Journal of ENDOVASCULAR RESUSCITATION and Trauma Management

JEVTM

Volume 8, Issue 3, Winter 2024, ISSN: 2002-7567

Issue Highlights

Long-term outcomes of stent graft implantation to treat traumatic AVF

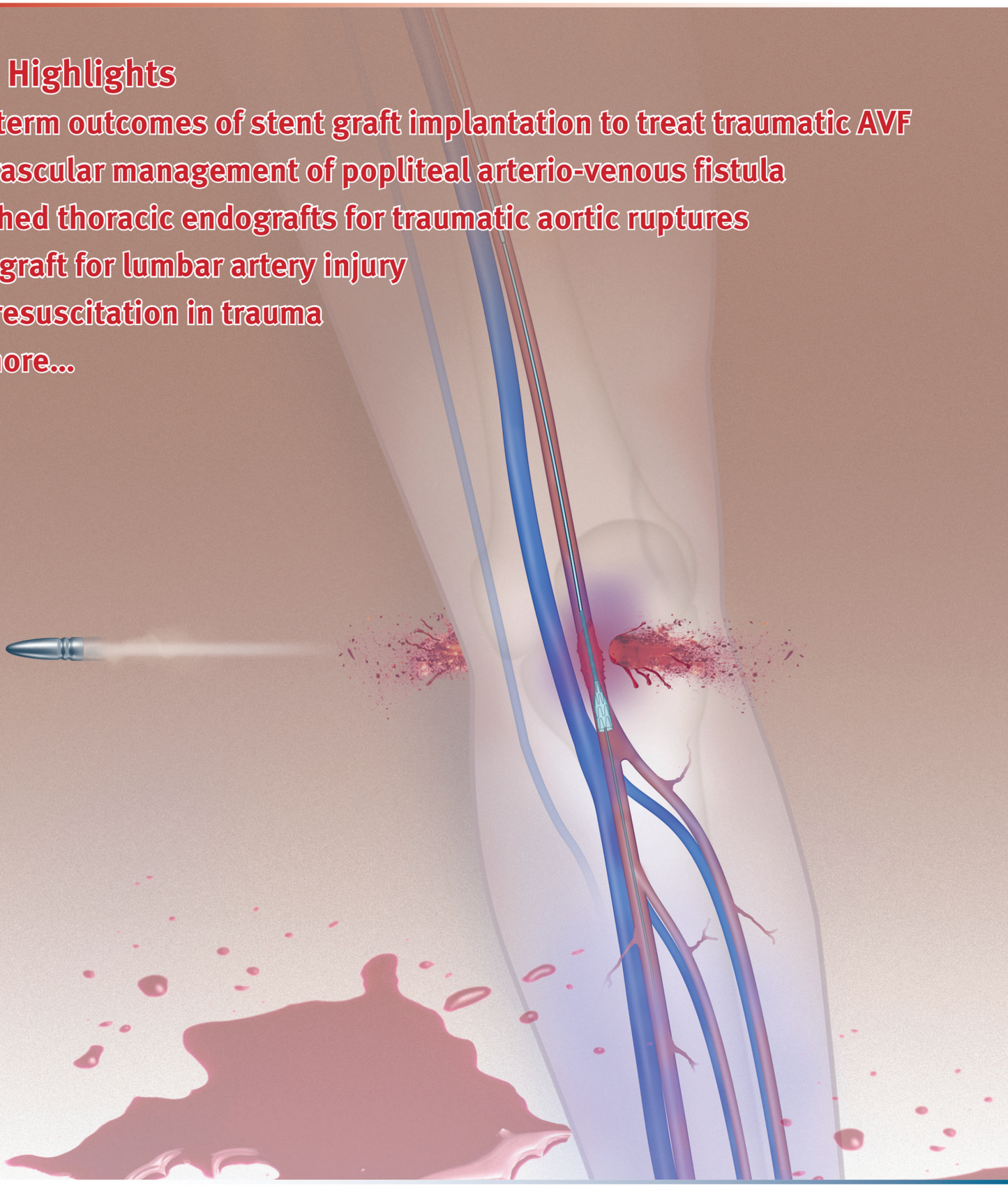
Endovascular management of popliteal arterio-venous fistula

Branched thoracic endografts for traumatic aortic ruptures

Stent graft for lumbar artery injury

Fluid resuscitation in trauma

And more...



Official publication of the Society of Endovascular Resuscitation and Trauma Management

WWW. JEVTM.COM

Journal of Endovascular Resuscitation and Trauma Management

Volume 8
Issue 3
Winter 2024

ISSN: 2002-7567
https://publicera.kb.se/jevtm

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 the Department of Cardiothoracic and Vascular Surgery, Örebro University Hospital, Sweden.

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 *https://publicera.kb.se/jevtm*.

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 3 times a year with additional special issues on specific topics, 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 https://publicera.kb.se/jevtm under journals and are there with no time or access limitations.

The Journal is an EBSCO and CrossRef Member and indexed in SCOPUS, Web Of Science, Clarivate, Sherpa Romeo, Google Scholar, EMBASE, and other indexing services. We are registered with DOAJ (Directory of Open Access Journals) and use Turnitin services.

Official publication of the Society of Endovascular Resuscitation and Trauma Management (EVTM)
In cooperation with Örebro University Hospital and Örebro University, Sweden.

Region Örebro County
Örebro University Hospital

Address:
EVTM Program
Tal Hörer
Dept of Cardiothoracic and Vascular Surgery
Örebro University Hospital and Örebro University
Södra Grev Rosengatan
701 85 Örebro
Sweden

Contact
tal.horer@regionorebrolan.se
jevtm@regionorebrolan.se

The EVTM Office
Mrs Åsa Strandberg
Email: asa.strandberg@regionorebrolan.se

National Library of Sweden

Hosted on the open journal digital platform provided by the National Library of Sweden (Kungliga biblioteket).

Author Guidelines

GUIDELINES FOR SUBMISSION

A manuscript submitted to the Journal must constitute a unique piece of work that is not previously published or under consideration for publication, in part or whole, elsewhere.

Submissions should preferably be produced using Microsoft Word, although other formats will be considered. Submissions should be anonymized.

The submission process requires three discreet documents:

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

Please ensure that the names and contact details of **all** authors are entered on the online submission system.

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. More information about the Journal's publication ethics can be found on the journal webpage https://publicera.kb.se/jevtm/policies.
6. A clear statement that the authors follow the ethical guidelines as stated on the Journal webpage.

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.
- Affiliations: The institution(s) that the authors are affiliated with should be listed. Ensure that sufficient information is included to identify the authors (full addresses are not required).
- Corresponding Author: This individual should be clearly identified, along with one full institutional address and email address.
- Presentation: The meeting where any of the submitted data was presented should be listed.
- Disclosure: To disclose any official information.
- Acknowledgements (Optional): Any acknowledgements that you would like to include.
- Conflicts of Interest (Compulsory): A conflict-of-interest statement regarding the authors. Where there is none, this should be clearly stated.
- Funding Declaration (Compulsory): Any grant funding should be listed or it should be noted if no grant funds were used.
- Author Contributions (Optional): All authors are expected to have substantially contributed to the study and manuscript writing (see https://publicera.kb.se/jevtm/policies).

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, FULL CAPITALS**
Sub-Heading ***Bold and Italicized, Title Case***
Sub-sub-heading *Italicized, sentence case*

Abstract
The abstract should be a maximum of 250 words and consist of the following headings (but see specific manuscript types below for exceptions):

- Background
- Methods
- Results
- Conclusions

Keywords
Three to six appropriate keywords should be included.

References

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

Example references:

Stannard W, Rutman A, Wallis C, O'Callaghan C. Central microtubular agenesis causing primary ciliary dyskinesia. Am J Respir Crit Care Med. 2004;169:634–7.

Tang AL, Diven C, Zangbar B, et al. The elimination of anastomosis in open trauma vascular reconstruction. J Trauma Acute Care Surg. 2015; *In Press*. doi: XXXXXXXXXX.

Rasmussen TE, Tai NRM. Rich's Vascular Trauma. 3rd ed. Philidelphia: Elsevier; 2015.

Thamm DH. Miscellaneous tumors. In: Withrow S, Vail D, editors. Small Animal Clinical Oncology. 5th ed. St. Louis: Elsevier; 2013. pp. 679–88.

Where there are more than six authors, the first three should be included followed by et al.

Figures/Tables

All figures/tables must be cited within the text, presented as Figure 1, Figure 2*a*,*b*, Figures 1 and 2, and Table 1.

Figure captions should be styled as follows.

Figure 1 Title of figure.
Details of figure described below. (**a**) First sub item. (**b**) Second sub-item.

Table captions are styled similarly.

Supplementary Digital Content

Where manuscripts would benefit from additional content (datasets, images, video) that does not necessarily need to be included 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. All supplementary digital content should be cited within the text, presented as e.g. Supplementary Video 1, Supplementary Dataset 1, Supplementary Image 1 etc.

TYPES OF ARTICLES

All of the following article types are peer reviewed.

Original Articles

This is a report of a formal basic science or clinical research study. Manuscripts reporting unique scientific studies should be no longer than 5000 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). 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. Numerical results and *P* values 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.

They should contain a structured abstract with a maximum of 250 words.

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. Abstracts are not included.

Narrative Reviews

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.

The submitted manuscript should be no longer than 5000 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). 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.

Systemic 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. The overall aim is to provide a pooled analysis that enables firm conclusions to be drawn on a particular subject.

Submitted manuscripts should be no longer than 5000 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). Authors should include a PRISMA checklist in their submission. The abstract should be no longer than 250 words.

Tips and Techniques

In the evolving world of endovascular hemorrhage control, the advice and opinion of actively practicing clinicians is of great importance. Both solicited and unsolicited submissions are reviewed, both on major and minor components of endovascular techniques. This can be presented in the context of "evidence" or just as an opinion. The use of quality images and diagrams is encouraged. This type of article permits the author to write from experience, rather than from the published literature. Articles explaining how to approach certain problems or how to accomplish certain maneuvers are welcomed.

The submitted manuscript should be no longer than 1500 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). The abstract should be unstructured and be a maximum of 150 words.

Images of Interest

The Journal accepts images of interest accompanied by 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 submitted manuscript should be no longer than 250 words for the main body of the text, references excluded. Abstracts are not included.

(*Continued*)

(*Continued*)

Case Reports

These are short case reports including current literature reviews.

The submitted manuscript should be no longer than 2000 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). An abstract can be included (under 150 words) but is not compulsory.

Letters to the Editor

Letters to the Editor that comment on anything within the Journal can be submitted for publication. Abstracts are not included.

EVTM-ST Section

The EVTM-ST Section will be a section of each JEVTM edition geared towards residents/fellows and education. The editors will invite one trainee to submit an interesting case report, and invite a reviewer to review and add a brief editorial. The editors should not be authors nor reviewers. The components of the section will include a standard case report presentation with figures of CT or angio or anything interesting and pertinent. The discussion should finish with a "what I learned" summary/bullet points for education purposes. The brief editorial by the reviewer is the final paragraph.

The submissions should be a maximum of 1500 words for the main body of the text (from introduction to conclusion, and excluding abstract, references, tables and legends). An abstract can be included (under 150 words) but is not compulsory.

Conference Proceedings

Where a conference is affiliated to the Journal, the proceedings will be published as agreed by the Editorial Board.

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.

AFTER ACCEPTANCE

Once your article has been accepted and undergone peer review, it will be processed and you will receive the proofs.

COPYRIGHT AND LICENSING

PROOFREADING

The purpose of the proof is to check for typesetting or conversion errors and the completeness and accuracy of the text, tables and figures. Substantial changes in content, e.g., new results, corrected values, title, and authorship, are not allowed without the approval of the Editor-in-chief.

After online publication, further changes can only be made in the form of an Erratum, which will be hyperlinked to the article.

ONLINE FIRST

The article will be published online after receipt of the corrected proofs. This is the official first publication citable with the DOI. After release of the printed version, the paper can also be cited by issue and page numbers.

ACCESS

All articles in the JEVTM are open access and upon acceptance are immediately and permanently free for everyone to read and download.

ETHICS AND POLICIES

The 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). The Journal also follows the guidelines for medical scientific publications (Vancouver, Uniform Requirements for Manuscripts Submitted to Biomedical Journals - URM - and The International Committee of Medical Journal Editors - ICMJE - regulations).

The Journal is committed to maintaining the highest level of integrity in the content published. The Journal has a conflict of interest policy in place and complies with international, national and/or institutional standards on research involving human and animal participants and informed consent. The Journal 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 is part of Similarity Check, a service that uses software tools to screen submitted manuscripts for text overlap. If plagiarism is identified, the COPE guidelines on plagiarism will be followed.

Content published in the Journal is peer reviewed (double blind review process). Detailed information follows in the text below.

Authorship Criteria

All the authors named as such in the manuscript must have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Each author, and any co-authors, must also meet the following criteria:

1. All must have made a significant contribution to the design of the study, the collection of data, or the analysis and interpretation of data and

2. All must, either by writing or by helping to edit the manuscript, have contributed to the design of its intellectual content to a significant degree.

Each author must also be able to take responsibility for part of the article's content and be able to identify which co-authors are responsible for the remaining parts.

The above text comes from the CODEX guidelines for research publications.

Peer Review Policy

- Authors of manuscripts and reviewers of the same manuscript must not be close colleagues, family members, work on the same research project, or otherwise have a close collaboration.
- Reviewers should only accept to assess manuscripts that fall within their own subject area.
- Reviewers should respond to invitations without delay and submit completed reviews within a reasonable time.
- Reviewers' comments must not be influenced by the author's nationality, religious or political beliefs, gender or commercial interests.
- Reviewers' comments must not contain hostile or provocative language and must not include personal attacks, slander or other derogatory comments.

Author Self-Archiving

Article authors have the right to self-archive the submitted ("preprint") version of the manuscript and the published version without any embargo period.

Submitted manuscripts and published versions of articles can, for example, be archived on:

- the author's personal website
- the author's employer's website and/or institutional repository or archive
- non-profit preprint servers or subject-based archives

Preprint Policy

The Journal's editors allow authors to upload earlier drafts of manuscripts/articles on the condition that authors agree to the following:

- Authors retain all rights to any previously published version and are permitted to submit their updated manuscript to the Journal.
- Authors accept that the Journal's editors cannot guarantee full anonymity in the review process, even if the author anonymizes the manuscript when earlier versions of the manuscript are made available.

If the manuscript is published in the Journal, the author is expected to cross-link, with DOI link, the different versions of the manuscript/article.

Orcid

The Journal's editors strongly recommend that authors submitting manuscripts register an "Open Researcher and Contributor Identifier" or ORCID.

This registration provides a unique and stable digital author identity that ensures that the article is attributed to the correct person and improves the searchability of all the author's publications. This helps to ensure that the author receives recognition for their work. As a person's ORCiD remains the same as long as the account exists, any name changes, change of employment, department affiliation or research field do not affect the searchability of previous publications. This facilitates correspondence between research colleagues.

The Journal's editors encourage all authors to include ORCiD along with other author information when the manuscript is registered in the system. If the article is accepted, this will be published with the article.

Open Data

As research funders' and universities' demands for open research data become increasingly common, some authors may be obliged to make their collected empirical material open and available to everyone.

In cases where this applies to the Journal's authors, the Journal's editors encourage that the material be made available according to the FAIR principles (Findable, Accessible, Interoperable, Reusable).

The material thus made available must be linked to within the submitted manuscript under a special heading. Research data should then be made public when the article is published. Empirical material obtained from other researchers must be referenced in the same way as other scientific sources. For further questions about guidelines for handling open data and guidelines about how data should be handled and published, please contact your university.

Archiving Policy

The Journal's current and future content, beginning when the Journal joins Publicera, is made available via Publicera and stored long-term on a secure and central server at the National Library of Sweden.

The Journal's owner and the National Library of Sweden aim for the journal's archive to be transferred and made available via Publicera, and thus the archive will also be stored long-term on a secure and central server at the National Library of Sweden.

In the event that the Journal ceases operations, the Journal's content on Publicera will remain archived at the National Library of Sweden.

Correction And Retraction Policies

The conditions of publication with persistent identifiers such as DOIs include that the object published is final and not changed without readers being clearly informed of such changes.

Articles published in the Journal cannot therefore be changed without a) an erratum or b) a change notice being published and linked to the original article.

If a factual error in an article is discovered, this should be reported to the Editor-in-chief, who decides on possible actions and possible corrections.

The Journal encourages post-publication discussion through Letters to the Editor or on an externally moderated website for review and post-publication discussion of research, such as PubPeer.

(*Continued*)

(*Continued*)

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 via their given email 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.
- 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
  an expression of concern may be placed with the article
  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 as to which parts of the article are impacted by the error.

Complaints and Appeals Policy

In the case of formal complaints, disputes, or appeals, authors should contact the Editor-in-chief, who is responsible for ensuring that a fair, deliberative, and thorough investigation is conducted.

Policy For Ethical Oversight

The journal follows the ethical guidelines and best practices set forth by the Committee on Publication Ethics (COPE). All cases of ethical misconduct will be dealt with in accordance with COPE's recommendations and guidelines.

Authors' Responsibilities

A submitted manuscript cannot be under consideration for publication in other journals. All authors are obliged to provide retractions or corrections of mistakes after the 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).

All published material will include the following Ethics Statement:

Ethics Statement

- All the authors named as such in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
- 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.

Detailed Ethical Guidelines

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

- The manuscript should not be submitted to more than one journal for simultaneous consideration.
- The submitted work should be an original 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 should be 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) must be used for verbatim copying of material, and permissions secured for material that is copyrighted.
- Authors should avoid untrue statements about an entity (which 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.

Financial conflicts of interest

Authors need to consistently disclose financial conflicts of interest.

Editors' Responsibilities

The Editors of the JEVTM have responsibilities toward the authors who provide the content of the Journal, the peer reviewers who comment on the suitability of manuscripts for publication, the Journal's readers and the scientific community, the owners/publishers of the Journal, and the public as a whole.

Reviewers' Responsibilities

Peer review assists editors in making editorial decisions and, through editorial communications with authors, may assist authors in improving their manuscripts. Peer review is an

essential component of formal scholarly communication and lies at the heart of scientific endeavor.

Any invited referee who feels unqualified to review the research reported in a manuscript or knows that its prompt review will be impossible should immediately notify the editors and decline the invitation to review so that alternative reviewers can be contacted.

Any manuscripts received for review are confidential documents and must be treated as such; they must not be shown to or discussed with others except if authorized by the Editor-in-Chief (who would only do so under exceptional and specific circumstances). This applies also to invited reviewers who decline the review invitation.

Reviews should be conducted objectively and observations formulated clearly with supporting arguments so that authors can use them for improving the manuscript. Personal criticism of the authors is inappropriate. Reviewers should identify relevant published work that has not been cited by the authors. Any statement that is an observation, derivation or argument that has been reported in previous publications should be accompanied by the relevant citation. A reviewer should also notify the editors of any substantial similarity or overlap between the manuscript under consideration and any other manuscript (published or unpublished) of which they have personal knowledge.

Any invited referee who has conflicts of interest resulting from competitive, collaborative, or other relationships or connections with any of the authors, companies or institutions connected to the manuscript and the work described therein should immediately notify the editors to declare their conflicts of interest and decline the invitation to review so that alternative reviewers can be contacted.

Unpublished material disclosed in a submitted manuscript must not be used in a reviewer's own research without the express written consent of the authors. Privileged information or ideas obtained through peer review must be kept confidential and not used for the reviewer's personal advantage. This applies also to invited reviewers who decline the review invitation.

The scientific editorial technical team has been created in order to support the authors, the editors and the Editorial Board in quality control of all submissions. The team review all submissions and check for scientific problems, errors/bias and quality. Their work is also aimed at checking the ethical issues of all submissions to the JEVTM.

In an effort to standardize the review process for the Journal of Endovascular Resuscitation and Trauma Management, we ask all reviewers to use our checklist when reviewing a manuscript.

Patient Anonymity and Informed Consent Policy

It is the authors' 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 (see, for example, https://www.hhs.gov/hipaa/for-professionals/special-topics/research/index.html). Authors should mask patient's eyes and as well as genital organs, as far as possible, and always remove patient names from figures.

Protection of Human Subjects and 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 document for animal studies is the ARRIVE reporting guidelines (PLoS Bio. 2010; 8(6), https://doi.org/10.1371/journal.pbio.1000412). We encourage authors 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 when possible if a waiver of regulatory requirements for obtaining and documenting informed consent applies.

Ethical Approval and Informed Consent

Authors should include information about ethical approval and informed consent, such as "Ethical approval to report these cases was given by XXXXX. Written informed consent was obtained from xxxx."

Or, in cases where approval and consent were not provided, "Ethical approval was not required. Informed consent was not possible because XXXX and the information has been anonymized or informed consent was not required."

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.

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.

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 (25 USD per year).
Contact information for payment: lotta@mkon.se

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 five 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.

The 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

EVTM Society News

We are delighted to welcome Dr. Charles Fox as the new President of the EVTM Society and Dr. Federico Coccolini as Vice President! Their leadership, expertise, and dedication to advancing endovascular trauma and resuscitation will be invaluable in shaping the future of the society.

We would also like to express our deepest gratitude to Dr. Boris Kessel for his outstanding leadership and dedication as the past President. His contributions have been instrumental in advancing the EVTM mission, and we truly appreciate his commitment to the society's growth.

Contents

Endovascular Evolution: Transforming rAAA and Trauma Care through Innovation and Collaboration 63
David T McGreevy

Fluid Resuscitation and Trauma Management: Permissive Hypotension, Restricted Volume, and Beyond 65
Rizki Rahmadian, Ruth Evlin Margaretha, Zikril Ariliusra and Handyka Milfiadi

Trans Arterial Embolization of Spontaneous Abdominal Muscle Bleeding 74
Pierpaolo Biondetti, Gaetano Valerio Davide Amato, Carolina Lanza, Serena Carriero, Velio Ascenti, Chiara Grilli, Edon Xhepa, Salvatore Alessio Angileri, Anna Maria Ierardi and Gianpaolo Carrafiello

Treatment Experience Using a Stent Graft for Lumbar Artery Injury that Failed Coil Embolization 81
Gil H Kim, Sang B Lee, Chan I Park, Jae H Kim and Chang W Kim

Endovascular Management of a Post-traumatic Popliteal Fossa Arteriovenous Fistula 86
Jayesh Patel, Haryax Pathak, Ayushi Rathod and Manushree Barot

Stent Graft Treatment of Traumatic Arteriovenous Fistula in a 35-Year-Old: What is the 10-Year Outcome? 90
Per Skoog

Delayed Acute Ischemia as a Consequence of Multi-Ligament Injury of the Left Knee Following a Motorcycle Accident 92
Laura Leci Tahiri and Lisa Tahiri

Successful Use of a Thoracic Branched Endograft in the Setting of Blunt Thoracic Aortic Injury 96
Jeremy Obrand, Melissa Jones, Anirudh Mirakhur, Kenton Rommens, Paul Cantle and Randy Moore

Use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in Trauma Patients in French Level-1 Trauma Centers: A National Survey 100
Pauline Glasman, Thomas Clavier, Hervé Quintard and Jonathan Charbit, on behalf of the ACUTE SFAR committee

Editorial

Vol. 8, No. 3; 2024; pp 63–64
DOI: https://doi.org/10.26676/jevtm.41338

Endovascular Evolution: Transforming rAAA and Trauma Care through Innovation and Collaboration

David T McGreevy

Department of Cardiothoracic and Vascular Surgery, Faculty of Medicine and Health, Örebro University, Örebro University Hospital, Örebro, Sweden

The management of ruptured abdominal aortic aneurysms (rAAAs) has undergone a remarkable transformation over the past three decades, driven by a relentless pursuit of better outcomes through innovation [1,2]. Historically dominated by open aortic surgery (OAS), which carried high perioperative morbidity and mortality rates, the introduction of endovascular aneurysm repair (EVAR) in the 1990s marked a paradigm shift [3,4]. This minimally invasive approach redefined possibilities in vascular surgery, enabling aneurysm exclusion without extensive surgical dissection. Initial skepticism gradually diminished as EVAR opened the door to treating patients once deemed inoperable, with pioneering centers like Zurich and Örebro demonstrating its feasibility even in challenging cases [2]. Over the last decade, EVAR for rAAA has become the standard of care in many institutions, now proven effective for all rAAA cases while maintaining low mortality rates and reducing the proportion of inoperable patients to just 3.5% [5].

This progress, however, did not come without its challenges. Anatomical constraints, such as short or angulated necks, continue to pose barriers in many centers for broader EVAR applicability. Moreover, higher rates of reintervention due to endoleaks have been noted, sparking ongoing debates about long-term durability and cost-effectiveness [6]. Yet, the advantages of EVAR, with reduced recovery times, minimized physiological insult, and lower perioperative mortality, have firmly established its role in rAAA management [7,8]. Importantly, advancements in adjunct techniques, such as aortic balloon occlusion, parallel grafts, and physician-modified, fenestrated, and branched stent grafts, continue to expand its applicability, ensuring that even patients with complex anatomies can benefit.

Drawing parallels between the evolution of rAAA management and other resuscitation advancements, the development of resuscitative endovascular balloon occlusion of the aorta (REBOA) further underscores the transformative potential of endovascular technology [9]. The evolution of REBOA mirrors that of EVAR, with advancements in device design and deployment improving its safety and utility over time. The EndoVascular resuscitation and Trauma Management (EVTM) concept has also emphasized the utility of other endovascular tools, such as stent graft placement and embolization, for managing hemodynamically unstable patients, now often serving as critical adjuncts in emergency care [10]. Additionally, emerging biomarkers hold great promise in guiding treatment decisions, not only for rAAA management but also for optimizing the use of REBOA. These biomarkers provide critical insights into patient inflammation and immune status, aiding clinicians in stratifying risk, determining the optimal timing for intervention, and tailoring strategies to stabilize patients effectively. This approach enhances treatment strategies and can further improve outcomes [11].

Beyond their technical innovations, these advancements exemplify the power of multidisciplinary collaboration. Vascular and trauma surgeons, interventional radiologists, and anesthesiologists have worked together to refine these techniques and integrate them into broader care pathways, streamlining all aspects of initial evaluation, diagnostics, and definitive management. Workshops and training programs, such-as those offered by EVTM, have been instrumental in fostering cross-disciplinary expertise, ensuring that the next generation of clinicians is well-equipped to leverage these tools effectively [12]. Looking ahead, the potential for endovascular solutions to revolutionize vascular and trauma care is immense. Next-generation stent grafts promise improved sealing and fixation, addressing current limitations in EVAR. Similarly, advancements in imaging technology and AI-driven decision-making tools are likely to enhance precision in device deployment and patient selection [13]. At the same time, expanding access to life-saving

Corresponding author:
David T McGreevy, MD, PhD, Department of Cardiothoracic and Vascular Surgery, Örebro University Hospital, SE-701 85 Örebro, Sweden.
Email: david.mcgreevy@regionorebrolan.se

technologies like EVAR and REBOA remains a critical challenge. Policies promoting affordability, investments in hybrid operating rooms, and training initiatives will be key to ensuring that these benefits reach all patients who need them, enabling broader access across different healthcare systems and geographic regions. Continued research and robust clinical trials will be essential to refine indications, improve long-term outcomes, and address lingering questions about cost-effectiveness.

By embracing these innovations and addressing these challenges together, we can continue to push the boundaries of what is achievable, ensuring that endovascular advancements translate into improved outcomes and broader accessibility, with opportunities to further reduce suffering and save lives.

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 author declares that they have no conflicts of interest.

