poor functional status and quality of life [1–3]. Correction of this sagittal imbalance is paramount to improving outcomes. Traditionally, this has been performed using open posterior approaches.

Within the last decade, minimally invasive techniques such as the anterior column realignment (ACR) have been used to restore lumbar lordosis and improve sagittal balance [4]. With this procedure, anterior longitudinal ligament (ALL) transection with partial anterior annulotomy and discectomy are performed through a lateral transpsoas approach [4–6]. Following this, a lordotic or hyperlordotic cage is placed to fully capitalize on the now lengthened anterior column and restore proper sagittal balance.

The most feared perioperative complications from ACR include injury to nearby structures such as the great vessels (iliac vessels, abdominal aorta, or inferior vena cava), visceral organs, or nearby nerves and plexuses [7–12]. The surgeon should take great care to identify these structures on preoperative imaging as these injuries can be fatal or significantly impact patient quality of life. While not as life threatening, segmental artery injuries during this surgery have also been discussed as a possible complication. Three were reported in a survey of 13,004 patients conducted by Uribe and Deukmedjian, although these were never detailed in the literature [8]. In this report, we describe a patient who suffered a segmental artery injury during ACR; we hope, by sharing these details, to prevent other surgeons from making a similar error and to guide them if facing this same situation.

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CASE DESCRIPTION

Clinical Presentation

A male in his 60s presented to the emergency department at our facility for back pain, bilateral posterior leg pain, worsening weakness of his bilateral lower extremities, and gait ataxia. On examination, the patient's strength was 4/5 throughout his bilateral lower extremities, although his right lower extremity was weaker than his left, he had decreased sensation in his bilateral lower extremities without any pattern, and experienced hyporeflexia. He showed no Babinski's reflex or clonus. The rest of his neurologic exam was intact, with no upper extremity deficits. Past history was significant for a C3–4 anterior cervical discectomy and fusion 5 years prior, and a spinal cord stimulator placement at T9–10 about 1 year prior, which had given him mild pain relief. The patient's preoperative films are seen in Figure 1. After discussion of the risks and benefits of surgery, he agreed to proceed with L3–5 lateral lumbar interbody fusion (LLIF) and ACR. The patient's preoperative hemoglobin was 13.7 g/dl.

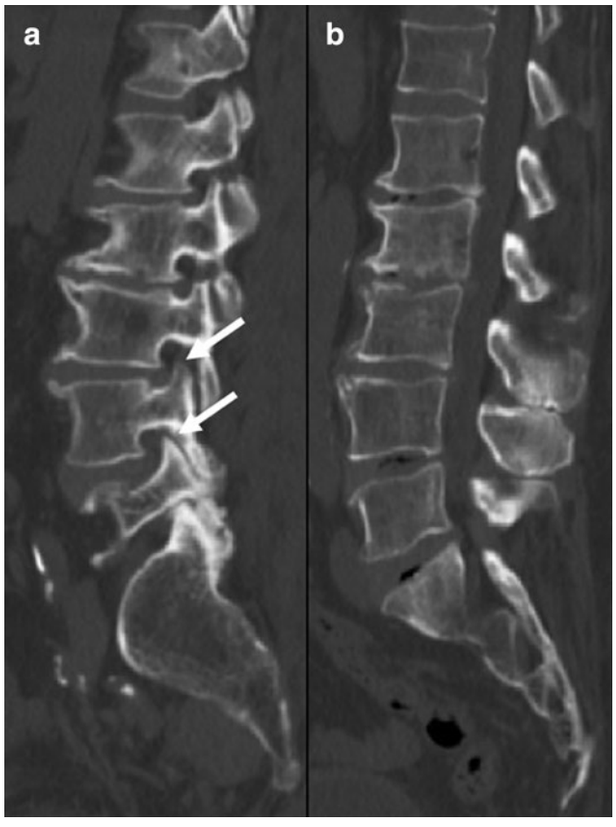

Figure 1 Preoperative images for patient described. (**a**) Sagittal computed tomography (CT) image showing the left neural foramina. The foramina at L3–4 and L4–5 appear significantly compressed, as demarcated by white arrows. (**b**) Sagittal CT image showing the spinal canal at its greatest diameter. Degenerative disk disease is seen with collapsed disk spaces at L2–3, L3–4, and L4–5.

Operative Procedure

After intubation and induction of general anesthesia, the patient was turned to the lateral position, right side up. We localized the L4–5 level using fluoroscopy. After sterile prepping and draping, a skin incision was made and we reached the lateral disk space via the retroperitoneal space. Our retractors were placed and stimulated, which showed safe docking of the system. Thorough discectomy was performed, the disk space was prepared, and a 10 × 22 × 60-mm^3 cage with allograft was placed. We then removed the retractor system, and X-rays confirmed satisfactory cage placement.

We shifted to the L3–4 disk space and docked our retractor system. Discectomy was begun using a curette and Kerrison rongeurs. We placed a small retractor between the aorta and ALL. Under direct visualization, the ALL was sharply transected with a knife halfway to the mid vertebral body, at which point we advanced the retractor all the way to the contralateral pedicle. During the final cut of the ALL, some red blood appeared on the contralateral side. We packed the area with Surgicel® Fibrillar™ and Floseal, which stopped the bleeding, and called the Vascular Surgery team for intraoperative consultation.

The vascular surgeons inspected the bleeding area and recommended closure of the area for the time being as well as further endovascular assessment, because the patient was hemodynamically stable, the wound was "extremely small and extremely deep", and the equipment was available in the operating room. After irrigation and hemostasis with packing, we removed the retractor and closed the incision in layers.

The patient was rotated to the supine position. The right groin was prepped, and field was sterilely draped. Access was achieved via a direct stick into the right common femoral artery. After placement of the sheath, the diagnostic catheter was advanced to the L3 vertebral body. Diagnostic arteriography showed a blush from a left lumbar artery at the area of presumed bleeding (Figure 2). This lumbar artery was accessed with a re-curved catheter, and one long coil was inserted to completely obstruct the lumen. Afterward, arteriography demonstrated that the bleeding had ceased (Figure 3). Catheters were removed and hemostasis was achieved using a Mynx® device. The patient was hemodynamically stable throughout the entire procedure.

Postoperative Course

Postoperatively, the patient reported his symptoms had improved. He denied any new neurologic deficits, and his bilateral lower extremities were now full strength throughout, with intact sensation. On postoperative

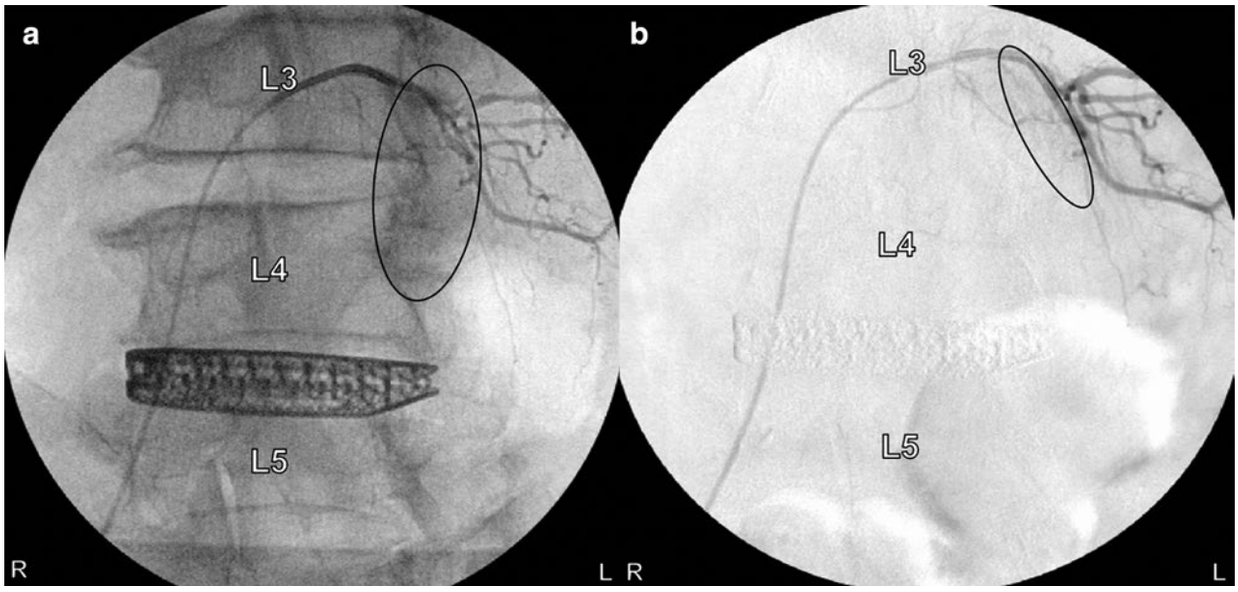

Figure 2 Intraoperative images before coil placement. (**a**) A still anteroposterior X-ray after dye injection into the left L3 segmental artery. The blush demonstrating active bleeding is encircled. Note how the segmental artery branches sag inferiorly and are tortuous. (**b**) A still image from a digitally subtracted anteroposterior angiogram is shown. A small area with a slight blush is encircled.

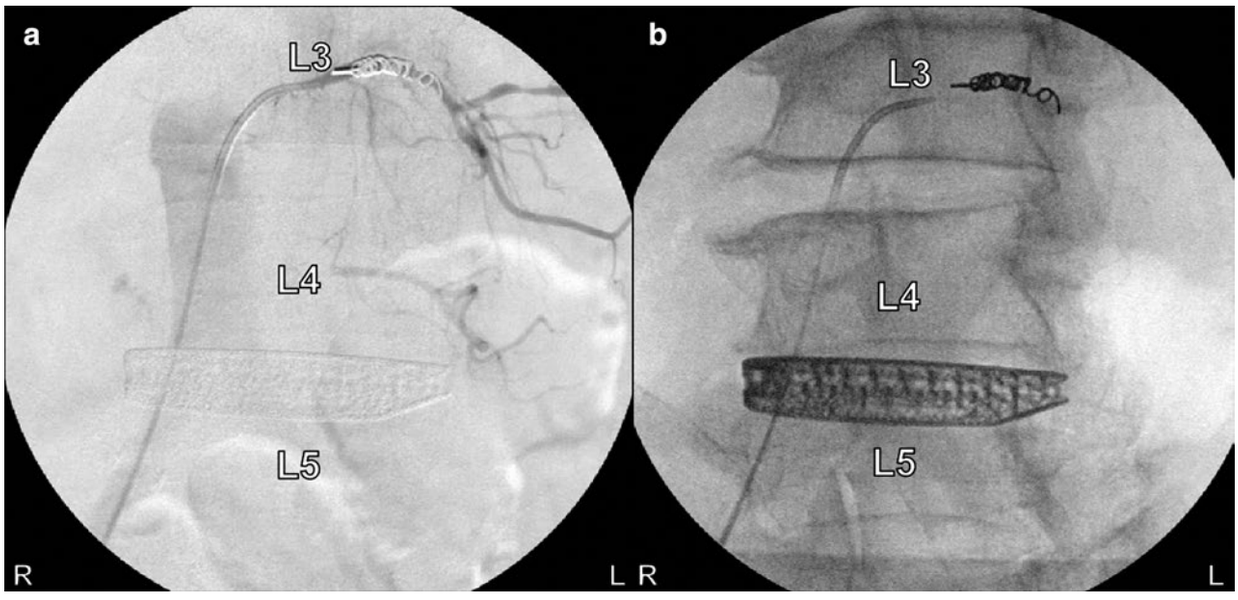

Figure 3 Intraoperative angiography images after coil placement into the left L3 segmental artery. (**a**) Anteroposterior digital subtracted angiogram with catheterization of the left L3 segmental artery. The coil was placed and detached. (**b**) Anteroposterior X-ray obtained while the left L3 segmental artery was still catheterized demonstrates the final coil position in reference to the bony anatomy.

day 1, a computed tomography (CT) angiography of the abdomen and pelvis showed postoperative changes and a right psoas collection of air and fluid. Also, on postoperative day 1, the patient received a lumbosacral orthosis and had upright X-rays and standing scoliosis films which were satisfactory. On postoperative day 3, the patient's hemoglobin reached its trough, 8.6 g/dl, after which it started to improve. The patient did not require transfusion. On postoperative day 4, a repeat CT angiography of the abdomen and pelvis showed a persistent

fluid collection in the right psoas major believed to be a hematoma or seroma. We discharged the patient without incident on postoperative day 10.

