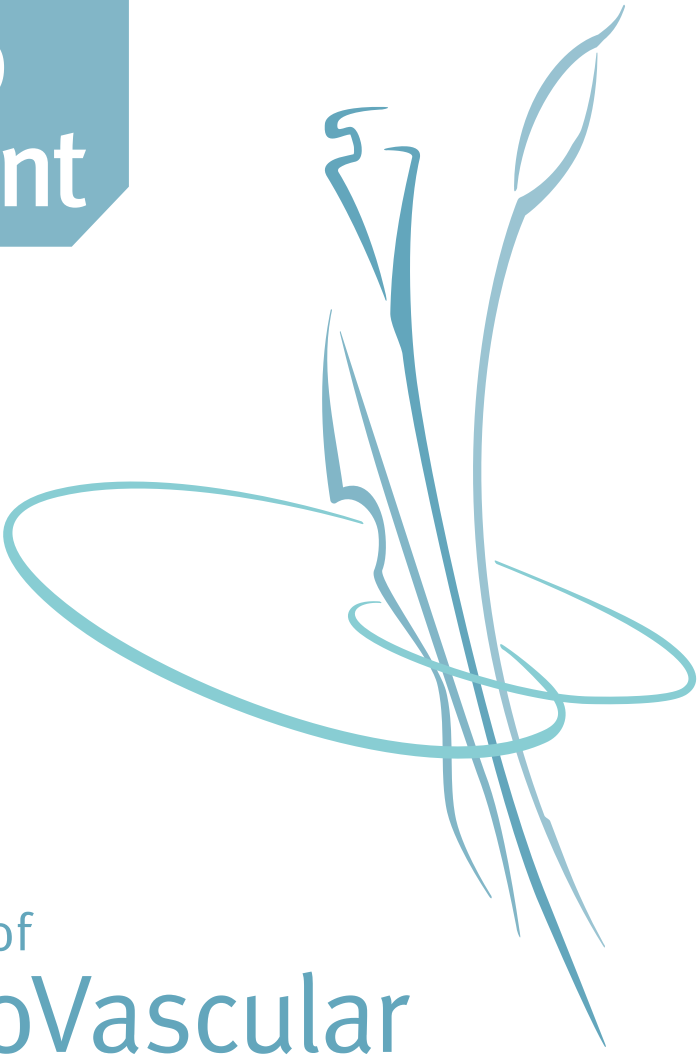
Top Stent



The Art of

EndoVascular hybrid Trauma and bleeding Management

1.

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The art of EndoVascular hybrid Trauma and bleeding Management

1.0

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Table of Contents

"If I have seen further, it is by standing on the shoulders of giants"

Newton, Isaac

Notice

This is a book **written in good will** to help doctors and medical teams treating trauma victims. None of the authors or the editor received any compensation for the work. There was no involvement of the industry in the manual in any form, but some photos were given without any commitment, as courtesy. The manual is written as part of the clinical research done in Örebro University Hospital and received financial support for printing from the hospital research division. The work was performed in accordance with the ethical and legal guidelines of the Swedish government and European Union. The manual is published by Örebro University Hospital, Sweden. **The editor, hospital and authors take no responsibility whatsoever** for the usage of the information in this manual. The book expresses **solely the authors' opinions,** and none of the author team or editor can accept any responsibility for any misusage or harmful treatment. All material in this book may be used for teaching and demonstrations, but without financial compensation, and with clear mention of its source. All photographs were taken with permission, and applicable and unique authors' own material was used whenever possible.

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We would also like to thank Mr. Jon Kimber for language revision and Alexey Chernoburov for great medical illustrations.
We hope that this collaboration will help save lives and decrease morbidity!

Introduction

Many of the readers of this text have been inspired by "Top Knife", a great book by Mattox and Hirshberg that has provided many surgeons with great approaches to the open surgical management of bleeding trauma victims. In "Top Stent", we have aspired to develop a similarly useful resource that is applicable for the modern era of **EndoVascular hybrid Trauma and bleeding Management (EVTM).** Although stents and stent grafts do not encompass the entirety of EVTM capabilities, we have called this text "Top stent".

Why is this text necessary? In the last 20 years, the use of endovascular capabilities for trauma applications has continued to expand. While the use of modern endovascular treatment modalities for bleeding patients began with the treatment of aortic aneurysmal disease, it has since spread into trauma care. In truth, there are anecdotal reports of centres treating bleeding patients with basic endovascular methods for many years, but the continued evolution of technologies and the arrival of the "endovascular era" has heralded a new age for the use of EVTM approaches. Advances in devices utilized in modern endovascular treatment, as well as improved diagnostic tools (CT and ultrasound, angiography, Doppler etc.), have resulted in the increased utilization of EVTM approaches all over the world. There is today a great variety of rapid diagnostic capabilities and endovascular tools suitable for use in a wide variety of clinical trauma scenarios. As a community, there is a need to better share lessons learned from these applications, and collaborate to define the optimal utilization of EVTM principles.

It must be recognized that, at this time, endovascular therapies continue to be viewed as complementary elements of initial trauma care. This is evident in both daily practice and general trauma guidelines such as the American College of Surgeons Advanced Trauma Life Support ™ guidelines as well as other guidelines. With continued experience, however, the collaborators of this text believe that EVTM is poised to become an integral element on trauma care in the earliest phases after injury. In brief, we envision that **EVTM represents a paradigm shift in trauma care**. It should be, and already is in some places, part of the initial treatment algorithm of the trauma patient, and combined with open surgery, as part of the hybrid concept. In other words, EVTM can be incorporated into the primary management of the trauma patient, already from the emergency room, on arrival. Probably, it could be established in the battlefield or, even in selected cases, in pre-hospital care.

Valuable examples of this paradigm shift are emerging from leading centres throughout the world. An important emerging example is the use of Aortic Balloon Occlusion (ABO) or Resuscitative Endovascular Balloon Occlusion of the Aorta (**REBOA** – the term we will utilize for Aortic balloon occlusion throughout this text). REBOA ("the new kid on the block") is being used now in many centres to gain hemodynamic temporary stability in severely injured trauma victims- even replacing to some extent traditional resuscitative thoracotomy.

The basic technologies necessary for REBOA and EVTM can, in most instances, be found in the majority of hospitals treating trauma victims. There remains a need, however, to better define the questions of "When", "Where" and "How" these approaches should be optimally utilized. A multidisciplinary approach to answering these questions is required – combining the existing knowledge of trauma surgeons, vascular surgeons, interventional radiologists, thoracic surgeons, orthopaedic surgeons, medics, emergency medicine and anaesthesiologists. While the utilization of EVTM principles will be dictated by many variables (local capabilities and local egos and credentials to name but a few) we believe that the effective integration of EVTM principles into modern trauma care will require the development and maintenance of multi-disciplinary, multi-national and multi-institutional collaborations.

This "manual" represents the **personal view of a small, but dedicated group of EVTM professionals** gathered to document how they think and act in the management of trauma and bleeding patients. These are all doctors with "blood on their hands", meaning they are active clinicians and working within this field. This text is the result of their efforts to cooperate and gather ideas on how to effectively conduct EVTM. There are probably many other ways of doing things, and time will show if some of the things we do, or want to do, are correct. As with all procedure-based interventions, there is less likely "one perfect way", and more likely several safe and effective approaches to any specific EVTM challenge. In Top Stent, we will not mention references or discuss any evidence, that the reader can find elsewhere. We will only give a personal view and try to outline hard learned "tips and tricks" of our collective experience with EVTM. You, the reader, must filter this information and decide what is acceptable, doable, and **what would fit your workplace and your environment**. It is also very important to recognize that EVTM does not replace open surgery, but combines with it into a comprehensive system of trauma care capability. In some cases, the only and best treatment is the "good old" open surgical exposure and bleeding control!

You might also notice that in this manual, different parts are written in different styles, which we tried to merge during the editing process. We find it important though, that different experts express their views and tips in a collective format – and adopted this format accordingly. The combination of different nationalities and conversion of a variety of native tongues into English represented an additional challenge, – but we hope the reader will appreciate, as we do, that language should not be an obstacle to knowledge sharing. At times you might feel that some points are repeated, but we find it useful as it reflects many authors' views in a text collection. We should also mention that, despite the frequent possible use of masculine pronouns ("he") – EVTM is and will always be gender, race and ethnicity blind. We are all "one" in the use of EVTM principles. We should mention that this text is not a consensus but a collection of expert opinions gathered into a manual friendly format. As so, the manual is done on a goodwill basis, with no economical compensation provided to any contributor. Feel free to use it as a resource as you see fit or even to distribute the material herein. We only request that as you cite or use the opinions or discussion of our work, that you refer to "Top Stent" as your source. This will be the first, or Beta edition of this manual. We hope to develop it further in the coming years, including through the use of other platforms such as www.jevtm.com.

In our view, there is no right or wrong as long as you collaborate to achieve the ultimate goal of every trauma provider, i.e. **saving life!** So, let's see if you think it has been worthwhile producing this first version of Top Stent. You will be the judge. Enjoy.

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Some guest words on this manual

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"A new era for surgery would become, if we were be able to stop the flow in a major artery without exploration, external compression and ligation…" (circa 1864)

Professor Nicolay Pirogov
Russian surgeon & founder of field surgery

In his quote, the Russian scientist and medical doctor Professor Nicolay Pirogov foresaw a time in the field of medicine when the bleeding vessel could be managed from a remote location without the need for an operative incision and direct exposure. Although he did not use the term "endovascular", one can infer he may have pictured the use of devices deployed inside of and proximal to, the disrupted vessel to control bleeding and repair the injury. Less than 100 years after Pirogov, Lieutenant Colonel Carl Hughes from the Walter Reed Army Medical Center reported on the use of a primitive intra-aortic balloon catheter to control hemorrhage during the Korean War. Fast forward another half century and the field of surgery is immersed in a technological revolution in which ever smaller and easier catheter-based devices are being innovated and applied to manage vascular disease. As documented in this Top Stent manual, today's advances promise to extend beyond the management of just vascular disease and will make the aspirations of Pirogov and Hughes to use endovascular techniques for injury and hemorrhagic shock a reality.