Funding

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

REFERENCES

[1] Mayer D, Pfammatter T, Rancic Z, et al. 10 years of emergency endovascular aneurysm repair for ruptured abdominal aortoiliac aneurysms: lessons learned. Ann Surg. 2009;249(3):510–5.
[2] Mayer D, Aeschbacher S, Pfammatter T, et al. Complete replacement of open repair for ruptured abdominal aortic aneurysms by endovascular aneurysm repair: a two-center 14-year experience. Ann Surg. 2012;256(5): 688–95; discussion 695-6.
[3] Ricotta JJ 2nd, Malgor RD, Oderich GS. Ruptured endovascular abdominal aortic aneurysm repair: part II. Ann Vasc Surg. 2010;24(2):269–77.
[4] IMPROVE Trial Investigators; Powell JT, Sweeting MJ, et al. Endovascular or open repair strategy for ruptured abdominal aortic aneurysm: 30 day outcomes from IMPROVE randomised trial. BMJ. 2014;348:f7661.
[5] McGreevy DT, Pirouzram A, Djavani Gidlund K, Nilsson KF, Hörer TM. A 12-year experience of endovascular repair for ruptured abdominal aortic aneurysms in all patients. J Vasc Surg. 2023;77(3):741–49.
[6] Wanhainen A, Van Herzeele I, Bastos Goncalves F, et al. European Society for Vascular Surgery (ESVS) 2024 clinical practice guidelines on the management of abdominal Aorto-Iliac artery aneurysms. Eur J Vasc Endovasc Surg. 2024;67(2):192–331.
[7] Kontopodis N, Galanakis N, Antoniou SA, et al. Meta-analysis and meta-regression analysis of outcomes of endovascular and open repair for ruptured abdominal aortic aneurysm. Eur J Vasc Endovasc Surg. 2020;59(3):399–410.
[8] Sweeting MJ, Balm R, Desgranges P, Ulug P, Powell JT; Ruptured Aneurysm Trialists. Individual-patient meta-analysis of three randomized trials comparing endovascular versus open repair for ruptured abdominal aortic aneurysm. Br J Surg. 2015;102(10):1229–39.
[9] Stannard A, Eliason JL, Rasmussen TE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock. J Trauma. 2011;71(6):1869–72.
[10] Hörer TM, Pirouzram A, Khan M, et al. Endovascular Resuscitation and Trauma Management (EVTM)-practical aspects and implementation. Shock. 2021; 56(1S):37–41.
[11] Wu B, Xia SB, Chen L, et al. Prognostic significance of preoperative neutrophil-to-lymphocyte ratio and platelet-to-lymphocyte ratio in patients with ruptured abdominal aortic aneurysm undergoing endovascular aneurysm repair. J Cardiothorac Surg. 2024;19(1):650.
[12] McGreevy DT, Sheffer D, Paran M, et al. EndoVascular resuscitation and trauma management specialists in training – The Future of EVTM Education. J Endovasc Resusc Trauma Manag. 2022;6(2):77–78.
[13] Darling JD, Caron E, Park J, et al. The effect of Fiber Optic RealShape technology on perioperative and postoperative outcomes following complex abdominal aortic repair. J Vasc Surg. 2024:S0741–5214(24)02233-X.

Narrative Review Article

Vol. 8, No. 3; 2024; pp 65–73
DOI: https://doi.org/10.26676/jevtm.26617

Fluid Resuscitation and Trauma Management: Permissive Hypotension, Restricted Volume, and Beyond

Rizki Rahmadian[1], Ruth Evlin Margaretha[2,3], Zikril Ariliusra[1] and Handyka Milfiadi[4]

[1]Orthopaedic and Traumatology Division, Department of Surgery, Faculty of Medicine Andalas University/ Dr. M. Djamil Central General Hospital, Padang, West Sumatera, Indonesia
[2]Department of Anesthesia and Intensive Care, Faculty of Medicine of Baiturrahmah University, Padang, West Sumatera, Indonesia
[3]Anesthesia and Intensive Care Department, Semen Padang Hospital, Padang, West Sumatera, Indonesia
[4]General Surgery Division, Department of Surgery, Faculty of Medicine Andalas University/ Dr. M. Djamil Central General Hospital, Padang, West Sumatera, Indonesia

Uncontrolled hemorrhagic shock is responsible for 40% of deaths among those under the age of 35, making it the primary cause of mortality in this age group. An optimal fluid therapy strategy can restore tissue perfusion and oxygenation in trauma patients. However, excessive fluid resuscitation can result in glycocalyx shedding, which leads to globally increased permeability syndrome, leading to complications such as changes in tissue perfusion, abdominal compartment syndrome, and respiratory distress syndrome. Permissive hypotension is a resuscitation strategy that aims to maintain systolic blood pressure below the normal threshold. Restricted volume replacement or restricted fluid resuscitation is a resuscitation principle that limits the amount of fluid used to prevent the worsening of diluted coagulopathy, hypothermia, and acidosis. This review article aims to discuss the recent concept of fluid therapy in trauma and to connect the understanding of fluid therapy in trauma with related topics such as trauma-induced coagulopathy and damage control resuscitation.

Keywords: *Permissive Hypotension; Restricted Fluid; Trauma-Induced Coagulopathy; Damage Control Resuscitation*

Received: 12 August 2024; Accepted: 21 September 2024

INTRODUCTION

Uncontrolled hemorrhagic shock is responsible for 40% of deaths among those under the age of 35, making it the primary cause of mortality in this age group [1,2]. Fluid resuscitation is the initial step in the treatment of catastrophic hemorrhagic shock, aimed at restoring the hemodynamics [3].

The metabolic response to trauma can be categorized into three distinct phases: the ebb phase, characterized by a drop in metabolic rate during the first shock period; the flow phase, also known as the catabolic phase; and the anabolic phase [4]. Certain patients are unable to naturally progress through the "flow" phase and instead experience a chronic condition of globally increased permeability syndrome with ongoing fluid accumulation [5]. Globally increased permeability syndrome refers to a condition characterized by an excessive accumulation of fluid in the body, which is accompanied by the sudden failure of one or more organs. This condition is also known as "the third hit of shock" [6].

Death can occur in both the acute and subacute phases after hemorrhagic shock. In the acute phase, the inability to control bleeding can lead to the heart's failure to maintain the minimum cardiac output, resulting in death. During the subacute phase, resuscitation and surgical interventions successfully stop the bleeding, allowing for sufficient blood supply to the brain and heart. However, the bulid-up of ischemia eventually leads to fatal consequences within a matter of days, weeks, or months because of multiple organ failure [7].

Previously, aggressive fluid resuscitation was a frequently employed approach to revive trauma victims [8]. Recent investigations have demonstrated that employing the principles of permissive hypotension and limiting

Corresponding author:
Rizki Rahmadian, Orthopaedic and Traumatology Division, Department of Surgery, Faculty of Medicine Andalas University/ Dr. M. Djamil Central General Hospital, Padang, West Sumatera, Indonesia.
E-mail: rizkipublication@gmail.com

volume yields superior outcomes. This article reviews the concept of permissive hypotension and restricted volume in fluid management for trauma.

PERMISSIVE HYPOTENSION AND RESTRICTED VOLUME RESUSCITATION

Permissive hypotension is a resuscitation approach that seeks to keep the systolic blood pressure (SBP) below the usual threshold. This approach is also referred to as "hypotensive resuscitation," "controlled resuscitation," and "balanced resuscitation." Restricted volume replacement, also known as restricted fluid resuscitation, is a resuscitation strategy that aims to limit the quantity of fluid administered in order to prevent the exacerbation of diluted coagulopathy, hypothermia, and acidosis. The approach to managing hypotension caused by trauma by restricted volume replenishment or permissive hypotension was initially influenced by a study conducted by Bickell et al. in 1994 [9]. The study conducted at a single facility examined the effects of immediate and delayed fluid resuscitation in patients with low blood pressure (≤90 mm Hg) caused by penetrating injuries to the torso. The study found that delaying vigorous fluid resuscitation until surgical intervention resulted in significantly greater survival rates (70% vs. 62%; p = 0.04) [9]. In 2015, Schreiber et al. found that in blunt trauma patients the use of 1 liter of crystalloid resulted in a 24-hour mortality rate of 3%, whereas the use of 2 liters of crystalloid resulted in a mortality rate of 18% [10]. In 2016, Carrick et al. [11] compared the outcomes of trauma-penetrating patients using minimum mean arterial pressure (MAP) targets of 50 mm Hg and 60 mm Hg. The study found that hypotensive resuscitation with MAP targets of 50 mm Hg resulted in significantly lower 30-day mortality rates [11]. Similar results were also reported by Morisson et al. in 2011; the trauma patients using the 50 mmHg MAP target had significantly better 30-day morbidity and mortality rates and required fewer blood products than those using the 65 mm Hg MAP target [12].

At present, multiple systematic review studies and meta-analyses demonstrate the benefits of employing the notion of permissive hypotension resuscitation [13–16]. In 2018, Owattanapanich et al. [14] discovered that hypotensive resuscitation results in reduced quantities of fluid resuscitation and packed red cell transfusion, along with a decreased occurrence of acute respiratory distress syndrome and multiple organ failure. The study also concluded that there was no notable disparity in resuscitation techniques in terms of the occurrence of acute renal damage [14]. According to the study by Albreiki and Voegeli in 2017, low-volume resuscitation resulted in a lower death rate than big-volume resuscitation, with values of 21.5% and 28.6%, respectively [17].

A meta-analysis conducted by Safienjko et al. in 2022 demonstrated that the use of hypotension fluid resuscitation is associated with reduced mortality and comorbidities [15]. Among the twenty-eight studies analyzed, the mortality rate for hypotension fluid resuscitation was found to be 12.5%, but for traditional fluid resuscitation it was 21.4%. The incidence of complications with hypotension fluid resuscitation is 10.8%, but in traditional resuscitation it is 13.4%. The primary distinction in the risk of complications between hypotensive and conventional fluid resuscitation is in the occurrence of acute respiratory distress syndrome (ARDS), with rates of 7.8% and 16.8%, respectively, as well as multiple organ damage syndrome (MODS), with rates of 8.6% and 21.6%, respectively.

The effectiveness of limited volume replacement in trauma was also documented in pediatric instances. In a study conducted by Mbadiwe et al. in 2021, it was found that administering resuscitation fluid of more than 20 cm^3/kg in cases of pediatric trauma is linked to higher fatality rates. This association is determined by the dosage, meaning that the higher the dosage, the more significant the impact on mortality [17].

Permissive hypotension and restricted volume replacement are not recommended for patients with severe brain damage and spinal cord injury. This concerns the ideal concentration of blood flow required to guarantee sufficient oxygen supply to the impaired central nervous system. Stable fluid infusions above 80 mm Hg are recommended for severe cerebral hemorrhagic damage that raises intracranial pressure. This prevents arterial ischemia and maintains cerebral perfusion pressure at 60 mm Hg [18]. Revised guidelines have been issued for the management of SBP in adult patients with traumatic brain injury (TBI), taking into account their age. The age-based guidelines set by the Brain Trauma Foundation exceed the acceptable thresholds for hypotension. The recommended blood pressure levels for those aged 15 to 49 are 110 mm Hg, for those aged 50 to 69 they are 100 mm Hg, and for patients aged 70 years and above they are 110 mm Hg [19,20].

The optimal approach to attain sufficient perfusion pressure through volume resuscitation and vasopressors remains a subject of ongoing research without a definitive solution. Geriatric patients and patients with chronic hypertension, in addition to situations of severe head injuries and spinal cord injuries, should be given additional care and may be considered a contraindication for permissive hypertension [21].

OVERVIEW OF FLUID MANAGEMENT: LIBERAL, STANDARD, AND RESTRICTIVE

In 2014, the acronyms ROSE and SOSD were introduced as concepts in fluid treatment. The acronym ROSE was introduced at the International Fluid Academy Day (IFAD) to represent the four phases of fluid therapy: Resuscitation, Optimization, Stabilization, and Evacuation [22]. On the other hand, the concept of SOSD

(Salvage, Optimization, Stabilization, De-escalation) was proposed by The Acute Dialysis Quality Initiative (ADQI) group [23]. During the Resuscitation or Salvage phase, the treatment focuses on restoring or correcting shock conditions by aiming for an appropriate perfusion pressure. During this stage, a fast infusion of fluid with a volume of 3–4 ml/kg is administered for 10 to 15 minutes (which can be repeated if necessary), typically accompanied by vasopressors. During the Optimization phase, the patient's hypovolemia is no longer severe, but their hemodynamics are still unstable. The objective of therapy in this phase is to prevent or minimize the risk of organ damage. The stabilization phase commences once the patient has achieved a condition of stability and continues for several days. During this stage, the goal is to achieve a fluid balance of zero or slightly negative. The evacuation or de-escalation phase is the final stage that seeks to eliminate surplus fluid. Typically, this stage happens naturally as the patient recovers. However, diuretics or ultrafiltration can be employed if necessary.

The terms liberal, standard, and restrictive are often used to compare fluid therapy regimens. Usually, researchers use their approach as a standard therapy and compare it with restrictive or liberal concepts that they define themselves. Even differences in definition make a restrictive group a liberal group in other studies [24]. The study of the comparison between restrictive and liberal is also sometimes more accurately seen as hypovolemia vs. normovolemia [25].

Definitions of liberal, standard, and restrictive fluid therapy vary widely across studies. The definition of this term probably should not only relate to the volume of fluid given but also to when to start and stop fluid therapy performed [26].

FLUID RESUSCITATION AND ENDOTHELIAL GLYCOCALYX

The fluid displacement between plasma and interstitium is an important concept that must be understood regarding fluid resuscitation in trauma situations. One of the earliest basic concepts of plasma and interstitial fluid transfer was proposed by Starling in 1896, that the movement of fluid across capillary membranes depends on a net imbalance between the osmotic absorption pressure of plasma proteins [colloidal osmotic pressure (COP)] and the capillary hydraulic pressure generated by the heartbeat [27]. The understanding of the existence of glycocalyx structures on the endothelial surface of blood vessels prompted Levick and Michel [28] to revise the concept proposed by Starling.

The endothelial glycocalyx is essential for controlling the permeability of blood vessels. The disruption of the glycocalyx increases the permeability of blood arteries, allowing for the facilitated passage of water, proteins, and other substances from the bloodstream to the external environment [29]. The molecular sieve effect of the glycocalyx structure determines the permeability of blood arteries. Additionally, the negatively charged nature of glycocalyx creates a charge barrier in blood vessels [30].

The type of resuscitation fluid used is known to affect the integrity of glycocalyx after hemorrhagic shock [31]. Crystalloids are reported to be associated with higher glycocalyx shedding than colloids [32,33]. Several different results regarding the relationship of resuscitation fluid with glycocalyx shedding have been reported, such as the type of fluid affecting post-hemorrhage glycocalyx thickness [34], but other studies report that such thickness changes do not affect membrane permeability [35].

An optimal fluid therapy strategy can effectively restore tissue perfusion and oxygenation in the body. However, excessive fluid resuscitation can result in glycocalyx shedding, which leads to globally increased permeability syndrome, which can lead to complications such as changes in tissue perfusion, abdominal compartment syndrome, and respiratory distress syndrome [3,36,37].

FLUID RESUSCITATION AND TRAUMATIC-INDUCED COAGULOPATHY

Excessive fluid resuscitation in trauma patients can trigger traumatic-induced coagulopathy. Overly administering fluids through crystalloids can lead to a decrease in the amount of oxygen that can be carried and a reduction in the concentration of substances that help with blood coagulation. Administering fluids at a temperature lower than the body's normal temperature worsens heat loss in the body due to bleeding, low energy levels, and exposure to the environment. It also reduces the effectiveness of enzymes involved in the clotting process [38]. Excessive administration of acidic crystalloid solutions will worsen the acidosis induced by reduced blood flow, leading to a decline in the effectiveness of clotting factors. This will result in a dangerous combination of coagulopathy, hypothermia, and acidosis, which can be fatal [39].

Trauma-induced coagulopathy (TIC) is the term used to describe the abnormal formation of blood clots that happens due to physical damage. During the early phases of TIC growth, there is typically a state of diminished hemostatic capacity, resulting in hemorrhaging. As TIC advances, there is a noticeable rise in blood clotting, which is linked to the development of venous thromboembolism and organ failure. Generally, TIC can be a mixed phenotype, including the bleeding and thrombogenic phenotypes [40].

Viscoelastic measures (VEM) are used frequently in the detection of traumatic-induced coagulopathy. These assays are whole blood tests that offer data on the speed at which a clot forms (fibrin cross-linking), reaches its maximum strength (platelet function), and ultimately breaks down (fibrinolysis). VEM tests can be employed

at the point of care, providing available data promptly within 5 minutes that can effectively guide resuscitation. Thromboelastography (TEG, Haemonetics) and thromboelastometry (ROTEM, Tem International GmbH) are the two main platforms used for these examinations.

Tissue injury and shock synergistically stimulate the activation of the endothelium, immune system, platelet, and clotting processes. The presence of the "lethal triad", which includes coagulopathy, hypothermia, and acidosis, significantly intensifies these activations [41].

Insufficient oxygen availability for aerobic metabolism leads to a shift towards anaerobic metabolism at the cellular level [42]. Consequently, this results in heightened lactic acid build-up, inorganic phosphates, and oxygen radicals [43]. Furthermore, on a cellular level, damage-associated molecular patterns (referred to as DAMPs or alarmins), such as mitochondrial DNA and formyl peptides, are released. These substances then initiate a widespread inflammatory response throughout the body [44].

The hemorrhaging also triggers significant alterations in the vascular endothelium across the body [45]. The endothelium and blood work together at the bleeding site to enhance the formation of a blood clot. However, the accumulation of oxygen debt and sudden increases in catecholamine levels eventually lead to the development of endotheliopathies, which occur when the protective glycocalyx barrier is shed systemically [32].

During severe hemorrhage, adaptive and maladaptive alterations occur either at the bleeding site or in tissues throughout the body. Hemostatic plugs form at the bleeding site [46]. There is an increase in fibrinolytic activity in tissues that are distant from the site of bleeding, potentially as a protective reaction to avoid the formation of blood clots in small blood vessels [47]. Nevertheless, an overabundance of plasmin activity and auto-heparinization caused by glycocalyx shedding might result in hyperfibrinolysis and widespread coagulopathy [48].

RESUSCITATION USING DAMAGE CONTROL TECHNIQUES

The word "damage control" originates from naval warfare. The word refers to a method of handling warships that have been damaged, with the goal of preserving the ship's ability to sail and operate rather than fully repairing all of the damage [49,50]. Subsequently, this concept was incorporated into the field of medicine as a strategy for treating patients who have sustained multiple and serious traumas [51].

Discussing damage control resuscitation (DCR) is essential when explaining the rationale and benefits of permissive hypotension in trauma resuscitation. Permissive hypotension, one component of DCR, aims to maintain a low but adequate blood pressure to reduce bleeding until bleeding control can be achieved, avoiding excessive fluid resuscitation that could dislodge clots and exacerbate hemorrhage. DCR integrates a broader strategy that includes rapid hemorrhage control, limited fluid resuscitation, and preventing coagulopathy [52]. By incorporating permissive hypotension within DCR, the patient's physiological condition is optimized during the critical pre-operative phase, minimizing the risk of worsening hemorrhage while maintaining vital organ perfusion [53]. Crystalloids are restricted in DCR to prevent dilutional coagulopathy, whereas hypotensive resuscitation is employed until significant bleeding is under control. Tranexamic acid is used empirically, and acidosis and hypothermia are prevented [54].

Rapid control of bleeding in non-compressible hemorrhage can be achieved by damage control surgery (DCS) or through Endovascular Resuscitation and Trauma Management (EVTM) [55], which is defined as "a term that represents a modern, multidisciplinary approach that integrates minimally invasive endovascular techniques to manage severe trauma, particularly in patients with hemorrhagic shock" [21,56]. In most simple terms, endovascular resuscitation can be defined as the use of catheter-based therapies to achieve rapid bleeding control, such as Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) [57–59]. REBOA is utilized to stabilize patients at high risk of death from build-up torso bleeding, but it is not a device for definitive hemorrhage control. Its use should be integrated into a comprehensive system that includes DCR, definitive hemorrhage management, and postoperative critical care [60,61].

The use of crossmatched packed red blood cells (pRBCs) is ideal in trauma resuscitation. However, when crossmatched blood is unavailable, type O pRBCs are recommended for patients experiencing exsanguinating hemorrhage. In situations requiring massive transfusion, early administration of pRBCs, plasma, and platelets in a balanced 1:1:1 ratio can improve survival by minimizing the need for excessive crystalloid resuscitation [62]. Recently, whole blood has re-emerged as a viable option for resuscitation in hemorrhagic shock [63]. However, clear guidelines regarding when to opt for whole blood over individual blood components remain absent.

The administration of blood products in the prehospital setting is also possible, although studies have produced mixed outcomes [64–68]. Currently, there are no definitive recommendations supporting or opposing prehospital blood product administration [21].

ATLS AND EUROPEAN GUIDELINES

In 2013, the Advanced Trauma Life Support (ATLS) course implemented multiple modifications to its resuscitation method. The adjustments involved eliminating the term "aggressive resuscitation" and suggesting permissive hypotension prior to bleeding control. Additionally, the advice is now to reduce the amount

of crystalloids from 2 liters to 1 liter and to administer plasma and platelets early in patients who need extensive transfusions [69]. The 2013 European guidelines on the management of bleeding and coagulopathy included a recommendation regarding hypotensive resuscitation [72]. According to this recommendation, the target SBP should be maintained between 80 and 90 mm Hg until major hemorrhage can be controlled in cases of traumatic injury without brain damage. The 2023 European guidelines for managing bleeding and coagulopathy recommends a limited volume replacement strategy with a blood pressure target of 80–90 mm Hg (MAP 50–60 mm Hg) until major bleeding is controlled and there is no clinical evidence of brain injury in patients with severe head trauma. If the Glasgow Coma Scale (GCS) score is less than or equal to 8, it is advised to maintain a MAP of at least 80 mm Hg. Table 1 compares the ATLS and European Guidelines on fluid resuscitation on trauma.

VASOPRESSORS AND FLUID RESUSCITATION IN TRAUMA

In trauma resuscitation, rapid hemorrhage control and restoration of adequate tissue perfusion are the primary goals to prevent further organ damage and mortality. Vasopressors, commonly used in non-trauma shock management, are not recommended for initial use in trauma resuscitation due to the risk of exacerbating hypoperfusion, as vasoconstriction can impair oxygen delivery to tissues already compromised by hemorrhagic shock [73]. The European guidelines on trauma management highlight that vasopressors may delay the recognition of bleeding by artificially maintaining blood pressure without addressing the underlying cause of hypovolemia [73]. Their inappropriate use can lead to a worsening of tissue ischemia, particularly in situations where vasoconstriction compounds existing circulatory compromise [74]. However, vasopressors may be indicated in cases of neurogenic shock or in patients with traumatic brain injuries where maintaining cerebral perfusion pressure is critical [71]. According to the ATLS guidelines, fluid resuscitation and hemorrhage control must be prioritized before considering the cautious use of vasopressors in trauma patients [71,75].

The 10th edition of ATLS suggests administering warm saline as resuscitation fluids up to a volume of 1 liter in patients with class I or II bleeding. In cases of hemorrhage classified as class II or higher, it is advisable to utilize blood products rather than adding more crystalloid or colloidal fluids. The ATLS guidelines do not include detailed advice for the use of vasopressors [71]. According to the recommendation of the European guidelines, vasopressors should be used when fluid resuscitation fails to achieve SBP objectives of 80–90 mm Hg or when severe hypotension caused by bleeding results in SBP below 80 mm Hg. Noradrenaline is a recommended vasopressor in situations where there is no dysfunction of the heart, whereas dobutamine is the recommended vasopressor in situations when there is dysfunction of the heart. If the amount of bleeding is too much and if the combination of crystalloids and vasopressors cannot adequately maintain the basic flow of blood to the tissues, colloid infusions might be considered as an additional alternative to restore blood flow [21].

Hemorrhagic shock is also reported to be related to a deficiency of arginine vasopressin. In 2019, Sims et al. [76] demonstrated that administering a low dose of arginine vasopressin (a surge of 4 IU followed by 0.04 IU/min) reduces the need for blood products. A previous double-blind randomized trial evaluated the safety and effectiveness of including vasopressin in resuscitative fluid, and the results are consistent with that study [77].

Ethical Approval and Informed Consent

Ethical approval was not required. Written informed consent was not required.

CONCLUSION

In conclusion, fluid resuscitation strategies in trauma management have shifted from traditional aggressive approaches to more refined methods such as permissive hypotension and restricted volume resuscitation. These strategies aim to limit the adverse effects of fluid overload, such as coagulopathy, hypothermia, and acidosis, while optimizing tissue perfusion and reducing mortality. Permissive hypotension has demonstrated significant survival benefits by maintaining lower SBP until definitive hemorrhage control can be achieved. Furthermore, restricted volume resuscitation minimizes glycocalyx shedding and prevents complications associated with excessive fluid administration.

The integration of these principles into DCR protocols has further improved trauma outcomes by reducing the need for large volumes of crystalloid solutions and emphasizing the early use of blood products. This approach aligns with contemporary guidelines such as those provided by ATLS and European trauma management, which advocate limited fluid use and hypotensive resuscitation in non-head trauma patients.

Despite these advances, the use of permissive hypotension and restricted volume resuscitation must be carefully tailored to individual patients, particularly those with traumatic brain injuries or spinal cord injuries, where higher perfusion pressures may be required. Further research is needed to refine the optimal resuscitation strategies for specific patient populations, especially in geriatric trauma and those with pre-existing chronic conditions. Overall, permissive hypotension and restricted fluid resuscitation represent key components of modern trauma care, contributing to improved survival and reduced morbidity in hemorrhagic shock management.

Table 1 ATLS and European Guidelines of fluid resuscitation on trauma.

Parameters	*ATLS 8th (2008) [8]*	*ATLS 9th (2013) [69,70]*	*ATLS 10th (2018) [62,71]*	*European guidelines (2013) [72]*	*European guidelines 6th (2023) [21]*
Volume	Up to 2 liter	Up to 1 liter	Up to 1 liter	1–1.5 liter	1–1.5 liter
Target of blood pressure without TBI	Systolic of ≥90 mm Hg	Support for hypotensive resuscitation	Support for hypotensive resuscitation	Systolic of 80–90 mm Hg (MAP 50–60 mm Hg)	Systolic of 80–90 mm Hg (MAP 50–60 mm Hg)
Target of blood pressure with TBI	Systolic of ≥90 mm Hg	15–49 y.o: 110 mm Hg 50–69 y.o: 100 mm Hg, ≥70 y.o: 110 mm Hg	15–49 y.o: 110 mm Hg 50–69 y.o: 100 mm Hg, ≥70 y.o: 110 mm Hg	GCS ≤ 8: MAP ≥80 mm Hg	GCS ≤ 8: MAP ≥80 mm Hg
Type of fluid	Warm isotonic electrolyte solution Ringer lactate is the initial fluid of choice Normal saline is the second choice	Class II hemorrhage: NaCl 0.9% (normal saline), resuscitation with blood and blood product for patient with transient- or non-responders Class III and IV hemorrhage: Early resuscitation with blood and blood products Class IV: Massive transfusion protocol	Class II hemorrhage: NaCl 0.9% (normal saline), resuscitation with blood and blood product for patient with transient- or non-responders Class III and IV hemorrhage: Early resuscitation with blood and blood products Class IV: Massive transfusion protocol	NaCl 0.9% or balance crystalloid Avoid ringer lactate in severe head trauma	NaCl 0.9% or balance crystalloid Avoid ringer lactate in severe head trauma

European guidelines on the management of bleeding and coagulopathy. ATLS, Advance Trauma Life Support; NaCl, sodium chloride; TBI, traumatic brain injury; MAP, mean artery pressure; y.o., years old; GCS, Glassgow Coma Scale.

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

All authors declare no conflicts of interest.

Funding

This review article receives no funding from any source.