Ethical Approval and Informed Consent

Ethical approval was not required. Informed consent was obtained from the patient in this study, including consent for publication of the figures.

DISCUSSION

In this case, we have described a patient who suffered a left L3 segmental artery injury during ALL release as part of an ACR and his clinical course. Although in terms of vascular injury much of the focus is on injury to one of the great vessels, segmental artery injury is also a possible complication associated with this procedure. Overall, the literature discussing segmental artery injury in ACR surgery is sparse. In a survey on 13,004 patients, Uribe and Deukmedjian found only three reports of a segmental artery injury, indicating a very low incidence [8]. To our knowledge, none of these injuries has been described in the literature in any detail; thus, we sought to describe such an injury, its resolution, and the effects on the patient.

Although this complication is not common, we hypothesize some reasons why it occurred in this case and some factors to consider pre- and intraoperatively to reduce its prevalence even more. First, the patient was in his 60s and regularly smoked three packs of cigarettes per day. Increased age is a major risk factor for increased arterial tortuosity and also iatrogenic arterial injury [13–15]. Because of this increased tortuosity, the patient's arteries may be slightly distorted in anatomical location. For example, his segmental artery's branches can be seen at the same level as the disk space (Figure 2) and closer in laterality to the disk space than one might typically expect, increasing the potential for injury. In addition, in a paper analyzing anterior approach lumbar spine surgeries, Fantini et al. found that anterior osteophytes increased the risk of vascular injury, likely because the increased inflammation results in the blood vessels being more fixed and resistant to movement [16]. While our patient had some anterior osteophytes (see Figure 1), he also had some significant lateral osteophytes. Thus, it is possible that the artery was at increased risk for shear injury given its resistance to outside motion.

Iatrogenic arterial injuries are an increasingly recognized cause of arterial injuries even at major trauma centers, although neurological surgery is not a common culprit [15,17]. Fortunately, our patient had no associated morbidity. However, his hemoglobin level did drop by about five points after the procedure and associated arterial injury—although he was never symptomatic from his anemia, nor did he need blood transfusions. Additionally, by good luck, our vascular colleagues were available for intraoperative consultation so we could address the injury immediately and, as it happened, endovascularly. Nevertheless, this complication is an important one to be aware of during ALL release.

CONCLUSIONS

Segmental artery injury during ACR is a very rare, but possible, complication. This injury can be treated concurrently with endovascular embolization if equipment and personnel are readily available. Increased arterial tortuosity and significant osteophytes may increase the risk of arterial injury. However, segmental artery injury does not appear to be as morbid as great vessel injury.

Ethics Statement

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Case Report

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Extra Anatomical Bypass for Common Femoral Artery Pseudoaneurysm following Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

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Background: Improvements in the instrumentation and guidelines for the use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) have increased its use as an adjunct in managing haemorrhagic shock. REBOA-related complications continue to be assessed and described.
Methods: We describe a case of a femoral artery pseudoaneurysm within an infected groin wound after REBOA usage in a 25-year-old male after several bouts of sepsis and complications related to the initial penetrating injury and associated stay in the intensive care unit.
Results: An extra-anatomical external iliac-to-superficial femoral artery bypass was performed using a 6-mm polytetrafluoroethylene graft to treat the femoral artery pseudoaneurysm successfully.
Conclusion: REBOA is a well-described adjunct in the management of haemorrhagic shock. The immediate and delayed complications should be not overlooked. Deviations from the expected post-operative course should be promptly recognised and managed by a clinician with appropriate expertise.

Keywords: *REBOA; Pseudoaneurysm; REBOA Complications*

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INTRODUCTION

Femoral artery pseudoaneurysm (FAP) is a well-known complication of common femoral artery (CFA) cannulation for diagnostic and interventional procedures, with rates of 0.05–2% for diagnostic [1] and up to 10% for interventional [2] procedures. Iatrogenic FAPs have been reported in the American Association for the Surgery of Trauma (AAST) prospective Aortic Occlusion for Resuscitation in Acute Care and Trauma Surgery (AORTA) registry, with one in a case series of 46 patients (2.1%) [3]. There are multiple treatment options for iatrogenic FAP, including ultrasound compression, thrombin injection, primary repair, endovascular stents and bypass procedures [4]. We present a patient who developed FAP following Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA), which necessitated an extra-anatomical bypass.

CASE PRESENTATION

A 25-year-old male with no comorbidities presented to a regional hospital in rural South Africa after being stabbed inferior to his umbilicus. On arrival, the patient was haemodynamically stable, with a single penetrating

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wound to his anterior abdominal wall and peritonitis. Standard Advanced Trauma Life Support (ATLS) protocols were followed, and the patient was taken to theatre for laparotomy. At laparotomy, an AAST grade-2 small-bowel injury was noted 50 cm from the duodeno–jejunal flexure, with a non-expanding central haematoma extending above the coeliac trunk. Intra-operatively, the patient became haemodynamically unstable and required resuscitation with blood products.

The small-bowel injury was stapled off, a size 7-F introducer was placed in the right CFA simultaneously, and a Rescue Balloon-ER® (Tokai Medical Products, Aichi, Japan) was placed over a guidewire into Zone 1 with tactile confirmation of the level of balloon placement, while a senior surgeon was called to assist with the procedure. The aorta and inferior vena cava were exposed using Cattel-Braasch and Mattox manoeuvres. An 8-mm puncture wound was noted on the intrarenal anterior aorta, and digital control was obtained. The REBOA catheter was retracted proximal to the injury using tactile confirmation of positioning, allowing flow into the superior mesenteric artery but not the renal arteries; this was confirmed by a palpable superior mesenteric arterial pulse. Partial REBOA was employed with proximal systolic blood pressure kept above 90 mmHg, while distal diastolic pressures remained above 35 mmHg during the procedure. Total time for REBOA placement was 40 min, during which the aortic injury was primarily repaired. At the end of the procedure, the patient was coagulopathic and an open repair of the right CFA was necessitated after sheath removal.

The patient was transferred to the intensive care unit (ICU) for physiological restoration. At re-look laparotomy 48 h later, a primary anastomosis of the small-bowel injury and definitive closure were performed.

Post-operatively, the patient developed a ventilator-associated pneumonia that resulted in a prolonged ICU stay. He also developed acute kidney injury that required haemodialysis but subsequently recovered. The patient was transferred to the ward 2 weeks after initial laparotomy; 1 week later, he developed signs of sepsis. A computed tomography (CT) scan revealed intra-abdominal collections. A re-look laparotomy was performed and a leak from the site of the small-bowel anastomosis noted, which was managed by performing a Bishop-Koop procedure [5]. The patient was treated with total parenteral nutrition and antibiotics, with subsequent clinical improvement.

At 28 days post-operatively, a pulsatile mass in the right groin was noted over the site of the previous CFA repair, with obvious superficial wound sepsis evident. A CT angiogram confirmed a right CFA pseudoaneurysm of 4.5 cm, with compression of the femoral vein. The patient was taken to the operating room, at which time the aneurysm ruptured freely and required digital control. The patient underwent extra-anatomical bypass from the right external iliac artery to the right superficial femoral artery. Because the saphenous vein was of insufficient calibre, a 6-mm polytetrafluoroethylene (PTFE) graft was used. Peri-operatively, prophylactic antibiotics were administered and extensive washout of the surgical bed with saline and iodine-containing solutions was performed. Post-operatively the patient was placed on intravenous antibiotics for 2 weeks to mitigate graft sepsis. Diligent wound care was also performed on the ward. The patient was anticoagulated with enoxaparin, post-operatively, as per local guidelines. The patient recovered with no evidence of further arterial complications. He was discharged home with negligible output from the Bishop-Koop jejunostomy and was scheduled for elective stoma closure at a later date.

Ethical Approval and Informed Consent

Ethical approval to report these cases was given by University of KwaZulu-Natal Bioethics Research Committee (BCA027/19).

DISCUSSION

REBOA use in trauma patients and others is a well-described technique to assist in managing, and in some cases preventing, potential catastrophic bleeding [6,7]. As indications for the use of REBOA in the management of life-threatening haemorrhage grow and its popularity amongst clinicians increases, more complications can be expected. Complications related to the usage of REBOA can be divided into the various phases of REBOA, as described by Davidson et al. [8] (Table 1).

Limb ischaemia related to sheath placement has been well described, with rates varying between 0% [3] and 3.6% [9]. The initial use of REBOA employed larger sheath sizes (10–14F); however, downscaling to smaller sizes of catheters (7F) has resulted in a decrease of limb ischaemia post-REBOA [2,10,11]. The use of ultrasound-guided puncture has also resulted in a decrease in local complications, as a higher success rate in CFA cannulation is associated with the use of ultrasound [12].

The difference in incidence of FAP between interventional and diagnostic procedures is reported to be related to the size of the sheath used during both procedures, with interventional cannulation requiring larger sizes. Local factors such as sepsis (specifically *Staphylococcus aureus* sepsis) and patient factors (older age, obesity, female gender, renal replacement therapy) [13], as well as technical factors such as multiple punctures, coagulopathy (iatrogenic) and site of puncture below the CFA increase the risk of formation of pseudoaneurysms [14]. Of these factors, local sepsis over the site of the repair is thought to be the biggest contributor to the development of FAP in our patient, although renal replacement therapy, systemic sepsis and the initial coagulopathy may have also contributed to the formation of FAP.

Table 1 Potential complications and challenges associated with each step of REBOA. Reproduced with permission from Davidson AJ, Russo RM, Reva VA, et al. The pitfalls of resuscitative endovascular balloon occlusion of the aorta: risk factors and mitigation strategies. J Trauma Acute Care Surg. 2018;84:192–202 [8].