In the pages and chapters that follow, a stellar line-up of authors has provided a timely summary of the most germane topics related to learning, performing and instructing a basic skillset of endovascular techniques to manage vascular injury, hemorrhage and shock. In its inaugural edition, Top Sent has struck a balance with comprehensive and candid content in a brief and versatile format. Included are chapters dedicated to proper and usable vascular access and the three main categories of endovascular techniques (i.e. the "toolbox") for trauma and injury care: 1. resuscitative endovascular balloon occlusion of the aorta (REBOA), 2. stents and stentgrafts and 3. embolization tools and devices. The manual also dedicates space to addressing less conventional, non-aortic uses of balloon occlusion and even speaks to the emerging model of the hybrid -open and endovascular- operating room.

Reflecting the military expertise among its contributors, Top Stent reports on the potential for endovascular techniques to be used across a spectrum of combat casualty care settings: point of injury, en-route and fixed facilities. This perspective is forward-leaning and sure to inform a diverse range of providers (military and civilian) as they consider the most appropriate location for application of these new and potentially lifesaving technologies; today and in the years to come. As evidence of its honest structure, Top Stent dedicates a chapter – and comments throughout – to the limitations of endovascular techniques and possible complications associated with their use. The text provides a "how to" summary of performing, learning and training these techniques and concludes with a fitting list of major points or "pearls".

To the credit of its leader and senior editor Dr. Tal Hörer, the Top Stent manual extends and formalizes past work from the Endo-Vascular hybrid Trauma and bleeding Management or EVTM movement. The Top Stent manual is timely and sure to serve as a resource for cases at hand and to spur the movement in a more informed manner to maximize the life-saving potential of endovascular approaches in years to come. Congratulations to the cast of dedicated authors and contributors on this impressive accomplishment – Pirogov and Hughes would certainly find this discussion fascinating!

Thomas Larzon
Pioneer in endovascular surgery

With cane and hat, without any delay, please send the patient to the operating room! These were the rules when I started to learn vascular surgery 30 years ago. Abdominal or back pain, a palpable pulsating abdominal mass and hemodynamic chock were the clinical signs, the triad for a ruptured abdominal aneurysm. That made sense when the scanning time for the abdomen was almost half an hour and the only available method was open surgery.

The diagnosis was not always correct and I have found myself with one and another kidney stone or pancreatitis but that was accepted by my senior colleagues as well having a 50% mortality rate. Over time treatment has drastically changed as you know well and EVAR has been accepted and now dominates treatment of ruptured aneurysms.

We all have moments we never forget and one of these golden moments was in 2000 when a patient literally dropped dead in the OR in front of me. A pending thoracic aortic aneurysm had actually ruptured. But it turned out that her days were not counted. We were to meet many times in the coming years – thanks to an aortic occlusion balloon, simultaneous CPR and a thoracic stentgraft.

I have been fortunate to have the right work at the right time in the right place and I now see that history repeats itself when it comes to trauma care. It will be very interesting to follow the development that up to now only is in its infancy with the REBOA concept. I congratulate all of you, young, established and future doctors who will dedicate your work to create the future of trauma care. Together we can do it. What a challenge!

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List of words and acronyms used in Top Stent

HYBRID open and endovascular management
REBOA Resuscitative Endovascular Balloon Occlusion of the Aorta
ABO Aortic Balloon Occlusion (or IABO)
tREBOA total REBOA (used frequently as REBOA in general)
iREBOA intermittent REBOA
pREBOA partial REBOA
fREBOA field REBOA (as well as transfer REBOA)
dREBOA Deflated REBOA in situ
RB Rescue Balloon catheter
ER REBOA Emergency room REBOA catheter
ER Emergency room
IFU Instructions for use
Sheath = introducer
SBP Systolic Blood Pressure
MAP Mean Arterial Pressure
US Ultrasound
OR operating room
BTAI Blunt Thoracic Aortic Injury
TBI Traumatic brain injury
TEVAR Thoracic Endovascular Aortic Repair
EVAR EndoVascular Aortic Repair
LSCA left subclavian artery
CTA Computer Tomography Angiography, at times we use the word CT
BCT Brachiocephalic trunk (or Innominate artery)
FAST- Focused Assessed sonography in Trauma
GI Gastro-intestinal (bleeding)
IR Interventional Radiology
GS Gelatin sponge
ATLS Advanced Trauma Life Support
PTA Percutaneous Transluminal Angioplasty
CFA Common Femoral Artery
SFA Superficial Femoral Artery
DFA Deep Femoral (profundal) Artery
ACS abdominal Compartment Syndrome
SIRS Systemic Inflammatory Response Syndrome
IVC Inferior Vena Cava
IIA Internal Iliac Artery
EIA External Iliac Artery

Chapter 1

It is all about the vascular access

Yosuke Matsumura, Junichi Matsumoto, Lauri Handolin, Lars Lönn, Jonny Morrison, Joe DuBose and Tal Hörer

Modern Advanced Trauma Life Support (ATLS) principles have revolutionized the treatment of trauma patients, providing a common protocol for treatment and diagnosis of the injured. ATLS principles (the ABCs of initial trauma care) emphasize early diagnosis and management of airway problems and major bleeding control, providing a protocolized approach that affords effective initial evaluation and treatment of a wide array of trauma victims. At present, however, ATLS does not provide guidance on the early utilization of evolving endovascular or hybrid management (EVTM) adjuncts to trauma care. For providers with appropriate skillsets and capabilities, EVTM adjuncts can provide **additional tools** for the early care of the severely injured trauma patient.

As a modification of the traditional "ABCDE" mnemonic advocated in the ATLS protocol approach to initial trauma evaluation and treatment, an EVTM enabled provider might consider using an "**AABCDE"** (airway **and simultaneous vascular access**, breathing, circulation etc.). Why might the use of the AABCDE-centered thought process prove useful? Very simply: this mnemonic may better represent actual modern trauma practice, including the establishment of vascular access in the peripheral or central veins for the early administration of fluids and medications. It is also important to consider that simultaneous vascular access in the early trauma setting also affords the medical team an opportunity to achieve IV access that may prove critical to patient survival – namely cannulation of the **common femoral artery (CFA)**.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 1-4: Vascular arterial access in place with 5Fr sheath in trauma patients, on arrival as part of the EVTM concept. Arterial femoral line seen in Figure 4.

While venous access is often critical in obtaining blood samples and facilitating life-saving blood product and medication administration, early arterial access may also provide crucial additional capability and should be routinely considered. Vascular arterial access enables the use of a variety of diagnostic and therapeutic adjuncts pertinent to trauma care – including **REBOA** (Resuscitative Endovascular Balloon Occlusion of the Aorta) and a variety of diagnostic and therapeutic capabilities. Continuous invasive central arterial blood pressure monitoring can significantly aid the assessment of hemodynamic stability, as can serial arterial blood gas chemistry. Arterial access can also permit formal angiography, affording precise and effective localization of the bleeding focus. In addition, arterial access can provide a platform from which to deploy a variety of hemorrhage control maneuvers, including REBOA, angioembolization and stent graft deployment. In extreme cases, arterial access can even be utilized for fluid administration (though this pathway is not as effective as venous administration). So, the femoral artery (and vein) can prove to be a critical pathway to your patient's cardiovascular system and subsequent patient salvage. Try to remember the last significant trauma case you helped care for – were the common femoral artery and vein accessed during the primary survey? It is likely the answer is no – and an opportunity to promote an improved outcome may have been missed.

Tips:

» Consider early arterial (and venous) femoral access. Use it for blood sampling and blood pressure monitoring once gained. Avoid access on injured side if possible.

The common femoral artery is relatively easy to access, is commonly characterized by a uniform anatomical position, and is typically reasonably sized (around 6-9 mm but depends on hemodynamic status and age). This vessel is relatively easy to access in young patients, and when done correctly, access is a relatively low risk endeavor – the term "relative" is emphasized here. Every procedure performed at the initial phases of trauma is associated with some risk. These include bleeding, arterial dissection, and thrombus formation. However, when a patient presents in hemorrhagic shock, the risk-benefit ratio is firmly on the side of expeditious and direct intervention. Femoral access can provide a platform from which to tackle some of the most challenging injuries as we mentioned above.

The general relationships of the femoral vasculature are fairly consistent from individual to individual. The femoral vein lies medially to the artery and both are relatively easy to control by compression, provided they are healthy. We will discuss the anatomy and specific concerns of arterial access: not only how to establish access, but also how to utilize it, maintain it, and close the site safely when vascular access is no longer needed. While our discussion will be thorough, we encourage you to seek out additional anatomical details from any of the established textbooks or atlases on the topic as you see fit. With that said, let us start our discussion by thinking about how "vascular access" can be incorporated into the early care of the bleeding patient – be it bleeding from trauma or other non-traumatic etiologies (gastro-intestinal, iatrogenic, post-partum etc...)

How to identify the femoral artery and access guidance techniques

The first rule in establishing vascular access is to avoid puncture on the side of any significant lower extremity injury if possible. Access on the contra-lateral side is preferable, but if the injury involves both inguinal areas, there are other solutions that we will discuss later. You also must consider if there could be a vascular injury ABOVE the site you intend to puncture. If so, access may not only prove useless (for example, infusing fluids through a vein that is lacerated just above the injury site) but may prove outright dangerous (advancing a wire from the femoral artery into a dissected proximal iliac artery or aorta, for example).