REFERENCES

[1] Alberdi F, García I, Atutxa L, Zabarte M. Trauma and neurointensive care work group of the SEMICYUC. Epidemiology of severe trauma. Med Intensiva. 2014; 38:580–8.
[2] Alexandrescu R, O'Brien SJ, Lecky FE. A review of injury epidemiology in the UK and Europe: some methodological considerations in constructing rates. BMC Public Health. 2009;9:226.
[3] Krzych ŁJ, Czempik PF. Effect of fluid resuscitation with balanced solutions on platelets: in vitro simulation of 20% volume substitution. Cardiol J. 2013;VM/OJS/J/50626.
[4] Şimşek T, Şimşek HU, Cantürk NZ. Response to trauma and metabolic changes: posttraumatic metabolism. Ulusal Cerrahi Derg. 2014;30:153–9.
[5] Duchesne JC, Kaplan LJ, Balogh ZJ, Malbrain ML. Role of permissive hypotension, hypertonic resuscitation and the global increased permeability syndrome in patients with severe hemorrhage: adjuncts to damage control resuscitation to prevent intra-abdominal hypertension. Anestezjol Intensywna Ter. 2015;47:143–55.
[6] Malbrain MLNG, Langer T, Annane D, et al. Intravenous fluid therapy in the perioperative and critical care setting: executive summary of the International Fluid Academy (IFA). Ann Intensive Care. 2020;10:64.
[7] Dutton RP. Haemostatic resuscitation. Br J Anaesth. 2012;109:i39–i46.
[8] Kortbeek JB, Al Turki SA, Ali J, et al. Advanced Trauma Life Support, 8th edition, the evidence for change. J Trauma Inj Infect Crit Care. 2008;64:1638–50.
[9] Bickell WH, Wall MJ, Pepe PE, et al. Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. N Engl J Med. 1994;331:1105–9.
[10] Schreiber MA, Meier EN, Tisherman SA, et al. A controlled resuscitation strategy is feasible and safe in hypotensive trauma patients: results of a prospective randomized pilot trial. J Trauma Acute Care Surg. 2015; 78:687–95; discussion 695–7.
[11] Carrick MM, Morrison CA, Tapia NM, et al. Intraoperative hypotensive resuscitation for patients undergoing laparotomy or thoracotomy for trauma: early termination of a randomized prospective clinical trial. J Trauma Acute Care Surg. 2016;80:886–96.
[12] Morrison CA, Carrick MM, Norman MA, et al. Hypotensive resuscitation strategy reduces transfusion requirements and severe postoperative coagulopathy in trauma patients with hemorrhagic shock: preliminary results of a randomized controlled trial. J Trauma. 2011;70:652–63.
[13] Albreiki M, Voegeli D. Permissive hypotensive resuscitation in adult patients with traumatic haemorrhagic shock: a systematic review. Eur J Trauma Emerg Surg Off Publ Eur Trauma Soc. 2018;44:191–202.
[14] Owattanapanich N, Chittawatanarat K, Benyakorn T, Sirikun J. Risks and benefits of hypotensive resuscitation in patients with traumatic hemorrhagic shock: a meta-analysis. Scand J Trauma Resusc Emerg Med. 2018; 26:107.
[15] Safiejko K, Smereka J, Filipiak KJ, et al. Effectiveness and safety of hypotension fluid resuscitation in traumatic hemorrhagic shock: a systematic review and meta-analysis of randomized controlled trials. Cardiol J. 2022;29:463–71.
[16] Wang C-H, Hsieh W-H, Chou H-C, et al. Liberal versus restricted fluid resuscitation strategies in trauma patients: a systematic review and meta-analysis of randomized controlled trials and observational studies*. Crit Care Med. 2014;42:954–61.
[17] Mbadiwe N, Georgette N, Slidell MB, McQueen A. Higher crystalloid volume during initial pediatric trauma resuscitation is associated with mortality. J Surg Res. 2021;262:93–100.
[18] Wise R, Faurie M, Malbrain MLNG, Hodgson E. Strategies for intravenous fluid resuscitation in trauma patients. World J Surg. 2017;41:1170–83.
[19] Carney N, Totten AM, O'Reilly C, et al. Guidelines for the management of severe traumatic brain injury, fourth edition. Neurosurgery. 2017;80:6–15.
[20] Dash HH, Chavali S. Management of traumatic brain injury patients. Korean J Anesthesiol. 2018;71:12.
[21] Rossaint R, Afshari A, Bouillon B, et al. The European guideline on management of major bleeding and coagulopathy following trauma: sixth edition. Crit Care. 2023;27:80.
[22] Malbrain MLNG, Marik PE, Witters I, et al. Fluid overload, de-resuscitation, and outcomes in critically ill or injured patients: a systematic review with suggestions for clinical practice. Anestezjol Intensywna Ter. 2014;46:361–80.
[23] Hoste EA, Maitland K, Brudney CS, et al. Four phases of intravenous fluid therapy: a conceptual model. Br J Anaesth. 2014;113:740–47.
[24] Bundgaard-Nielsen M, Secher NH, Kehlet H. 'Liberal' vs. 'restrictive' perioperative fluid therapy – a critical assessment of the evidence. Acta Anaesthesiol Scand. 2009;53:843–51.
[25] Chappell D, Jacob M, Hofmann-Kiefer K, Conzen P, Rehm M. A rational approach to perioperative fluid management. Anesthesiology. 2008;109:723–40.

[26] Meyhoff TS, Hjortrup PB, Wetterslev J, et al. Restriction of intravenous fluid in ICU patients with septic shock. N Engl J Med. 2022;386:2459–70.
[27] Starling EH. On the absorption of fluids from the connective tissue spaces. J Physiol. 1896;19:312–26.
[28] Levick JR, Michel CC. Microvascular fluid exchange and the revised Starling principle. Cardiovasc Res. 2010; 87:198–210.
[29] Butler MJ, Down CJ, Foster RR, Satchell SC. The pathological relevance of increased endothelial glycocalyx permeability. Am J Pathol. 2020;190:742–51.
[30] Kolářová H, Víteček J, Černá A, et al. Myeloperoxidase mediated alteration of endothelial function is dependent on its cationic charge. Free Radic Biol Med. 2021; 162:14–26.
[31] Anand T, Reyes AA, Sjoquist MC, Magnotti L, Joseph B. Resuscitating the endothelial glycocalyx in trauma and hemorrhagic shock. Ann Surg Open. 2023;4:e298.
[32] Johansson PI, Henriksen HH, Stensballe J, et al. Traumatic endotheliopathy: a prospective observational study of 424 severely injured patients. Ann Surg. 2017;265:597–603.
[33] Genét GF, Johansson PI, Meyer MAS, et al. Trauma-induced coagulopathy: standard coagulation tests, biomarkers of coagulopathy, and endothelial damage in patients with traumatic brain injury. J Neurotrauma. 2013;30:301–6.
[34] Torres Filho IP, Torres LN, Salgado C, Dubick MA. Plasma syndecan-1 and heparan sulfate correlate with microvascular glycocalyx degradation in hemorrhaged rats after different resuscitation fluids. Am J Physiol-Heart Circ Physiol. 2016;310:H1468–78.
[35] Ergin B, Guerci P, Uz Z, et al. Hemodilution causes glycocalyx shedding without affecting vascular endothelial barrier permeability in rats. J Clin Transl Res. 2020;5:243–52.
[36] Solomonov E, Hirsh M, Yahiya A, Krausz MM. The effect of vigorous fluid resuscitation in uncontrolled hemorrhagic shock after massive splenic injury. Crit Care Med. 2000;28:749–54.
[37] Varela JE, Cohn SM, Diaz I, Giannotti GD, Proctor KG. Splanchnic perfusion during delayed, hypotensive, or aggressive fluid resuscitation from uncontrolled hemorrhage. Shock. 2003;20:476–80.
[38] Sihler KC, Napolitano LM. Complications of massive transfusion. Chest. 2010;137:209–20.
[39] Cosgriff N, Moore EE, Sauaia A, Kenny-Moynihan M, Burch JM, Galloway B. Predicting life-threatening coagulopathy in the massively transfused trauma patient: hypothermia and acidoses revisited. J Trauma Inj Infect Crit Care. 1997;42:857–62.
[40] Woolley T, Thompson P, Kirkman E, et al. Trauma hemostasis and oxygenation research network position paper on the role of hypotensive resuscitation as part of remote damage control resuscitation. J Trauma Acute Care Surg. 2018;84:S3–S13.
[41] Moore EE, Moore HB, Kornblith LZ, et al. Trauma-induced coagulopathy. Nat Rev Dis Primer. 2021;7:30.
[42] Barbee RW, Reynolds PS, Ward KR. Assessing shock resuscitation strategies by oxygen debt repayment. Shock. 2010;33:113–22.
[43] Chaudry IH. Cellular mechanisms in shock and ischemia and their correction. Am J Physiol-Regul Integr Comp Physiol. 1983;245:R117–R134.
[44] Zhang Q, Raoof M, Chen Y, et al. Circulating mitochondrial DAMPs cause inflammatory responses to injury. Nature. 2010;464:104–7.
[45] White NJ, Ward KR, Pati S, Strandenes G, Cap AP. Hemorrhagic blood failure: oxygen debt, coagulopathy and endothelial damage. J Trauma Acute Care Surg. 2017;82:S41–S49.
[46] Hoffman M, Cichon LJH. Practical coagulation for the blood banker. Transfusion (Paris). 2013;53:1594–1602.
[47] Chang R, Cardenas JC, Wade CE, Holcomb JB. Advances in the understanding of trauma-induced coagulopathy. Blood. 2016;128:1043–9.
[48] Moore HB, Moore EE, Liras IN, et al. Acute fibrinolysis shutdown after injury occurs frequently and increases mortality: a multicenter evaluation of 2,540 severely injured patients. J Am Coll Surg. 2016;222:347–55.
[49] Ball C. Damage control resuscitation: history, theory and technique. Can J Surg. 2014;57:55–60.
[50] Duchesne JC, McSwain NE, Cotton BA, et al. Damage control resuscitation: the new face of damage control. J Trauma Inj Infect Crit Care. 2010;69:976–90.
[51] Giannoudi M, Harwood P. Damage control resuscitation: lessons learned. Eur J Trauma Emerg Surg. 2016;42:273–82.
[52] LaGrone LN, Stein D, Cribari C, et al. American Association for the Surgery of Trauma/American College of Surgeons Committee on Trauma: clinical protocol for damage-control resuscitation for the adult trauma patient. J Trauma Acute Care Surg. 2024;96:510–20.
[53] Leibner E, Andreae M, Galvagno SM, Scalea T. Damage control resuscitation. Clin Exp Emerg Med. 2020;7:5–13.
[54] Cap AP, Pidcoke HF, Spinella P, et al. Damage control resuscitation. Mil Med. 2018;183:36–43.
[55] Joint Trauma System. Damage Control Resuscitation Clinical Practice Guideline. USA: Department of Defense; 2019. https://jts.health.mil/index.cfm/PI_CPGs/cpgs.
[56] Hörer T, McGreevy DT, Hoencamp R. The concept of endovascular resuscitation and trauma management: building the EVTM team. In: Hörer T, DuBose JJ, Rasmussen TE, White JM, editors. Endovascular Resuscitation and Trauma Management. Cham: Springer International Publishing; 2019. pp. 1–12.
[57] Chen Y-S, Lin J-W, Yu H-Y, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. The Lancet. 2008;372:554–61.
[58] Tremblay LN, Rizoli SB, Brenneman FD. Advances in fluid resuscitation of hemorrhagic shock. Can J Surg J Can Chir. 2001;44:172–9.
[59] Barnard EBG, Manning JE, Smith JE, Rall JM, Cox JM, Ross JD. A comparison of selective aortic arch perfusion and resuscitative endovascular balloon occlusion of the aorta for the management of hemorrhage-induced traumatic cardiac arrest: a translational model in large swine. PLOS Med. 2017;14:e1002349.
[60] Bulger EM, Perina DG, Qasim Z, et al. Clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in civilian trauma systems in the USA, 2019: a joint statement from the American College of Surgeons Committee on Trauma, the American College of Emergency Physicians, the National Association of

Emergency Medical Services Physicians and the National Association of Emergency Medical Technicians. Trauma Surg Acute Care Open. 2019;4:e000376.

[61] Zakaluzny SA, Beldowicz BC, Salcedo ES, DuBose JJ, Moore LJ, Brenner M. Guidelines for a system-wide multidisciplinary approach to institutional resuscitative endovascular balloon occlusion of the aorta implementation. J Trauma Acute Care Surg. 2019;86:337–43.

[62] American College of Surgeons Committee on Advanced Trauma Life Support (ATLS). Student Course Manual. 10th ed. Chicago, IL: American College of Surgeons; 2018.

[63] Gurney JM, Staudt AM, Del Junco DJ, et al. Whole blood at the tip of the spear: a retrospective cohort analysis of warm fresh whole blood resuscitation versus component therapy in severely injured combat casualties. Surgery. 2022;171:518–25.

[64] Sperry JL, Guyette FX, Brown JB, et al. Prehospital plasma during air medical transport in trauma patients at risk for hemorrhagic shock. N Engl J Med. 2018;379:315–26.

[65] Moore HB, Moore EE, Chapman MP, et al. Plasma-first resuscitation to treat haemorrhagic shock during emergency ground transportation in an urban area: a randomised trial. The Lancet. 2018;392:283–91.

[66] Reitz KM, Moore HB, Guyette FX, et al. Prehospital plasma in injured patients is associated with survival principally in blunt injury: results from two randomized prehospital plasma trials. J Trauma Acute Care Surg. 2020;88:33–41.

[67] Gruen DS, Guyette FX, Brown JB, et al. Association of prehospital plasma with survival in patients with traumatic brain injury: a secondary analysis of the pamper cluster randomized clinical trial. JAMA Netw Open. 2020;3:e2016869.

[68] Pusateri AE, Moore EE, Moore HB, et al. Association of prehospital plasma transfusion with survival in trauma patients with hemorrhagic shock when transport times are longer than 20 minutes: a post hoc analysis of the pamper and combat clinical trials. JAMA Surg. 2020;155:e195085.

[69] The ATLS Subcommittee, American College of Surgeons' Committee on Trauma, and the International ATLS Working Group. Advanced Trauma Life Support (ATLS®): the ninth edition. J Trauma Acute Care Surg. 2013;74:1363–6.

[70] American College of Surgeons (ed). Advanced Trauma Life Support: ATLS; Student Course Manual. 9th ed. Chicago, IL: American College of Surgeons; 2012.

[71] Galvagno SM, Nahmias JT, Young DA. Advanced Trauma Life Support ® update 2019. Anesthesiol Clin. 2019;37:13–32.

[72] Spahn DR, Bouillon B, Cerny V, et al. Management of bleeding and coagulopathy following major trauma: an updated European guideline. Crit Care. 2013;17:R76.

[73] Spahn DR, Bouillon B, Cerny V, et al. The European guideline on management of major bleeding and coagulopathy following trauma: fifth edition. Crit Care. 2019;23:98.

[74] Maegele M, Lefering R, Yucel N, et al. Early coagulopathy in multiple injury: an analysis from the German Trauma Registry on 8724 patients. Injury. 2007; 38:298–304.

[75] Guyette FX, Sperry JL, Peitzman AB, et al. Prehospital blood product and crystalloid resuscitation in the severely injured patient: a secondary analysis of the prehospital air medical plasma trial. Ann Surg. 2021;273:358–64.

[76] Sims CA, Holena D, Kim P, et al. Effect of low-dose supplementation of arginine vasopressin on need for blood product transfusions in patients with trauma and hemorrhagic shock: a randomized clinical trial. JAMA Surg. 2019;154:994.

[77] Cohn SM, McCarthy J, Stewart RM, Jonas RB, Dent DL, Michalek JE. Impact of low-dose vasopressin on trauma outcome: prospective randomized study. World J Surg. 2011;35:430–9.

Narrative Review Article

Vol. 8, No. 3; 2024; pp 74–80
DOI: https://doi.org/10.26676/jevtm.33472

Trans Arterial Embolization of Spontaneous Abdominal Muscle Bleeding

Pierpaolo Biondetti[1], Gaetano Valerio Davide Amato[2], Carolina Lanza[1], Serena Carriero[1], Velio Ascenti[2], Chiara Grilli[2], Edon Xhepa[2], Salvatore Alessio Angileri[1], Anna Maria Ierardi[1] and Gianpaolo Carrafiello[1,3]

[1]Radiology Department, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy
[2]Postgraduate School of Radiology, University of Milan, Milan, Italy
[3]Università degli Studi di Milano, Milan, Italy

Spontaneous abdominal muscle bleeding is an uncommon condition that usually arises in elderly and fragile patients. Commonly affected areas include body wall muscles, particularly the rectus sheath and the iliopsoas, with clinical manifestations such as abdominal pain, groin pain, anemia, and in severe cases, hemorrhagic shock. A computed tomography multiphase scan is the preferred modality of examination, as it allows the characterization of hematomas and the assessment of active bleeding. Conservative management of coagulopathy is standard care for stable patients while embolization and surgical options are reserved for those with hemodynamic instability or significant bleeding. Current literature provides incongruous results on outcomes, while some authors consider embolization only after conservative treatment failure, other authors advocate for a more aggressive approach in patients who are at high risk of developing a poor outcome. This discrepancy underlines the need for further standardized research to optimize management approaches in this fragile patient population.

Keywords: *Spontaneous Abdominal Bleeding; Intramuscular Hematoma; Hemorrhage Control; Trans Arterial Embolization; Interventional Radiology.*

Received: 7 November 2024; Accepted: 5 December 2024

SPONTANEOUS ABDOMINAL BLEEDING

Spontaneous abdominal bleeding is defined as a hemorrhage not caused by a traumatic injury. The reported incidence for this condition varies between 0.6% and 6% but may be under-reported. However, the frequency of these events in Western countries is expected to increase due to the aging population and the increasing number of indications for anticoagulation therapies, which are a significant risk factor for spontaneous bleeding [1].

Cases due to anticoagulation or bleeding diatheses commonly involve multiple sites, especially the abdominal muscles (e.g. the iliopsoas or rectus sheath muscle), while viscera are less frequently involved [2].

Clinical presentation varies and is non-specific, including abdominal pain or mass, groin or hip pain, anemia, and hypotension. Most cases are indolent and do not require any intervention other than correction of the underlying coagulopathy, but if not promptly recognized and strictly monitored, they could result in a sudden and catastrophic evolution.

Ethical Approval and Informed Consent

Ethical approval was not required. Written informed consent was not required.

DIAGNOSIS

The effects of hemorrhage on laboratory testing, in particular hemoglobin and hematocrit, could manifest only after hours, and misdiagnosis is frequent. In worst-case scenarios, spontaneous abdominal muscle bleeding could lead to hemodynamic instability and become life-threatening, with reported mortality rates of 30% for retroperitoneal hematomas [3,4].

Corresponding author:
Gaetano Valerio Davide Amato, Postgraduate School of Radiology, University of Milan, Via Festa del perdono 7, Milan, Italy.
Email: gaetano.amato@unimi.it

The cornerstone for diagnosis is the multiphase computed tomography (CT) scan: it allows evaluation of size, location of hematoma, and signs of active or recent bleeding, and also the detection of responsible arteries [5].

The reported sensibility of a multiphase CT scan in detecting active (arterial) contrast extravasation is between 47% and 93% [6–8]. Another CT sign of bleeding is the so-called "hematocrit sign," a cellular–fluid level caused by the settling of cellular elements in the dependent portion of a hematoma, which is a very sensitive (87%) and specific sign of coagulopathic hemorrhage [9].

Digital subtraction angiography is the gold standard for the diagnosis and localization of active bleeding, but spasm, tamponade, shock, and technical limitations may limit the visibility of bleeding during angiographic procedures. The CT scan plays a key role in pre-procedural planning to reduce procedural time in difficult cases.

PHYSIOPATHOLOGY

Physiopathology of spontaneous muscle hematomas is complex and based on a multifactorial microangiopathy. Risk factors include age, atherosclerosis, vascular lesions from chronic arterial hypertension, and especially diabetes. Anticoagulant-induced immune microangiopathy has been reported to be a predisposing factor. Bleeding is the result of micro-traumatic damage (e.g. closed glottis straining, isometric muscle contractions) causing tears in muscles and fragile capillary vessels [3,10].

RISK FACTORS

Approximately two-thirds of spontaneous retroperitoneal and rectus sheath hemorrhages are associated with therapeutic anticoagulation and/or with conditions that either increase the effect of anticoagulation drugs (chronic renal insufficiency and dialysis, estimated glomerular filtration rate (eGFR) <30) or directly affect coagulation function (coagulation disorders, hepatic insufficiency, international normalized ratio (INR) ≥2.0) [5,11].

However, spontaneous fatal bleeding or major bleeding in patients undergoing anticoagulation therapy is relatively uncommon, ranging from 0.06% to 0.30% and 1.1% to 4%, respectively [12,13]. Direct oral anticoagulants (DOACs) present a lower bleeding risk compared to classical vitamin K antagonists, but routine coagulation tests cannot evaluate the degree of anticoagulation, and treatment relies on specific reversal agents which are expensive and may not be readily available [14,15].

Antiplatelet therapy is also considered a risk factor accounting for 30–40% of patients with spontaneous retroperitoneal hematoma, but usually alongside anticoagulation [16].

Spontaneous muscle hematomas occur in a fragile population: the mean population age is advanced (mean range of different studies reported between 68 and 72 years), with most patients (96%) having documented known comorbidities prior to presentation [8,17].

Frequently, a slight female predominance is noted and this is thought to be caused by a lower muscular mass fraction [8].

SITES OF BLEEDING AND ANATOMY

The localization of spontaneous abdominal muscle hematomas occurs mainly in the rectus in the anterior compartment (Figure 1) and in the iliopsoas muscle in the posterior compartment, while it happens more rarely in other muscles such as the oblique, the thigh, and the gluteal region [8,18].

The arteries most involved in rectus muscle bleeding are the inferior epigastric artery, the circumflex iliac artery, and the superior epigastric artery, while the ileo-lumbar artery and the lumbar arteries are involved in iliopsoas muscle bleeding [5].

Anatomically, the anterior compartment is divided into two parts by the arcuate ligament, located at the junction of the middle and inferior third of the rectus muscles, at the level of which the posterior sheath of the rectus muscles becomes anterior. Above the arcuate ligament, where the posterior aspect is covered by both the posterior rectus sheath and the transversalis fascia, hematomas usually result from distal lesions of the inferior epigastric artery and are usually contained and self-limiting. Below the arcuate ligament, only the transversalis fascia is found posteriorly, and hematomas result from proximal lesion of the artery which has weakened walls. Moreover, the lowest part of the rectus muscle is the longest and subject to the greatest shortening with contraction, generating higher tensional forces [19–21].

All these factors result in larger inferior anterior wall hematomas that dissect the muscle, possibly crossing the median line and creating new foci of bleeding while expanding.

MANAGEMENT

There are no clear guidelines regarding which subgroup(s) of patients require an intervention. Generally, in hemodynamically stable patients the standard of care is conservative treatment, including management of hemostasis disorders, stop and/or antagonization of anticoagulants, vascular filling, and transfusion.

In the last decades, the role of surgery in the management of this condition has been progressively reduced.

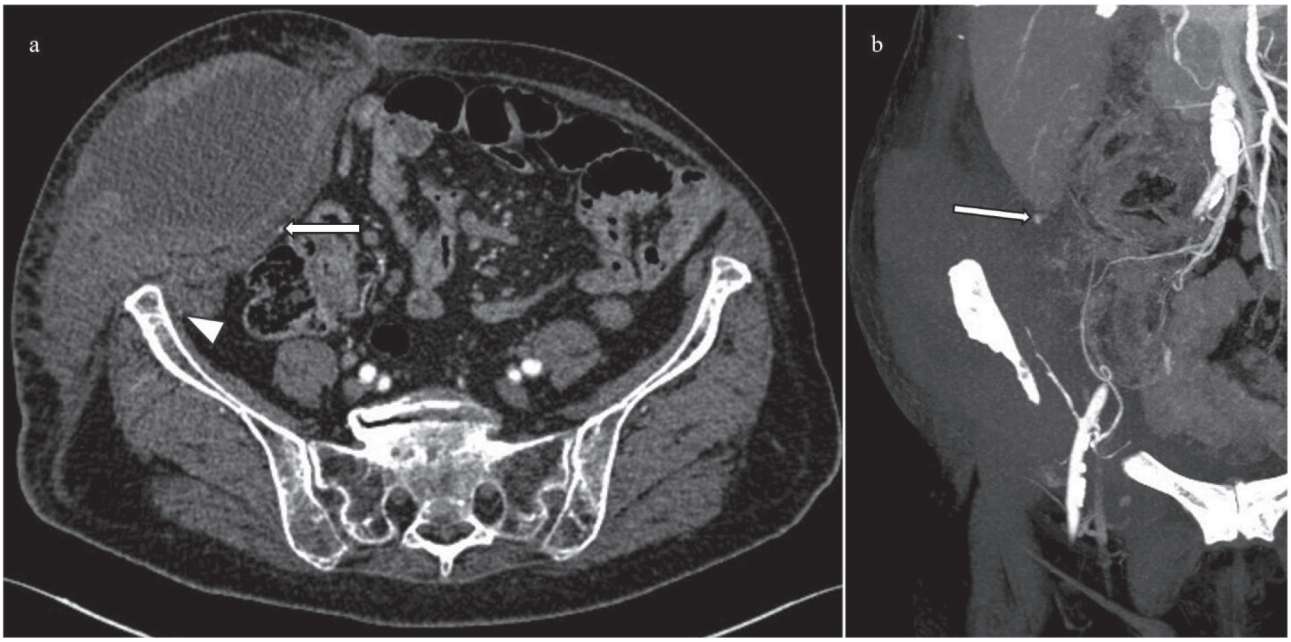


Figure 1 Right rectus sheath hematoma. (**a**) Pre-procedural axial arterial-phase CT image showing a large right rectus sheath hematoma refurnished by the inferior right epigastric artery (thin arrow) and the circumflex artery (arrowhead). (**b**) Pre-procedural coronal CT maximum intensity projection (MIP) reconstruction image showing the active bleeding (thin arrow) refurnished by the inferior right epigastric artery.

In patients with hemodynamic instability surgical arterial ligation may be challenging, and considering the comorbidities that usually occur in this patient population, surgery is often not a feasible option. Surgery is usually reserved for hematoma evacuation or in cases of compression ischemia.

Nowadays the most performed treatment is trans arterial embolization (TAE), which is fast, safe, and effective; moreover, it does not require general anesthesia and is less invasive, reducing morbidity, and mortality [6,22].

INDICATION FOR EMBOLIZATION AND TREATMENT ALGORITHM

Hemodynamic instability, uncontrolled bleeding despite adequate conservative treatment, low hemoglobin (Hb) values, and the need for continued transfusions account for 80% of the indications for embolization reported in the literature [8].

Other indications reported are active arterial-phase bleeding, rupture of fascia or muscles with hemoperitoneum, and clinical conditions, including the impossibility of stopping anticoagulation due to comorbidities.

Active arterial iliopsoas bleeding is a strong predictor of treatment, which is correlated with severity of hematoma and associated with unsuccessful conservative treatment [5,17].

Factors that are also considered are hematoma localization, as retroperitoneal hematomas are reported to be more severe, and the hematoma volume, even if no clear cutoff exists [8,17,23].

Most of these factors are included in the interesting treatment algorithm for patients with spontaneous intramuscular hematoma proposed by Popov et al. [24].

Stable patients with no active bleeding found on a CT scan are treated conservatively; the same treatment is performed in unstable patients and/or those with CT identified active bleeding that have no fascia rupture and that can stop anticoagulation.

Conversely, patients who are unstable and/or have CT identified active bleeding with fascia rupture, who cannot stop anticoagulation, or who are not on anticoagulation therapy then undergo TAE. Lastly, embolization is performed when conservative treatment fails [24].

TIMING AND FINDINGS AT ANGIOGRAPHY

Indications for treatment should be a joint decision after discussion in a multidisciplinary team composed of interventional radiologists, surgeons, and internal and emergency medicine physicians. Embolization should be performed as soon as possible, but the reported time between CT scan and angiography varies widely in the literature; average mean procedural time has been reported to be between 43 min and 7 h 50 min in different studies [6,23,24].

At angiography, the signs of active bleeding (Figure 2) may be direct (contrast blush extravasation, focal spot of enhancement, hemorrhagic petechiae, pseudoaneurysm) or indirect (vessel cutoff sign or massive vasospasm).

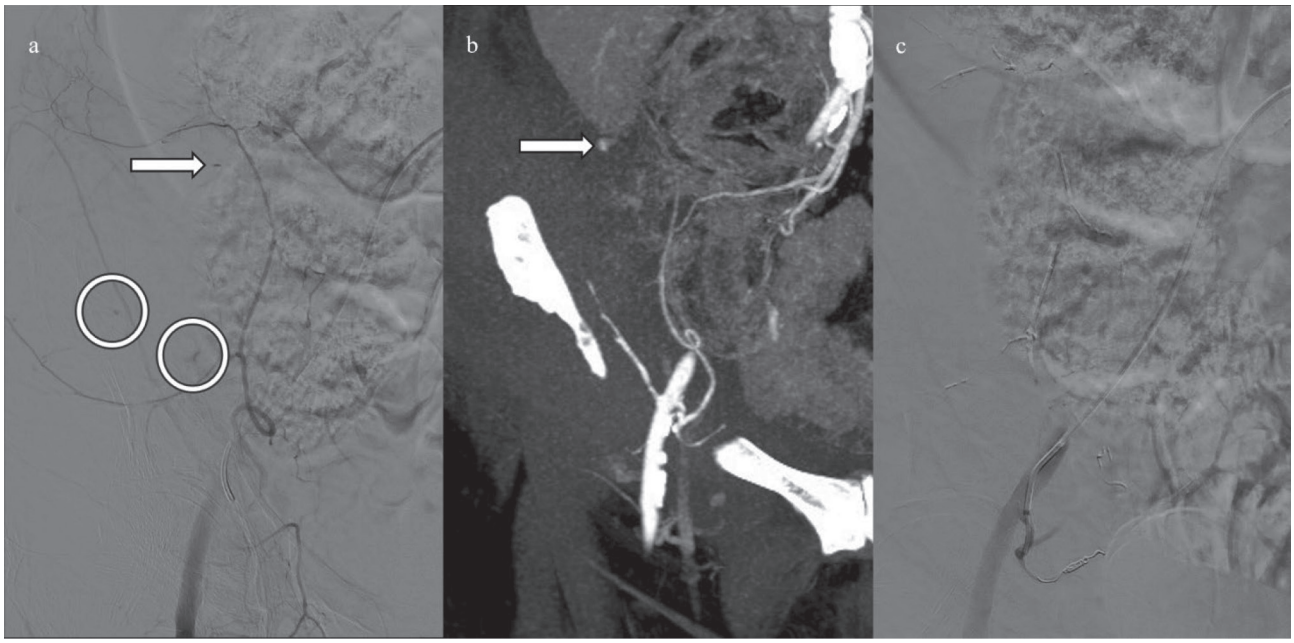


Figure 2 Transarterial embolization of the right rectus sheath hematoma. (**a**) Selective DSA from the right inferior epigastric artery which confirmed the presence of multiple active arterial blushes (circles), one of the bleeding spots, matched the CT findings (arrow). (**b**) Magnification of the pre-procedural coronal CT MIP reconstruction image showing active bleeding (arrow) matching the DSA findings. (**c**) DSA after glue and coils embolization of the right inferior epigastrig artery showing complete devascularization.