Step	*Potential Complication*	*Challenges*
Arterial access	Inability to obtain access	Body habitus
	Bleeding	Hypotension
	Improper location of arterial puncture	Hypoxia
	Venous access	Vasospasm
		Variant anatomy
		Calcified lesions
		Inexperience
		Junctional injury
Balloon positioning	Wrong anatomical location	Arterial injury
	Inability to pass catheter	Misalignment of arterial access
		Preexisting vascular pathology
Balloon inflation	Arterial injury/rupture	Requires tactile feedback
	Balloon rupture	Balloon burst pressure
	Unintended ischemia	Balloon misalignment
	Exacerbation of proximal injuries	Undiagnosed proximal injury
Management during balloon occlusion	Balloon migration/prolapse	Duration of occlusion
	Increasing ischemic burden	Active resuscitation
	Supraphysiologic proximal pressures	Increasing proximal pressure
	Thrombosis of access site	Arterial occlusion due to sheath
		Distal ischemia
Balloon deflation	Cardiovascular collapse/hypotension	Ischemia-reperfusion injury
	Clot disruption with ongoing haemorrhage	Coordination of resuscitation
	Hyperkalemia	Rapid/unpredictable return of distal flow
	Acidosis	
Sheath removal and postoperative management	Hematoma or pseudoaneurysm	Access site vascular injury
	Thromboembolism	Vasospasm
	Arterial dissection Limb loss/amputation	Additional procedure(s) required

In patients who underwent cannulation of the CFA for cardiac catherization, 94% of FAP appeared before 7 days post-puncture, with 98.3% presenting with a groin mass [14]. However, patients with large FAP requiring surgery presented only 1–4 weeks after arterial puncture [15], while cases of delayed presentation of FAP have been reported up to 5 months after [16].

Routine screening of all patients with duplex doppler 1 day post-CFA cannulation for diagnostic procedures revealed an incidence of 2.75% [17], which was similar to studies that relied only on clinical symptoms to diagnose patients with FAP [14]. This suggests that no routine radiological surveillance is required following arterial cannulation.

In our facility, we perform regular clinical examinations (twice daily while in ICU) of the groin after REBOA placement, and clinical findings suggestive of FAP are followed up with CT angiography to confirm the presence and extent of the FAP. Treatment options for FAP are based on size and symptoms and time of diagnosis [18]. Pseudoaneurysms smaller than 2–3 cm may close spontaneously or with ultrasound compression [4,18]. Other treatment options are injection of local sclerosing agents, coiling and endovascular stent placement, each based on the individual characteristics of the FAP, technical resources, and skills available [4,19]. Surgery is reserved for patients in centres where the aforementioned modalities are not available and when pressure symptoms are present, distal ischaemia is noted, a "wide" aneurysmal neck is noted on ultrasound, enlargement of the aneurysm exists, infection is present, and other therapies have failed [1,15]. Surgical options for managing FAP are ligation, primary repair, vein patch angioplasty, resection and reverse interposition vein graft, synthetic graft or extra-anatomical bypass in the case of sepsis [15,20,21].

In our centre, we do not have access to endovascular facilities, and thus an open repair was performed for this patient. Emergency repair was necessary because of rupture and profuse bleeding. With local sepsis present, an interposition graft was not deemed feasible and, therefore, we opted for extra-anatomical bypass. Because of insufficient calibre of the saphenous vein, a PFTE graft was placed. This highlights the importance of having surgeons on board who are trained in vascular techniques at those centres with no endovascular facilities, when REBOA is employed.

CONCLUSION

Patients who undergo REBOA often have multiple complex injuries, such as in the case we have described. Although the risk has lessened with the use of smaller sheaths, the expected coagulopathy, renal failure, hospital-acquired sepsis and underlying patient factors place such patients at risk for FAP development. This is the first case that we are aware of that necessitated extra-anatomical bypass for treatment of FAP after REBOA and serves as a reminder that REBOA is not without complication.

Ethics Statement

(1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
(2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article. Ethical approval was obtained from University of KwaZulu-Natal Bioethics Research Committee (BCA027/19).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Case Report

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Embolization of Giant Post-Traumatic Arteriovenous Renal Fistula using the Penumbra Occlusion Device

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A 48 year-old-man with history of abdominal trauma came to the emergency department reporting back pain. The patient underwent abdominal ultrasonography for lumbar pain with detection of voluminous vascular alteration. Immediately, computed tomography angiography (CTA) was performed that demonstrated renal artero-venous fistula with aneurysmatic dilatation. After multidisciplinary discussion, an endovascular treatment was decided upon. Angiography confirmed a high-flow renal AV fistula, and the aneurysmatic dilatation and very tortuous renal artery. The complex anatomic situation was resolved with neuro derivated embolic metallic spirals. Complete exclusion of the fistula and aneurysm was obtained. CTA after the endovascular procedure demonstrated that renal perfusion was completely preserved.

Keywords: *Arteriovenous Malformations; Embolization; Post Traumatic; Renal*

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INTRODUCTION

Renal artery aneurysm (RAA) concomitant with a renal arteriovenous fistula (RAVF) is extremely rare, often an acquired renal vascular abnormality, and usually caused by biopsy, percutaneous nephrostomy, or trauma [1–3]. This pathology is usually complex and difficult to treat using normal techniques. Previously, nephrectomy was an optional treatment for RAA and RAVF [4]. Recently, endovascular treatment has offered a viable alternative with a high technical success rate and low procedure-related morbidity and mortality.

Here, we report the endovascular management of a post-traumatic giant renal aneurysm with high-flow AVF using a new hybrid coil, the Penumbra occlusion device (POD).

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CASE PRESENTATION

A 48-year-old male patient initially presented with a 6-month history of left flank pain. The pain was dull, intermittent, and non-radiating. His history included a bicycle accident from 10 years ago, the trauma from which had been in the left flank. On physical examination, a continuous bruit was audible over the left flank. Ecocolordoppler (ECD) evaluation revealed a large cystic lesion at the left renal superior polar, with increased flow velocity and decreased arterial resistance; mixing of arterial and venous waveform was also observed. A computed tomography angiography (CTA) was performed which revealed contrast opacification of the renal vein during the arterial phase, suggesting RAVF. A RAA was also observed occupying the mid and higher poles of the left kidney and measured 4×3 and 7×3 cm^2, respectively (Figure 1*a–c*).

The main renal artery was the possible feeder artery to the AVF which was seen directly opening into the RAA, suggesting an ultrashort segment of fistulous communication. The main renal vein appeared to be directly communicating with the pseudoaneurysm and was also dilated grossly with aneurismal morphology. The morphology and extension of the vascular lesion was well demonstrated on the angiogram (Figure 2*a–c*).

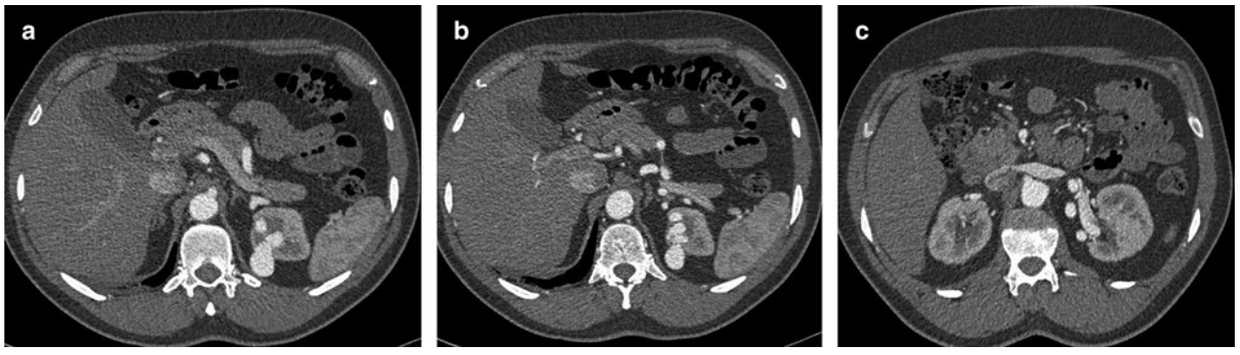

Figure 1 (**a–c**) Computed tomography angiogram **(**CTA) demonstrates renal arteriovenous fistula with aneurysmatic dilatation.

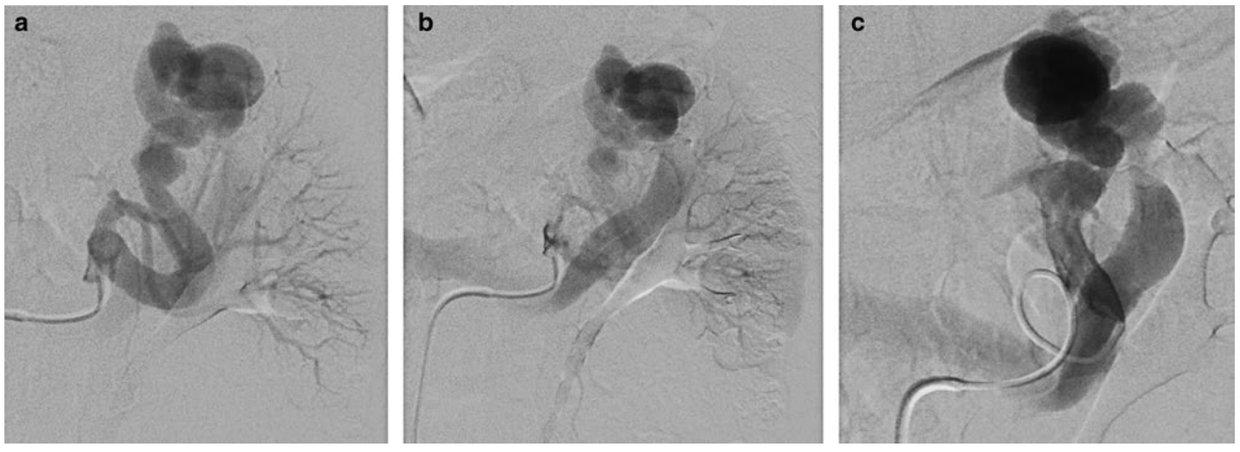

Figure 2 (**a–c**) Angiography confirms a high-flow arteriovenous fistula and the aneurysmatic dilatation.

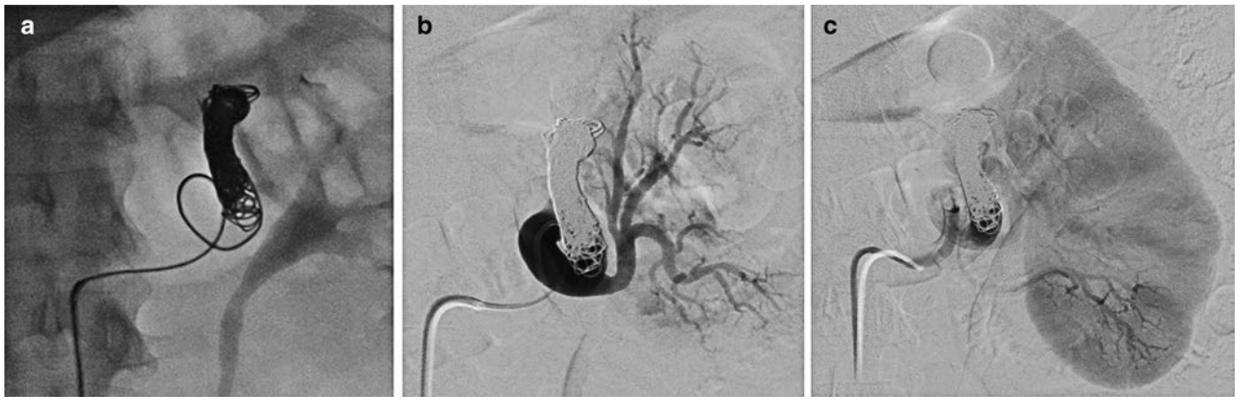

Figure 3 (**a–c**) The embolization technique and final angiography that demonstrates completed fistula and aneurysmatic dilatation occlusion with complete renal perfusion.