Ultrasound (US) guided puncture: This is a very useful tool for all kinds of things in medicine, but its Achilles heel is "inter-user variability" – not everyone is able to obtain the same quality images in the same patient. As a first step, you must understand how your department's machine works – at minimum, how to engage a vascular setting, and how to set the depth (how far the scan will penetrate) and the gain (the greyness of the screen).

We would recommend that you go on a formal course or train with people who are familiar with ultrasound and FAST scanning. Doing it 10-15 times will give you basic (!) knowledge on how to recognize the structures and, most importantly, on whether you are following the procedure in a safe way. There is a learning curve, and we believe that this is highly dependent on your motivation and not your profession! (We know great cardiologists who can obtain vascular access faster than the blink of an eye…).

So, again, especially in emergency cases, when you have someone that can do it better or faster (or just an experienced colleague next to you), ask him or her to do it. Trauma bay patients are not training cases and you need a functional and safe access now. Again, do not let your ego rise, **do the right thing for your patient**, which may involve calling on your colleague.

Advice:

» Start training in an elective setting before working up to the critical patient.

In terms of practical approach, we would recommend the following sequence:

1. Check the US probe orientation. Does the left side of the probe correlate with the left side of the screen?
2. Scan the groin in a transverse view, where the vein should be medial and compressible. The artery should be pulsing – but not always! Ideally, you should also be able to identify the division of the common femoral artery (CFA) into the superficial (SFA) and deep/profundal (PFA) branches. This is an important landmark!

3. Turn the probe into a longitudinal view and see if you can obtain an image that demonstrates the external iliac coming up out of the retroperitoneum, the CFA with the femoral head behind it, followed by the division of SFA and PFA. Your ideal puncture zone is in the CFA, over the femoral head. While this view sounds complicated, it is great practice to get into the habit of seeking out all these structures.

4. Having picked your puncture zone in the artery, make a skin incision below (not all of us do that in acute settings) and insert your needle using the technique described above. You can see the needle in either longitudinal or transverse probe view. The longitudinal view is good if you can get comfortable with it, but the transverse view is what most people use.

5. Once you get a flashback, put the probe down, but do not discard it. Advance the wire into the vessel – if it travels in easily, great, discard the probe. BUT, if it does not travel easily, put the probe back on the patient and have a look. If you can see the "J" tip of the wire is clearly in the lumen, then great, but chances are you are not intra-luminal. Not sure? Time to think again!

Figure 5: Ultrasound assisted puncture in a trauma patient.

Tips:

- Get to know the ultrasound in the ER and make sure it's "on" in the trauma bay. It is a powerful tool when used for FAST but you can use it for arterial or venous vessel puncture.
- The ultrasound should be on and ready 24/7, with a vascular probe at hand.
- Make sure you use an "echogenic" needle – these are designed to stand out on the screen and make the procedure easier.
- Train US guided puncture! It's a great tool. The more you train, the better you become.

Access without imaging, or the "blind" puncture – how to do it

In the modern era, ultrasound guided access has emerged as the safest and most effective means for accessing the common femoral artery and vein – even in emergency situations. Ultrasound should always be considered an invaluable tool when attempting vascular access for trauma. If you have it available in a timely fashion, USE IT!! As mentioned, when using ultrasound to support access, the bifurcation of the SFA and deep femoral artery is typically easily visible, allowing identification of the CFA. This imaging modality may not be available when needed, however, for a variety of potential reasons. If ultrasound is not available, be aware of common placement pitfalls. Without ultrasound, a precise appreciation of anatomic relationships becomes paramount to successful venous and arterial access in the groin.

The inguinal ligament can typically be palpated and distinguished at the thigh upper border (although this may be more challenging in obese patients). You do not want to puncture too high, or above the ligament. You can palpate the iliac crest on the lateral side, and the pubic bone on the medial side, to identify the origin and insertion of the inguinal ligament in most patients. Punctures above this ligament might result in damage to both intra- or extra-peritoneal structures such as bowel injury or retroperitoneal hemorrhage. High punctures also complicate closure – making arterial repair challenging and time-consuming. We would suggest staying approximately **two fingers below** (distal to) the inguinal ligament with puncture attempts. As a reminder, the femoral vein will be located medial to the artery.

When attempting an arterial puncture, if you inadvertently access the vein, do not be discouraged; the placement of a 5-7Fr sheath in the vein may be of great benefit to your patient. This large vein access can prove very useful in the resuscitation of trauma patients. It is important to remember that communication and appropriate labeling of all placed sheaths is also important – **your team must know which sheath goes where**.

Comment:

» When we speak about the access "sheath", it is synonymous with "introducer" – meaning a catheter with valve that is a working entrée tool to the vessel.

Another piece of useful advice – if you access “something”, but are not sure if it is successfully in the artery or vein, **leave the sheath in place** and try again with a new puncture. **You can remove the faulty access later**, after the chaos of the initial situation is resolved. If you take it out in the midst of trying to obtain emergent vascular access, the site might bleed and contribute to additional blood loss. Any attempt to hold pressure at this site in these situations takes hands away from tasks that might be useful at other locations – i.e. you cannot hold pressure and get vascular access at another site at the same time.

Advice:

» Leave the sheath in place even if unsuccessful (it might bleed). Deal with it later in the ICU or in the OR.

A common “failure” in groin puncture is the puncture that is undertaken too low / distal – usually in the case of arterial access this results in a superficial femoral artery (SFA) puncture. The SFA might be palpable and you might think this is the CFA, but you should rely on the external landmark mentioned above, more than just palpation. Large-bore sheath placement in the SFA (a smaller-diameter vessel than the CFA) may be associated with a greater risk of leg ischemia, especially in a patient in profound shock. Got a functional access? Use it and worry about these details later, but don’t forget it.

When utilizing anatomic landmarks as the primary means for facilitating

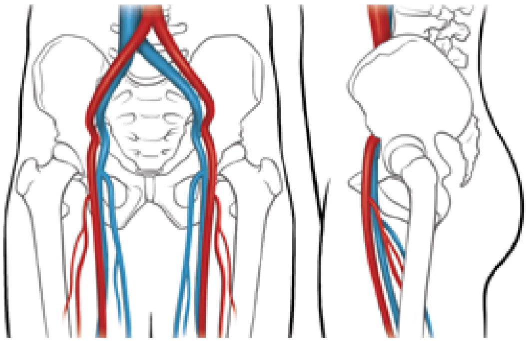


Figure 6.1

Figure 6.2

Figure 6 1-2: Anatomy of the inguinal region showing the vein and artery localization relative to the inguinal ligament, iliac crust and pubic bone. Your access site is about two cm distal to the inguinal ligament. 3D-reconstruction CTA. Notice the angulation of the iliac vessels as they dive into the retroperitoneal space.

Figure 7.1: Palpation of the CFA on the left side of the patient (during elective endovascular surgery). Parallel puncture on patient's right side. Blind puncture and angiography assisted.

Figure 7.2: Landmarks for vascular access. Inguinal ligament (upper) and inguinal fold (lower) marked. In young and slim patients, this is obvious but less clear in obese or older patients.

Practical tip:

» Use two fingers to palpate the pulse and arterial structure. Move in lateral-medial directions slowly (side to side) to catch the area of maximal pulse. Yes, test it on yourself!

vascular access in the groin, it is of vast importance to appreciate common pitfalls and how to avoid them. You may be too high, too low, outside, or too deep even when you are using only palpable arterial pulsation to guide placement – particularly if the patient is hypotensive and the pulse is difficult to palpate. A useful approach is to start puncture attempts at a point 1/3 of the way down the inguinal ligament from the pubic bone, approaching laterally to the vein (if the vein has been identified by access), 2 fingers from the pubic bone edge – the artery is typically at this location.

If the patient has an appreciable blood pressure, palpate and find the strongest pulse impulse. Keep in mind that, in older patients, pronounced calcification of the artery may make the vessel more easily palpable, but it also should raise suspicion of potential access challenges in the vessels (heavy calcifications). If your patient has acceptable blood pressure (e.g., > 80mmHg), you might feel the pulse, see the pulsation with your ultrasound, or hear the sounds on hand-Doppler. If your patient is skinny, you are lucky – it is much easier than in obese patients. Furthermore, be conscious of the longitudinal (cranio-caudal) anatomical direction and continuity of the artery to ensure that you stay luminal. Try to imagine the "3D course" of the artery as this will help you to "catch" the vessel.

Puncture methods and blind puncture

There are several ways to get access to the femoral artery or vein, but in our view the safest method is an **ultrasound-guided single puncture technique**. The principle of access is to introduce your needle into the vessel, so-much-so that you obtain a "flashback" of blood, whereupon you can advance a wire into the vessel lumen. The needle ideally should penetrate the vessel as close to the 12 o'clock position (i.e., most anteriorly) as possible. The wire is used to secure luminal access and to guide endovascular devices into position (sheaths, catheters, balloons etc.). This method is referred to as the "**Seldinger**" (or **over the wire**) technique, in deference to the interventional radiologist that to who described this method in the fifties.

The "flashback" of blood is important to observe as this tells you a lot about the vessel you have punctured, as well as the state of your patient. A flashback of cherry red pulsatile blood is clearly arterial; however, that is rarely the whole story. In the setting of a bleeding patient, who is hypotensive, the pulse may be weak and the blood may be dark or non-pulsatile. It is important to hold your nerve in such circumstances and to proceed with obtaining access in the vessel you have punctured. If you have punctured a vein – then use it for IV access (both sampling and resuscitation) – your team will thank-you. A venous puncture is usually dark and continuously flowing.