The detection rate of active bleeding on digital subtraction angiography (DSA) is reported to be between 70% and 86% [6,25].

In a recent systematic review, the rate of active bleeding at DSA was higher than at CT, confirming that a decision to perform angiographic studies in a patient with spontaneous bleeding relies on multiple factors [8].

EMBOLIC MATERIALS

There is a great heterogeneity of data regarding the embolic materials which are used, with still no evidence to recommend one embolic material over the other [23].

In a systematic review, coils were used in 30.7% of cases, glue in 18.1%, gelfoam in 16.4%, microparticles in 6%, a combination of coils and gelfoam in 13%, and a combination of coils and microparticles in 12.2% of the cases [8]. Coils are frequently reported as the most commonly used embolic agents in the literature even if they have the significant limitation in this patient population of being dependent on the coagulation status.

Gelfoam, which is frequently reported, has the significant disadvantage of being temporary.

Polyvinyl alcohol (PVA) particles are appreciated by some authors due to the filling of the distal diseased microvasculature and have demonstrated their efficacy in the setting of spontaneous bleeding even if they theoretically carry the disadvantage of a higher ischemia degree in the anterior compartment hematomas. Glue has also demonstrated its efficacy, can be prepared in different ways to control polymerization time, and can fill the diseased branches quickly without causing a distal-end embolization.

Non-adhesive liquids could theoretically be good options but are significantly limited by their high cost and relatively long preparation time.

In a study on embolization of anterior abdominal wall hematomas (not all but the majority were spontaneous), no difference in clinical success, survival, and complications was found comparing mechanical, liquid/particulate agents (including gelfoam, PVA, and glue), and their combination [22]. Other authors registered that most cases of recurrent bleeding after embolization of life-threatening retroperitoneal hematomas were associated with coils, concluding that glue may be preferable, with or without mechanical embolic agents [7].

Similar recurrence rates were found with resorbable and non-resorbable materials in a recent systematic review [8].

EMBOLIZATION TECHNIQUES

In this setting, two main strategies are adopted: blind embolization or targeted embolization.

Blind or empiric embolization (Figure 3) is the closure of the suspected vessel based on topographic reference and/or findings of CT in the absence of bleeding at DSA and is performed in patients with spontaneous abdominal muscular bleeding in 13–21% of cases [6–8,23].

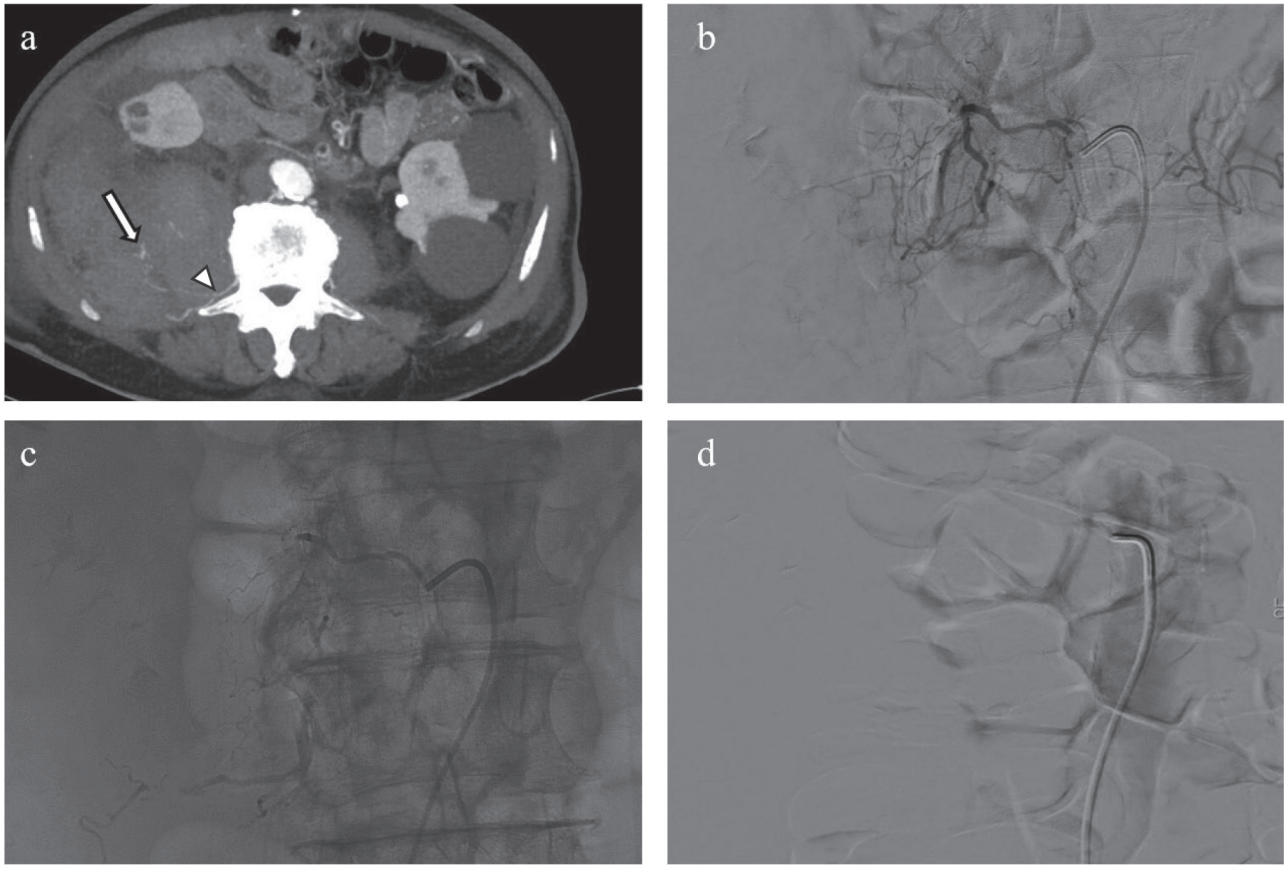


Figure 3 "Blind" embolization technique. (**a**) Pre-procedural axial arterial-phase CT MIP reconstruction image showing a large right iliopsoas hematoma with active arterial spots (arrow) refurnished by a (third lumbar spine vertebra (L3) level) right lumbar artery (arrowhead). (**b**) Selective DSA from a (L3 level) right lumbar artery without evidence of direct or indirect signs of bleeding. (**c**) Fluoroscopic image showing the blind embolization technique. Despite no evidence of active arterial blush, the lumbar artery was occluded with glue that formed multiple casts across the lumbar artery branches. (**d**) DSA after embolization of the (L3 level) right lumbar artery showing complete devascularization.

Targeted embolization consists of the closure of arteries where direct or indirect signs of active bleeding were demonstrated in the DSA study.

In a recent study there were no differences in clinical success or rebleeding rates between patients treated with targeted versus blind embolization, with success rates of 77% and 78% and rebleeding in 22% and 23% of patients, respectively [6].

The same clinical success rate (86%) after embolization in patients treated with targeted or blind embolization was also found in another recent study, in which patients from the two groups did not differ regarding gender, age, mean pre-procedural hemoglobin, localization of hematoma, or time to DSA [23].

Regarding embolization technique, one important aspect is to consider systematic embolization of anastomotic arteries if there is a high risk of backflow. This concept is particularly important in the retroperitoneum, which has a high collateral supply, and in which closure of the lumbar/iliolumbar arteries above and/or under the bleeding site, as well as the bleeding artery itself, may be advised to reduce the possibility of procedure failure or rebleeding.

In one study, the bleeding recurrence rate after first embolization was as high as 24.1% [7]. Other authors reported their experience showing that, among 42% of their patients who underwent embolization in >1 arterial territory, the majority had bleeding in the posterior compartment.

TAE OUTCOMES

Technical success rates, defined as the complete occlusion of all target vessels, reported in the literature are between 96% and 100% while reported clinical successes, defined as absence of signs of rebleeding in the following 96 h, range between 65% and 93% [6,8,22,23].

In a recent systematic review, the estimated mortality rate after TAE was 23.1%, with 22.7% of deaths occurring within the first 30 days after embolization; multiorgan failure, cardiogenic shock, and secondary infection were the main reported causes of deaths [8]. Notably,

up to 50% of patient deaths are not related to bleeding but to coexisting conditions [17].

In patients who underwent TAE, rebleeding occurred in 10.1% of patients, with 92.9% of these cases occurring in patients still on anticoagulation. A second embolization attempt is often performed in most patients with rebleeding, with this being successful in 75% of cases.

Complication rates after TAE range between 0.7% to 4%, with most being related to vascular access sites (e.g. femoral artery pseudoaneurysm, groin haematoma) [8,22].

Non-target embolization and skin necrosis are very rare, the latter being described only in a case report after embolization of an anterior muscle wall spontaneous bleed with gelfoam [26].

CONSERVATIVE TREATMENT VERSUS EMBOLIZATION – WHAT IS KNOWN AND WHAT IS NEEDED

Actual guidelines lack clear indications on which subgroup of patients should be treated conservatively and which should be treated with embolization. In the absence of clear treatment algorithms, some authors have tried to directly compare conservative treatment and embolization. In a recent single-center case control retrospective study, 54 patients with spontaneous retroperitoneal hemorrhage were divided into two groups based on the treatment received within the first 24 hours from diagnosis. Group 1 was treated conservatively while group 2 was treated with TAE. In this study, conservative management presented a higher clinical success rate compared to TAE and both all-cause and bleeding-related mortality were more likely to occur after TAE [13].

Nevertheless, the TAE group patient population presented a higher percentage of active bleeding on CT scan, a shock index >1, and received a higher volume of blood transfusion; moreover, the latter two characteristics were more likely to be present in fatal cases (15%). The authors stated that most patients with spontaneous retroperitoneal hemorrhage can be safely treated conservatively, with conservative treatment being successful also in 13% of initially unstable patients, but also acknowledge that the lower success rate in the embolization group was likely caused by underlying coagulopathy, which develops in cases of major blood loss [13].

The paper stimulated some discussion among experts. Although a common agreement was reached on the importance of prompt medical management, early diagnosis, and treatment in all cases, the authors concluded that a variety of factors can affect success, including patient-, operator-, and technique-related factors. The difference in these factors is likely to justify the difference in clinical success obtained with embolization in different centers. Therefore, the preference of conservative management over embolization should be carefully debated, and there is a strong need for standardization in reporting and in the use of materials and techniques [27,28].

Moreover, as some predictors of outcome are known, including volume of hematoma and simplified acute physiology score, randomized, prospective, controlled studies with patient stratification would be highly valuable for further advancement of knowledge [29].

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 declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

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

REFERENCES

[1] Zissin R, Ellis M, Gayer G. The CT findings of abdominal anticoagulant-related hematomas. Semin Ultrasound CT MRI. 2006;27:117–25.
[2] Becker LS, Dewald CLA, Wacker FK, et al. Spontane retroperitoneale und Rektusscheidenhämatome und ihre interventionelle Therapie: ein review. RöFo – Fortschr Röntgenstr Bildgeb Verfahr. 2024;196(2):163–75.
[3] Llitjos JF, Daviaud F, Grimaldi D, et al. Ilio-psoas hematoma in the intensive care unit: a multicentric study. Ann Intensive Care. 2016;6:8.
[4] Bargellini I, Cervelli R, Lunardi A, et al. Spontaneous bleedings in COVID-19 patients: an emerging complication. Cardiovasc Intervent Radiol. 2020;43:1095–6.
[5] Dohan A, Darnige L, Sapoval M, et al. Spontaneous soft tissue hematomas. Diagn Interv Imaging. 2015; 96:789–96.
[6] Di Pietro S, Tiralongo F, Desiderio CM, et al. Efficacy of percutaneous transarterial embolization in patients with spontaneous abdominal wall hematoma and comparison between blind and targeted embolization approaches. J Clin Med. 2022;11:1270.
[7] Klausenitz C, Kuehn J-P, Noeckler K, et al. Efficacy of transarterial embolisation in patients with life-threatening

spontaneous retroperitoneal haematoma. Clin Radiol. 2021;76:157.e11–e18.
[8] Touma L, Cohen S, Cassinotto C, et al. Transcatheter arterial embolization of spontaneous soft tissue hematomas: a systematic review. Cardiovasc Intervent Radiol. 2019;42:335–43.
[9] Furlan A, Fakhran S, Federle MP. Spontaneous abdominal hemorrhage: Causes, CT findings, and clinical implications. Am J Roentgenol. 2009;193:1077–87.
[10] Cherry WB, Mueller PS. Rectus sheath hematoma. Medicine. 2006;85:105–10.
[11] Sunga KL, Bellolio MF, Gilmore RM, et al. Spontaneous retroperitoneal hematoma: etiology, characteristics, management, and outcome. J Emerg Med. 2012;43:e157–61.
[12] Gunasekaran K, Rajasurya V, Devasahayam J, et al. A review of the incidence diagnosis and treatment of spontaneous hemorrhage in patients treated with direct oral anticoagulants. J Clin Med. 2020;9:2984.
[13] Lukies M, Gipson J, Tan SY, et al. Spontaneous retroperitoneal haemorrhage: efficacy of conservative management and embolisation. Cardiovasc Intervent Radiol. 2023;46:488–95.
[14] Giugliano RP, Ruff CT, Braunwald E, et al. Edoxaban versus warfarin in patients with atrial fibrillation. N Engl J Med. 2013;369:2093–104.
[15] de Courcy L, Connaughton J. Spontaneous rectal sheath bleed while on DOAC anticoagulation. BMJ Case Rep. 2023;16:e254313.
[16] Ibrahim W, Mohamed A, Sheikh M, et al. Antiplatelet therapy and spontaneous retroperitoneal hematoma: a case report and literature review. Am J Case Rep. 2017;18:85–9.
[17] Baekgaard JS, Eskesen TG, Lee JM, et al. Spontaneous retroperitoneal and rectus sheath hemorrhage—management, risk factors and outcomes. World J Surg. 2019;43:1890–7.
[18] Rimola J, Perendreu J, Falcó J, et al. Percutaneous arterial embolization in the management of rectus sheath hematoma. Am J Roentgenol. 2007;188:W497–W502.
[19] Albuquerque TVC, Monsignore LM, de Castro-Afonso LH, et al. Transarterial embolization with n-butyl cyanoacrylate for the treatment of abdominal wall hemorrhage. Diagn Interv Radiol. 2020;26:216–22.
[20] Sheth HS, Kumar R, DiNella J, et al. Evaluation of risk factors for rectus sheath hematoma. Clin Appl Thromb. Hemost. 2016;22:292–6.
[21] Ozaras R, Yilmaz MH, Tahan V, et al. Spontaneous hematoma of the rectus abdominis muscle: a rare cause of acute abdominal pain in the elderly. Acta Chir Belg. 2003;103:332–3.
[22] Cacioppa LM, Floridi C, Cocozza MA, et al. The prominent role of percutaneous transarterial embolization in the treatment of anterior abdominal wall hematomas: the results of three high volume tertiary referral centers. Radiol Med. 2023;128:1125–37.
[23] Tiralongo F, Giurazza F, Di Pietro S, et al. Spontaneous abdominal wall hematoma treated with percutaneous transarterial embolization: diagnostic findings, procedural outcome, and efficacy—a multicenter study. J Clin Med. 2023;12:4779.
[24] Popov M, Sotiriadis C, Gay F, et al. Spontaneous intramuscular hematomas of the abdomen and pelvis: a new multilevel algorithm to direct transarterial embolization and patient management. Cardiovasc Intervent Radiol. 2017;40:537–45.
[25] Barral M, Pellerin O, Tran VT, et al. Predictors of mortality from spontaneous soft-tissue hematomas in a large multicenter cohort who underwent percutaneous transarterial embolization. Radiology. 2019;291:250–8.
[26] Djaber S, Bohelay G, Moussa N, et al. Cutaneous necrosis after embolization of spontaneous soft-tissue hematoma of the abdominal wall. Diagn Interv Imaging. 2018;99:831–3.
[27] Li X, Guan J, Partovi S. Embolization of spontaneous retroperitoneal hemorrhage: an individualized approach is needed. Cardiovasc Intervent Radiol. 2023;46:498–9.
[28] Calabrese F, Palumbo D, De Cobelli F. A call for standardization in interventional radiology practice: how to deal with spontaneous retroperitoneal haemorrhage? Cardiovasc Intervent Radiol. 2023;46:543–4.
[29] Lerardi AM, Ascenti V, Carrafiello G. How to manage spontaneous retroperitoneal haemorrhage. Cardiovasc Intervent Radiol. 2023;46:496–7.

Case Report

Vol. 8, No. 3; 2024; pp 81–85
DOI: https://doi.org/10.26676/jevtm.27112

Treatment Experience Using a Stent Graft for Lumbar Artery Injury that Failed Coil Embolization

Gil H Kim[1,2], Sang B Lee[1,2], Chan I Park[1,2], Jae H Kim[1,2,3] and Chang W Kim[2,3,4]

[1]*Department of Trauma and Surgical Critical Care, Pusan National University Hospital, Busan, Korea*
[2]*Biomedical Research Institute, Pusan National University Hospital, Busan, Korea*
[3]*Pusan National University School of Medicine, Busan, Korea*
[4]*Department of Radiology, Pusan National University Hospital, Busan, Korea*

Transcatheter embolization currently constitutes the primary treatment for lumbar artery injury due to blunt trauma. We present a case where a stent graft effectively treated a lumbar artery injury after coil embolization failed to achieve hemostasis. Aortic stent graft implantation is a safe procedure that can prevent surgical morbidity and has minimal complications. It may serve as an effective alternative for achieving hemostasis when coil embolization is not feasible or is unsuccessful.

Keywords: *Endovascular Treatment; Lumbar Artery Injury; Coil Embolization*

Received: 23 August 2024; Accepted: 21 September 2024

INTRODUCTION

Today, endovascular treatment is a critical component of trauma patient care. In patients with lumbar artery injury (LAI), it is challenging to accurately control bleeding through surgery. Hence, endovascular treatment involving coil embolization is the preferred treatment option. Furthermore, a vascular injury in the retroperitoneal space can be simultaneously diagnosed and treated using arteriography. However, if coil embolization is not possible, an aortic stent can be placed to prevent persistent bleeding. Here we describe our experience of efficiently treating with a stent graft bleeding that persisted following coil embolization.

CASE PRESENTATION

A 53-year-old man was admitted to the hospital after becoming trapped between equipment while working in a factory. He reported severe back pain, weakness, and reduced sensation in both legs. He was rescued by paramedics and subsequently underwent a computed tomography (CT) scan at a nearby hospital. He arrived at our hospital five hours after the injury and, during this time, he received a transfusion of five bags of packed red blood cells. The patient's vital signs at the time of admission were as follows: blood pressure, 70/40 mm Hg; heart rate, 95 per min; respiratory rate, 23 per min; oxygen saturation SpO_2, 94% (room air); and a Glasgow Coma Scale score of 15. No external injury was observed, except for a facial laceration. No signs of internal bleeding were detected on ultrasonography employing the Focused Assessment with Sonography in Trauma protocol. However, retroperitoneal hematoma with overt bleeding due to LAI and multiple vertebral fractures were diagnosed after a CT scan at the first hospital (Figures 1 and 2).

The patient was transfused with two bags of packed red blood cells and two bags of fresh frozen plasma. The patient's blood pressure returned to 101/52 mm Hg following fluid resuscitation. Given the LAI and hemorrhage in other regions, the patient was transferred to the intervention room for embolization. During the angiography, multiple lumbar arteriograms revealed extravasation in the right lumbar arteries. Each lumbar artery was selected using an angiocatheter and microcatheter and then embolized with eight microcoils and a lipiodol–histoacryl mixture (Figures 3 and 4).

The patient's vital signs were consistently maintained without the necessity of vasopressors following

Corresponding author:
Sang Bong Lee, Department of Trauma and Surgical Critical Care, Pusan National University Hospital, Busan, Korea; 179, Kudeok-ro, Seo-gu, Busan, Korea, 49241.
E-mail: scout79x@hanmail.net

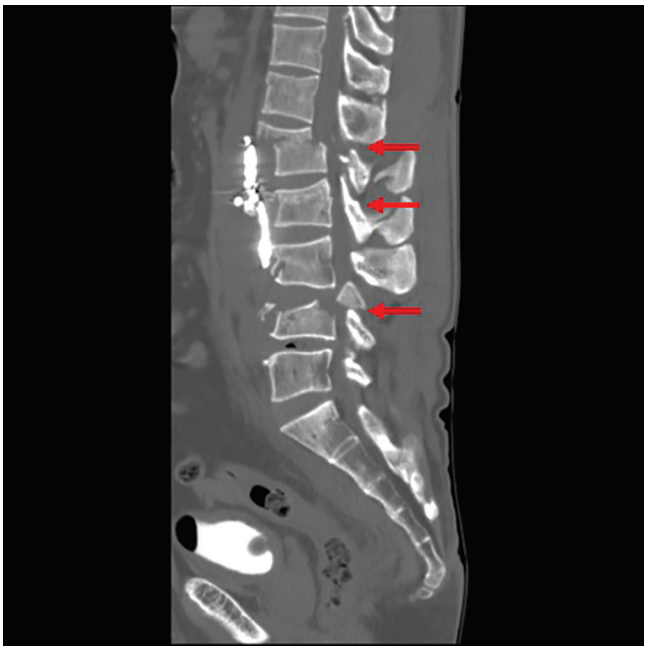


Figure 1 Injuries of the lumbar vertebrae (L): L1 burst fracture, L2–4 recent compression fracture (arrows), and multiple fractures of both the transverse and spinous processes.

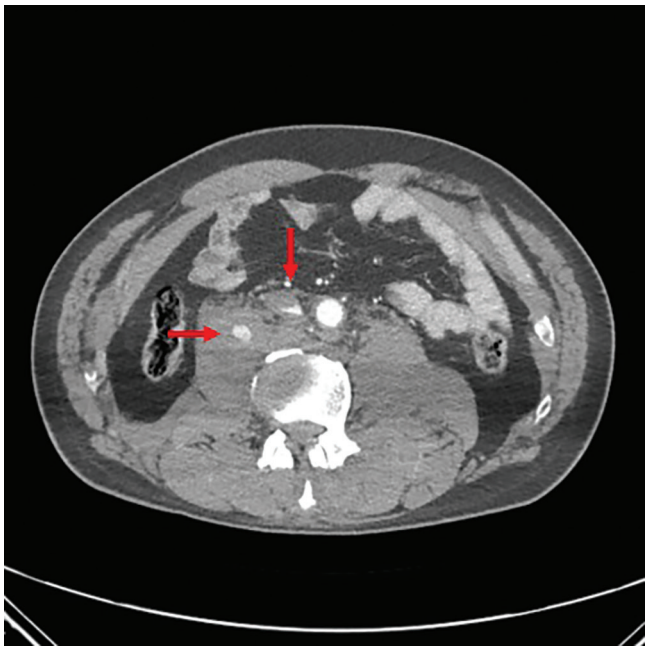


Figure 2 Extensive hematoma in the retroperitoneal space including the pararenal space. Right psoas muscle hematoma at the lumbar vertebrae L2 level indicative of acute arterial bleeding (arrows) originating from the lumbar artery.

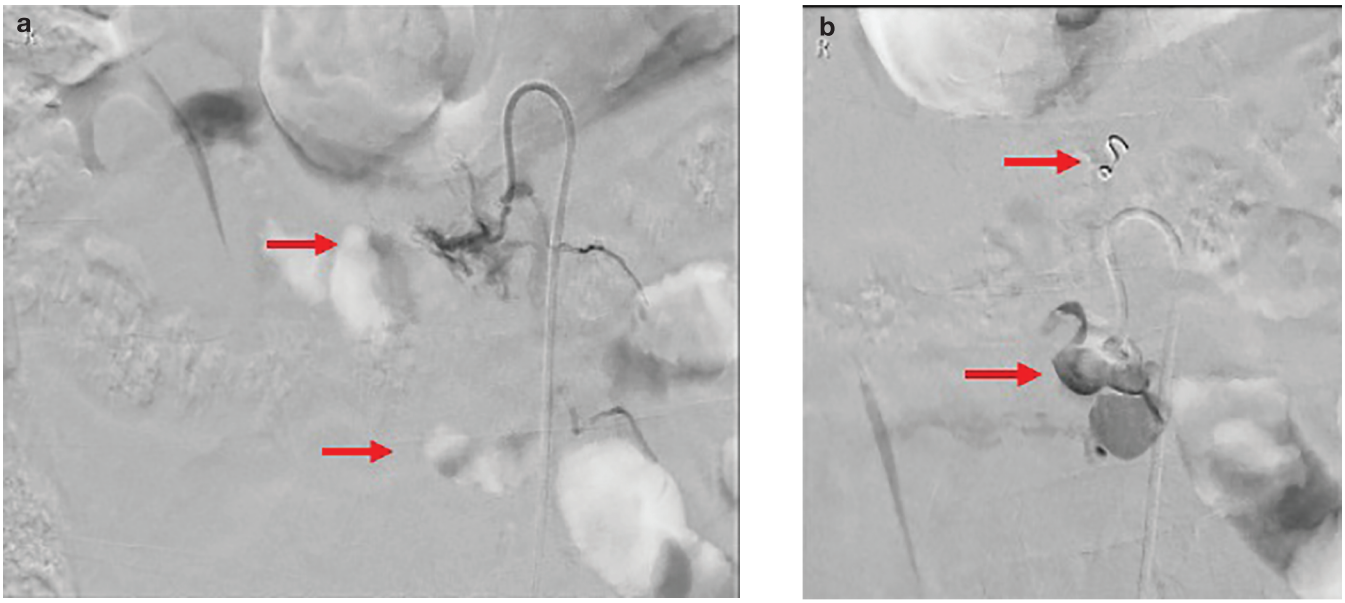


Figure 3 (**a**) Multiple lumbar arteriograms revealing extravasation from the right lumbar arteries (arrows). (**b**) Coil embolization and a lipiodol–histoacryl mixture (arrows) of selected lumbar arteries.

admission to the intensive care unit. However, on the second day after the injury, an abdominal CT scan was performed after the laboratory findings revealed that hemoglobin levels had dropped from 14.3 to 7.6 g/dL. The abdominal CT scan revealed continued overt bleeding at the site of the previous coil embolization, and therefore re-embolization was planned (Figure 5). However, the aortography demonstrated that there was insufficient space for coil embolization, and it was determined that an aortic stent placement would instead be implanted. The aortogram identified the tear at the origin of the lumbar artery. Therefore, a 20 mm × 20 mm × 80 mm stent graft (Medtronic, Minneapolis, MN, USA) was inserted and placed in the infrarenal aorta. The aortogram confirmed that the tear was covered and the lumen of the stent graft was patent (Figures 6 and 7). The patient's condition stabilized after stent insertion, and no complications were observed

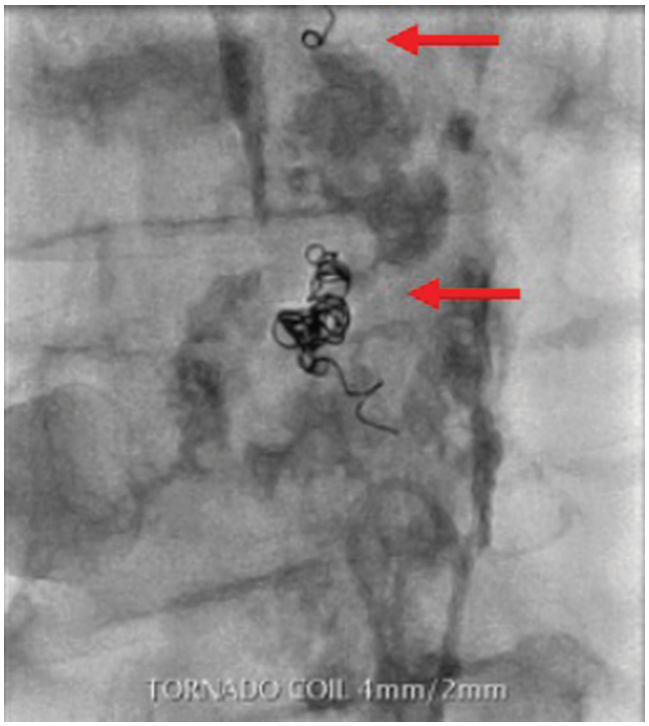


Figure 4 After identifying each lumbar artery using an angiocatheter and microcatheter, embolization was performed with eight microcoils (arrows) and a lipiodol–histoacryl mixture.