The patient was referred to our department for endovascular management. A 4-F introducer sheath (Terumo, Tokyo, Japan) was placed using an ultrasound-guided Seldinger technique through the right common femoral artery, under local anesthesia.

The left renal artery was then catheterized using a 4-F Simmons 1 catheter. Digital subtraction angiography revealed similar findings to the CTA, consistent with giant AVF fed by RA. Subsequently, the 4-F arterial sheath was upsized to a 6-F guiding sheath to gain access into the renal artery ostium. A POD was placed at the junction of the feeding artery and the first part of the AVF through a 0.027-inch microcatheter (Progreat, Terumo, Tokyo, Japan) (Figure 3*a–c*). The position was then confirmed by means of an angiogram, and the device was completely released.

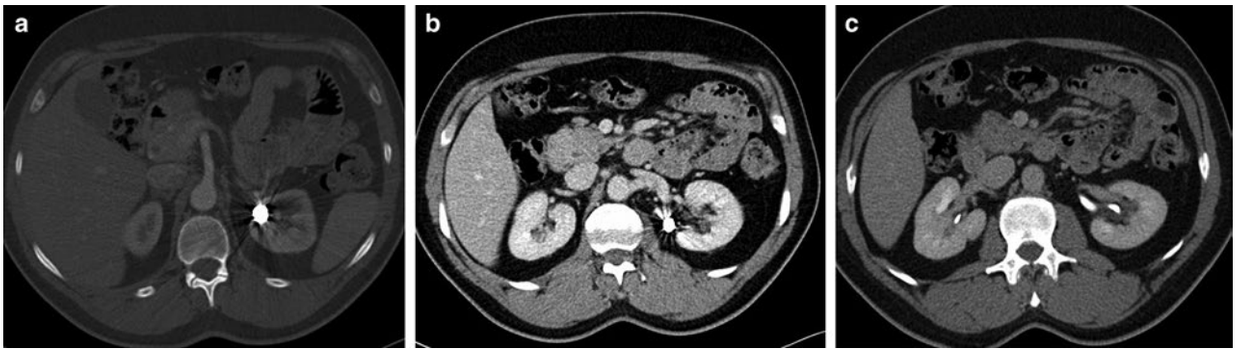

Figure 4 (**a–c**) CTA post-embolization confirms the complete exclusion of AV fistula and aneurysm with complete renal perfusion.

Follow-up CTA (Figure 4*a–c*) showed non-filling of the sac with complete vascular exclusion. A repeat Doppler study after 12 h showed complete non-filling of the AVF. After an unremarkable recovery, the patient was discharged in a stable condition and patient is being followed for 1 year.

Ethical Approval and Informed Consent

Ethical approval was not required. Written informed consent was obtained from the patient on the day of procedure.

DISCUSSION

Renal AVF is generally secondary to those processes that are invasive to the renal parenchyma or renal vascular system (approximately 70%), such as biopsy, percutaneous nephrostomy, and trauma; it might also be congenital. Its proper management has been controversial [1]. Symptomatic patients and those with large AVFs are referred for treatment, the mains aim of which are eradication of the AVF and its consequent symptoms, along with preservation of the renal parenchyma. Indications for treatment are progressive increases in the size of AVF; non-resolving hematuria; and hemodynamic features, especially decompensation, hypertension, and high-output heart failure.

Surgery in the form of arterial feeder ligation and total or partial nephrectomy is considered as the last resort. Coil embolization is now the standard endovascular approach to the management of symptomatic AVF [5,6]. However, transcatheter embolization of large, high-flow AVF always carries a significant risk for migration of embolic material into the pulmonary arteries and the use of the Amplatzer vascular plug is unsuitable for vessels that are too small or too large [7–9]. This risk can be minimized using a POD system. This new hybrid coil (Penumbra Inc, Alameda, California, USA) is designed specifically to achieve occlusion in relatively large arteries. The POD is a 0.020-inch system with a specific anchoring segment (double nitinol coating with a precise loop) to grip the vessel wall. The POD delivery only requires the use of a 0.025-inch microcatheter. After these anchor loops are deployed, the device then transitions to a soft packing segment with a smaller diameter and increased softness to nest tightly and create a dense, cross-sectional plug [10].

The POD has many advantages over other embolic materials. Its position after the release is checked with contrast injection and can be retracted, if required, and repositioned. Its migration risk is less than those of coils. Furthermore, there is no need for a large sheath to put the POD system into the vessels. This case illustrates the feasibility of the use of the POD in the treatment of renal AVF with giant pseudoaneurysm with complete preservation of renal parenchyma.

Ethics Statement

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Case Report

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Management of Persistent Perfusion of an Excluded Popliteal Artery Segment Following Penetrating Vascular Injury

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Exclusion and bypass for penetrating vascular injury remains the gold standard. Persistent hemorrhage via retrograde perfusion of the injured vessel by collateral vessels is rare and may, therefore, be overlooked as a cause of postoperative hemorrhage following bypass for vascular injury. We report a case of a 49-year-old male who presented to our institution 2 weeks following a bypass graft of his popliteal artery after sustaining a gunshot wound to the vessel. His ongoing complaints of pain and pressure in the popliteal fossa were found to be related to persistent collateral perfusion of the injured segment of his proximal popliteal artery. His symptoms resolved completely following coil embolization of the injured native artery. While quite rare in clinical practice, the pathophysiology of this case is analogous to persistent perfusion of the aneurysm sac following open abdominal aortic aneurysm repair or bypass and exclusion of a popliteal artery. In the setting of bypass grafting for vascular trauma, postoperative hemorrhage or compressive symptoms should prompt a complete evaluation for a potentially missed patent collateral vessel.

Keywords: *Peripheral Vascular Trauma; Embolization; Endoleak*

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INTRODUCTION

A standard technique for the management of penetrating vascular injury with arterial disruption is exclusion and bypass. While little has been reported in the literature regarding persistent retrograde perfusion of the injured segment via collateral vessels, this entity is recognized in the pathophysiology of endovascular leaks (endoleaks) following endovascular aneurysm repair (EVAR), branch vessel bleeding into the aneurysm sac following open repair of abdominal aortic aneurysms, and persistent pressurization of the aneurysm sac following treatment of popliteal artery aneurysms (PAA). We present a case of lower extremity compressive symptoms following exclusion and bypass of an injured popliteal artery that resolved immediately and completely following coil embolization of the feeding vessel and residual excluded segment.

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CASE REPORT

Following a gunshot wound to the right distal thigh above the knee, a 49-year-old male presented to the regional trauma center complaining of pain, paresthesia, and motor weakness of the leg. His right femoral pulse was palpable, but there were no palpable pulses or audible Doppler signals in the popliteal or pedal arteries. A computed tomography (CT) scan demonstrated acute occlusion of the proximal popliteal artery with distal reconstitution of the tibial arteries via geniculate

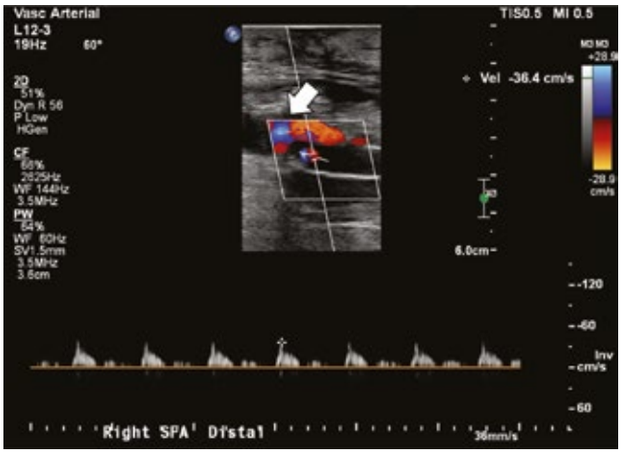

Figure 1 Demonstration of pulsatile flow in the most proximal portion of the excluded popliteal artery (labeled as "Right SFA Distal"). The proximal graft anastomosis is represented by the white arrow.

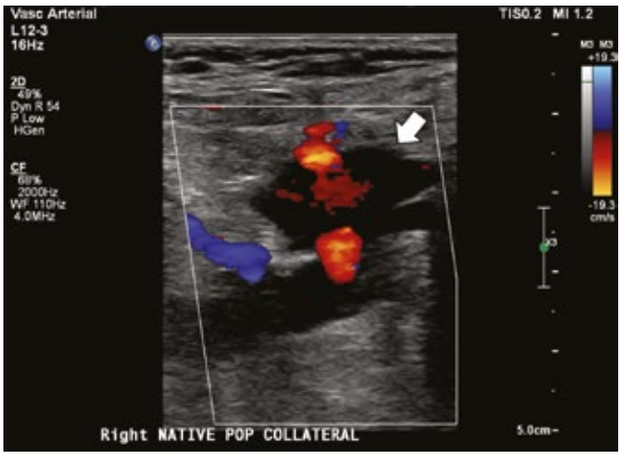

Figure 2 Flow through collaterals is visualized entering into the native popliteal artery as well as an extraluminal fluid collection (arrow).

collaterals. No active contrast extravasation was seen on the CT scan. The patient underwent above-to-below knee popliteal artery bypass grafting using reversed great saphenous vein from the contralateral leg and native artery ligation. A completion arteriogram was performed from the proximal superficial femoral artery, demonstrating a widely patent bypass graft with three-vessel runoff. The pedal pulses were palpable at the end of the procedure. However, the case was complicated by postoperative hemorrhage, requiring two additional explorations, although the source was never identified. The patient was discharged from hospital several days later, still complaining of pain and fullness in the popliteal fossa.