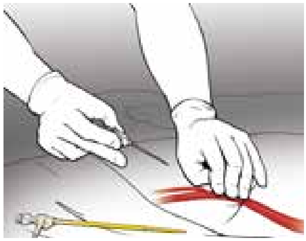


Figure 8.1

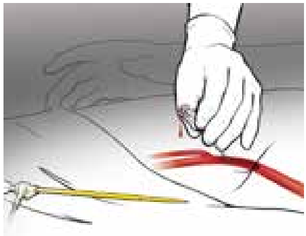


Figure 8.2

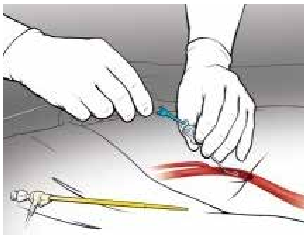


Figure 8.3

Figure 8.4

Figure 8 1-4: Main steps in the Seldinger (over the wire) method. You can also find some videos and other material on the www.jevtm.com or other sites. The Seldinger method described in the text below.

Remark:

» Yes, it's bleeding from the needle and you lose some drops until you get the wire in. This is negligible now and usually not more than some 10-20ml blood. So do not get stressed now, continue and get the wire in! As long as blood is flushed out, you are in the luman.

In trauma, the majority of clinicians would use a big needle (18G) with a reasonable sized wire (0.035"), but you could consider a micro-puncture set. This generally consists of a 21G needle, followed by a narrow 0.014" wire. In the bleeding patient, some experienced providers would encourage the use of the larger needle (18G), as it provides a more brisk and re-assuring flashback of blood – making it more likely that you have performed a "good" puncture and will secure access easily. The use of a micro-puncture set can be challenging as the flashback is often less brisk. We can't get a consensus on that yet, but at least for REBOA it seems that the big needle wins.

Tips:

» Make sure your needle is clean and washed with sterile water after every puncture or change needle! Make **slow movements** when you puncture. and once there is a flow of blood, try not to move the needle and get the wire in. You don't have flow suddenly? You are not in or against the vessel wall. Manipulate the needle **slowly and carefully** to restore flow. Not sure? Go to plan B (the other side? ask for help?)

In terms of the puncture, there are two main methods described

Single wall puncture: This is probably the most intuitive technique, where the needle is introduced at around 40-45 degrees to the vessel. Remember that due to this angle, the skin puncture and vessel puncture are not at the same location! That is why we recommend staying 2 cm distal to the inguinal ligament. Once you see the flashback, lower the hub of the needle somewhat to bring it near parallel to the vessel and advance **a couple of millimeters** (different ways to do it. Some of us do not move the needle when there is good flow). Keep the needle stable, confirm a constant flashback of blood, and advance your guide wire into the vessel. Yes, it is bleeding through the needle, but this is a negligible volume of blood and you must be sure that you are in the vessel! The risk of this technique is that, if the needle has not cleanly penetrated the anterior vessel wall, when advancing the guidewire, it can travel into the media of the artery, dissecting the arterial wall. This can create a major ischemic problem, especially if you follow the wire with a sheath. The "quality" of the flashback is key to avoiding this; if it is clearly strong, then the risk of dissection is likely minimal…perhaps easier said than done in a hypotensive trauma patient.

Tips:

- » Try puncture on different training models (plastic, simulator or whatever). It will give you an idea how it feels when you are in with the needle and how the wire feels when advancing!
- » **Never force you wire in.** it should glide in and if it does not, you are not in the luman.

Double wall puncture: This is a slightly less controlled method of arterial access – when the flashback is observed, deliberately advance the needle until the blood flow stops. Then reduce your needle angle (as described above) and withdraw slowly. If you are using a small syringe with the needle, pull back on the plunger of the syringe to apply slight negative pressure. After getting a flashback again, advance the guide wire. The needle is more stable in the vessel with this approach, so it may prove a more useful when employed for access of small or collapsed vessels. Although passage of the wire through the artery is a concern with this method – it rarely occurs when done correctly. More common perhaps is the risk of posterior hematoma made from the posterior puncture hole – which can result in retroperitoneal hematoma.

Figure 9.1

Figure 9.2

Figure 9.3

Figure 9 1-3: Puncture in an elective endovascular case: Palpation and orientation. Needle 45 degrees in; when blood flow is stable, the guide wire is inserted, while the needle can be redirected to a more horizontal position.

More material and videos can be found on **www.jevtm.com**

So, to summarize about blind puncture:

The idea is to locate the vessel with your fingers and puncture as mentioned above. Blind puncture is not optimal, but knowing how to do it might save you when the US is not available or in panic situations…

Some of us are using blind puncture as routine in acute situation, but we do recommend US if possible.

Cut-Down

Arterial or venous cut-down – or open exposure of the vessels can be an approach of either first or last resort – Some providers use this procedure as the first resort in the critical trauma patient. If you think that a puncture will be difficult, it may be prudent to go straight to a cut-down. Do not try and do something that you think will have a low chance of success in a critical patient – get the odds on your side – cut down early is a good advice.

When conducting open cut-down it is important to remember **this is not elective groin surgery**; this is a dying patient. In a crisis, accept that there may be no time for optimal sterility or local anesthetics; however, if you can have a pre-prepared cut-down pack, which has everything, then all the better. Get a surgical knife, do a 5 cm longitudinal cut on the medial-central side under the inguinal ligament, and get down with the knife or Metzenbaum scissors, while palpating your way to the CFA. When you have dissected down onto the artery, it can typically be palpated and, ideally the anterior wall can be visualized for puncture. You do not need full proximal and distal control now; puncture the artery as described above, and get a wire into the lumen. A small self-retaining surgical retractor often helps with the exposure.

Remark:

» Let us add a word of caution – this might be a stressful situation and you should avoid doing any further damage! You dont want to have a new arterial bleeding or dissection now!

X-Ray guided puncture

Another described technique that may prove useful to know involves the use of portable x-ray (static images) or fluoroscopy (dynamic images) to help guide the puncture; however, such support is rarely available quickly in acute

Figure 10.1

Figure 10.2

Figure 10.3

Figure 10.4

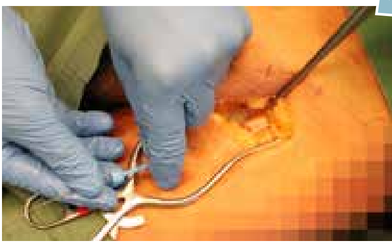


Figure 10.5

Figure 10.6

Figure 10.7

Figure 10 1-7: Cut-down arterial access on a cadaver model from left to right. Dissection by landmark and palpation, exposure of the anterior vessel wall. Puncture by Seldinger method, wire and sheath. The puncture done here is percutaneous but can be done directly in the anterior vessel wall.

Figure 10.9

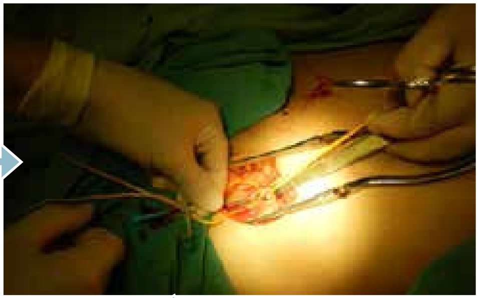


Figure 10.10

Figure 10.11

Figure 10.12

Figure 10.13

Figure 10.14

Figure 10.15

Figure 10 9-15: Cut down REBOA in a trauma case. Seldinger technique used. From left to right puncture, wire, sheath in place. Last photo shows suturing of the artery to remove the sheath.

Figure 11.1

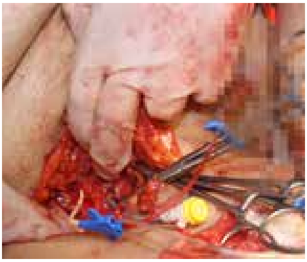


Figure 11.2

Figure 11 1-2: Cut down vascular access on an obese patient for REBOA. Access might be (and was) very challenging in this patient.

Advice:

» Sometimes, you will need to take the wire out and start again or do a new puncture. This is a minor failure. If you need to perform a fresh puncture, take your time. Compress your previous site, and freshen up your needle by flushing and cleaning the needle before attempting puncture again.

situations. X-ray imaging is used to locate the femoral head (caput), where the **artery will be on the medial side**, mid-caput – that is your puncture site! X-ray imaging can be used as an adjunct to support both percutaneous and open access and has the advantage of allowing the procedures that follow to be conducted with x-ray guidance. It is mainly used in the angiography or surgical suite but can be used in the ER in select settings.

Comment:

» When using x-ray guidance in an emergency situation, do not forget radiation safety. The ER (or OR) often has a lot of people coming and going, and not all will have lead ware on. Use any ionizing radiation sparingly and communicate with your team before you "press-the-button" to ensure that all precautions have been followed. In some centres, we all wear protection gear when entering the surgical suite with trauma cases.

Ok, you are in? What to do and what to use now?

Once you have obtained needle access to the vessel, **do not move the needle** and get the wire into the needle and vessel! Keep your left hand on the patient's body to maintain a secure and stable needle position. The choice of wire is important as they all have risks and benefits. A safe wire is a short 0.035" "Starter-J" wire, which is introduced straightened; the "J" tip re-forms in the vessel, presenting a benign profile when advanced. A more advanced option is a Bentson, which has a straight, floppy tip,

Figure 12: Sheath "half way in" over a wire – be careful not to push it without the inner part (dilatator); you might cause vessel damage or dissection.

but has a greater risk of side branch cannulation – ideally, this wire would be observed with x-ray guidance. **Advance the wire slowly and stop if there is any resistance.** You must "feel" the wire, as sometimes you may not see it, if you do not have fluoroscopy. Before the wire gets into the needle, you might change the needle angulation to be more parallel to the vessel, and continue checking for resistance. If things do not feel right, use available imaging adjuncts, such as x-ray or US, to help you.