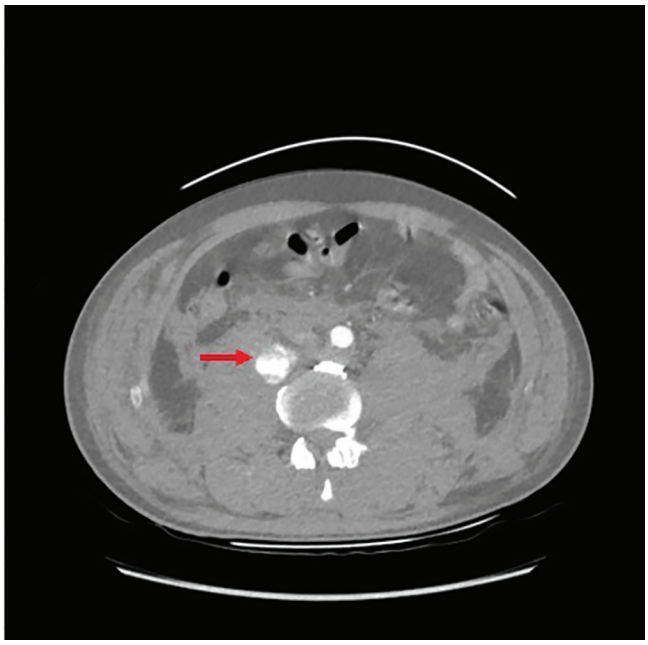


Figure 5 Post-embolization state following acute arterial bleeding from the paraspinal vessels (arrow), which originate from the abdominal aorta, visible at the right psoas muscle, lumbar vertebrae L2 level.

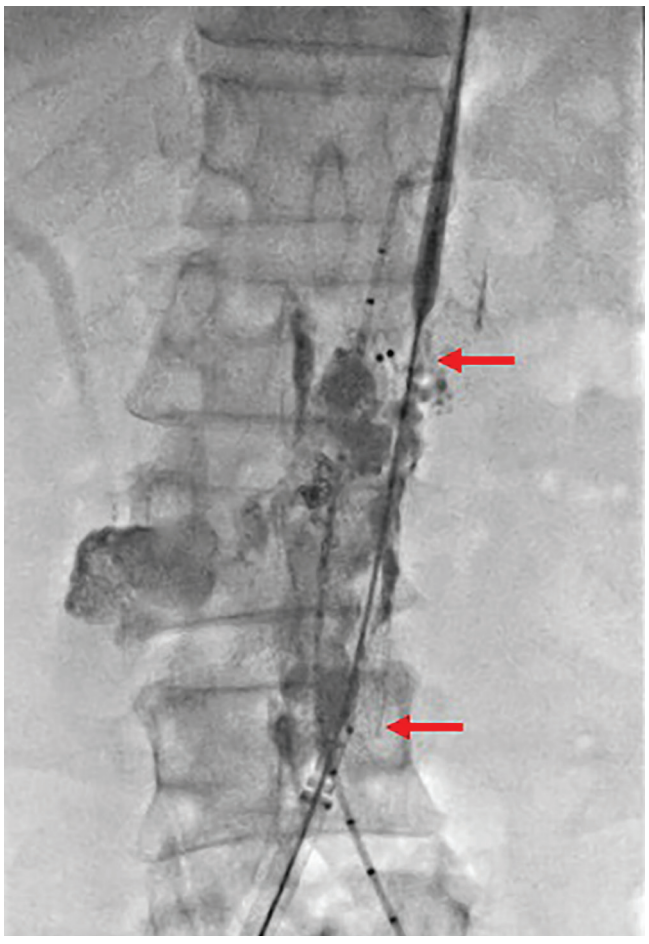


Figure 6 A 20 mm × 20 mm × 8 cm stent graft (Medtronic, Minneapolis, MN, USA) was placed in the infrarenal aorta (arrows).

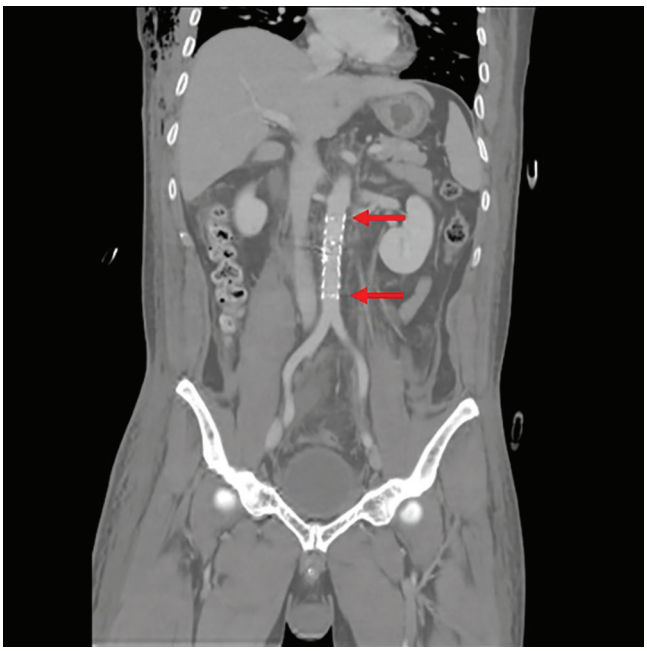


Figure 7 Follow-up CT scan. The aortic stent is patent (arrows), and no findings to suggest active contrast leakage were observed in the current CT scan.

following the procedure. A magnetic resonance imaging scan was performed on the sixth day after the injury, prior to the spinal surgery. Following spinal fixation on the seventh day after the injury, the patient was transferred to the neurosurgery department and eventually monitored on an outpatient basis.

Ethical Approval and Informed Consent

This study was approved by the Institutional Review Board of Pusan National University Hospital, Busan, Korea, and was performed in accordance with the ethical standards set forth in the 1964 Declaration of Helsinki and its later amendments (IRB No.: 2048-011-142). Informed consent was waived owing to the retrospective nature of the study.

DISCUSSION

LAI frequently occurs concurrently with a fracture of the spine or pelvis in patients who have sustained blunt trauma. The treatment approach is determined based on the associated injuries and hemodynamic status. In hemodynamically unstable cases, lumbar artery injuries are treated surgically. However, it is challenging to localize the source of bleeding and, consequently, the mortality rate is high [1,2].

In the present case, coil embolization was implemented because the patient responded to fluid resuscitation; however, retroperitoneal exploration would have been performed if the fluid resuscitation were unsuccessful. However, identifying the bleeding site accurately and conducting proximal hemostatic procedures would have been difficult, resulting in a deterioration of the patient's condition.

In hemodynamically stable cases, the primary treatment for LAI is transcatheter embolization. During endovascular treatment, embolic substances such as coils or gelfoam are employed. However, coil embolization is preferred to prevent complications such as retroperitoneal infarction. Coil embolization has a hemostasis success rate of 70–100% and is a safe treatment modality with minimal complications [1–3]. However, if there is insufficient space for embolization or if the selection of the lumbar artery proves difficult, there is a risk of persistent bleeding. If hemostasis is not achieved, conservative management can be implemented, provided the patient's hemodynamic signs are stable [1]. Nevertheless, if persistent bleeding occurs, an aortic stent may be inserted to arrest the hemorrhage [4,5]. Aortic stents are currently employed extensively in trauma patients to treat thoracic aortic injuries. Placement of an aortic stent is a minimally invasive procedure that does not require aortic cross-clamping.

In addition, recent studies have demonstrated favorable outcomes in long-term follow-up, and it is considered a safe treatment that can reduce surgical morbidity [6]. Compared to thoracic aortic stents, abdominal aortic stent implantation is a safe procedure with fewer reported complications of spinal cord injury [7]. This procedure has been effectively employed in the treatment of lumbar artery pseudoaneurysms caused by specific diseases when coil embolization is difficult [8]. In conclusion, aortic stent placement may serve as an effective alternative to coil embolization when hemostasis proves difficult to accomplish.

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 no conflicts of interest.

Funding

This work was supported by a clinical research grant from Pusan National University Hospital in 2023.

Author Contribution

Conceptualization, Chang won Kim and Jae Hun Kim. Writing – original draft, Gil Hwan Kim. Writing – review & editing, Sang Bong Lee and Chan Ik Park. All authors have read and agreed to the published version of the manuscript.

REFERENCES

[1] Yuan KC, Hsu YP, Wong YC, Fang JF, Lin BC, Chen HW. Management of complicated lumbar artery injury after blunt trauma. Ann Emerg Med. 2011;58:531–5.
[2] Akpinar E, Peynircioglu B, Turkbey B, Cil BE, Balkanci F. Endovascular management of life-threatening retroperitoneal bleeding. ANZ J Surg. 2008;78:683–7.
[3] Sofocleous CT, Hinrichs CR, Hubbi B, Doddakashi S, Bahramipour P, Schubert J. Embolization of isolated lumbar artery injuries in trauma patients. Cardiovasc Intervent Radiol. 2005;28:730–5.
[4] Schumacher H, Böckler D, von Tengg-Kobligk H, Allenberg JR. Acute traumatic aortic tear: open versus stent-graft repair. Semin Vasc Surg. 2006;19:48–59.
[5] Miura K, Komiya T, Matsushime S, Oka N, Kamo K. Stent graft placement for traumatic lumbar artery injury in which coil embolization is not feasible. Trauma Case Rep. 2023;43:100774.

[6] Rahman T, Halonen LM, Handolin L, Juvonen T, Jormalainen M, Dahlbacka S. 16-year outcomes of blunt thoracic aortic injury treated with thoracic endovascular aortic repair: a single-institution experience. Scand J Surg. 2024;25:14574969241255242.
[7] Morisaki K, Matsumoto T, Matsubara Y, et al. A rare complication of spinal cord ischemia following endovascular aneurysm repair of an infrarenal abdominal aortic aneurysm with arteriosclerosis obliterans: report of a case. Ann Vasc Dis. 2016;9:255–7.
[8] Tsuchida K, Kokaguchi K, Hasegawa T, Akamatsu D, Namiki K. Endovascular treatment for a ruptured lumbar artery aneurysm in a patient with neurofibromatosis type 1. J Vasc Surg Cases Innov Tech. 2023;9:101208.

Case Report

Vol. 8, No. 3; 2024; pp 86–89
DOI: https://doi.org/10.26676/jevtm.26872

Endovascular Management of a Post-traumatic Popliteal Fossa Arteriovenous Fistula

Jayesh Patel[1], Haryax Pathak[2], Ayushi Rathod[2] and Manushree Barot[3]

[1]Department of Vascular Surgery, Shree Krishna Hospital and Pramukh Swami Medical College, Bhaikaka University, Gokalnagar, Karamsad, Anand, Gujarat 388325, India
[2]Department of General Surgery, Shree Krishna Hospital and Pramukh Swami Medical College, Bhaikaka University, Gokalnagar, Karamsad, Anand, Gujarat 388325, India
[3]Narendra Modi Medical College and L G Hospital, Gujarat University, Opposite Adani CNG Station, Near Rambaug, Maninagar, Ahmedabad, Gujarat 380008, India

Background: Arteriovenous fistulas (AVFs) are abnormal communications between an artery and a vein. Post-traumatic AVFs, including those in the popliteal fossa, are rare but require prompt management to prevent complications.
Case Report: A 35-year-old male presented with a painful, pulsatile swelling over the left knee, 15 days post-arthroscopic anterior cruciate ligament and posterior cruciate ligament reconstruction. Clinical examination showed a 5 × 5 cm^2 tender swelling with a palpable thrill. Computed tomography angiography revealed a communication between the popliteal artery and vein. An endovascular intervention was performed using two Bentley covered balloon expandable stents. Post-procedure, the patient showed uneventful recovery, with follow-up Doppler scans indicating normal vascular flow and no residual abnormalities.
Conclusions: Post-traumatic AVFs, often resulting from penetrating injuries or iatrogenic causes, can present with painful, pulsatile swellings and may lead to severe complications if untreated. Advances in endovascular techniques, such as stenting, have improved outcomes such as reduced post-operative morbidity, eliminating complications associated with open surgery.

Keywords: *Arteriovenous Fistula; Endovascular Procedures; Stents; Popliteal Artery; Vascular Fistula*

Received: 16 August 2024; Accepted: 21 September 2024

INTRODUCTION

Arteriovenous fistulas (AVF) are defined as abnormal communications between an artery and a vein, which may be congenital or acquired (iatrogenic – as in haemodialysis; or traumatic). Congenital AVFs are the rarest of all, followed by post-traumatic AVFs. The popliteal fossa AVF is a rare vascular anomaly, usually found because of abnormal communication between the popliteal artery and vein. It leads to shunting of blood from the arterial system and can cause symptoms such as varicose veins, localised swelling, aneurysmal dilatation of the popliteal vessels and venous hypertension leading to heart failure. It requires a high index of clinical suspicion and prompt management to prevent further complications [1].

We present here a case of a 35-year-old male patient who presented with a post-traumatic popliteal fossa AVF, managed with endovascular stenting as damage control surgery, resulting in resolution of symptoms such as pain, swelling and movement restriction.

CASE REPORT

A 35-year-old obese male presented with a painful swelling over the back of his left knee. The patient had a history of left lower limb trauma for which he underwent arthroscopic reconstruction of the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) over the left knee. Following surgery, the patient recovered uneventfully. However, one and a half months following

Corresponding author:
Haryax Pathak, Department of General Surgery, Shree Krishna Hospital and Pramukh Swami Medical College, Gokalnagar, Karamsad, Anand, Gujarat 388325, India.
Email: haryax0909@gmail.com

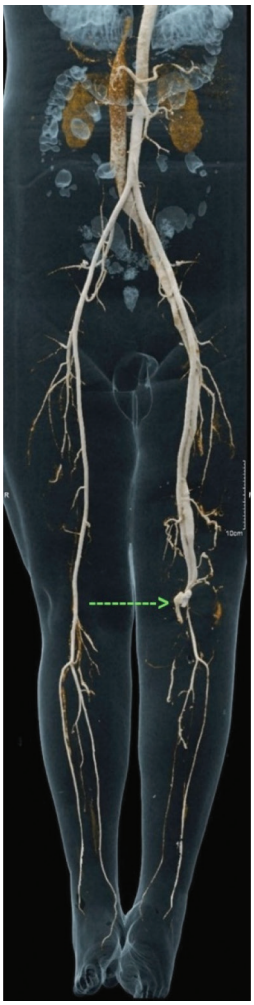


Figure 1 CTA showing left popliteal AVF (green arrow).

the surgery, the patient developed a swelling over the back of his left knee, gradually increasing in size, which was pulsatile in nature and associated with a moderate amount of pain. Upon examination, a 5 × 5 cm^2 tender, pulsatile swelling was present over the popliteal fossa, with a palpable thrill, and dilated superficial veins around the knee joint with pitting oedema over the left leg distal to the knee joint. The patient also had significant restriction of joint movement at the knee. Peripheral pulses were palpable, but the left lower limb distal to the knee joint appeared pale and was cold to the touch.

The patient underwent a computed tomography angiography (CTA) of the left lower limb, which was suggestive of a well-defined communication between the popliteal artery and the popliteal vein, likely to be a fistula, with width of 5.7 cm and antero-posterior dimension of 2.5 cm, associated with slowing of arterial flow below the left knee (Figure 1). A normal two-dimensional echocardiography ruled out the possibility of cardiac overload.

Based on clinical findings and the CTA report, the need for surgical intervention, either open exploration or endovascular intervention, was explained to the patient. In view of the patient's history of recent knee surgery and prolonged immobilisation, obesity, clinical features of a cold limb and the presence of an AVF, the patient was taken up for percutaneous angioplasty and stenting as a minimally invasive and damage control procedure. The left common femoral artery was punctured antegrade and progressed under duplex guidance. An active leak was noted in the left popliteal artery just behind the knee

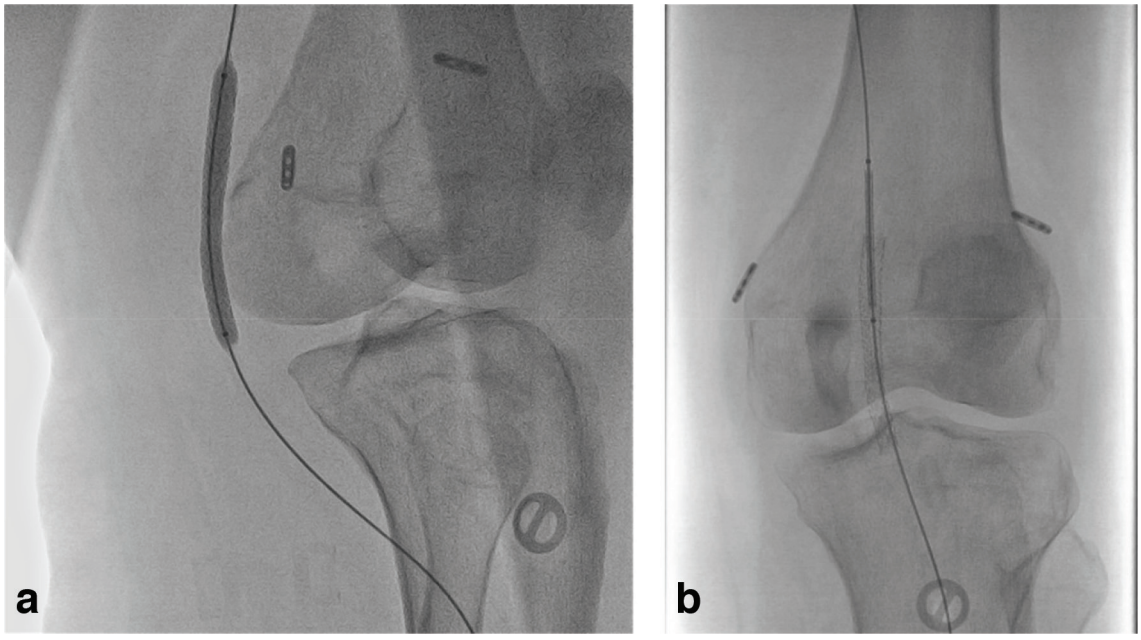


Figure 2 Dual overlapping covered balloon expandable stenting of the popliteal artery. (**a**) Lateral view. (**b**) Anterior view.

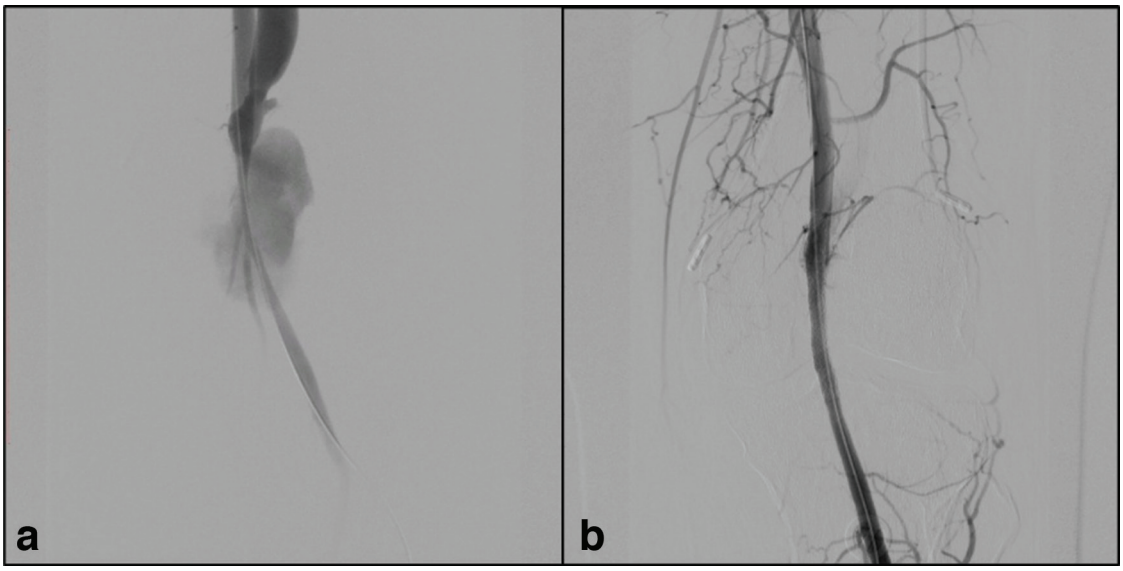


Figure 3 Intra-operative angiograms. (**a**) Pre-stent showing leakage and evidence of fistula at the level of the popliteal artery. (**b**) Post-stent showing good flow and no leakage.

joint, with evidence of AVF. A command wire was crossed using a Rubicon catheter under road-map guidance. Two Bentley covered balloon expandable stents, 6 × 38 mm^2 and 6 × 58 mm^2, were placed across the leak. Brisk flow was noted in the popliteal artery and the tibial vessels, with no evidence of leak or AVF (Figures 2 and 3).

Following the procedure, the patient made an uneventful recovery. Subsequent repeated Doppler scanning upon follow-up at 1 month and 3 months post-surgery revealed no residual abnormalities and good flow in the left lower limb, with no evidence of leakage or vascular insufficiency. The patient exhibited complete recovery, with no residual pain, swelling or restriction in mobility.

Ethical Approval and Informed Consent

Ethical approval to report these cases was given by the Institutional Ethics Committee, Bhaikaka University. Written informed consent was obtained from the patient.

DISCUSSION

Post-traumatic AVFs are a rare entity, the majority of which occur due to penetrating injuries such as gunshot wounds, which disrupt the regional vascular anatomy. They may also be iatrogenic, caused during the course of medical procedures. Such fistulas may become symptomatic within a few days or weeks following the causative event, while some may remain dormant and may be diagnosed even months or years later. Certain fistulas may even prove to be fatal and require rapid diagnosis and management. Patients have varying clinical presentations such as painful pulsatile swellings, the presence of a thrill or a bruit, evidence of distal limb ischemia, cardio-respiratory overload, heart failure, etc. Diagnosis can be confirmed on clinical examination and after radiological investigations such as Doppler ultrasound or a CTA [2,3].

In the previous century, traumatic AVFs were usually managed conservatively, while open surgery was reserved for complicated cases. With the advent of endovascular therapies, the management of traumatic AVFs has become much more rapid and effective. A variety of options are available such as the use of covered balloon expandable stents, coiling, glue, grafts, etc. Endovascular management is now the mainstay of treatment for traumatic AVFs, while open surgery is carried out in cases where endovascular management fails [4,5].

Among traumatic AVFs, popliteal AVFs are relatively less common, occurring due to direct penetrating trauma to the lower limbs, and may be associated with concomitant injuries such as fractures or ligament injuries, requiring surgical intervention. Patients present with a painful swelling in the popliteal region, days to weeks after the traumatic event. Delayed presentations may show signs of peripheral limb ischemia and cardiac overload or heart failure. CTA shows abnormal communication between the popliteal artery and vein, around the level of the knee joint, with surrounding hematoma or aneurysmal dilatation of the popliteal artery. It may also show shunting of blood leading to peripheral vascular insufficiency. Management is usually by endovascular treatment with the use of covered stents or coiling [6].

Ilijevski et al. report a series of seven cases with post-traumatic popliteal AVFs, two of which required amputation of the lower limbs, while the rest recovered uneventfully following surgical intervention in the form of vessel reconstruction [7]. Another case report of a popliteal fossa AVF describes hybrid management of the fistula, wherein open surgery was carried out following failure of endovascular stenting [8]. Popliteal AVFs are

also known to occur following knee surgery. Ceallaigh et al. conservatively managed a case of popliteal AVF following total knee replacement surgery, with no ensuing complications noted on follow-up [9]. Another report by Dinh et al. emphasizes endovascular management of a popliteal AVF following knee surgery, using a covered stent [10].

In our case, the patient had a history of a road traffic accident with trauma to the left lower limb, requiring surgery for reconstruction of the ACL and PCL. The subsequent popliteal AVF could have been a result of the direct trauma or the knee surgery. While there are recommendations to pursue open surgery for such cases, especially for AVFs over joints, certain patient factors must be considered when deciding the correct course of management. In our case, the patient was obese and had a recent history of knee surgery – which were both deterrents for open surgery in the prone position. Endovascular intervention was preferred as a minimally invasive damage control surgery and a potentially life-saving procedure. The patient was managed using two covered balloon expandable stents, overlapping with each other, with no evidence of failure or complications, such as pain, joint movement restriction or recurrence, noted on extended follow-up.

CONCLUSIONS

Post-traumatic AVFs are a rare occurrence and require a high index of clinical suspicion, especially in the presence of a thrill/bruit on examination. Popliteal AVFs may be due to direct trauma or following knee surgery, and can effectively be managed using endovascular techniques if diagnosed early, thereby preventing complications such as amputation.

Ethics Statement

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

Conflicts of Interest

The authors have nothing to disclose.

Funding

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

REFERENCES

[1] Jayroe H, Foley K. Arteriovenous fistula. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2024. Accessed 17 July 17. http://www.ncbi.nlm.nih.gov/books/NBK559213/.
[2] Morgan MA. Radiopaedia. Accessed 17 July 2024. Arteriovenous fistula | Radiology Reference Article | Radiopaedia.org. https://radiopaedia.org/articles/arteriovenous-fistula?lang=us.
[3] Nagpal K, Ahmed K, Cuschieri RJ. Diagnosis and management of acute traumatic arteriovenous fistula. Int J Angiol. 2011 28;17:214–6.
[4] Yousuf KM, Bhagwani AR, Bilal N. Management of chronic traumatic arteriovenous fistula of the lower extremities. Eur J Trauma Emerg Surg. 2013;39(4):393–6.
[5] Clark RA, Gallant TE, Alexander ES. Angiographic management of traumatic arteriovenous fistulas: clinical results. Radiology. 1983;147(1):9–13.
[6] Pritchard DA, Maloney JD, Barnhorst DA, Spittell JA Jr. Traumatic popliteal arteriovenous fistula: diagnostic methods and surgical management. Arch Surg. 1977;112(7):849–52.
[7] Ilijevski N, Radak D, Radevic B, et al. Popliteal traumatic arteriovenous fistulas. J Trauma Acute Care Surg. 2002;52(4):739.
[8] Góes Junior AM de O, Jeha SAH, Franco RSM. Hybrid treatment of arteriovenous fistula between popliteal vessels. J Vasc Bras. 2014;13:325–9.
[9] Ceallaigh PÓ, Hogan N, McLaughlin R, Bouchier-Hayes D. Popliteal arteriovenous fistula post total knee replacement. EJVES Extra. 2004;7(2):33–5.
[10] Dinh K, Ying A, Al-Asady R, Vicaretti M. Endovascular treatment of a large iatrogenic popliteal arteriovenous fistula. Interv Cardiol Rev. 2021;16:e15.

Commentary

Vol. 8, No. 3; 2024; pp 90–91
DOI: https://doi.org/10.26676/jevtm.33220

Stent Graft Treatment of Traumatic Arteriovenous Fistula in a 35-Year-Old: What is the 10-Year Outcome?

Per Skoog

Department of Vascular Surgery and Institute of Medicine, Department of Molecular and Clinical Medicine, Sahlgrenska University Hospital and Academy, Gothenburg, Sweden

Received: 30 October 2024; Accepted: 30 October 2024

In a detailed case report, Patel et al. examine the management of a traumatic arteriovenous fistula (AVF) in the popliteal segment of a 35-year-old male. This patient presented with a painful swelling at the back of his left knee following arthroscopic cruciate ligament repair after a knee injury. The authors conducted thorough diagnostic investigations, identifying a post-traumatic AVF, and subsequently performed endovascular treatment using two balloon-expandable stent grafts.