He presented to our military medical center 18 days following the injury with the ongoing complaint of right

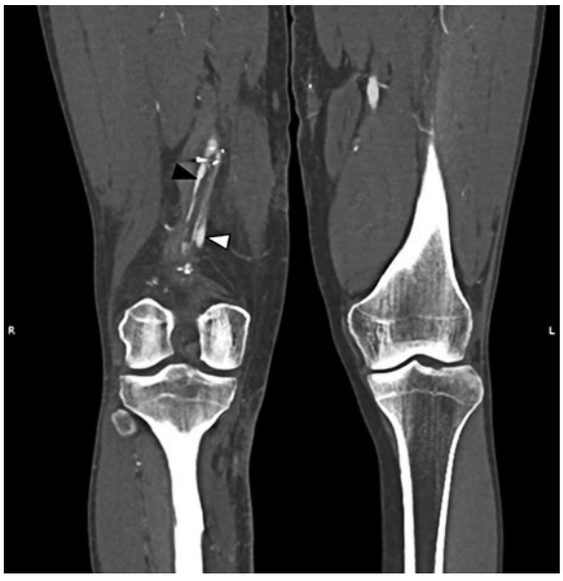

Figure 3 Coronal view of the injured superficial femoral and popliteal artery. Intraluminal thrombus is clearly visualized beyond the proximal vascular clip in the native, "excluded" artery with surrounding contrast (dark arrowhead). The bypass graft is seen only partially as it is mostly out of plane in this view (white arrowhead).

leg pain localized to the region of injury. He reported persistent swelling in the popliteal fossa and pain with ambulation, and stated that he was unable to perform his activities of daily living due to the pain and sense of instability. His physical examination was notable for easily palpable pedal pulses, and his foot was warm and well perfused with normal motor and sensory function. His incisions were well-approximated without evidence of infection. A duplex study, however, demonstrated multiphasic flow within the injured popliteal artery segment, which was perfused by collaterals (Figures 1 and 2). A CT angiogram confirmed these findings; the proximal portion of the surgically excluded popliteal artery was found to be filling on arterial phase contrast imaging (Figures 3 and 4). The underlying pathophysiology seemed to be a popliteal fossa hematoma originating from the injured popliteal artery and under near-systemic arterial pressure via collaterals.

Based on the imaging findings, the patient underwent a right lower extremity arteriogram via left common femoral access. The arteriogram demonstrated a widely patent graft with three-vessel runoff (Figure 5). The excluded segment of the popliteal artery was visualized filling via distal profunda femoris arterial collaterals (Figures 6–8). The profunda femoris artery was selected and a mildly hypertrophied distal branch was subselected. Digital subtraction angiography (DSA) imaging verified this branch filling the excluded segment. Smaller collateral branches extending from the excluded segment were identified supplying soft tissue in the immediate

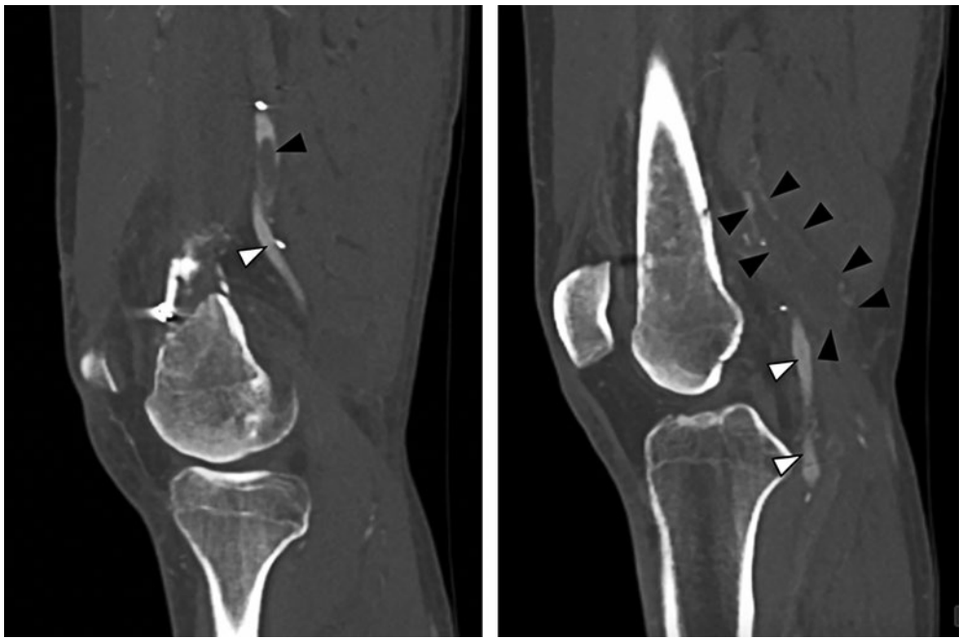

Figure 4 Sagittal view of the native artery with contiguous hematoma in the distal thigh and proximal popliteal fossa (dark arrowheads). The arterial contrast can be seen along the edges of the hematoma. The bypass graft is shown by the white arrowheads.

vicinity. A Progreat microcatheter was manipulated into the excluded arterial segment and approximately 3–5 ml of dilute 700–900 micron microspheres (Embosphere; Biosphere Medical, Rockland, MA) were injected to decrease the risk of retrograde flow into the excluded segment. These microspheres lodge in the arterial outflow branches above the capillary bed level, thereby limiting the potential for ischemic injury and necrosis of the soft tissues. Immediate post-embolization DSA imaging demonstrated markedly decreased flow through the segment and into the surrounding tissue. Next, multiple Azur CX (Terumo, Somerset, NJ) and VortX (Boston Scientific, Marlborough, MA) metallic coils were deployed (Figures 9 and 10) into the excluded segment and post-embolization DSA imaging demonstrated no filling of this excluded segment. The patient noted immediate relief of his symptoms at the conclusion of the procedure. He has been seen multiple times in followup with no recurrence of his symptoms. His bypass graft remains widely patent.

Ethical Approval and Informed Consent

Ethical approval was not required. The information has been anonymized and informed consent was not required.

DISCUSSION

In the setting of hemorrhage or compressive symptoms following bypass for vascular trauma, strong consideration must be given to the possibility of an unrecognized patent collateral. The complication of persistent retrograde perfusion of an injured arterial segment following exclusion and bypass for trauma has not been well-reported in the literature. It is, however, physiologically similar to three relatively well-recognized phenomena: post-EVAR type II endoleak, aneurysmal sac hemorrhage following open abdominal aortic aneurysm repair, and persistent geniculate artery perfusion of a PAA following exclusion and bypass.

Blood flow entering an excluded segment of native artery by retrograde flow through a branch vessel (e.g., a type-II endoleak following an EVAR procedure) demonstrates both pulsatility and magnitude similar to systemic blood pressure. In 17 patients undergoing treatment for persistent type-II endoleaks following EVAR, Baum et al. observed pulsatile waveforms in the excluded aneurysm sac within 20% of systemic pressure in all patients [1]. Following 1218 open abdominal aortic aneurysm repairs, Darling reported 48 cases (4%) of persistent flow into the aneurysm sac seen on duplex imaging; in 7 of these cases (0.5%), this led to aneurysm sac rupture [2]. Hartung et al. reported a case of persistent retroperitoneal hemorrhage following EVAR repair for a ruptured abdominal aortic aneurysm that resulted in persistent back pain, hypotension, and hemodynamic instability and, subsequently, required coil embolization, leading to a successful outcome [3]. In another case, Sharma et al. presented a case of persistent lumbar branch vessel bleeding 5 months following open repair of a

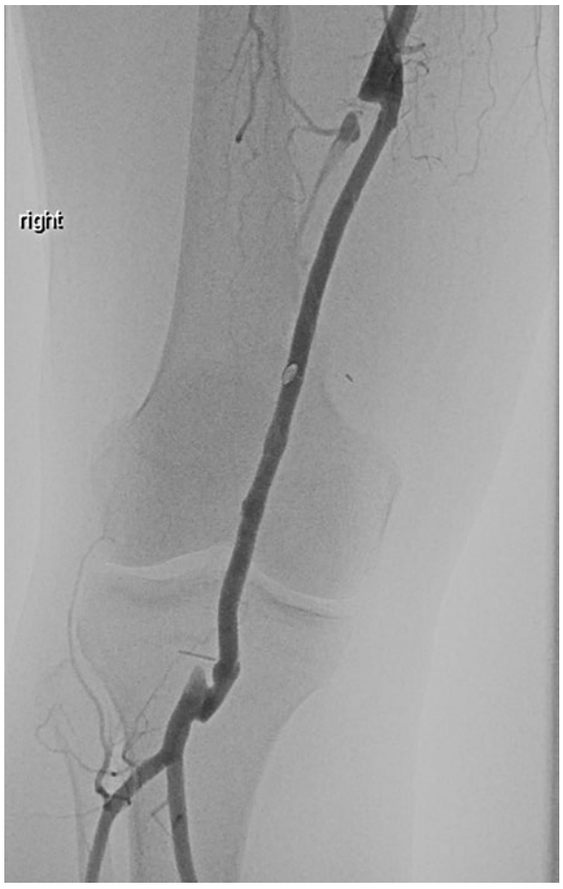

Figure 5 Nonselective right lower extremity angiogram demonstrating persistent filling of the proximal excluded segment of the superficial femoral artery via profunda femoris collaterals.

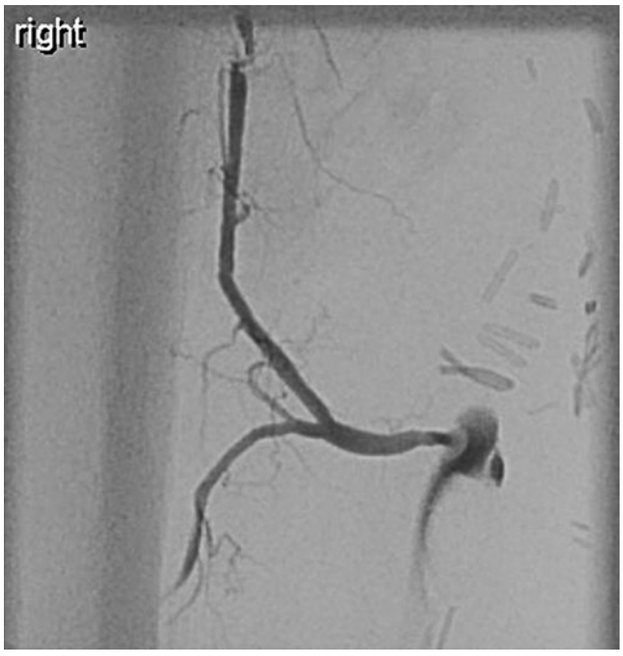

Figure 6 Selective angiogram demonstrating antegrade filling of the injured superficial femoral artery. Note the proximal vascular clip placed at the time of the bypass graft.

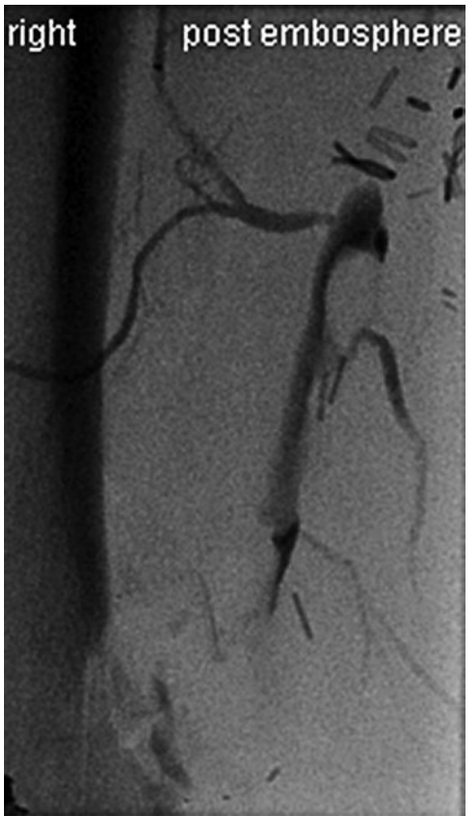

Figure 7 Following the injection of embolospheres, a repeat arteriogram was performed, which demonstrated persistent flow into the native excluded artery with outflow via multiple collaterals as well as contrast extravasation.

ruptured aneurysm with associated sac expansion that was successfully treated with Onyx embolization [4].