Once your wire is in at least 20cm, it is time to take the needle out and position the sheath. **Ensure that the sheath diameter is big enough to accommodate what you are planning on doing** – a 4 or 5Fr sheath will permit most diagnostic maneuvers, but a larger size is needed for stents and balloons (>6 or 7Fr). Remember to check that the sheath has been prepared properly before insertion – in an acute setting, it is best to do it yourself! Generally, a sheath comes with a dilatator and both components need to be flushed with sterile saline before inserting the introducer into the sheath. Make sure the introducer "clicks" into the hub of the sheath – you do not want the introducer to be pushed out of the sheath as you advance it into the patient.

You should <u>not</u> use long sheaths (25-30cm) without confirming by fluoroscopy or ultrasound (due to risk of dissecting the aorta), so use the short ones (11cm usually). Guide wires that have advanced smoothly may not be positioned in the iliac or aorta – there is always the risk of an aberrant side branch cannulation. A short sheath should permit safe access into the common femoral and external iliac, but not beyond. Short sheaths are the safest choice in blind cannulation in the ER. Once your sheath is inserted, this is your entry to the vessel – take good care of it!

So, now you have a 5Fr (or 7Fr) sheath in place – great, you have a vascular access. Do not forget to flush it with sterile saline and now you can use it (upgrade for the REBOA or fluids, or just connect to the blood pressure module for monitoring). Take a skin stapler or do a 3.0 skin suture – just **make sure it stays in place!** Do not forget to secure the sheath with a suture, staples or a viscous tape at least before moving to another department (CT/angiography suite/ OR) or connecting to an arterial line. This is crucial as iatrogenic withdrawal might cause severe bleeding that you cannot afford now! Do not forget to **inform your colleagues** about the access – which sheath goes where if there are multiple devices. If the sheath is not to be used in the coming hours, keep it in connected to the arterial blood pressure set, or flush it with around 10-20 drops/min (or just a slow flush) saline to prevent thrombus formation.

Here comes a table that shows what you might need for simple femoral artery or vein access. You should have multiple sets in place since you might need both arterial and venous lines and both for possible failure. The costs

Figure 13.1

Figure 13.2

Figure 13.3

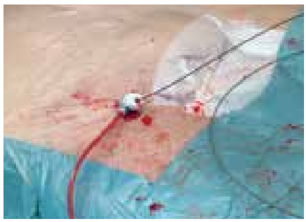


Figure 13.4

Figure 13 1-4: Preparation and sheaths in place (5Fr) in trauma patients and acute bleeding patient before laparotomy.

Figure 14: Puncture set and REBOA kit (ER in Örebro, Sweden). This is only an example how you can have it, but build it to be functional in your hospital.

Figure 15.1

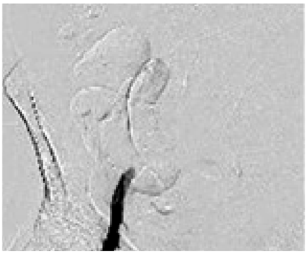


Figure 15.2

Figure 15 1-2: Access through a dissection on prior puncture. A Bolia catheter was used to verify the placement (upper foto) and change to a new sheath. The dissection (contrast) seen even later as it stays in the vessel wall after C-arm angiography.

are not dramatic and every intervention department/vascular department can help you pick them to be available in the trauma bay. We recommend having an "**ACCESS kit**" and with it, separately, a "**REBOA kit**".

Your vascular ACCESS kit
(should be marked as one)

- Local anesthetics (Carbocaine) and 2x10ml syringe/needles
- Puncture needle (18G or another that can take the wire)
- Standard wire (i.e. Cook) or Bentson wire (0.035inch)
- 4-5-7-10 (and 12) Fr sheaths (i.e. Cordis or Cook) (>12Fr for certain REBOAs)
- Sterile water and 10-20ml syringe
- Skin stapler, 3.0 skin suture and skin tape
- Simple drape (with hole preferred)
- Contrast material and some extra 10ml syringe
- REBOA kit (different companies available, with different sizes of sheaths)

Tips:

» Build your own kit based on what you have or your experience. Keep it fresh and available at all times. You and the team must know what is in it and how to use it!

Troubleshooting Access

You think you are in with the wire, but you are not certain? Take a small catheter (such as a Bolia catheter, which is a small, 4Fr short catheter, easy to use) and push it in over the wire to verify that blood is coming out, or that contrast is seen on angiography if available. Than push in a 0.035 wire when you know you are in the lumen and to upgrade. Get it up, take out this small catheter and position a sheath. Any resistance should raise suspicion of malposition. This small catheter will usually not do major damage to the vessel, even if dissected, but be careful. If there is a problem, try a new puncture, use the ultrasound, or ask for help from a colleague who has just arrived. Don't waste time! You need this access now. Your colleagues are busy intubating and getting brachial venous access. The patient needs you now, so take a deep breath, a new needle, and get the work done! You might even leave a failed introducer in place for now. You can take it out later. If you have taken out the needle, compress with your hand or ask someone else to do that, and change your strategy.

What about the timing of the vascular access?

If you feel your patient is hemodynamically unstable, now is the time for vascular access. Even if the patient has no obvious ongoing bleeding, consider femoral access, EVTM has a lot to offer your patient. Especially if he deteriorates later on.

Some decisions can be made even before patient arrival, judging from mechanism of injury, vital signs, and evaluation by paramedics as reported before arrival. If your patient has good vital signs, getting access might be easy. However, some hemorrhagic shock patients are compensated at the early phase. Your patient seems "stable" looking at blood pressure, but might have ongoing bleeding and collapse within the next few minutes! As we said before, an arterial sheath is useful for various reasons, such as arterial invasive pressure monitoring, access for IR or REBOA, and, of course, you can take a blood sample. Don't hesitate to get early access. Do it while the patient is being intubated or during primary survey by the ATLS (anyway, nobody is working on the inguinal area at this time point).

If you judge that your patient not an "easy access case", you can ask your colleague to support you on the other side and place bilateral sheaths. If your patient has a pelvic fracture and embolization is required, bilateral access will reduce your procedure time. If the patient needs REBOA, arterial pressure monitoring from a counter side sheath is helpful to assess distal perfusion during partial occlusion (pREBOA). It will be difficult to position another

Figure 16: REBOA in place under T-pod pelvic binder. The patient has also a femoral 5Fr sheath on the left side.

Figure 17: Manual compression and Femo-Stop (St. Jude Medical). Most of us will use it up to 8Fr sheath size but it has been used even with ECHMO 18-20Fr sheaths. **Be careful** and think before using it- do I trust this to work in my patient?

arterial sheath after REBOA insertion. You will no longer feel an arterial pulse at the patient's groin. Therefore, if you consider using REBOA, try bilateral accesses at both groins simultaneously. You can stabilize your patients by REBOA and embolize for pelvic fracture from a contralateral side introducer. If using a T-pod or any other pelvic stabilizing instrument, make sure you puncture site can be seen. Lift the T-pod a bit and make room. Let everyone know that you have a sheath there.

How and when to remove the sheath?

Well, the easiest answer would be: when the patient is hemodynamically stable, with a normal coagulation profile and needs no more interventions. The problem is that you never know. It might be a venous bleeding, or something else missed on CT like intermittent bleeding. We have seen stable patients with no ongoing extravasation of CT that had later major bleedings! A small-size sheath (5-7Fr) can be placed overnight (sometimes for several days, but we do not recommend such an approach). Large size sheaths (10-12-14Fr) **should be removed as soon as possible** after essential procedures to avoid ischemia and thrombus complications. But, in patients who are unstable, you can leave the sheath in place if you make sure you flush it as mentioned previously. Assessment of the peripheral circulation should be done hourly (!) and before you remove the sheath, aspirate blood. If you see a clot on aspiration, think thrombus and potential embolization. In this setting, it is best to go on with open femoral artery exploration and embolectomy if needed.

Word of caution:

» A sheath is a source of emboli/thrombus as long as it is there...

When you remove the sheath, you can use one of several different methods: external compression (by hand or device), closure device, fascia suture, or direct surgical repair.

External Compression: This is appropriate up to a 7Fr (some say 8Fr) sheath size, and can be accomplished manually or via a device. However, if the patients become coagulopathic, there is a risk of re-bleeding. Make sure that your staff examine the puncture site at least every hour (yes, we repeat that!) and **don't cover the puncture site in the first hour** (if possible). You don't want to lose your patient due to femoral bleeding when you have just saved him. Mechanical devices are available, such as the Fem-Stop, but only use these if you are very familiar with them.

Closure Device: Various devices are available, such as the Perclose, Starclose, Exoseal, Angioseal or others. All of these devices require formal training and cannot be just picked up and used. If you are familiar with the deployment of such devices, then excellent – but do not give your first patient a high-risk puncture! See IFU of each device to know what sheath size they can manage!

Figure 18: Fascia closure. A small skin incision done, the subcutaneous fat retracted and the fascia palpated. One gliding suture is used. The details about the method are published elsewhere. This method can and have been used in the OR or ICU. Works in trained hands but should be considered if to be used before applying it.

Fascial Suture: This is a practical method (formally described in the literature), and it is a useful skill to have. It can be done in the ICU in selected patients and can be used also for downsizing sheaths (e.g., from 12Fr to 5Fr). The idea is to open the skin and feel the femoral fascia. Than place a suture around the sheath with a gliding knot. **This requires training** and we will not describe it here in details. Excellent method in selected situations.

Direct Suture Repair: This is a gold standard; although it requires an OR and a vascular surgeon. Formally dissect and control the vessel and place interrupted 5'0 prolene sutures in the arteriotomy. The advantage of this approach is that you can assess the back bleeding and perform an embolectomy if required. You can also do control angiography and get some additional information.