A review of the literature on traumatic AVF treatments reveals only about 20 publications addressing a handful of cases, and notably, no long-term follow-up data. This highlights the limited scientific foundation for treating post-traumatic AVFs.

Broader investigations into popliteal injuries, including treatment of popliteal injuries in general, yield more information. Studies by Potter et al. [1] and Abdou et al. [2] analyzed outcomes from the American National Trauma Data Bank (NTDB), examining 2,873 and 3,698 patients, respectively, although only a small fraction underwent endovascular treatment (5.7% and 5.3%). Recent reviews by Vaidya et al. [3] and Qi et al. [4] in 2024 include meta-analyses comparing open and endovascular treatments for popliteal injuries. However, the quality of data in these studies is limited due to the studies included. Qi et al.'s meta-analysis primarily relies on NTDB data, which only tracks in-hospital outcomes, failing to provide insights into long-term vascular reconstruction performance. Vaidya et al.'s review involves 864 patients, but 3 out of 8 studies on endovascular treatment lacked follow-up, and the other studies (56 patients) had a mean follow-up of just 33 months.

Overall, these studies indicate minimal differences between open and endovascular techniques for popliteal injuries in the short perspective. However, the significant issue of long-term patency with endovascular methods remains largely unaddressed. It is therefore concerning that many authors still describe the endovascular approach as "promising."

A notable study by Jiang et al. in 2020 [5] evaluated 46 patients with popliteal injuries treated with 41 stent grafts, reporting a primary patency rate of 75.3% at 12 months, 61.9% at 24 months, and 55.7% at 48 months, with an assisted patency rate of 85.2% at 48 months. These long-term results are strikingly similar to those for other popliteal stent graft treatments. In line with Jiang et al.'s result, Saxon et al. [6] reported a primary patency of only 55% after four years for stent grafts used in popliteal artery aneurysm treatments, while Cervin et al. [7] found a 44% occlusion rate after stent grafting compared to 17.6% for open bypass surgery at three years.

Given these findings, I express concerns about using a stent graft in a young, healthy patient. In cases of popliteal AVF presenting electively, my concerns intensify. If endovascular treatment is considered, a self-expanding stent graft—exclusively used in the studies cited—should be the choice.

Open surgical repair of a traumatic AVF in the popliteal segment is typically straightforward, raising the question of why a young patient should face the risks of stent graft occlusion. Reporting only in-hospital or six-month results seems inadequate, especially for a 35-year-old man whose long-term function is at stake.

I strongly believe that stent grafts in highly mobile arteries, such as the popliteal artery, should be reserved for young patients facing immediate life-threatening conditions or, rather, used temporarily, with plans for open reconstruction. Additionally, I urge the authors

Corresponding author:

Per Skoog, Department of Vascular Surgery and Institute of Medicine, Department of Molecular and Clinical Medicine, Sahlgrenska University Hospital and Academy, Gothenburg, Sweden.

Email: peraskoog@yahoo.se

to ensure that their patient undergoes long-term ultrasound monitoring to facilitate timely management of the stent graft occlusion.

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.

REFERENCES

[1] Potter HA, Alfson DB, Rowe VL, et al. Endovascular versus open repair of isolated superficial femoral and popliteal artery injuries. J Vasc Surg. 2021;74(3):814.e1–822.e1.
[2] Abdou H, Edwards J, Stonko D, et al. The role of endovascular repair of popliteal arterial injuries in the acute setting. Ann Vasc Surg. 2022;87:522–28.
[3] Vaidya A, Rilo N, Steigerwald S, Rajani RR. Outcomes of endovascular and open surgical therapy for popliteal artery injury. Ann Vasc Surg. 2024;104:282–95.
[4] Qi Y, Wang J, Yuan D, Duan P, Hou L, Wang T. Systematic review and meta-analysis of endovascular therapy versus open surgical repair for the traumatic lower extremity arterial injury. World J Emerg Surg. 2024;19(1):16.
[5] Jiang C, Chen Z, Zhao Y, Zhang WW, Zeng Q, Li F. Four-year outcomes following endovascular repair in patients with traumatic isolated popliteal artery injuries. J Vasc Surg. 2021;73(6):2064–70.
[6] Saxon RR, Coffman JM, Gooding JM, Ponec DJ. Long-term patency and clinical outcome of the Viabahn stent-graft for femoropopliteal artery obstructions. J Vasc Interv Radiol. 2007;18(11):1341–49; quiz 1350.
[7] Cervin A, Acosta S, Hultgren R, Grip O, Björck M, Falkenberg M. Results after open and endovascular repair of popliteal aneurysm: a matched comparison within a population based cohort. Eur J Vasc Endovasc Surg. 2021;61(6):988–97.

Case Report

Vol. 8, No. 3; 2024; pp 92–95
DOI: https://doi.org/10.26676/jevtm.32077

Delayed Acute Ischemia as a Consequence of Multi-Ligament Injury of the Left Knee Following a Motorcycle Accident

Laura Leci Tahiri[1,2] and Lisa Tahiri[1]

[1]*Faculty of Medicine, University of Prishtina, Prishtina, Kosovo*
[2]*Clinic of Vascular Surgery, University Clinical Center of Kosovo, Prishtina, Kosovo*

Motorcycle accidents can cause complex orthopedic and vascular injuries, posing diagnostic and treatment challenges. We present a case of a 34-year-old Albanian man with a multi-ligament knee injury and arterial thrombosis in his left leg following a motorcycle accident. The patient initially received conservative care but developed severe leg pain, coldness, and numbness, prompting urgent vascular imaging. Imaging confirmed popliteal artery thrombosis, necessitating surgical intervention. This case highlights the severe complications of motorcycle accidents, emphasizing the need for prompt vascular injury detection and a multidisciplinary approach in trauma management. Early recognition and timely intervention are crucial to prevent long-term morbidity and to optimize recovery. Further research is needed to improve diagnostic and treatment strategies for vascular complications in such injuries.

Keywords: *Arterial Trauma; Imaging Techniques; Limb Ischemia*

Received: 9 October 2024; Accepted: 30 October 2024

INTRODUCTION

Multiple ligament knee injuries are usually the result of knee dislocations following either high-energy motor vehicle accidents or low-velocity sports injuries [1]. Significant morbidity is associated with knee dislocation including multiple ligament disruption, infections, vascular and neurologic complications following injury and surgery, compartment syndrome, complex regional pain syndrome, deep venous thrombosis, and neurovascular damage. The term multi-ligament knee injury includes all ruptures of two or more major ligaments. Therefore, it has a broad spectrum of clinical presentation, creating a great challenge for orthopedists and surgeons involved in this topic. Motorcycle accidents can result in severe musculoskeletal injuries and vascular complications, presenting significant challenges in diagnosis and management. Vascular injury secondary to an acute knee dislocation is a known complication. However, wide discrepancies exist in the reported rate of vascular injury in this setting [2–5]. Even when a knee dislocation is diagnosed, a neuro-vascular lesion may go unnoticed if the patient is not properly examined and if some simple tests, such as the Ankle-Brachial index that can alert us to a popliteal arterial lesion, are not used. On some occasions when patients arrive unconscious in the emergency department, a peroneal nerve lesion may be neglected, which can have serious consequences [5–8]. Here we present a case report of a 34-year-old Albanian man who sustained a multi-ligament injury to the left lower extremity and developed arterial thrombosis following a motorcycle accident. The patient's clinical presentation, diagnostic workup, and management are discussed, highlighting the importance of prompt recognition and multidisciplinary care in optimizing outcomes for trauma patients.

This case presentation aims to highlight the diagnostic and therapeutic challenges encountered in managing a patient with arterial ischemia following a motorcycle accident, emphasizing the importance of prompt recognition and multidisciplinary intervention in optimizing patient outcomes.

CASE PRESENTATION

A 34-year-old Albanian man was brought to the Regional Hospital following a motorcycle accident. Initial evaluation revealed multi-ligament injury of the

Corresponding author:
Laura Leci Tahiri, MD, MSc, PhD, Faculty of Medicine, University of Prishtina, 10000 Prishtina, Kosovo; Clinic of Vascular Surgery, University Clinical Center of Kosovo, 10000 Prishtina, Kosovo.
E-mail: laura.leci@uni-pr.edu

left knee, including damage to the geniculate arteries, and associated soft tissue trauma. The patient was immobilized, and conservative management was initiated with pain control and elevation of the affected limb. However, on the fourth day of hospitalization in the Regional Hospital, the patient reported severe pain, coldness, and numbness in the left lower extremity. Physical examination revealed absent pedal pulses and sensory deficits in the foot, raising concerns for vascular compromise. Urgent Doppler ultrasound confirmed the presence of thrombosis in the left popliteal artery, necessitating immediate intervention from a vascular surgeon. Despite anticoagulation therapy, antibiotics, immobilization, and analgetics, the patient continued to experience persistent pain, sensory deficits, and motor dysfunction in the affected limb for over a week in the Regional Hospital. Urgently transferred to a University Clinical Center, diagnostic imaging with angio computed tomography (angioCT) of the lower extremities revealed a laceration and extravasation of the left popliteal artery with intramural thrombosis and massive hematoma.

Additionally, magnetic resonance imaging (MRI) demonstrated a fracture of the intercondylar eminence of the left knee, consistent with a multi-ligament knee injury (KD IV), along with associated knee contracture and paralysis of the left peroneal nerve.

On the 13th day post-injury, the patient underwent surgical intervention by a vascular surgeon. An arterial bypass was established from the superficial femoral artery to the second segment of the popliteal artery within Hunter's canal, using a 25 cm autograft from the contralateral vena saphena magna. The procedure was performed through a medial approach. Intraoperatively, while accessing the popliteal artery on the posterior aspect of the knee, considerable damage to knee structures was observed during the evacuation of a large hematoma.

The surgery lasted approximately 5 hours. Medial and lateral fasciotomy of the crural region was performed, revealing that the muscles in that area did not have preserved vitality. Postoperatively, the patient was treated with high-molecular-weight anticoagulants, broad-spectrum antibiotics, blood products, plasma, and albumin. Immediately after the surgery, the patient's foot warmed up; however, the peroneal nerve paresis persisted.

By the third day after surgery, local infection was detected while cleaning the wound, with significant undermining observed (Figure 1).

Therefore, a swab was taken from the wound, isolating *Enterobacter* spp. Local antibiotics were applied, and it was recommended that the patient undergo debridement of necrotic muscles, especially in the area of the anterior tibial artery, under anesthesia (Figure 2).

The patient underwent arterial duplex ultrasound while in bed, revealing triphasic flow in the dorsalis pedis artery and the posterior tibial artery. Due to the infection and radical necrectomy of the tibialis anterior muscle, the anterior tibial artery was completely visualized in the lateral portion, significantly limiting local manipulations. Therefore, a vacuum pump at very low pressure was applied, which noticeably promoted local granulation (Figure 3).

After four weeks of treatment, the patient underwent a final procedure where a plastic surgeon sutured the medial side of the lower leg, leaving the lateral side for secondary healing, with dressings twice daily. The patient remained immobile in bed, without foot sensation or movement. Measures were taken to prevent heel ulcers, although knee pain led to a contracture. Due to persistent infection in the lateral wound, a vacuum pump was reapplied, which was changed every three days. Consultations with a neurosurgeon, physiatrist, and orthopedic surgeon were sought, although no interventions were carried out due to the foot's condition.

After five weeks of hospitalization, the patient was discharged home in an overall improved condition, with mildly elevated inflammatory markers, secondary healing wounds in the lateral aspect of the crural region, and persistent pain and contracture in the left knee, without

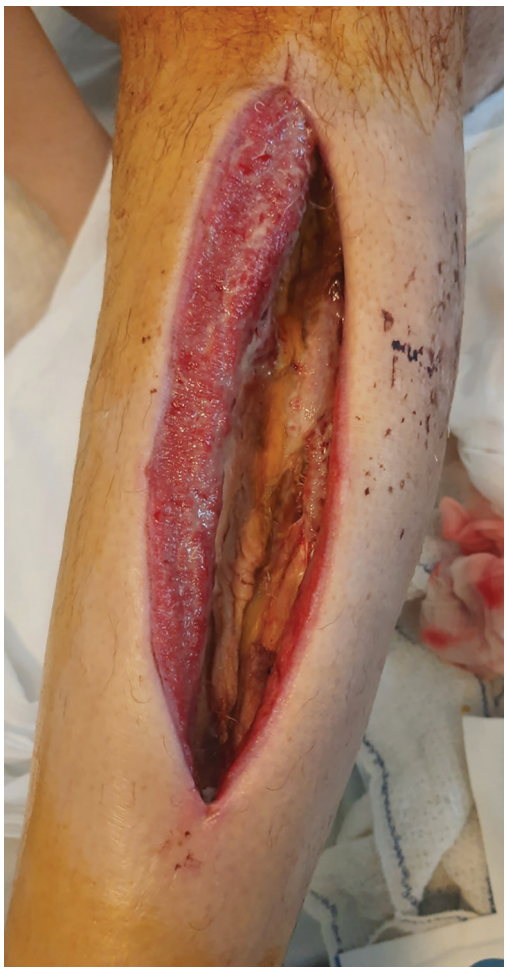


Figure 1 Open wound on the lateral aspect of the crural region.

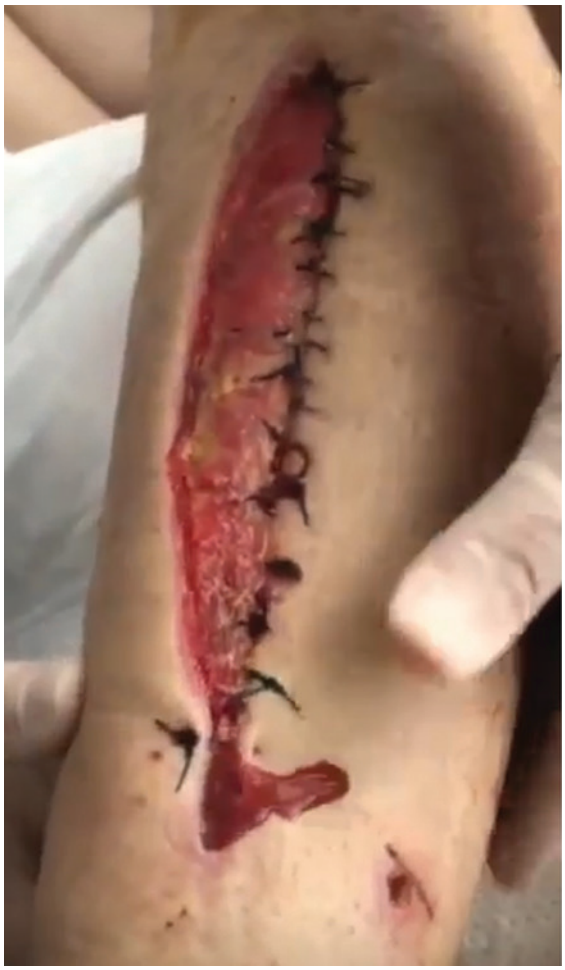


Figure 2 Wound infection after its closure.

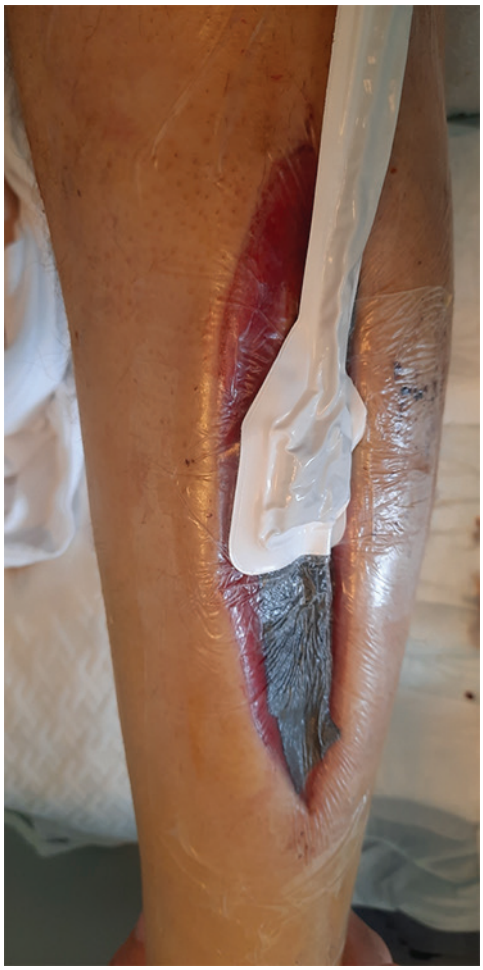


Figure 3 Vacuum pump application.

bending the knee, with pulses present in the dorsalis pedis and tibialis posterior arteries. The wound healing process took several months, with phases of exacerbation and improvement, accompanied by continuous monitoring of wound swabs with antibiotics.

Additionally, therapy with antiplatelet agents was prescribed, including an Aspirin 100 mg tablet once daily and a Clopidogrel 75 mg tablet once daily. Meanwhile, the patient, although engaging in physical exercises for other parts of the body, has never rested the leg on the ground.

Seven months after injury, once the wound was fully healed, the patient underwent electromyography of the left leg, an MRI of the left knee, and knee arthroscopy. Orthopedic surgery included anterior cruciate ligament (ACL) reconstruction with a 9.5 mm quadriceps graft, secured by an ACL TightRope and bioabsorbable screw. Posterior cruciate ligament (PCL) reconstruction used a 7.0 mm hamstring graft from the opposite leg, with ACL TightRope and bioabsorbable screws for fixation. PCL reconstruction utilized a 5.0 mm ipsilateral semitendinous graft, fixed by a bioabsorbable screw (modified Larson technique). Post-surgery, the left peroneal nerve was explored and decompressed. The patient was discharged on the second day, instructed to weight-bear as tolerated. After physical therapy, the patient walks without issues, with plantar flexion, and uses an ankle-foot orthosis for dorsiflexion.

Ethical Approval and Informed Consent

Ethics committee approval was not required for this study. Informed consent was obtained from the patient.

DISCUSSION

Motorcycle accidents can result in complex orthopedic injuries and vascular complications, posing significant challenges in diagnosis and management [1–3]. Knee dislocations associated with vascular injuries generally have a poor prognosis. It has been reported that one in five patients who present to a trauma center with an avascular limb associated with a knee dislocation will require amputation [5–8]. The risk of popliteal artery injury with a knee dislocation has varied from 7 to 40%, with more contemporary studies reporting an injury in

the range of 7 to 15%. In addition, if the vascular repair is delayed past 8 hours of ischemia, there is a reported 86% amputation rate [9–12]. In this case, the patient's presentation of severe pain, coldness, and sensory deficits in the left lower extremity raised concerns for vascular compromise, prompting urgent vascular imaging and intervention. In our case, the patient was diagnosed with arterial ischemia 7 days after the injury.

Thrombosis of the popliteal artery is a known complication of lower extremity trauma and can result in limb-threatening ischemia if left untreated [5–10]. Prompt recognition and intervention are essential to prevent complications, such as post-thrombotic syndrome and limb loss. The peroneal nerve is often severely stretched, and no treatment to date has been very encouraging. An ankle-foot orthosis or tendon transfer to achieve dorsiflexion may be needed [7–12].

CONCLUSION

Motorcycle accidents can lead to severe musculoskeletal and vascular injuries, posing challenges in diagnosis and treatment. Popliteal artery injury after knee dislocation often follows a fall, while, with knee fractures, it is rare and usually linked to motor vehicle accidents. This case underscores the need for a multidisciplinary approach for trauma patients with complex orthopedic and vascular issues. Prompt detection of vascular injury is essential to improve outcomes and reduce long-term complications. Delayed treatment in major arterial injuries raises amputation risks, but timely revascularization in stable patients may save limbs. Further research could enhance diagnostics and treatment for these vascular injuries.

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

All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Funding

All authors have declared that no financial support was received from any organization for the submitted work. All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.

Author Contributions

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

REFERENCES

[1] Ammori MB, Evans AR, McLain AD. Popliteal artery pseudoaneurysm after total knee arthroplasty. J Arthroplasty. 2016;31:2004–7.
[2] Bernhoff K, Michawlsson K, Björck M. Incidence and outcome of popliteal artery injury associated with knee dislocations, ligamentous injuries, and fractures near the knee: a nationwide population-based cohort study. Eur J Vasc Endovasc Surg. 2021;61:297–304.
[3] Bernhoff K, Rudström H, Gedeborg R, et al. Popliteal artery injury during knee replacement: a population-based nationwide study. Bone Joint J. 2013;95:1645–9.
[4] Cook S, Ridley TJ, McCarthy MA, et al. Surgical treatment of multiligament knee injuries. Knee Surg Sports Traumatol Arthrosc. 2015;23:2983–91.
[5] Manske RC, Hosseinzadeh P, Giangarra CE. Multiple ligament knee injury: complications. N Am J Sports Phys Ther. 2008;3:226–33.
[6] Merrill KD. Knee dislocations with vascular injuries. Orthop Clin North Am. 1994;25:707–13.
[7] Mosquera MF, Jaramillo A, Gil R, et al. Controversies in acute multiligamentary knee injuries (MLKI). J Exp Orthop. 2020;7(1):38.
[8] Nicolino TI, Costantini J, Astore I, et al. Incidence of vascular injury associated with knee arthroplasty: series of cases. Eur J Orthop Surg Traumatol. 2024;34(5):1012–20.
[9] Pardiwala DN, Rao NN, Anand K, et al. Knee dislocations in sports injuries. Indian J Orthop. 2017;51:552–62.
[10] Qin C, Roth C, Lee C, Athiviraham A. National trends, 90-day readmission, and subsequent knee surgery following a multi-ligament knee reconstruction. J Orthop. 2020;3:49–52.
[11] Stannard JP, Schreiner AI. Vascular injuries following knee dislocation. J Knee Surg. 2020;33(2):108–14.
[12] Tejero-Garcia S, Lirola Criado JF, Ast MP, et al. Popliteal pseudoaneurysm after unicompartmental knee replacement: a case report. Knee. 2014;21:597–9.

Case Reports

Vol. 8, No. 3; 2024; pp 96–99
DOI: https://doi.org/10.26676/jevtm.33826

Successful Use of a Thoracic Branched Endograft in the Setting of Blunt Thoracic Aortic Injury

Jeremy Obrand[1], Melissa Jones[2], Anirudh Mirakhur[3], Kenton Rommens[2,4], Paul Cantle[2,5] and Randy Moore[2,4]

[1]*Undergraduate Medical Education, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada*
[2]*Division of Vascular Surgery, Department of Surgery, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada*
[3]*Department of Radiology, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada*
[4]*Calgary Aortic Program, Libin Cardiovascular Institute, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada*
[5]*Section of Trauma Surgery, Department of Surgery, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada*

Keywords: *Endovascular; Aortic Injury; Blunt Trauma*

Received: 7 November 2024; Accepted: 5 December 2024

INTRODUCTION

Blunt thoracic aortic injury (BTAI) presents a significant challenge in trauma management in patients presenting with multi-system injury. It remains the second most common cause of death in the setting of blunt chest trauma [1]. The pathogenesis is secondary to rapid deceleration, which exerts shear and tensile forces on the aortic wall, concentrated at the aortic isthmus, distal to the left subclavian artery (LSA) [2]. These forces can cause intimal tears, intramural hematomas, and even aortic transection as summarized in the GRADE classification (Table 1) [3].

Most patients with BTAI die before arriving at the hospital and in-hospital mortality has been reported to be as high as 46% [4]. Early diagnosis is critical as many in-hospital deaths occur within the first 24 hours [5]. In the absence of competing management priorities for hemodynamic instability and concomitant injuries, such as traumatic brain injury (TBI), medical management of BTAI includes anti-impulse therapy. In the context of descending thoracic aortic injuries, anti-impulse therapy consists of maintaining a target blood pressure of 100–120 mmHg and a heart rate of less than 60 bpm [6].

Corresponding author:
Jeremy Obrand, 3500 26 Ave NE, Room 5940, Calgary, Alberta, T1Y 6J4, Canada.
Email: jeremy.obrand@ucalgary.ca

Surgical management depends on both the degree of injury and the required triaging of concomitant injuries. Aortic rupture is a surgical emergency requiring immediate intervention. Intimal tears are managed with anti-impulse therapy alone. Intramural hematomas are usually treated using anti-impulse therapy, with surgical intervention individualized to the patient considered in a delayed fashion [5]. Management of an aortic pseudoaneurysm is surgical, with timing of surgical intervention dependent on the presence of high-risk features (Table 2). An emergency intervention is indicated when

Table 1 GRADE classification of blunt thoracic aortic injury (BTAI).

GRADE classification of BTAI
1. Intimal tear
2. Intramural hematoma
3. Aortic pseudoaneurysm
4. Aortic rupture

Table 2 High risk features of aortic pseudoaneurysm in blunt thoracic aortic injury (BTAI).

High risk features of aortic pseudoaneurysm in BTAI
Aortic arch hematoma
Ascending aortic, aortic arch, or great vessel involvement
Mediastinal hematoma causing mass effect
Posterior mediastinal hematoma > 10 mm
Lesion to normal aortic diameter ratio > 1.4
Disruption of > 50% of aortic wall circumference
Pseudocoarctation of the aorta
Large left hemothorax

high risk features are present. Otherwise, an intervention is recommended within the first 24 hours [5].

Thoracic endovascular aortic repair (TEVAR) is the mainstay of surgical intervention due to its superior survival rate compared to open repair, especially in unstable patients [7]. The challenge remains in the management of BTAI with extension into the aortic arch, without a suitable landing zone distal to the LSA. Coverage of the LSA with a Zone 2 TEVAR deployment may be required in some cases to ensure adequate seal of the site of injury, and concomitant injuries may preclude safe extra-anatomic revascularization of the arch vessels.

Novel innovations such as the Gore Thoracic Branched Endoprosthesis (TBE) add to the toolbox of the vascular surgeon in the setting of BTAI. In Canada, the TBE device has recently received Health Canada approval with limited authorized special access across the country. The use of a TBE device allows for Zone 2 stent graft deployment with simultaneous endovascular revascularization of the LSA. The following is the presentation of the first two Canadian cases of BTAI treated with the Gore TBE.

CASE SERIES

Case Report 1

A 27-year-old male was involved in a motor vehicle collision at highway speeds. On arrival at a peripheral hospital, he was hemodynamically stable with a Glasgow Coma Scale score of 8. Endotracheal intubation was attempted for airway protection but failed, following which a cricothyrotomy was performed. The computed tomography (CT) scan showed a large traumatic hematoma centered in the left submandibular space, bilateral pulmonary hemorrhage, pneumomediastinum, subarachnoid hemorrhage, and a traumatic aortic injury with intimal tearing in Zones 2 and 3 of the aorta. This scan was initially interpreted as a Grade 1 injury.

The patient was transported to our tertiary level 1 trauma center. The BTAI was managed with anti-impulse therapy with agreement from the neurosurgery team. A repeat CT scan seven days later demonstrated progression to a Grade 3 BTAI, with a 1 cm pseudoaneurysm extending into Zone 2 on the inner curve of the aortic arch, as well as a codominant left vertebral artery (Supplementary Video 1; Supplementary Digital Content is available online at https://doi.org/10.26676/jevtm.33826). Due to the presence of the codominant vertebral artery and in the setting of TBI, it was felt that a Zone 2 TEVAR without subclavian revascularization was not appropriate. It was also felt that the presence of a surgical airway significantly increased the risk of a bypass graft infection with a left carotid-subclavian bypass. A Gore TBE device was immediatetly acquired.

The patient was brought urgently to the operating room. Using ultrasound guidance, percutaneous arterial and venous access was obtained. Systemic heparin was administered. A 12 F Gore dryseal sheath was advanced from the right femoral vein to the cavoatrial junction. A pigtail catheter was positioned in the ascending aorta from the left common femoral artery. A Lunderquist wire was positioned at the aortic root of the right common femoral artery and a 22 F Gore Dryseal sheath was advanced to the descending thoracic aorta. A snare sheath was advanced in a coaxial fashion from the right common femoral artery within the 22 F sheath and positioned in the descending thoracic aorta. From the left radial access, a 6F Terumo R2P sheath was advanced retrograde into the LSA. The descending thoracic aorta was cannulated from the LSA with a hydrophilic glide wire, which was subsequently snared. A 26 mm by 15 cm Gore TBE Aortic Component was advanced into the aortic arch, the C-arm was positioned with an extreme cross-table angulation, and an angiogram was performed. A cava balloon was advanced into the right atrium and inflated to induce systolic hypotension, allowing for precise deployment of the device. Final positioning of the graft was confirmed to be in Zone 2, just distal to the left common carotid artery as desired. The cava balloon was deflated, and a 12 mm by 6 cm long subclavian branch was then advanced, deployed, and post-dilated. Completion aortography demonstrated wide patency of the carotid and subclavian arteries. All devices and wires were subsequently removed, and all access sites were closed. A CT Angiogram obtained on post- operative day 4 demonstrated widely patent stent grafts with no endoleaks (Supplementary Video 2). The patient was discharged home on post-operative day 10. A 3-month follow-up CT demonstrated exclusion of the traumatic pseudoaneurysm and patent aortic and LSA stents.