The other situation analogous to this case is persistent geniculate artery blood flow perfusing a PAA sac following exclusion and bypass. Flynn et al. reported two cases of continued aneurysm expansion with compressive symptoms following exclusion and bypass of PAA due to geniculate side-branch perfusion [5]. In a study of 26 PAAs treated via exclusion and bypass technique with at least 24 months of followup data, there was a 38% incidence of retrograde flow into the aneurysm sac via geniculate collaterals; 23% of aneurysms increased in size, and 12% ruptured [6]. In all cases that underwent posterior sac decompression following a previous exclusion and bypass, the sac demonstrated pulsatile waveforms at nearly systemic pressures. Battey et al. presented a case of a ruptured previously bypassed PAA, demonstrating that the pressures transmitted via geniculate collaterals were sufficient to lead to this outcome. Rupture of a PAA is rare, occurring in only 2–3% of cases. Rupture of excluded aneurysms is much less common, making this entire pathologic entity extremely rare

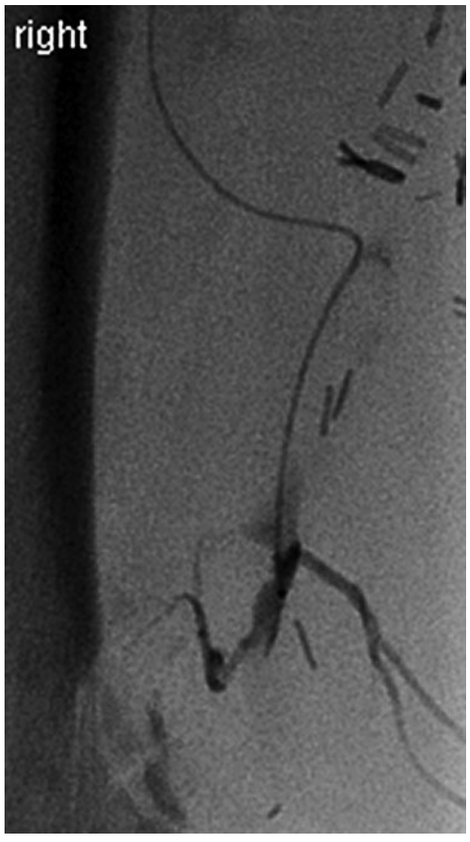

Figure 8 Subselective catheterization of the injured native artery.

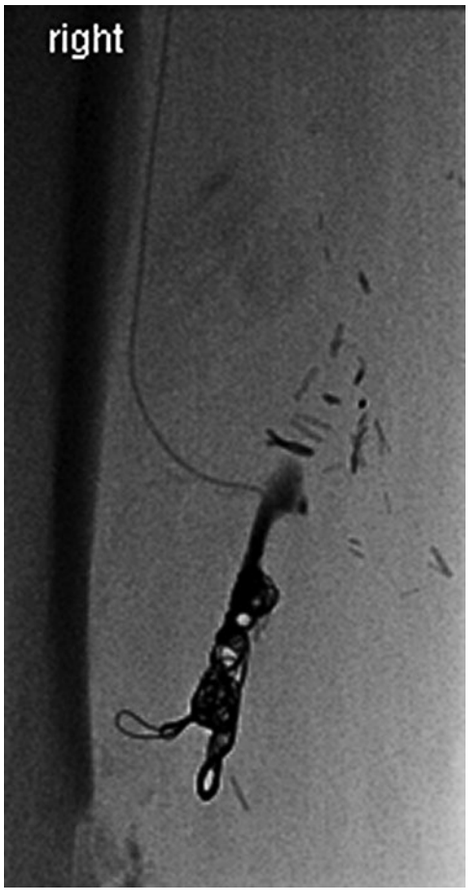

Figure 9 Multiple thrombogenic coils were placed in the excluded segment of the artery.

in clinical practice [7]. Bypass and exclusion of the PAA remains the gold standard operation, given decreased complexity vis a vis the posterior approach. Awareness of the potential for retrograde perfusion via geniculate collaterals and early intervention should symptoms develop seems an appropriate tradeoff for the reduced risk of surgical complications [5]. Szilagyi et al. specifically warned about the risk of leaving geniculate collateral vessels unligated. "It must be emphasized, however, that the ligation of the aneurysm must be carefully carried out and no potential collateral arterial branches must be left between the aneurysm and the ligature if a recurrence of the aneurysm is to be prevented [8]."

These same principles would arguably hold in the case of penetrating arterial trauma. While we were unable to find other reports in the literature describing persistent retrograde arterial perfusion from branch vessels into an injured and excluded arterial segment, the situation is directly analogous to type-II endoleak following EVAR, hemorrhage into the aneurysm sac of an open abdominal aortic aneurysm repair, and persistent geniculate collateral flow into an excluded PAA sac with expansion. While all of these entities are uncommon, they are well documented in the literature. Once the pattern is recognized, the solution is straight forward—occlusion of flow via the branch vessel into the excluded arterial segment. While endovascular approaches to the culprit vessel are ideal in settings in which this capability is available, in austere or low-resource environments, open exploration might be necessary. Just as open-sac exploration is the proper solution for persistent type-II endoleaks following EVAR, if catheter-based techniques are either not available or have proven unsuccessful [9, 10], then open exploration is the proper course in these resource-constrained environments.

CONCLUSIONS

Analogous to symptomatic type-II endoleak following EVAR, persistent aneurysm sac bleeding following open abdominal aortic aneurysm repair, and geniculate flow leading to a pressurized excluded PAA sac, the pain and compressive symptoms following exclusion and bypass of an injured native artery should prompt

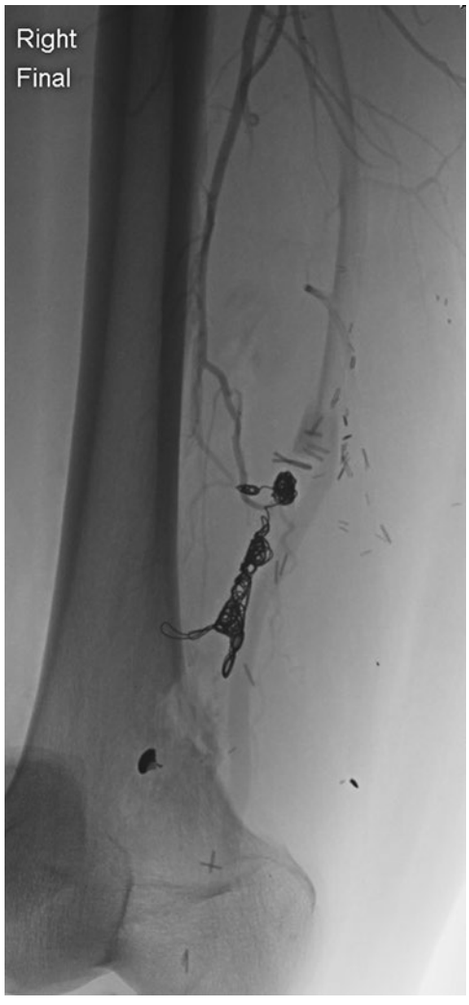

Figure 10 Completion arteriogram which demonstrates complete thrombosis of the native injured segment of the superficial femoral artery with preserved flow through the bypass graft.

an evaluation for a missed patent branch vessel. In addition, duplex ultrasound followup for exclusion and bypass of injured peripheral arteries as well as popliteal aneurysms should include an evaluation of the injured segment to rule out persistent flow into the native segment, a pseudoaneurysm, or a contained hematoma. This is generally overlooked on routine postoperative surveillance studies.

Ethics Statement

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

Conflict of Interest

The authors declare that there are no conflicts of interest to disclose.

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Case Report

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Management of Subintimal Position of Kissing Stents using Re-entry Catheter with Cone Beam-Computed Tomography Image Overlaid onto Live Fluoroscopy

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Background: Several endovascular or surgical treatments have been proposed to treat total chronic occlusions of the iliac bifurcation. Nowadays, endovascular options are considered as a first choice because of the decreased perioperative morbidity–mortality. Nevertheless, unexpected intraoperative events may occur, such as dissection or rupture of the iliac artery. We report a case of inadvertent bilateral false-lumen kissing-stent positioning, rescued with stent extensions maneuvered using image fusion guidance.

Case presentation: A 60-year-old male patient was referred to our department because of a severe bilateral claudication, 8 months after placement of an iliac kissing stent for common iliac artery occlusion. A computed tomography angiography (CTA) was performed, showing a bilateral dissection of the aorto-iliac bifurcation at the proximal part of the stents, which were placed into the false lumen; the distal part was placed into the true lumens (TL). Lower-limb perfusion was maintained by inferior mesenteric and hypogastric arteries. Because a CTA performed before the first endovascular intervention showed no dissection of the aortic bifurcation, the flaps were probably created during previous interventions. An endovascular revision was planned. After bilateral femoral access, the proximal part of the flap was pierced with a needle-based re-entry device, deployed under three-dimensional cone-beam CT image overlay with bi-planar fluoroscopy. The lumen patency was then restored with stent extensions up to the renal ostia. The final angiography showed stent patency. No complication occurred during the intervention. The patient was dismissed the following day, with good arterial femoral pulse and no further complications. An ultrasound color Doppler performed 1 month after the intervention showed satisfactory blood flow of both iliac and femoral arteries as well as a good flow in the lower limbs.

Conclusions: The integration of modern 3D image guidance and novel endovascular devices allows for the management of adverse events using a minimally invasive approach.