So, again, "if there is doubt, no doubt"- **Do a full cut-down and check the vessel flow**. Use a Doppler at the end to be sure you have good flow. Not sure? Angiography and embolectomy might be indicated. Use open surgery and do not avoid it!

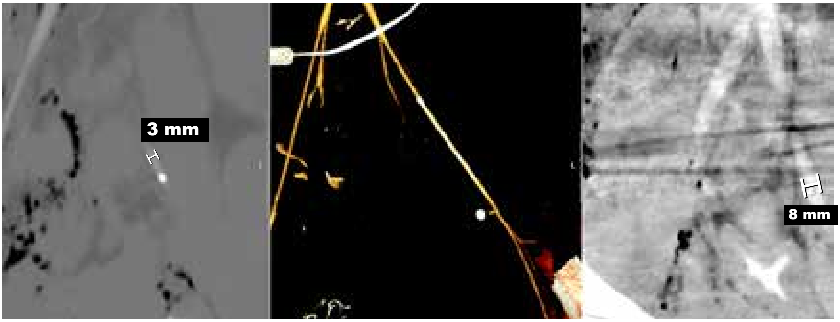


Figure 19: 5Fr sheath in a trauma patient (left to right). Thrombus and ischemia after REBOA later on with 11Fr sheath. The patient was hypovolemic and you can see the size differences: Left and middle photos first CT during hypovolemic shock, on the right side, the vessels at their normal size, on CTA after rescucitaion.

Upsizing your sheath

If you decide to place a large endovascular device, such as a REBOA catheter, you will likely need a larger sized femoral sheath. Sheaths between 7-12Fr are used in clinical practice and depend on available REBOA catheter size.

Tip:

» Remember that the sheath can take a certain diameter of catheter or REBOA. If you want to use it for flushing or angiography, you will need a bigger sheath in diameter than the REBOA catheter. It is not always so bad to have a bigger sheath that you can flush. When you realy need it, the size of the sheath matters!

Before upsizing, fill up the sheath's lumen with saline, put the dilator in the newlarge introducer. Insert the guide wire to the aorta and DO NOT LOSE THE WIRE POSITION! The guidewire should be at least twice the length of the introducer in order to swap the smaller sheath for the larger access device using an over-the-wire exchange technique. Usually you already have one in the introducer kit. Insert the guide wire to the aorta, then the dilator and introducer. When using the dilator, you will feel resistance against soft tissue, but this is ok – do not rush! You don't want to deviate from the correct way. To avoid kinking the dilator and guidewire, grab the dilator 2-3cm above the skin. Twist the dilator, and keep moving the guide wire to and from. Don't push the dilatator or introducer blindly. Moving the guidewire smoothly means the dilator will follow the guidewire appropriately. Gently pushing the dilator in a stepwise fashion will also help you (some of us call it the "Parkinson maneuver").

As a word of caution, watch out for hydrophilic coated guidewires, as they can easily migrate without your knowledge during these maneuvers. Your partner should grab the guide wire so as not to change its tip position. Unfortunately, you must perform all the procedure by yourself, to make sure the wire will not be removed when you withdraw the dilator. This is the most dangerous point. Unexpected removal of the guide wire will induce hemorrhagic disaster.

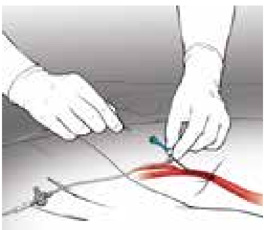


Figure 20.1

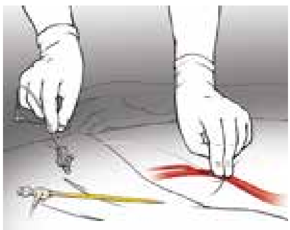


Figure 20.2

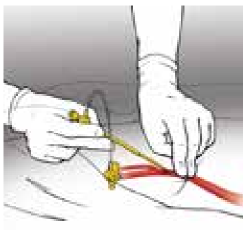


Figure 20.3

Figure 20 1-3: Upsizing your sheath. You change your sheath over a wire.

Maintaining a vascular access

You really do not want a clot in the sheath or around the catheter. After insertion, flush with saline. If you use this sheath for angiography or embolization, periodic flushing will help you avoid any clot in the sheath. We might be repeating here, but it is for a reason – been here, done that! Cloth formation might be a problem.

The situation becomes more complex when you have no flow in the vessel and a large sheath. This is the case during REBOA, where your sheath might occupy the entire lumen in the CFA lumen – such an arrangement is at high risk for clot formation and ischemia of the leg. Slow and continuous saline flushing by pressure bag might help prevent the thrombus. Local heparin might be useful but is problematic in trauma/bleeding patients due to general coagulopathy, and we cannot yet get a consensus on that, so make your own choice. We can say that you should remove the large-bore sheath as soon as possible. Again, if you don't want to remove it, take care of it as your best friend. It might save you that night, but when the next day comes, it might bring you some problems. So, again take care of it!

There are some advanced methods to downsize the sheath with the help of fascia suture. You can use this method to maintain a vascular access with a 5 or 7Fr sheath but it is doubtful if it has a place in trauma management. Take it out when you don't need it anymore.

Other vascular accesses (veins, brachial, axillary)

As we mentioned, CFA access is essential for severe trauma patients. But at times your catheter will be placed in the femoral vein, unexpectedly. Don't remove it! Femoral vein access gives a good route for resuscitation fluid. Always remove some blood for lab work if you can, just take a 10ml syringe and aspirate. However, if your patients have severe pelvic fracture, assume common iliac vein injuries. Femoral vein access will not work well, but in selected cases might be used for endo repair as well as being your highway to the vena cava and liver (via portal vein) or even a vena cava filter later on. In general, though, femoral vein access is safe and can be removed with manual compression, even with very large sheaths (some of us do manual compression on 18-20Fr venous sheaths).

The subclavian vein can be used as a good venous access without removing neck color. Of course, you must assume the risk of iatrogenic pneumothorax. The axillary vein can be accessed by ultrasound puncture. We will not deal so much with these access possibilities, since they are widely used and you can read about them elsewhere.

On the arterial side, the brachial artery is an option. There are cases of REBOA performed via brachial or axillary access, but the majority of the modern endovascular surgeons dealing with trauma prefer the CFA. Why? Well, the brachial artery is easy to expose (not so easy to puncture, as it is small, around 3-4mm). The problem is that you have to manipulate it across the subclavian artery into the aortic arch and then downstream to the descending aorta. For this, in general, you need fluoroscopy and it is time-consuming to place the REBOA using this route as well as problematic in unstable patient requiring airway attention. Dealing with the arch might be challenging and there is a risk of emboli going up the carotid. You will find some more information and illustrations in other places in this manual.

All methods have merits and demerits, and you should use the method you are comfortable with. Initially train on models, progressing to elective arterial punctures, before you throw yourself into the ring with a bleeding and hypotensive patient. Access, as part of the EVTM concept is vital – do what you do best and if a colleague next to you can do it better or faster, let him or her do that. This is no time to play around, you can do it next time!

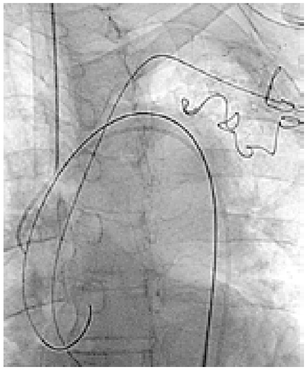


Figure 21: The aortic arch with wires from the femoral artery and brachial artery. Observe the tracheal tube and the anatomical complexity. An elective TEVAR case.

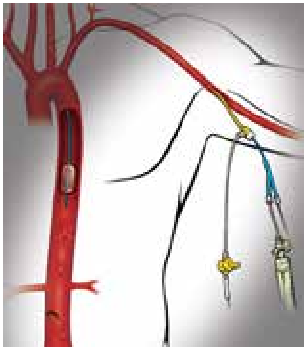


Figure 22: REBOA with axillary access. Most of us do not recommend this approach in trauma, but at times it might be useful.

When some of us teach REBOA or discuss these issues, we recommend as a first step to do femoral A-lines or small sheaths in some patients (elective cases or trauma cases when clinically indicated). Succeeding with femoral artery and vein placement of sheaths will make it much easier for you to place a REBOA when needed. There has been a tremendous amount of publicity regarding REBOA these days but remember: "**It's not the REBOA, it's all about the vascular access**"!

Some summarizing tips:

» Get your access early; Some of us think that every major trauma patient should get it during the primary survey as AABCDE!

» Get a femoral vein access as well if possible and time allows it.

» Take care of the access – suture or hold. Communicate about it. You have a powerful tool in your hand.

» **Think before using it** – what do I need. What's best for the patient NOW?

» Don't forget the risks – embolization, bleeding, dissection etc.

Notes

Chapter 2

The bleeding patient and your tool kit What and how to use?

Practical tips and tricks

Yosuke Matsumura, Mårten Falkenberg, Martin Delle, Mikkel Taudorf, Lars Lönn and Tal Hörer

You just had a call from emergency services. Motor vehicle accident, patient seems in deep shock and is on his way in. Estimated time of arrival is 10 minutes. It is late in the evening, weekend.

How to prepare even in the Emergency Room?

Ok, the first thing is to take a deep breath. Evaluate the situation and consider who you need. If your institute has clear routines, activate them. If not, which resources are available, who is in the team, and who will be the team leader. Act upon that.