Case Report 2

The second case is that of a 65-year-old male who fell 10 m off scaffolding. The patient had loss of consciousness at the time of the event. His concomitant injuries included bilateral wrist fractures, rib fractures, and a right-sided pneumothorax. A CT scan was performed that demonstrated an aberrant right subclavian artery (RSA) and a Grade 3 BTAI, with a focal pseudoaneurysm at the origin of the aberrant RSA that projected superomedially and was surrounded by a mediastinal hematoma (Supplementary Video 3). The patient was transferred to our level 1 trauma center and anti-impulse therapy was initiated.

Upon arrival, the patient was taken to the operating room for a combined cervical debranching procedure and placement of the Gore TBE. It was determined that bilateral carotid subclavian bypasses would not be appropriate given the increased risk of airway compromise due to neck edema post-operatively, and a plan to revascularize his RSA with an open bypass and concomitant endovascular repair of his LSA was undertaken.

Appropriate exposure of the second portion of the aberrant RSA was obtained. The dissection was then extended medially allowing for exposure of the carotid sheath; the common carotid artery was proximally and distally controlled. In this case, the left axillary artery was exposed for direct placement of the LSA stent to avoid the use of radial access at the left wrist fracture.

After ultrasound-guided arterial and venous access was obtained, the patient was systemically heparinized. A bypass was then performed using a 6 mm polytetraflouroethylene propaten graft from the right common carotid artery to the second portion of the RSA.

After completion of the right carotid to subclavian bypass, the same procedure as described above was performed for deployment of the 34 mm × 15 cm TBE Aortic Component with a 15 mm × 6 cm LSA stent over a "through and through" wire passed from the left axillary artery. A aortography on completion demonstrated wide patency of the left subclavian branch and no signs of an endoleak. A CT angiogram obtained on post-operative day 1 demonstrated the expected persistent type II endoleak from retrograde flow related to the aberrant RSA (Supplementary Video 4). On post-operative day 2 the patient underwent the planned second stage of the intervention: successful coil embolization of the remnant pseudoaneurysm along the origin of the aberrant RSA. The patient was discharged home on post-operative day 9.

Ethical Approval and Informed Consent

Ethical approval was not required. Informed consent was obtained from both patients in this case series.

DISCUSSION

The surgical management of BTAI continues to evolve. Historic management of BTAI prior to the endovascular era involved open repair via thoracotomy, aortic cross-clamping, and left-heart bypass, or deep hypothermic circulatory arrest. The advent of TEVAR ushered in a new era of management of BTAI with substantially reduced mortality and morbidity for patients [7]. Ongoing challenges with the surgical management of BTAI involve patients with injuries extending proximal to Zone 3 that have contraindications to primary LSA coverage where revascularization of the LSA is required (Table 3) [8].

Non-revascularization of the LSA in TEVAR is associated with increased risk of stroke and spinal cord ischemia [9–10]. Literature specific to BTAI supports additional considerations for LSA revascularization as trauma patients are at significantly higher risk of developing ischemic symptoms of the left upper extremity than non-trauma patients after coverage of the LSA [11].

In trauma patients where proximal TEVAR and LSA revascularization is required, cervical debranching has been the intervention of choice. Complications due to cervical debranching procedures are not insignificant and can be observed in up to 30% of patients [12]. These complications include phrenic nerve injury, brachial plexus trauma, thoracic duct injury with chylothorax or prolonged wound drainage, swallowing dysfunction with aspiration, graft thrombosis, graft infection, and wound complications [12–14]. In addition, cervical debranching remains a challenge in patients with concomitant neck trauma, lacerations, C-spine injury and immobilization, or tracheostomy. TBE offers a minimally invasive operation in these patients that may avoid many of the complications associated with debranching.

Table 3 Contraindications to left subclavian artery coverage in thoracic endovascular aortic repair (TEVAR) [8].

Contraindications to left subclavian artery coverage in TEVAR
1. Presence of left internal mammary artery coronary artery bypass graft
2. Termination of the left vertebral artery in a posterior inferior cerebellar artery (PICA)
3. Dominant left vertebral artery or occlusion of the right vertebral artery
4. Functioning left arm arteriovenous fistula
5. Prior infrarenal aortic repair with ligation or coverage of lumbar arteries
6. Planned long-segment (20 cm) coverage of the descending thoracic aorta
7. Hypogastric artery occlusion

The TBE device has allowed vascular surgeons to electively treat proximal aortic arch pathology while maintaining perfusion to the LSA with excellent results to date in experienced centers [15]. Additionally, results from a non-randomized trial performed in the United States across 34 sites suggest TBE in BTAI has favorable outcomes [16]. The wider availability of this device will allow for the application of this technology in the hyperacute setting for patients with BTAI, the most lethal of the thoracic traumatic injuries. Careful patient consideration is required with respect to anatomic suitability; a retrospective review evaluating various anatomical features in patients undergoing TEVAR found that only 32% of patients are suitable candidates for theoretical TBE intervention [17]. We have demonstrated the clinical utility of this emerging technology in the setting of acute BTAI and will continue to use this device in appropriately selected patients.

CONCLUSION

This report demonstrates two successful percutaneous endovascular repairs of BTAI using the Gore TBE device to preserve left subclavian perfusion. Off-the-shelf branched thoracic endografts in BTAI should be considered by experienced TEVAR trauma centers in

patients requiring LSA revascularization with appropriate anatomy who are at increased risk of complications from either Zone 2 TEVAR coverage alone or cervical debranching procedures. Widespread access to these devices will allow for further review of outcomes in this challenging patient population.

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

Dr. Kenton Rommens serves as a consultant for Gore Medical and Terumo Aortic. The remaining authors have no other disclosures or conflicts of interest.

Funding

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

SUPPLEMENTARY DIGITAL CONTENT

Available online at https://doi.org/10.26676/jevtm.33826.

Supplementary Video 1. Video of pre-operative computed tomography scan for case report 1.

Supplementary Video 2. Video of post-operative computed tomography scan for case report 1.

Supplementary Video 3. Video of pre-operative computed tomography scan for case report 2.

Supplementary Video 4. Video of post-operative computed tomography scan for case report 2.

REFERENCES

[1] Dahal R, Acharya Y, Tyroch AH, Mukherjee D. Blunt thoracic aortic injury and contemporary management strategy. Angiology. 2022;73(6):497–507.
[2] Sevitt S. The mechanisms of traumatic rupture of the thoracic aorta. Br J Surg. 1977;64(3):166–73.
[3] Akhmerov A, Dubose J, Azizzadeh A. Blunt thoracic aortic injury: Current therapies, outcomes, and challenges. Ann Vasc Dis. 2019;12(1):1–5.
[4] de Mestral C, Dueck A, Sharma SS, et al. Evolution of the incidence, management, and mortality of blunt thoracic aortic injury: A population-based analysis. J Am Coll Surg. 2013;216(6):1110–5.
[5] Mouawad NJ, Paulisin J, Hofmeister S, Thomas MB. Blunt thoracic aortic injury – concepts and management. J Cardiothorac Surg. 2020;15(1):62.
[6] Riambau V, Böckler D, Brunkwall J, et al. Editor's choice – Management of descending thoracic aorta diseases: Clinical practice guidelines of the European Society for Vascular Surgery (ESVS). Eur J Vasc Endovasc Surg. 2017;53(1):4–52.
[7] Elkbuli A, Dowd B, Spano PJ, 2nd, et al. Thoracic endovascular aortic repair versus open repair: analysis of the National Trauma Data Bank. J Surg Res. 2020; 245:179–82.
[8] Matsumura JS, Rizvi AZ. Left subclavian artery revascularization: Society for Vascular Surgery practice guidelines. J Vasc Surg. 2010;52(4):65S–70S.
[9] Bradshaw RJ, Ahanchi SS, Powell O, et al. Left subclavian artery revascularization in zone 2 thoracic endovascular aortic repair is associated with lower stroke risk across all aortic diseases. J Vasc Surg. 2017;65(5):1270–9.
[10] Teixeira PG, Woo K, Beck AW, Scali ST, Weaver FA. Association of left subclavian artery coverage without revascularization and spinal cord ischemia in patients undergoing thoracic endovascular aortic repair: a Vascular Quality Initiative® analysis. Vascular. 2017;25(6):587–97.
[11] Grigorian A, Lewis M, Wlodarczyk JR, et al. Left subclavian artery coverage during endovascular repair of thoracic aorta injury in trauma and non-trauma patients. Eur J Trauma Emerg Surg. 2022;48(6):4425–9.
[12] Voigt SL, Bishawi M, Ranney D, et al. Outcomes of carotid-subclavian bypass performed in the setting of thoracic endovascular aortic repair. J Vasc Surg. 2019;69(3):701–9.
[13] Konstantinou N, Debus ES, Vermeulen CFW, et al. Cervical debranching in the endovascular era: a single centre experience. Eur J Vasc Endovasc Surg. 2019; 58(1):34–40.
[14] Bellamkonda KS, Yousef S, Nassiri N, et al. Trends and outcomes of thoracic endovascular aortic repair with open concomitant cervical debranching. J Vasc Surg. 2021;73(4):1205–12.e3.
[15] Dake MD, Fischbein MP, Bavaria JE, et al. Evaluation of the Gore TAG thoracic branch endoprosthesis in the treatment of proximal descending thoracic aortic aneurysms. J Vasc Surg. 2021;74(5):1483–90.e2.
[16] Chou EL, Lu E, Dake MD, et al. Initial outcomes of the Gore TAG thoracic branch endoprosthesis for endovascular repair of blunt thoracic aortic injury. Ann Vasc Surg. 2024;104:147–55.
[17] Yoon WJ, Mani K, Wanhainen A, Rodriguez VM, Mell MW. Anatomic feasibility of off-the-shelf thoracic single side-branched endograft in patients with blunt traumatic thoracic aortic injury. J Vasc Surg. 2021;74(5): 1456–63.e2.

Original Article

Vol. 8, No. 3; 2024; pp 100–106
DOI: https://doi.org/10.26676/jevtm.34828

Use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in Trauma Patients in French Level-1 Trauma Centers: A National Survey

Pauline Glasman[1,6], Thomas Clavier[2,3,6], Hervé Quintard[4,6] and Jonathan Charbit[5,6,*], on behalf of the ACUTE SFAR committee

[1]*Department of Anesthesiology and Critical Care, Hôpital La Pitié Salpêtrière, APHP, F-75013 Paris, France*
[2]*Department of Anesthesiology, Critical Care and Perioperative Medicine, Rouen University Hospital, Rouen, France*
[3]*Rouen University, INSERM U1096, EnVi, 76000, Rouen, France*
[4]*Division of Intensive Care Medicine, Department of Anesthesiology, Clinical Pharmacology, Intensive Care, and Emergency Medicine, Geneva University Hospital, Geneva, Switzerland*
[5]*Trauma and Polyvalent Critical Care Unit, Lapeyronie University Hospital, Montpellier, France*
[6]*ACUTE committee of Société Française d'Anesthésie et de Réanimation (SFAR), F-75016 Paris, France*

Background: The goal of the present national survey was to describe the practices and use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in France in level-1 trauma centers.
Methods: Between January and December 2023, the ACUTE SFAR (Société Française d'Anesthésie et de Réanimation) committee sent a numeric survey to each French level-1 trauma center. This survey was focused on REBOA in trauma management including: use, protocol (indications, placement, aortic occlusion durations), aortic occlusion location (Zone 1/Zone 3), partial occlusion (pREBOA), device characteristics, operator, specific complications.
Results: Among the 41 French level-1 trauma centers, 18 (44%) had incorporated REBOA in their algorithm. In 2022, 78% (14/18) of these centers had experienced between 1 and 5 REBOA placements, 11% (2/18) between 6 and 10, and 6% (1/18) 10 or more placements. The frequency of REBOA procedures increased with the duration of REBOA availability at the center. A protocol for REBOA placement was present in 28% (5/18) of centers. An anesthesiologist-intensivist was the operator in 50% (9/18), a surgeon in 28% (5/18), and a radiologist in 22% (4/18) of centers. The proportion of centers using REBOA in Zone 1 was 39% (7/18), and pREBOA 33% (6/18). The maximum duration of complete aortic occlusion was specified in 50% of centers for Zone 1 and 78% for Zone 3.
Conclusions: Use of REBOA is modestly spread among the French trauma centers, and in less than half of centers. Specific protocols are present. Anesthesiologist-intensivists are the operators in only half of these centers.

Keywords: *Anesthesiologist; Aortic Occlusion; Bleeding Control; Hemorrhagic Shock; Trauma Management*

Received: 27 November 2024; Accepted: 19 December 2024

INTRODUCTION

The management of severe trauma casualties is a significant public health concern in most countries. Uncontrolled bleeding remains responsible for early death in nearly 10% of traumatic patients [1]. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is an emergency procedure used to achieve an abdominal intra-aortic occlusion for hemodynamic unstable trauma patients awaiting life-saving management [2]. Data have been increasingly published since the introduction of REBOA by Hughes [3]. The integration of REBOA these past 10 years has offered a deep change of view on the acute management of bleeding trauma patients. With a REBOA placement upon hospital admission, the duration

Corresponding author:
Jonathan Charbit, Département d'Anesthésie Réanimation Lapeyronie, Hôpital Lapeyronie, 371 Avenue du Doyen G. Giraud, 34295 Montpellier, France.
Email: j-charbit@chu-montpellier.fr
*A list of members and their affiliations is available in Supplementary File 1.

of active bleeding ends with the aortic occlusion, which differs from management without REBOA, where the time required for hemostatic procedures must be added [4–6]. This difference is particularly interesting in countries in which surgeons are not the designated physicians to manage first-line trauma patients upon hospital admission [4].

In France, severe trauma patients are directed from the trauma scene towards regional level-1 trauma centers based on prehospital medical team reports and severity clinical criteria [7]. In most of these centers, anesthesiologist-intensivists are the designated physicians to provide immediate care upon admission. Because of their skills in many fields, such as ultrasonography or percutaneous vascular catheter insertion, the REBOA device could be an interesting tool in order to limit incompressible delays in the presence of hemodynamic instability or to the need to call the appropriate surgeon or organize a hemostatic intervention [8,9]. However, several concerns still exist among French trauma experts, making the place of REBOA unclear in the French trauma system. The discussions between these French trauma experts suggest that REBOA has not been widely adopted in the trauma centers across France. Furthermore, no study has comprehensively described the use of REBOA on a national scale.

The main objective of the present work was therefore to provide an up-to-date overview of REBOA use in French level-1 trauma centers. A secondary objective was to characterize and detail the clinical practices related to REBOA in centers with experience in this procedure.

METHODS

Study Design

A prospective study was conducted in France using a declarative survey between January 2023 and December 2023. A link to an open *Google Form Internet Survey* was sent by email to the referents of all medical teams in each of the 41 level-1 trauma centers (Supplementary File 2). All participants also received information about the survey objectives in the preface of the questionnaire. The design of the present study was clearly indicated in order to obtain informed consent. It was especially stated that the survey questioned institutional habits of the trauma center rather than individual ones. Only one response by each trauma center was considered. The data were treated in a blinded manner to maintain the anonymity of responses. This survey was developed in accordance with available guidelines for self-administered surveys [10]. No patient case was mentioned. Responses were made on a single web page with one "submit" button that only allowed submissions via these unique links, thus making non-invited responses impossible. The survey was conducted in accordance with the Checklist for Reporting Results of Internet E-survey (CHERRIES [11], Supplementary File 3).

Data Collection

The survey was designed and written by PG and then reviewed, tested, and validated by JC, HQ, and TC (as trauma experts) before being sent out. The survey was constructed in four parts:

- Identification of the trauma center (region, city, and department).
- Department organization regarding REBOA: written service protocol for indications or placement of REBOA, maximum duration of complete aortic occlusion, availability of a REBOA kit, presence of a physician referent in the trauma center.
- Experience in REBOA management: number of institutional procedures in 2022, indications, diameters of sheath, and balloon catheter, durations of aortic occlusion, used zones of aortic occlusion (Zone 1 [left subclavian artery to celiac trunk] and/or Zone 3 [lowest renal artery to aortic bifurcation]), and specific modalities of use (partial aortic occlusion [pREBOA], performance of computed tomography scan or embolization with a REBOA).
- Practice improvement: wish to receive REBOA training or to participate in a national register focused on REBOA.

Statistical Analyses

Given the purely descriptive nature of this survey, no specific statistical analysis was planned. The analysis was focused on the subgroup of trauma centers that used REBOA. Continuous variables were described as medians (interquartile ranges [IQR]) and categorical variables as absolute numbers and percentages (%). A stratification of these data was proposed according to duration of REBOA availability, as well as number of placements in 2022.

Ethical Approval and Informed Consent

Ethical approval was not required. This was an anonymous numeric survey considering no patient data, but merely an institutional organization, so no individual informed consent was required.

RESULTS

A total of 41 online responses were obtained during the study period, representing 100% of the French level-1 trauma centers. Eighteen (44%) of the centers reported REBOA use in their traumatic management. Figure 1 provides details of the distribution of these trauma centers

across the country. Among the centers using REBOA, 78% (14/18) had performed between 1 and 5 REBOA placements during 2022, 11% (2/18) between 6 and 10, and 6% (1/18) 10 or more placements during the year. This number of annual procedures increased with the duration of REBOA availability in the center (Figure 2*a*,*b*).

In the subgroup of centers using REBOA, 28% (5/18) implemented a protocol for procedure and placement. According to hemorrhagic context, 100% (18/18) of the centers used REBOA on the source of pelvic bleeding, 78% (14/18) on the source of abdominal bleeding, and 67% (12/18) on the source of lower limb bleeding. An anesthesiologist-intensivist served as the operator in half of the centers (9/18), while the operator was a surgeon in 28% of centers (5/18), and an interventional radiologist in 22% of centers (4/18). The duration of REBOA availability in the center did not appear to directly influence the involvement of anesthesiologist-intensivists (Figure 2*c*).

Concerning aortic occlusion practices, 39% (7/18) of the centers used REBOA in Zone 1. The maximum durations of complete occlusion allowed in the

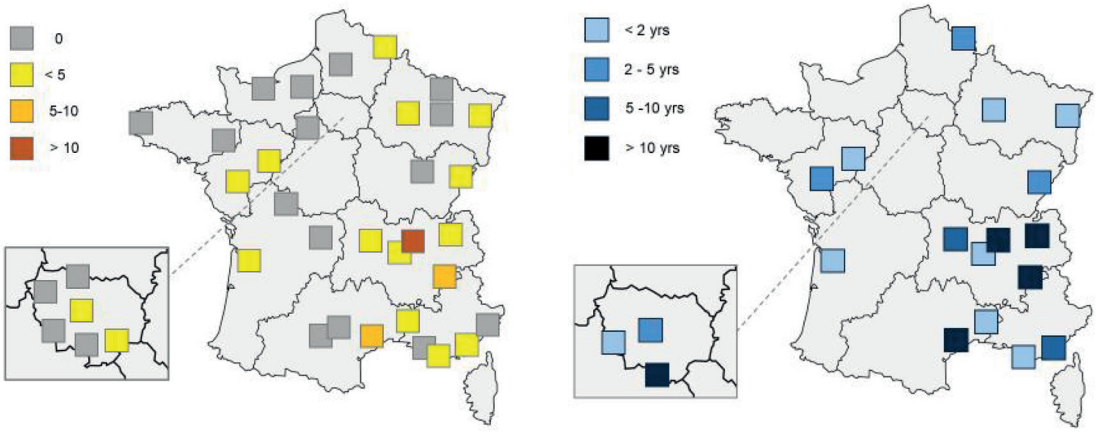


Figure 1 REBOA use in French level-1 trauma centers.

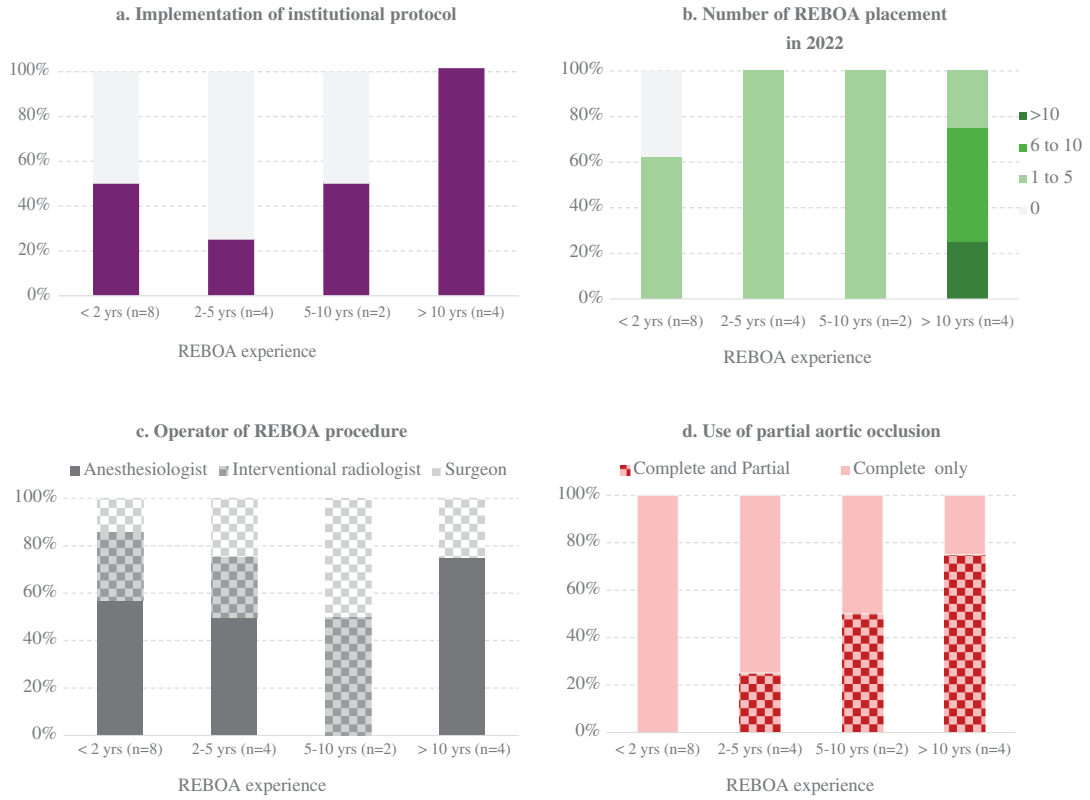


Figure 2 Clinical practices focused on REBOA in French level-1 trauma centers.

protocols were, as expected, higher for Zone 3 (Figure 3). Only 50% of centers (9/18) had a protocol for Zone 1 with a duration limit of complete aortic occlusion; there were 22% (4/18) at 30 minutes, 17% (3/18) at 45 minutes, 11% (2/18) at 60 minutes, and none at 120 minutes. This rate was 78% (14/18) for Zone 3; corresponding values were 6% (1/18), 11% (2/18), 28% (5/18), 17% (3/18), and 39% (7/18), respectively. The practice of pREBOA was used in 33% (6/18) of the centers, increasing with REBOA experience (Figure 2*d*).

Figure 4 provides details of the types of complications observed in the trauma centers with REBOA use. The main reported complication was vascular, either distal ischemia or dissection injury, with 50% (9/18) of the centers reporting this complication, albeit in a minor proportion of cases. Hemorrhagic complications were also observed (28%; 5/18) as well as septic complications (17%; 3/18).

Finally, a majority of the 41 French level-1 trauma centers declared their wish to receive theoretical information (80%; 33/41) or practical training (83%; 34/41) on the placement of REBOA. Eighty-eight per cent of centers (36/41) also declared that they were interested in participating in a national register or study.

DISCUSSION

In our national survey that specifically assessed the use of REBOA in all French level-1 trauma centers, we highlighted that less than half of these institutions had experienced at least one REBOA placement. While almost all of these centers had a specific protocol, the proportion of those using REBOA in Zone 1 was lower than 40%, and only one-third of centers used partial REBOA. In half of these centers, REBOA procedures were performed by anesthesiologist-intensivists. For the year 2022, the majority of centers using REBOA

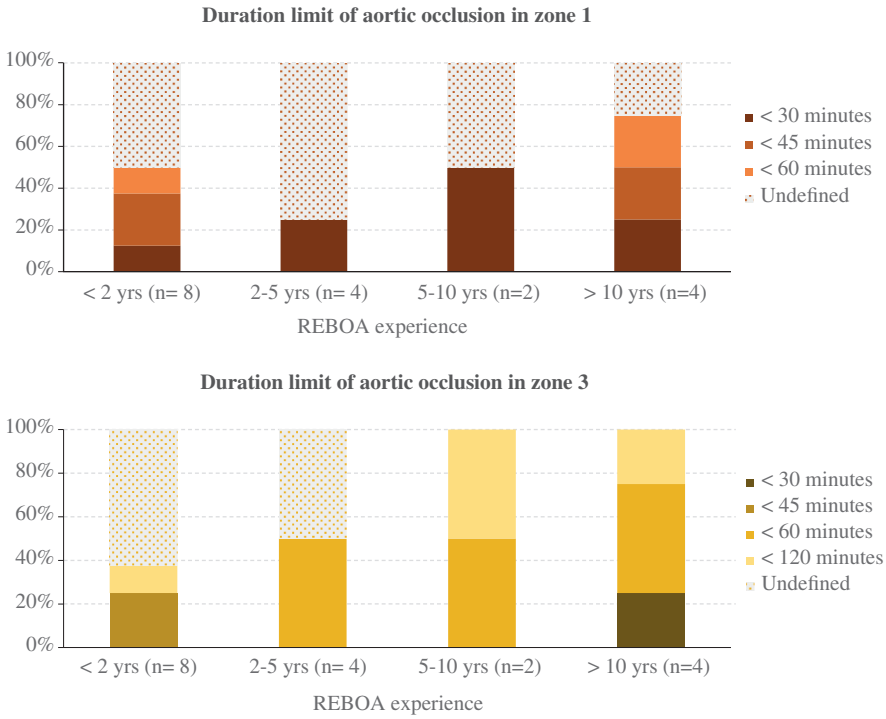


Figure 3 Protocol of aortic occlusion durations.

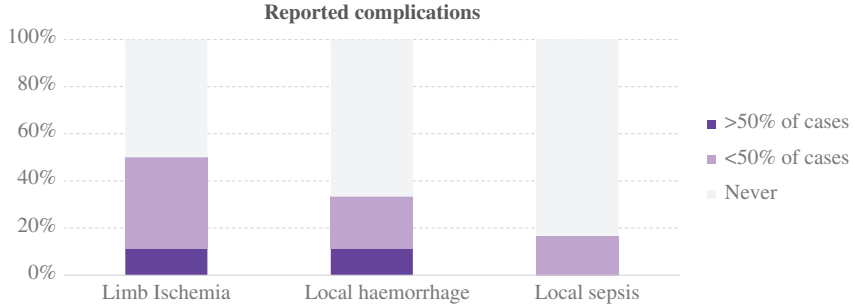


Figure 4 Specific local complications related to REBOA.

reported a number of placements lower than 5, with almost all reporting a number of placements lower than 10. Therefore, to date, REBOA remains poorly distributed and rarely used in the context of trauma in France.

Several characteristics of REBOA would seem to make this life-saving procedure an attractive tool in the French trauma system. Firstly, there is its simplicity of placement for an anesthesiologist-intensivist, who receives trauma patients in most French level-1 trauma centers [7,12]. Historically, REBOA has been proposed using a surgical approach, making this hemostatic intervention relevant mainly in countries where trauma surgeons are the first physicians upon admission [13]. These last years, the percutaneous approach has been successfully adopted by many teams, establishing it as the current standard of care [14]. The percutaneous approach appears thus to be more suitable for anesthesiologist-intensivists who are accustomed to these vascular access techniques, especially helped by ultrasonography [8,9]. Secondly, REBOA is reputed to be more relevant in cases of multiple injuries or multiple bleeding sources [15,16]. REBOA could therefore be of valuable help for the anesthesiologist-intensivist in the presence of multiple bleeding sources to limit blood loss, while activation and coordination of different physicians may be challenging [16]. In addition to temporarily stopping the bleeding, aortic occlusion in cases of massive blood loss helps maintain acceptable hemodynamic targets to preserve cerebral and coronary perfusion [17]. Optimization of these physiological parameters, which are the cornerstone of trauma resuscitation, is indeed crucial in the presence of traumatic brain injury or multiple organ failure. All these arguments therefore play in favor of REBOA use in French trauma centers and its placement by anesthesiologist-intensivist in the emergency room. However, one of our main findings is that less than 50% of French trauma centers had used REBOA up until the start of our survey. We hypothesize that the transfer of a surgical technique to another specialty takes longer to implement. Moreover, only half of the centers that have incorporated REBOA into their therapeutic arsenal have declared in our study that this procedure was performed by anesthesiologist-intensivists. A better understanding of clinical experience could probably help to propose guidelines for this practice in a trauma setting.