Keywords: *Re-entry Catheter; Subintimal Recanalization; Kissing Stent; CBCT; Fusion Imaging*

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INTRODUCTION

Atherosclerotic occlusion of the aorto-iliac bifurcation is a common cause of claudication and/or critical limb ischemia, with a prevalence ranging between 3 and 10% [1]. Different treatment options exist to restore blood flow to the lower limb (i.e. surgical or endovascular), but unexpected intraoperative events may occur, such as dissection or rupture of the iliac artery [1,2]. Herein, we

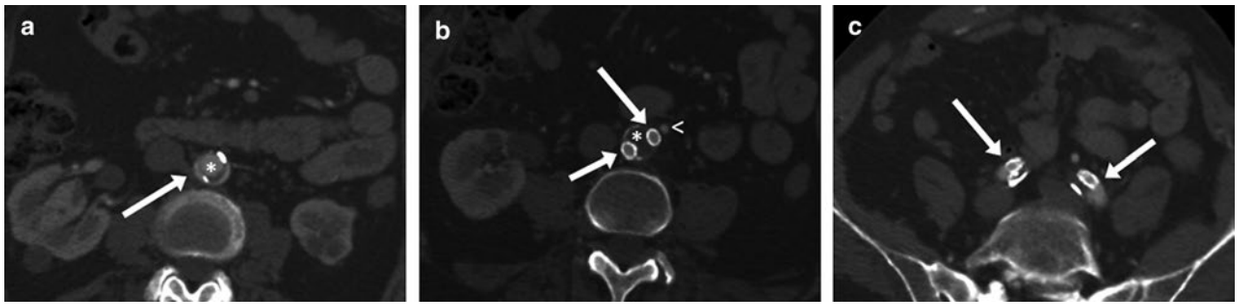

Figure 1 (**a**) Axial view of the aortic dissection over the proximal part of the iliac stents, with both the true lumen (asterisk) and the false lumen (arrow) still patent. (**b**) Dissection of the distal part of the aorta, showing thrombosis of the true lumen (asterisk) and patency of the two iliac stents (arrows). Axial view of a hypertrophic inferior mesenteric artery is shown (arrowhead). (**c**) Distal part of the iliac stents, showing patency of the lumen and the native iliac arteries (arrows).

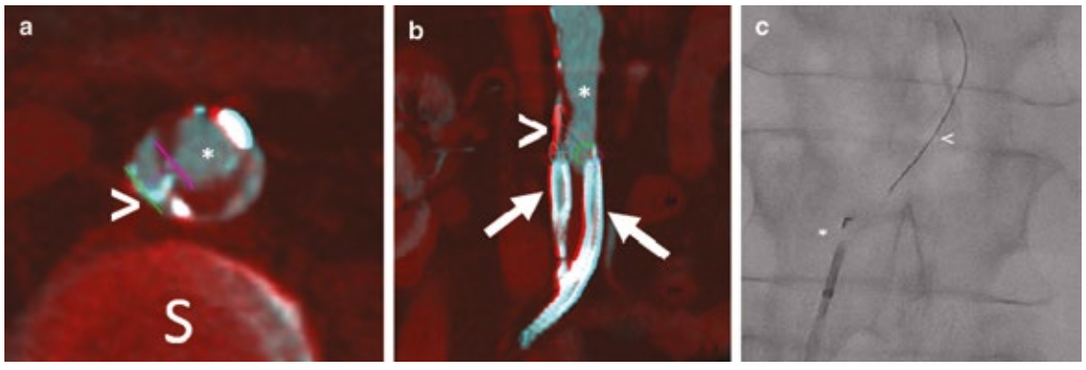

Figure 2 Axial (**a**) and coronal (**b**) cone beam computed tomography (CBCT) merged with pre-operative computed tomography angiography (CTA) showing the stents (arrows) in the false lumen, a virtual needle trajectory drawn between the true (asterisk) and false lumen (purple, green and light blue circles). The tip of a 0.014″ guidewire is stuck at the top of the false lumen (arrowhead). (**c**) Outback re-entry catheter with the distal part in the false lumen (asterisk) and the opened sharp tip piercing the intimal flap. The tip of the guidewire (arrowhead) is passed through the flap into the true lumen.

report a case of an inadvertent bilateral false-lumen kissing-stent positioning into the aorto-iliac bifurcation, rescued with stent extensions maneuvered using image fusion guidance.

Ethical Approval and Informed Consent

Ethical approval is not required for retrospective works, at our Institution. Written informed consent was obtained from the patient.

CASE REPORT

A 60-year-old male patient was referred to our institution at the beginning of April 2019 because of a severe claudication of both legs, occurring after 50 m of walking. Because he had been treated with an iliac kissing stent for common iliac artery occlusion 8 months prior, an in-stent restenosis was suspected.

Computed tomography angiography (CTA) of the abdominal aorta and lower limbs was performed, showing dissection of the aorto-iliac bifurcation at the proximal portions of the stents that were placed into the false lumen; in contrast, the distal portions of both stents were shown situated in the true lumens (TL). Despite focal obliteration of the TL, lower-limb perfusion was maintained via inferior mesenteric and hypogastric arteries (Figure 1). Because CTA performed before the first endovascular intervention showed no dissection of the aortic bifurcation, we hypothesized that the flaps were created during the previous intervention and the stents were inadvertently deployed into the false lumen. Thus, an endovascular revision was proposed.

Endovascular Management

The intervention was carried out in an interventional radiology suite equipped with a biplanar flat panel, a cone beam CT (CBCT) (Azurion 7 B20/15, Philips Healthcare, Best, The Netherlands) and XperCT 3D reconstruction software (Philips Healthcare).

A 6-Fr, 13-cm-long sheath was introduced into the femoral common artery, on both sides. Then, 4-Fr catheters (Bernstein, Cordis, Milpitas, CA) were directed

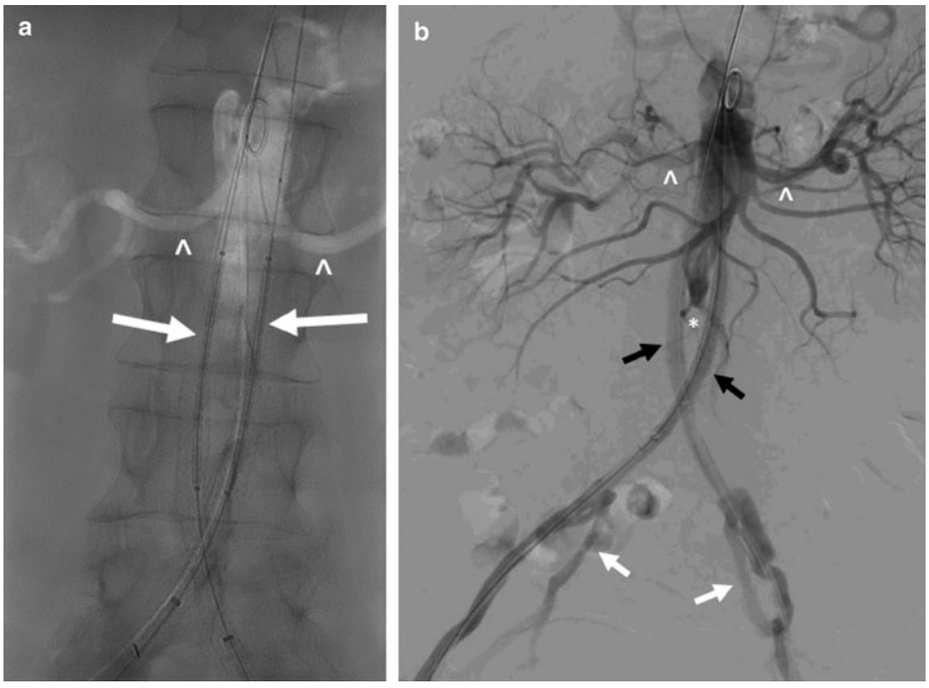

Figure 3 (**a**) Once the guidewires were placed into the true lumen on both sides, two balloon-expandable covered stents (arrows) were deployed in the abdominal aorta, with the proximal part just below the renal arteries (arrowheads) and the distal part overlapping the stents previously deployed. (**b**) Final angiography showing restored aorto-iliac flow through the stents (black arrows), with thrombosis of the dissected distal aorta (asterisk), patent renal (arrowheads) and hypogastric (white arrows) arteries.

into the top of the iliac stents. A CBCT was performed to merge images with those of the pre-treatment CTA, as described elsewhere [3].

After review of the multiplanar overlaid images, ideal virtual re-entry needle trajectories were marked on the workstation. C-arm inclinations corresponding to entry point and needle progression views were defined for each trajectory; virtual needle trajectories were merged onto fluoroscopy images to create 3D images providing guidance for the re-entry devices (Figure 2).

A re-entry catheter (Outback Elite Re-Entry Catheter, Cordis, Miami, FL) was passed through the iliac stents, and the tip of the device was deployed according to the trajectory provided by the 3D images (Figure 2) and followed by means of bi-planar fluoroscopy in order to keep control of the re-entry point and the needle progression, simultaneously.

The flap was perforated on the first attempt, on both sides, and a steel guidewire (0.014″ Spartacore, Abbott Vascular, Abbott Park, IL) was placed in the TL of the aorta. Two glide catheters were inserted, and a control angiography was performed to confirm the position into the TL.

Subsequently, two 7-Fr, 55-cm-long sheaths (Cook Medical, Bloomington, Ind) were inserted and two 7-mm-wide, 59-mm-long Advanta V12 balloon expandable covered stents (Atrium Europe B.V, Mijdrecht, The Netherlands) were deployed, with 1 cm overlapping the previous stents and the remaining part inserted in the TL of the aorta, thus restoring direct connection between the aorta and iliac arteries (Figure 3). A final angiography showed stent patency and no complications occurred during the intervention (Figure 3).

At the end of the procedure, the femoral accesses were closed using 8-Fr Angioseals (Terumo, Tokyo, Japan). The patient was dismissed the following day, with a good arterial femoral pulse and no further complications. An ultrasound colour Doppler performed 1 month after the intervention showed satisfactory blood flow of both iliac and femoral arteries as well as a good flow in the lower limbs.

CONCLUSION

We have reported the endovascular management of a complication that occurred during stenting of the aorto-iliac bifurcation. Dissection, especially when bilateral, can cause distal embolization, worsening claudication or loss of hypogastric vascularization, with subsequent gluteal necrosis, ischemic colitis, impotence and spinal ischemia [4]. Typically, the operator should suspect an intraprocedural iliac dissection when the pressure gradient between the pre- and post-stenotic tract is lost. During the operation, the suspicion can be confirmed in several ways, although the most reliable seems to be an evaluation

of either the artery wall using intravascular ultrasound or the vascular network using an injected CBCT, allowing to check for both the position of the catheter and the patency of the artery [5].

Days after the procedure, the patient should undergo a duplex ultrasound to explore the flow restoration. In the case of neither flow restoration nor clinical improvement, a CTA should be performed to search for the reasons behind the procedure's inefficacy.

In the presented case, dissection was limited to the common iliac arteries and did not cause an acute lower-limb ischemia as the patient suffered from chronic claudication due to bilateral iliac artery occlusion and he already had a hypertrophic collateral vascular supply to the pelvis and lower limbs.

Nowadays, the kissing-stent technique is the first-line treatment for proximal common iliac artery stenosis, because of its lower complication rate relative to open surgery [1]. Nevertheless, iliac manipulation remains challenging, because complications, although rare, can lead to major consequences [4]. Different rescue options have been discussed, and an endovascular approach has been decided as first choice, in order to keep surgery as a second option, in case of failure. Thus, the intervention was carried out using a combination of tools and techniques, well known but never used together so far.

Aortic fenestration was described in 1990 for the first time [6] and, since then, many techniques have been proposed for this purpose. The re-entry catheter with a needle tip facilitates passage through the endothelial flap and allows direct cannulation of TL [7]. The maximal extension of the tip is 10 mm, which was enough in this case as the TL was narrowed and compressed between two flaps on both sides.