Arterial access

As we have mentioned earlier, the first active step in EVTM is to insert a common femoral arterial sheath. You might have already used a small diameter (4 or 5Fr) CFA sheath in the ER. You have more catheter choices via a larger sheath of 5-7Fr, and therefore recommend a **5Fr short sheath** and a J-tip guide wire as the start kit. There are many types of wires, but try to get something you can work with, not too stiff and not too soft. Standard (e.g., Cook Medical), Schneider wire or Bentson wire might do. Check with your colleagues in radiology or vascular surgery, they can guide you. You will need

Figure 1.1

Figure 1.2

Figure 1 1-2: Introducer kit, Puncture needle (by Cook Medical and Cordis, with permission). There are many products on the market and these photos illustrate how a kit might look like.

to set up a kit for access and a kit for REBOA (as we mentioned before). Some of the sheath kits include a short wire and this can be also used for access. The most common sheaths are short (7-11cm), which might affect usage of REBOA later on, but, for vascular access, they are great and will minimize the risk of iliac dissection. You can choose to have bilateral accesses and place a second sheath on the contralateral side, for angiography while the REBOA is in the ipsilateral sheath. Also, bilateral pelvic embolization can be performed with a shorter procedure time.

So, a short 5Fr sheath is your first access tool after a successful puncture. However, with growing experience, we recommend starting with a larger 7Fr sheath when REBOA is considered a must. Some of us use a 7Fr sheath on any patient showing a hemodynamic instability or a major trauma mechanism. Remember, it is an early move so it is **safer to deploy a small sheath** (4Fr/5Fr) if you do not know if it will be used or not. Some of us use a 4Fr sheath that is used only for blood pressure measurements when not upgraded (arterial line). Femoral access **before a circulatory collapse** gives you a safe entry for REBOA. The majority of us though would start with 5-7Fr, as mentioned above. This is because you can use more tools (as embolization catheters) with 5Fr, and the potential risk of the size difference is minimal. Note though, that the authors here are experienced in endo/REBOA methods.

Tips:

- Get a kit with all you might need, mark it and have it available.
- Get to know what you have and how to use it.
- Staff working with you should also know its content, where it is stored and how to use it.
- Maybe you should do some team training in the ER...

Oops, you punctured the vein? Slow dark blood flow without pulsation? Use the puncture as a venous access. Do not remove it; get a 5-7Fr sheath in instead. Just use it for fluids (blood) as you may use the internal jugular or subclavian (axillary) veins for access. Your 5-7Fr access is a massive transfusion tool, and you can always upgrade it to > 9Fr, getting an even higher caliber massive transfusion tool. Just get the sheath in and go on to the artery (you don't want to stand with hand compression on the vein now when you are needed for other things). We should mention again that during CPR (or when there is no flow in the CFA), there will be no pulsatile flow, and the color of the blood can be darker, which my be misleading. Anyway, if you have it in, keep it in, and decide what to do with it later on.

Tips:

- Don't remove your sheath until the panic is over. Do it in a "safe" place (ICU/OR).
- In the femoral vein, use a bigger sheath. The risk of bleeding after removal is relatively low and it is a massive transfusion access.
- Reconsider if there is a potential ipsilateral iliac vein injury before using vascular access on the injured side

General on upgrading to a REBOA sheath

If your calculated risk decision is that it is time to use REBOA, you will need to prepare for it. It depends, of course on where you are (pre-hospital, ER, hybrid suite, surgical suite) and time is your limit. Upsizing from 5Fr to an appropriate (7-14Fr) sheath should be performed over a **stiffer guide wire**, as the larger sheath will be easier to insert and the REBOA balloon requires the stiffness to be located safely. So, either you do a puncture with a 5Fr sheath and upgrade to an appropriate sheath that depends on your REBOA, or if you have already a low profile REBOA (Rescue Balloon or ER-REBOA), you can puncture directly with a 7Fr and use it for REBOA.


Figure 2


Figure 3.1


Figure 3.2


Figure 4

Figure 2: Mobile vascular access/REBOA trolley in the surgical department, Örebro, Sweden. Used in any iatrogenic or gynecological bleeding in the OR, or in rAAA for vascular access and aortic balloon. Should include all basic tools for percutaneous and open surgical cut-down vascular access.

Figure 3 1-2: The entrance to the surgical suites in Örebro, Sweden. Note the three angiography tables ready for use. Surgical suite with hybrid capabilities (right). You can build a very simple hybrid room with just a few "accessories". We call it "Semi-hybrid suite".

Tips:

- Get early femoral arterial access with a 5Fr sheath and upgrade **if** needed.
- Remember, REBOA is **just a bridging tool** and will not replace definitive treatment! Don't delay the treatment if you cannot get access; change strategy and move on.

So, it depends on where you are and this affects the choice of the "tools" for access and REBOA. In the ER you have to build this kit while in the hybrid suite it is there (among other products, so you need to be able to find it fast!). You might want to fix a mobile trolley in the hybrid suite, so you can take it to other places if needed (i.e., iatrogenic injury in the orthopedic surgical suit or post-partum bleeding). The different REBOA products are discussed elsewhere.

Tips:

- Decide if you want one REBOA kit with everything and then build one. Some of us have two kits: one for vascular access, and one for REBOA.

Figure 4: Trauma patient (penetrating abdominal injury) in the surgical suite. The C-arm ready to use if needed. The patient is placed (always) on a sliding or angiography table. The C-arm, when not in use, is "on" and stays at the side with its monitors, ready-to-use.

Ultrasound and/or CT

Are you familiar with ultrasound? You will use ultrasound (US) in the FAST exam, of course. If you prefer to access the CFA by an US-guided puncture, the vascular probe (linear) gives you a clear image. The US or FAST machine should be "on" and the linear probe available. We will discuss the US puncture in other sections, but it can be used for vascular access, REBOA or wire arterial lumen confirmation and much more.

Experiencing difficulty in getting your access? This is rarely a problem in experienced US guided hands, but if it happens, do not hesitate to do a cut-down. Remember to have your equipment ready. An open vascular access kit with surgical knife, scissors, retractor and pincett should be at hand. All this basic stuff should be in your "Access Kit" and you should know how to use it!

You have to consider whether to do a CT and how fast you need it. It would be wise to inform the CT staff that you need them (depends on your institute). Some of us inform them about every major trauma and get a CT scan available directly, but in other places it can take some time. Today, with modern imaging, scan time itself is short (up to one minute for a whole-body scan). The time-consuming matter is the transfer of the patient to and from the CT. These patients require many tubes, monitoring lines and people around them. Before and after scanning, how long does it take to fix and move these lines? Make sure that you know what to do with all the lines and monitors, and use a transfer bed, if possible with place for the equipment. Some of us will not use FAST but can get a very fast CTA (even in the emergency department, door-to-door), where you can get much more information on the patient's status and exclude, for example, cerebral bleedings. We cannot reach a consensus here. Practice what you think and what your institute allows.

Remark:

- Remember that **time is running**, and you don't want to be in the CT scanner when things happen, unless you have a hybrid suite in your trauma bay (a CT-on-rail hybrid solution). Remember: CT does not stop bleedings…
- Even in the CT scanner, plan your moves, where to go, who you need, etc. Always have a Plan B.

Training of transfers can be advocated as this might reduce errors and time of transfer. The CT protocol itself should be a fast one. You can use different

Figure 5.1

Figure 5.2

Figure 5.3

Figure 5.4

protocols but you need both an arterial and a venous phase (with a 60 seconds' delay between the phases). Some of us use a "trauma CT protocol" or "massive bleeding protocol", with a head-to-knees one scan with contrast, and then, 60 seconds later, a new scan. A majority use highly concentrated contrast media with high volume (e.g., 370mg/ml Visipaque, 100–150ml total volume). Talk to the CT staff. They can adjust the protocol. The CT time today, with both phases, will be less than three minutes! But, you need to prepare the patient and transfer to the CT.

Tips:

- **For fast CTA you need fast, safe transfer;** train on it and get all the things on the patient's bed that you can move quickly. Take good care of the catheters and tubes!
- Get a good trauma CTA protocol (trauma CTA) and cooperate with the CTA staff. In major trauma, do not use an elective CTA protocol.
- **Monitor your patient at ALL times during the transfer and procedure.**

And a word of caution:

- You don't feel the patient should go through the CT, too unstable? Take him to the place you feel is best in your hospital and solve the problem! CT should be done only if you know what you are doing, on the proper patient and with a proper protocol!
- What's the plan? where should we be after the CTA? prepare the next step now!

Figure 5 1-4: Transfer to CT. The logistics may be complicated. Good transfer kit/bed and training as well as good communication might solve many problems. The patient must be monitored during transfer and examination, which is challenging.

In the Angiography Suite/Hybrid OR

Guidewires, catheters and sheaths: As we mentioned above, a femoral sheath might be placed in the ER, but again, it depends on where you work and your settings! When you place the sheath in the angiography suite, you can see your wire using fluoroscopy. You might decide to use a long sheath in the angiography suite (>11 cm). A long sheath will make your catheter operation smoother, particularly in atherosclerotic and tortuous arteries/older patients. Your advance with longer sheaths in the vessels might save time in the long run due to fewer obstacles when exchanging wires and catheters. Some of us use a 7Fr sheath and then upgrade to longer and larger sheaths, depending on the situation. You should know that in young patients in hemodynamic shock, even small sheaths will block the flow (occupy the whole vessel lumen), and with longer sheaths it is the entire femoral and iliac length. Something to think about and bear in mind when you are there and when you want to take them out!

The choice of type of sheath is up to you: what do you have, what are your hospital routines, and what do you feel comfortable with?

Guidewires: Guide wires are fundamental tools in endovascular procedures. You should know that there are different lengths of wires. They are used to change the systems you are working with and to guide you to the target. For example, in REBOA, short wires are enough (about 150cm) but longer wires are necessary for exchange when working in the thorax region. Especially in tortuous and dilated aortas, a 45-60cm sheath (12-14Fr) in combination with a stiff guidewire (Lunderquist, Back-up Meier or Amplatzer, around 260-300cm) gives the necessary support for the occlusion balloon in REBOA. Tortuosity is less of a problem in young patients but is a major issue in older ones.