While the efficacy of REBOA for trauma has been widely recognized compared to resuscitative thoracotomy or open aortic occlusion, its use in the country appears to be limited [6,18,19]. This technique may indeed be intimidating for physicians due to the potential for misuse, which could lead to local complications or ischemia-reperfusion injuries. Another concern is the possible additional delays that could be generated by the introduction of REBOA in acute bleeding management. So, how should we analyze the specific constraints related to REBOA in the French trauma system? Firstly, the risk of time loss is a significant concern when considering REBOA. Delaying hemostatic control is obviously undesirable and could result in a higher mortality rate [20]. Using a Bayesian analysis, a prospective randomized series indeed suggested that lost time in the REBOA group might induce a higher mortality rate. However, there were limitations in this cohort, such as a low proportion of hemostatic interventions, questioning of selection criteria for included patients, or delays in achieving hemostatic interventions. Anyway, this specific concern is still unresolved, leading to possible doubts as to the benefit of REBOA. What is certain, in contrast, is that the REBOA procedure must be timed, and a maximum duration must be defined in the center protocol. Following this reasoning, Brenner et al. [2] demonstrated that aortic occlusion can be achieved within a few minutes in most cases when physicians are trained, whether in cardiac arrest or circulatory shock. Secondly, the morbid consequences of mesenteric or hepatic ischemia-reperfusion are well known in cases of aortic occlusion, necessitating a limit on occlusion duration to 30–40 minutes in Zone 1 and 120–180 minutes in Zone 3 [21,22]. Physicians must know that failure to respect this timing can be lethal, even if the bleeding source is controlled. However, a partial occlusion was demonstrated to allow a longer use of REBOA without major consequences [23,24]. Simple monitoring of arterial pressure level below the balloon on the sheath is easy, simple, and allows one to maintain an acceptable perfusion pressure in the mesenteric, pelvic, and lower limb areas. In our survey, only one-third of the trauma centers using REBOA were familiar with pREBOA. Intermittent aortic occlusion was also proposed as an alternative to pREBOA, but with lower tolerance [25,26]. We suppose that the increase of REBOA experience could be associated with an increase of pREBOA use in the French centers, which is associated with less adverse consequences related to ischemia-reperfusion [23,24]. It is of note that, to date, only 50% of the French teams had performed aortic occlusion in Zone 1, which may explain why pREBOA was less commonly used. Thirdly, concerns about ischemic risk for the lower limb may also act as a barrier. A significant size of sheath is indeed necessary to be able to insert the balloon with a catheter that often reaches a diameter of 7Fr. Historic sheaths had large diameters (14–12Fr), and therefore it was legitimate to fear significant ischemia and local complications [18]. However, such complications were described as low in most series, particularly when sheath diameters were lower than 10Fr [14]. To date, new devices exist with lower diameters of sheath, 7Fr or smaller. These were previously not available in France. The reduction of this diameter may be the key to diffusion of REBOA in our country, simplifying its placement and decreasing the fear of critical limb ischemia or vascular complications. Fourthly, REBOA indications are very rare,

even in a level-1 trauma center, with a few per year [27]. This low rate contributes to a low knowledge of the procedure and to the fear of its complications. The more experienced clinicians are, the less fearful they become and the more comfortable they are, leading to an increase in the number of REBOA placements. This was demonstrated by our national survey where the number of annual procedures increased with the duration of REBOA availability in the center.

Although our study provides interesting and comprehensive results at a national level, it has several limitations. Firstly, numerical surveys are subject to a declarative bias. However, we clearly stated in our methodological instructions that the responses should strictly reflect the situation and practices in the centers. Secondly, our survey was conducted before the publication of two major trials, presenting a risk of changes in practices [6,20]. Thirdly, the number of annual REBOA placements was low and varied from year to year. Therefore, our analysis, which focuses on 2022, may not fully represent the usage of REBOA in France. Fourthly, the UK-REBOA study [20] reported a potential negative impact associated with misuse of REBOA, which may slow down the development of this procedure. Data collection for the present survey was, however, achieved before the publication of this work, allowing us to affirm it had a minor impact on our analysis.

To conclude, our survey revealed that the utilization of REBOA in French trauma centers prior to 2023 was modest, with less than half of the level-1 centers employing this technique. The annual number of placements in these centers remains low, highlighting the need for written and multidisciplinary protocols in each facility. These protocols should include clinical indications for REBOA placement, material, and procedural rules, as well as the timing of aortic occlusions and the modalities of balloon deflation. Interestingly, only half of the centers declared that placements were performed by anesthesiologist-intensivists, despite their primary role in patient admission. However, a large majority of centers expressed interest in receiving practical and/or theoretical training in REBOA use. Divergent conclusions from several studies, the low number of indications, and technical complexity have so far been obstacles to the development of REBOA in our country. The emergence of a national academic program and the determination of a consensual and safe place for REBOA may facilitate its adoption in expert centers.

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.

Funding

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

SUPPLEMENTARY DIGITAL CONTENT

Supplementary File 1. The ACUTE SFAR Committee 2023–2024.

Supplementary File 2. French numeric survey for practice organization in level-1 trauma centers.

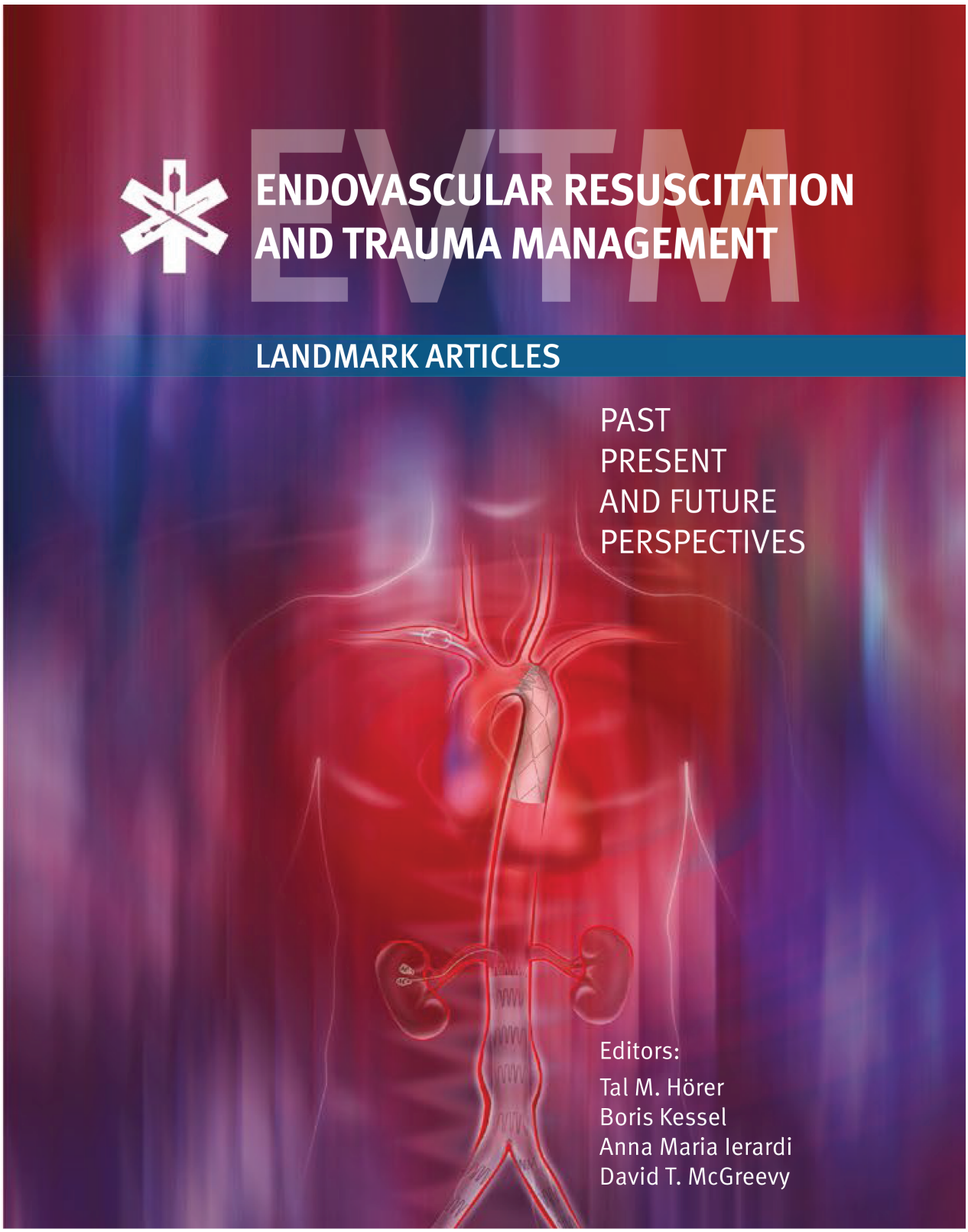
Supplementary File 3. Checklist for Reporting Results of Internet E-Surveys (CHERRIES)*

REFERENCES

[1] Charbit J, Lakhal K, Deras D, et al. Influence of surgical bleeding on the relationship between admission coagulopathy and risk of massive transfusion: lesson from 704 severe trauma patients. Vox Sang. 2016;111:151–60.
[2] Brenner M, Teeter W, Hoehn M, et al. Use of resuscitative endovascular balloon occlusion of the aorta for proximal aortic control in patients with severe hemorrhage and arrest. JAMA Surg. 2018;153:130.
[3] Hughes C. Use of an intra-aortic balloon catheter tamponade for controlling intra-abdominal hemorrhage in man. Surgery. 1954;36:65–8.
[4] Abe T, Uchida M, Nagata I, Saitoh D, Tamiya N. Resuscitative endovascular balloon occlusion of the aorta versus aortic cross clamping among patients with critical trauma: a nationwide cohort study in Japan. Crit Care. 2016;20:400.
[5] Brenner M, Zakhary B, Coimbra R, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) may be superior to resuscitative thoracotomy (RT) in patients with traumatic brain injury (TBI). J Trauma Surg Acute Care Open. 2022;7:e000715.
[6] Cralley AL, Vigneshwar N, Moore EE, et al. Zone 1 endovascular balloon occlusion of the aorta vs resuscitative thoracotomy for patient resuscitation after severe hemorrhagic shock. JAMA Surg. 2023;158:140.
[7] Gauss T, Balandraud P, Frandon J, et al. Groupe d'intérêt en traumatologie grave (GITE). Strategic proposal for a national trauma system in France. Anaesth Crit Care Pain Med. 2019;38:121–30.

[8] Moussa Pacha H, Alahdab F, Al-Khadra Y, et al. Ultrasound-guided versus palpation-guided radial artery catheterization in adult population: a systematic review and meta-analysis of randomized controlled trials. Am Heart J. 2018;204:1.
[9] Rashid MK, Sahami N, Singh K, et al. Ultrasound guidance in femoral artery catheterization: a systematic review and a meta-analysis of randomized controlled trials. J Invasive Cardiol. 2019;31:E192.
[10] Burns K, Duffett M, Kho M, et al. for the ACCADEMY Group. A guide for the design and conduct of self-administered surveys of clinicians. CMAJ. 2008;179: 245–52.
[11] Eysenbach G. Improving the quality of Web surveys: the Checklist for Reporting Results of Internet E-Surveys (CHERRIES). J Med Internet Res. 2004;6:e34.
[12] Charbit J, Millet I, Martinez O, et al. Does the size of the hemoperitoneum help to discriminate the bleeding source and guide therapeutic decisions in blunt trauma patients with pelvic ring fracture? J Trauma Acute Care Surg. 2012;73:117–25.
[13] Brenner M, Moore L, DuBose J, et al. A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. J Trauma Acute Care Surg. 2013;75:506–11.
[14] Shum-Tim L, Bichara-Allard S, Hopkins B, et al. Vascular access complications associated with resuscitative endovascular balloon occlusion of the aorta in adult trauma patients: a systematic review and meta-analysis. J Trauma Acute Care Surg. 2024;96:499–509.
[15] Ordoñez CA, Parra MW, Manzano-Nunez R, et al. Intraoperative combination of resuscitative endovascular balloon occlusion of the aorta and a median sternotomy in hemodynamically unstable patients with penetrating chest trauma: Is this feasible? J Trauma Acute Care Surg. 2018;84:752–7.
[16] Ordoñez CA, Rodríguez F, Parra M, et al. Resuscitative endovascular balloon of the aorta is feasible in penetrating chest trauma with major hemorrhage: proposal of a new institutional deployment algorithm. J Trauma Acute Care Surg. 2020;89:311–9.
[17] Benham DA, Calvo RY, Carr MJ, et al. Is cerebral perfusion maintained during full and partial resuscitative endovascular balloon occlusion of the aorta in hemorrhagic shock conditions? J Trauma Acute Care Surg. 2021;91:40–6.
[18] Laverty RB, Treffalls RN, McEntire SE, et al. Life over limb: arterial access-related limb ischemic complications in 48-hour REBOA survivors. J Trauma Acute Care Surg. 2022;92:723–8.
[19] Bini JK, Hardman C, Morrison J, et al. Survival benefit for pelvic trauma patients undergoing resuscitative endovascular balloon occlusion of the aorta: results of the AAST Aortic Occlusion for Resuscitation in Trauma Acute Care Surgery (AORTA) Registry. Injury. 2022;53:2126–32.
[20] Jansen J, Hudso J, Cochran C, et al. for the UK-REBOA Study Group. Emergency department resuscitative endovascular balloon occlusion of the aorta in trauma patients with exsanguinating hemorrhage: The UK-REBOA randomized clinical trial. JAMA. 2023;330:1862–71.
[21] Yamashiro K, Galganski L, Grayson K, et al. Resuscitative endovascular balloon occlusion of the aorta in a pediatric swine model: is 60 minutes too long? J Trauma Acute Care Surg. 2020;89:616–22.
[22] Avaro JP, Mardelle V, Roch A, et al. Forty-minute endovascular aortic occlusion increases survival in an experimental model of uncontrolled hemorrhagic shock caused by abdominal trauma. J Trauma. 2011;71:720–6.
[23] Kemp MT, Wakam GK, Williams AM, et al. A novel partial resuscitative endovascular balloon aortic occlusion device that can be deployed in zone 1 for more than 2 hours with minimal provider titration. J Trauma Acute Care Surg. 2021;90:426–33.
[24] Forte DM, Do WS, Weiss JB, et al. Validation of a novel partial resuscitative endovascular balloon occlusion of the aorta device in a swine hemorrhagic shock model: fine tuning flow to optimize bleeding control and reperfusion injury. J Trauma Acute Care Surg. 2020;89:58–67.
[25] Johnson M, Hoareau G, Beyer C, et al. Not ready for prime time: intermittent versus partial resuscitative endovascular balloon occlusion of the aorta for prolonged hemorrhage control in a highly lethal porcine injury model. J Trauma Acute Care Surg. 2020;88:298–304.
[26] Cambronero G, Sanin G, Patel N, et al. Automated partial resuscitative endovascular balloon occlusion of the aorta reduces blood loss and hypotension in a highly lethal porcine liver injury model. J Trauma Acute Care Surg. 2023;95:205–12.
[27] Charbit J, Dagod G, Darcourt S, et al. Use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in a multidisciplinary approach for management of traumatic haemorrhagic shock: 10-year retrospective experience from a French level 1 trauma centre. Injury. 2024;13:111952.

EVTM Landmark Articles



Order now!

Send an email to asa.strandberg@regionorebrolan.se

Education

EndoVascular resuscitation and Trauma Management – Specialists in Training (EVTM-ST) is a group within the EVTM Society and EVTM Council who represent the interests of trainees, especially with regards to training, education, research and exchange programmes.

One of the main EVTM-ST events is the monthly multidisciplinary international case discussions on Zoom. An appreciated concept with focus on allowing the participating trainees to discuss a presented EVTM case, with only one consultant present for guidance. Participants are from all around the world, from various disciplines and with different levels of experience. We have great discussions, exchange of knowledge and hear about different local experiences that everyone can learn from.

If you are interested in joining the EVTM-ST case discussions,

please email: david.mcgreevy@regionorebrolan.se

Coming Meetings

24th European Congress of Trauma and Emergency Surgery, 13–15th April 2025, Aachen, Germany

47th Annual CX Symposium, 23–25th April, 2025, London, UK
https://www.cxsymposium.com/

SSVS Swedish Vascular Meeting, 7–9th May 2025, Göteborg
https://ssvs.nu/event/ssvs-nationella-mote-2025-goteborg/

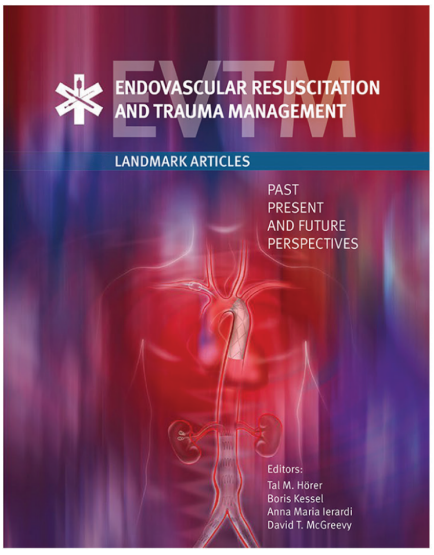
AAST Annual Meeting, 10–13th September 2025, Boston, MA, USA
https://www.aast.org/annual-meeting/2025-annual-meeting

ESVS Annual Meeting, 23–26th September 2025, Turkey
https://esvs.org/events/annual-meeting/annual-meeting-2025/

VEITH Symposium, 18–22nd November 2025, New York, USA
https://www.veithsymposium.org/

EVTM workshop dates, 11–12th September 2025
https://jevtm.com/evtm-news/

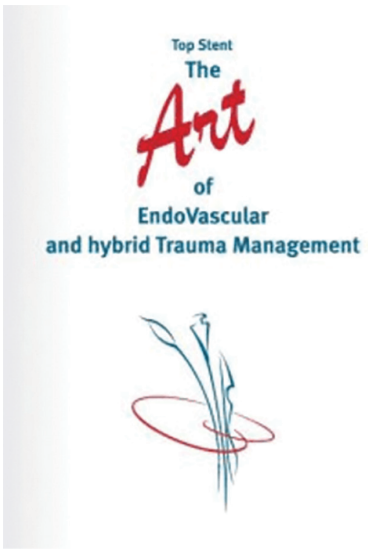
Books



Out now!

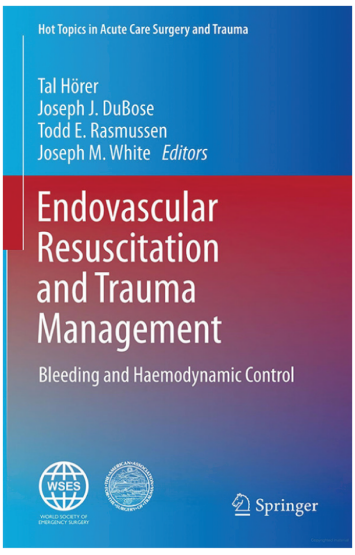
Order by mail:

asa.strandberg@regionorebrolan.se



Now available in Spanish, Turkish, Russian, Italian, Korean, Portuguese and Chinese.

jevtm.com/top-stent



Now available at Springer

Region Örebro County
Örebro University Hospital

HANDLED BY
Dept. of Cardiothoracic and Vascular Surgery, Prof. Tal Hörer

DATE
2025-02-12, **www.jevtm.com**

EndoVascular resuscitation and Trauma Management (EVTM)

Hands-on Workshop

Örebro University Hospital, Sweden 11– 12 September 2025

EndoVascular Resuscitation and Trauma Management

Local team: Tal Hörer, David McGreevy, Kristofer Nilsson, Artai Pirouzram, Rami Hammadi, Anna Stene, Johan Josefsson, Jonas Berlin, Ida Liljeholm, TBA

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

Date: 11–12/9/25

Workshop Directors: Tal Hörer and David McGreevy

Workshop Registration: lotta@mkon.se or Hilda@mkon.se

Cost (cover expenses only): 500Eu. 400Eu for EVTM Society members

Place: Facility for experimental studies and surgical training, Örebro University Hospital.

Partners: See partner list on EVTM symposium site via www.jevtm.com

The aim of this one-day workshop is to train, stimulate discussion, **mutual learning and sharing** of experiences while practicing EndoVascular resuscitation *and* Trauma Management (EVTM) using a multidisciplinary team approach with emphasis on local resources. “No ego, just good science, care and collaboration” is the main motion of the event. We are all here to share, learn and develop, for our patients.

Tal Hörer, Örebro University Hospital, tal.horer@regionorebrolan.se
+46196024632 (direct) / +46702383495 / +46196021111 (switchboard)
More info at www.jevtm.com/workshop and social media #EVTM

The workshop is built on an individual, professional level and we will together explore different methods for resuscitation, bleeding control, hemostasis, trauma management and bail-outs. Some methods are used clinically world-wide, while some are under development and have been used on selected patients. This workshop concentrates on basic and advanced aspects of *open and endovascular* bleeding control techniques. We will combine open hemostasis and endo aspects with vascular access, angiography, embolization, endografts, shunts and other endo/hybrid solutions for the unstable patient. Hemodynamic instability with a focus on trauma, non-trauma, bleeders and non-bleeders. From ruptures to gastrointestinal and gynecological bleeders with a wide range of hemodynamic instabilities in focus. We will explore how methods used by some disciplines can be used by others.

We will focus on clinical data and lessons learned from more than 20 years use of these methods in clinical practice.

- Vascular access:
  - Different methods (blind, doppler, ultrasound, fluoroscopy and cut down)
  - Its use in hemodynamic unstable patients
- Aortic Balloon Occlusion (REBOA) basic and advanced methods and SAAP
- Basic/advanced angiography principles and practical tips
- Damage control EVTM and bailout methods – open, endo and hybrid
- Maintaining and closing a vascular access
- Basic and advanced postoperative considerations
- Up-to-date research and clinical experience
- Cases/discussions
- Knowledge of basic/advanced material and new technologies on the market
- Endografts, embolization material on the market, and what to use and when
- Open and endo/hybrid hemostasis. From junctional bleeding to rAAA
- Intensive training on live tissue
- ICU and post-operative aspects (such as IAH and ACS and its treatment)
- Basics for building an “EVTM service”; tools needed
- Advanced experimental methods in resuscitation using REBOA and ECMO with CPR on live tissue models.
- When should we choose open surgery and stop playing with endo?

The workshop is individually tailored during the practical parts (advanced and basic as needed). Participants will get basic training and knowledge of vascular access, angiography, endografts, embolization and REBOA placement and other basic catheters and hybrid tools as part of the EVTM concept. This will be combined with open techniques and bleeding control maneuvers. The workshop has been certificated by the EACCME and acknowledged by collaboration with

societies such as the European Society for Trauma and Acute Care Surgery, the European Vascular Society and others.

08:00 meeting in the training center ("Technical house" near the CAMPUS USÖ)- instructions by mail till participants.

Introduction on EVTM and agenda of the day - Tal Hörer and David McGreevy

08:30–09:00 Breakfast with the industry.

Hands-on animal lab including:

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

Practical training points in the animal lab:

1. Material usage in bleeding patients, general considerations and management scenarios
2. Open techniques for bleeding control/hemostasis and combinations with endo/hybrid.
3. Vascular access
    - Basic principles/advanced methods
    - Cut-down techniques
    - Endoshunts and shunts
    - Hybrid procedures
    - Puncture methods
    - Seldinger technique
    - The failing access – alternatives
    - Venous access and ultrasound
    - Basic and advanced methods
4. Upgrading/introducers/guide wires
5. REBOA
    - Material and REBOA kit
    - Deflation and re-positioning
    - Intermittent/partial inflation (MAP as target – iREBOA/pREBOA)
    - Ongoing bleeding practice
    - CPR procedures and pending arrest
6. Balloon in alternate locations (Iliac, Subclavian, Brachiocephalic trunk/Zone 1 neck)
7. Hybrid procedures for hemostasis – junctional bleedings, balloons/xchange
8. Aortography and angiography considerations (type, volume, etc.)
9. Endografts/embolization advanced as needed – what, when, how
10. Junctional bleedings- solutions
11. Bailouts in endovascular and hybrid surgery

All training aspects will be modified to the participants' level and interest.

15:00 End of workshop and evaluation/feedback; Diploma

Email us for interest and follow www.jevtm.com and social media for details

REGISTRATION: lotta@mkon.se or Hilda@mkon.se

General information: tal.horer@regionorebrolan.se

"No ego, just good science, clinical care and collaboration"

Tal Hörer, Örebro University Hospital, tal.horer@regionorebrolan.se
+46196024632 (direct) / +46702383495 / +46196021111 (switchboard)
More info at www.jevtm.com/workshop and social media #EVTM

Octopus Limedic

Terumo Aortic – Custom Solutions

TERUMO Aortic
Powered by Bolton & Vascutek

Angiodroid – The CO_2 injector

Automated Carbon Dioxide Angiography

- Hepatic Artery
- Embolization Tace
- SMA
- Renal Artery
- GI bleeding and trauma
- EVAR
- Iliacs
- SFA – POP
- BTK
- Foot

Jan Andersen
+46 708 95 65 35
jan@limedic.se

Gustav Friberg
+46 70 141 61 36
gustav@limedic.se

Odysseas Zacharopolos
+46 76 277 63 21
odysseas@limedic.se

Limedic AB
Hägernäsvägen 10
183 60 Täby
Sweden
www.limedic.se

TAKE CONTROL
OF SMALL VESSEL EMBOLIZATION

- AZUR® CX coil provides superior cross-sectional coverage with unique coil design and is now available in 2 and 3 mm sizes, for expanded treatment options
- Progreat® microcatheter allows you to easily access small vasculature e.g. in the GI tract

from ACCESS to CLOSURE
INTERVENTIONAL ONCOLOGY

www.terumo-europe.com

PUSHING BOUNDARIES

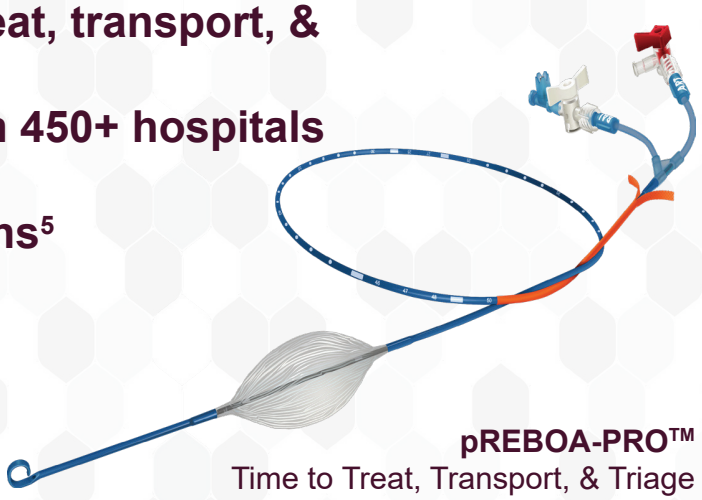
TERUMO INTERVENTIONAL SYSTEMS

IS765GB04191TII

The pREBOA-PRO™ Catheter: Now in Limited Market Release in Europe

PRYTIME MEDICAL™
The REBOA Company™

- **The first and only FDA-cleared and CE-marked catheter for True Partial REBOA**
- **Equipped with central aortic pressure monitoring technology**
- **4x more occlusion time than complete REBOA[1,2,3], buying time to treat, transport, & triage**
- **10,000+ total REBOA uses[4] in 450+ hospitals globally**
- **700+ total REBOA publications[5]**



pREBOA-PRO™
Time to Treat, Transport, & Triage

1. Centers of Excellence data. Internal data on file. Available upon request. 2. Ho et al., (2023) J Trauma Acute Care Surg. 3. Individual patient tolerance to occlusion may vary based on a variety of factors including age, health, status, injury pattern and severity, previous ischemic insult, etc. Surgical judgment is necessary when determining duration of occlusion for each patient. 4. Applies to all complete and partial REBOA uses. 5. Applies to all publications about complete and partial REBOA.