As shown, the possibility to acquire 3D images in the angiography suite and to overlay them with pictures from fluoroscopy, allows safe and precise planification of challenging interventions that, otherwise, would require multiple controls and long X-ray exposure [8].

In this case, the availability of a biplanar machine may have reduced the intervention time, allowing simultaneous control of entry point and progression trajectory, unfeasible with a single panel.

In conclusion, the opportunity to integrate modern 3D image guidance and the high-performing endovascular devices allowed safe and rapid management of adverse events using a minimally invasive approach.

Ethics Statement

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

Conflicts of Interest

The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

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Author Contributions

HK, HD, PD, and VT conceived the presented case. LCP wrote the manuscript. VT and HK supervised the project. All authors discussed the results and contributed to the final manuscript.

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Residents Corner

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Embolization of Type 1 Endoleak Due to Migration of Nellix Endograft System: Clinical Photos of Interest

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Keywords: *Nellix; Embolization; Endoleak; Rupture*

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An 85-year-old male patient, 3 years after Nellix endograft implantation due to abdominal aortic aneurysm, presented to the clinic for annual follow-up with a huge endoleak secondary to aneurysm expansion and Nellix endograft migration. In order to prevent a rupture of the aortic aneurysm, and as the patient was not a candidate for open surgery, the endoleak was sealed with Ruby Coils (Penumbra, Alameda, USA) and Onyx (Medtronic, Santa Rosa, CA). Figure 1 shows the endoleak on computed tomography (CT; arrows mark the endoleaks). Figure 2*a–c* shows the angiography procedure with Ruby Coils and Onyx filling the endoleak space. Figure 3*a*,*b* shows the post-operative CT. The endoleak diminished on post-operative CT and was not detected by contrast enhanced ultrasound and the patient is planned for follow-up. Tight follow-up is recommended as this is a rescue procedure that we have used in several patients but long-time follow-up is unknown. This method has been used in symptomatic and ruptured aortic aneurysms with different endograft configurations.

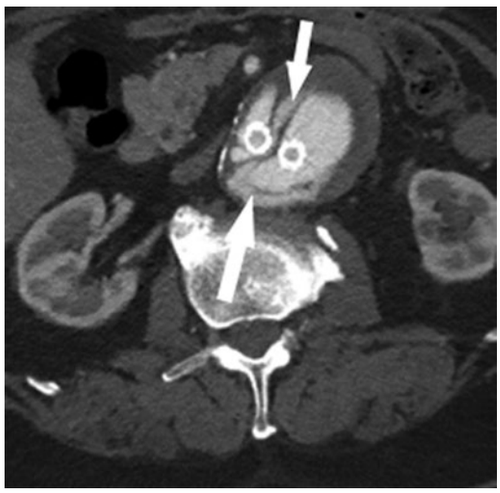

Figure 1

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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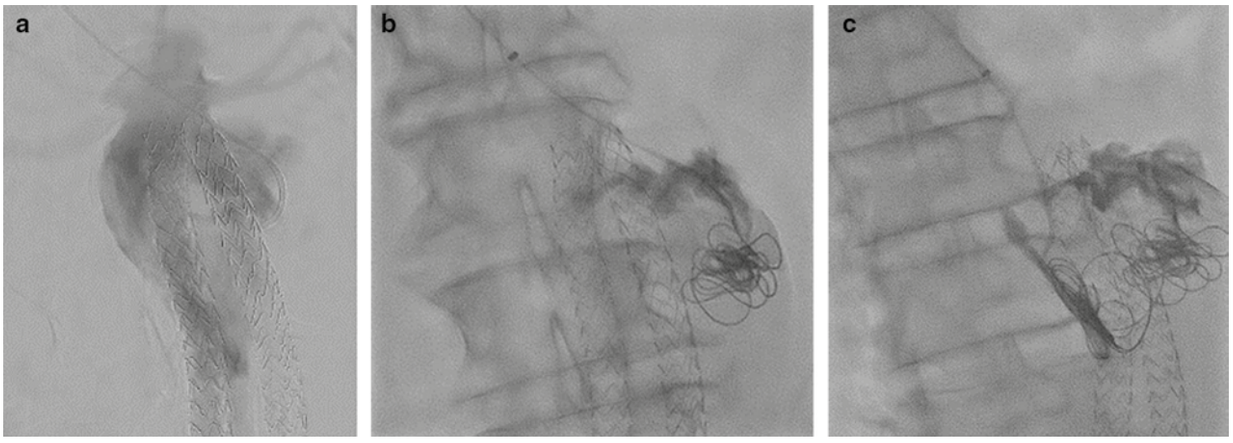

Figure 2

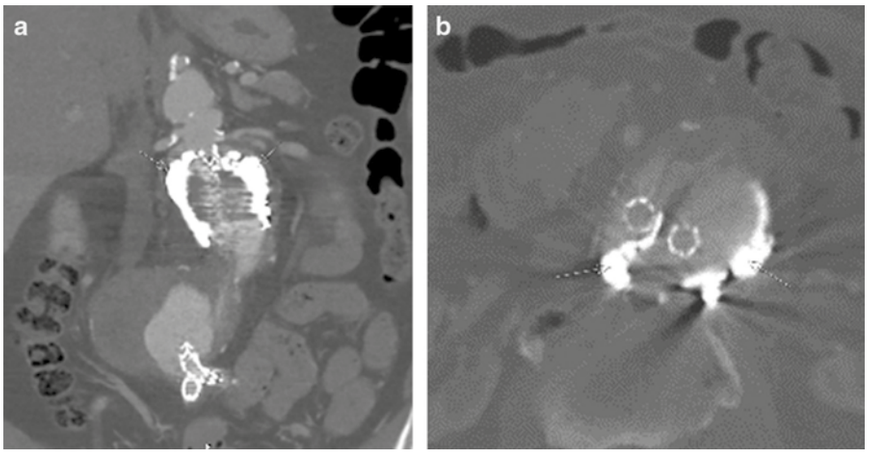

Figure 3

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Author Contributions

TMH and DTM drafted, wrote and revised the manuscript.

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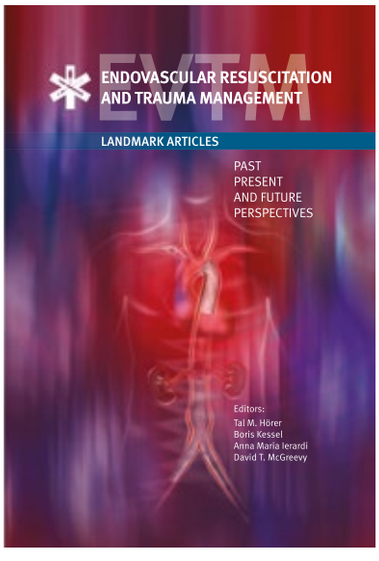

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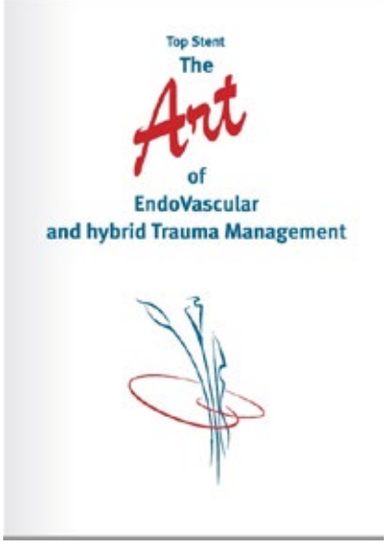

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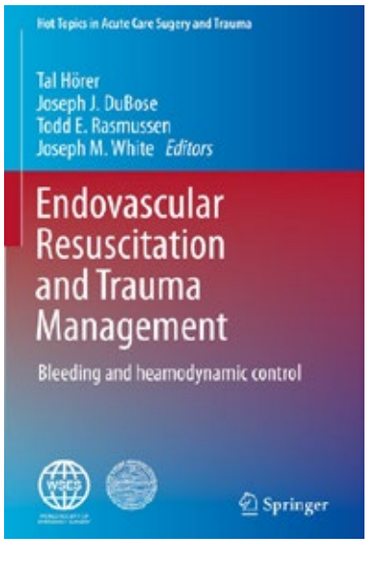

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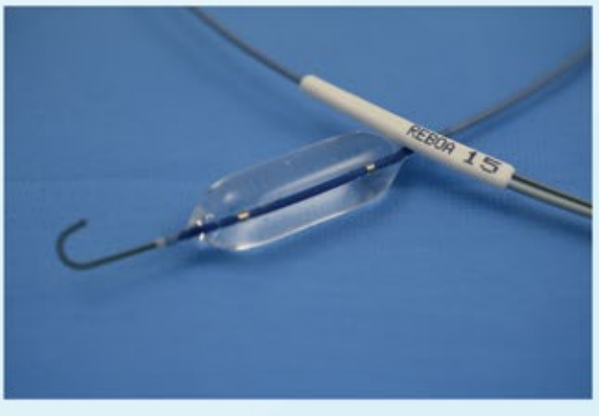

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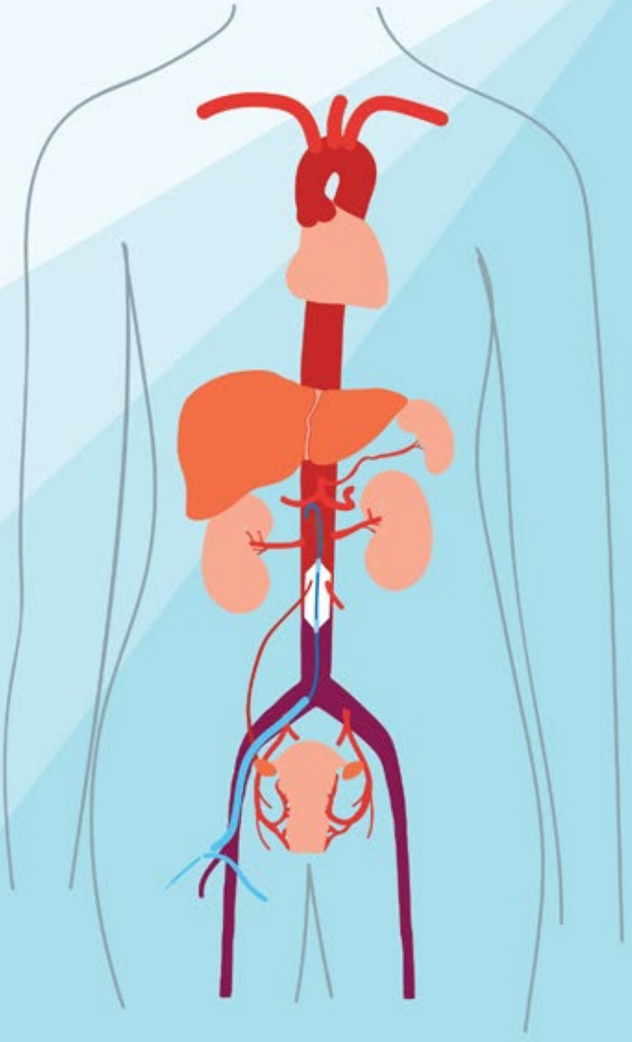

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