When using fluoroscopy to place the catheter in the target artery, angled nitinol hydrophilic guide wires (0.035inch) may be the standard for most people. When you want to navigate to a visceral organ, 150cm is long enough. If you expect to exchange the catheter over the wire, you need at least 180cm (depending on what you have and are going to use). However, longer guide wires, 260cm or longer, are inconvenient to handle. Some of us would recommend long wires at the start to prevent problems. Dont expect any clear consensus here. These things will come with experience!

Figure 6 1-3: Example of some 0.035inch guidewires. There are many products with different characteristics and prices. Try to minimize the volume of products and work with intruments you know or have practiced with.

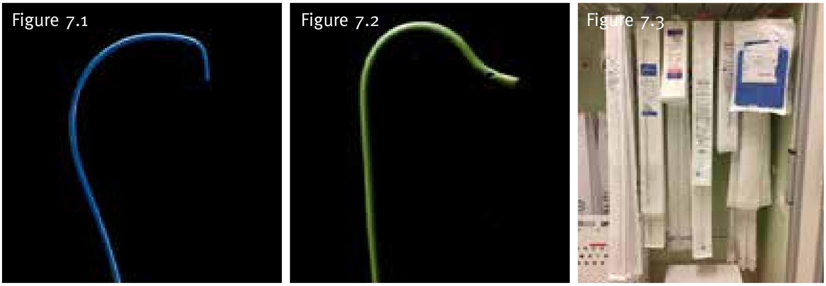


Figure 7 1-3: Cobra and Shepherd Hook caheter. You will find many products in the cataloges of different companies. These are just examples. Ask around for advice and do your selection. You can see here how they are exposed on shelters for easy selection.

Catheters

» Next, you have to decide on which angiographic catheter to use. There are many kinds. Expert opinions may be inconsistent about the best or preferred catheter. However, you should be familiar with three types (only a suggestion, there are many types!): Berenstein, Cobra, and a catheter with a reversed tip like Shepherd's Hook. Using one of these three types, you can exchange and cannulate most branches below the aortic arch. The important thing is that you need support from the opposite aortic wall when navigating into branches; thus, in elderly patients with larger aortas you need wider loops of the catheters.

In principle, the Cobra is useful for branches going upwards, cranial, from the aorta, and the Shepherd Hook is handy for branches heading downwards. Of course, there are many other catheters: Headhunter, Michaelson, Simmons, SOS Omni and VanSchie just to mention a few. Catheters work in different ways depending on variations in the aorta and their different forms.

Most likely you will change tools on your way to the target. A straight catheter (like Berenstein) will allow a smooth exchange (but, as said, you can use others). An angulated catheter (as Cobra and others), will allow your wire to get into the artery you aim for. There are some catheter sheaths that are long and provide support to embolization or other angiography procedures (all major companies has some of these products). You will get to know them if you train in a IR or vascular unite.

If you try to enter the branches of the aortic arch (carotid, internal mammillary, subclavian or axillary artery), constant perfusion to avoid thrombus in the catheter might be recommended, in principle. However, it consumes time and its use depends on whether your patient is life-threatened or not. Some of us do not use this method, and a majority just flush with saline in the sheaths. If you are not trained in angiography, just aim to get as fast and safely as possible into the target vessel and embolize it.

Tips:

» We are getting into more advanced angiography methods and you should be aware of it. Train if you can. Call someone experienced if there's something you cannot do. **Don't play around with bleeding patients!** Probably, there are people around you who will do it very fast and safely!


Figure 7.4

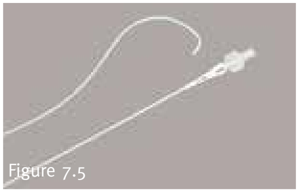


Figure 7.5

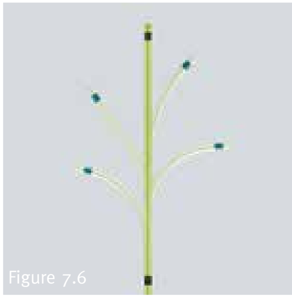


Figure 7.6


Figure 7.7

Figure 7.8


Figure 7 4-8: Some examples of catheters in different forms as well as sheath catheter (courtesy of Cook Medical).

List of <u>some</u> common catheters and wires that can be used in emergency situations:

- 5-7-10Fr sheaths
- Standard Cook or Bentson wire (Standard catheterization)
- Terumo 150cm (or longer) floppy angled wire (selective catheterization)
- Terumo stiff wire, Lunderquist or Amplatser wire (support for ex occlusion balloons)
- Berenstein (short and long 45-110cm) catheter (selective catheterization and exchange)
- Cobra (selective catheterization)
- Shepherd Hook, reversed tip (selective catheterization, angulated take-offs)
- kink resistant sheaths for catheter support (6-9Fr) 45-90cm
- Sheaths for REBOA support 45-60cm 12-14Fr (depends on your REBOA catheter)

Microcatheters: If you need to go further, more peripheral, micro catheters and micro guide wires will be needed. Various companies offer you many kinds of microsystems. Difficult to say which is the best in which situation. But if you plan to use coils, you have to consider an appropriate combination. If you want to select a small diameter vessel (particularly in GI bleeding or peripheral liver), you should use a "selective" type (2.7 or 2.8Fr) of microcatheter. In general, a microcatheter system is put into a 0.035 catheter that has been placed in the desired main branch from which the more distal bleeding branch can be reached. There are some new smaller catheters on the market and your choice depends on your experience. We will not get into details here as these are advanced methods that should be used by experienced people in our opinion.

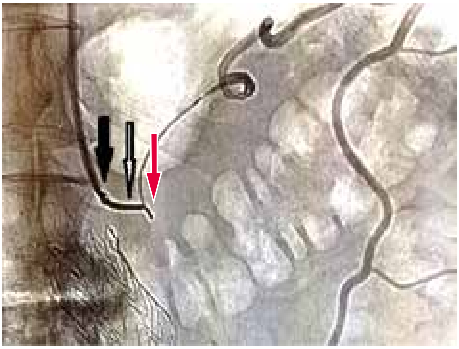


Figure 8: Sheath (black arrow), macro-catheter (black and white arrow), and, inside, a micro-catheter (red arrow) used in an elective case of embolization.

Embolization – what can be used and where?

Your catheter is in the target vessel. You check by contrast injection (fluid a bit diluted, 70/30) that you are near the target. Which embolic material do you use? You have many options. In a trauma setting you must consider "time", "coagulopathy", "difficulty of the material", "your skill", "catheter position" and "bleeding point". You also have to know – what do you have? What is best for this patient? **What can you do?** As a general principle there is a balance between more proximal and "safe" embolization (plugs, coils), which lowers perfusion pressure in the bleeding area, and a more effective but risky distal embolization when using smaller particles. These might cause ischemic damage in the target area. Embolization in general may cause target organ ischemia and it is better to do super selective embolization if possible. We will discuss different products and possibilities. Their usage depends on experiences and availability as well as the situation.

Gelatin sponge particle: Gelatin sponge (GS) is probably the most common embolic material in embolization globally. Particularly in trauma patients, you can prepare and embolize quickly and it is cheap. GS is a kind of temporary embolic agent. It is easier and quicker to place than coils, and it is easier to control than liquid embolization agents such as NBCA or Onyx. GS is appropriate for pelvic fractures and liver injury (without AV shunt). Some example are Gelfoam, 20×60×7mm and Spongel 2.5cm×5cm×1cm. GS is "solved" in a contrast-saline mix of about 50/50. The volume depends on the amount of GS used.

There are two types of GS preparation: Cutting method and pumping method. With the cutting method, you can make GS fragments in any size you want but it takes time, up to around 5 minutes. Usually you slice the GS cube into 2 or 3 layers, and then cut into 0.5mm to 2mm squares. Using too small a particle size will require more GS injection volume, and the small particles migrate more distally, and might induce excessive ischemia like gluteal necrosis. With the pumping method, you can perform the task in a much shorter time, within a minute or so. 5-time pumped is used for a 4 or 5Fr catheter, and 20-time pumped is used for a microcatheter (one reciprocation is counted as two pumps). Is there any advanced evidence for this pumping time? No. But if you fix your pumping time constantly, you will recognize the appropriate injection amount more easily.

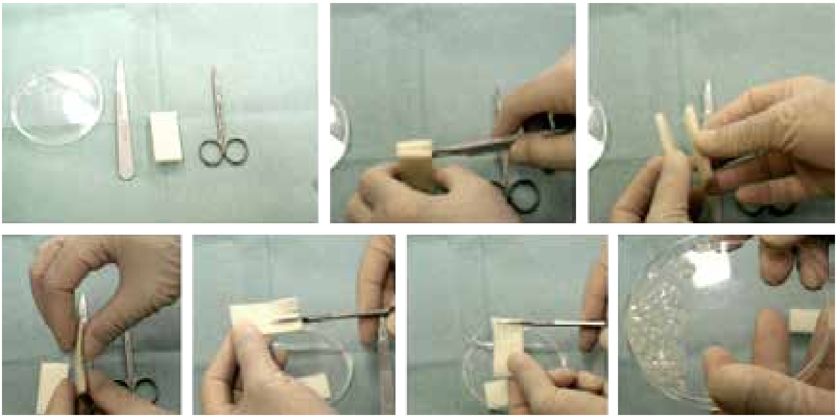


Figure 9: Gelatin sponge preparation for use in a cutting method. Slice the gelatin sponge into 2 or 3 layers, then press and flatten. Using scissors, cut it to target size (usually 0.5 to 2mm squared). Dip the GS fragment into a 50/50 mixture of saline and contrast agent.

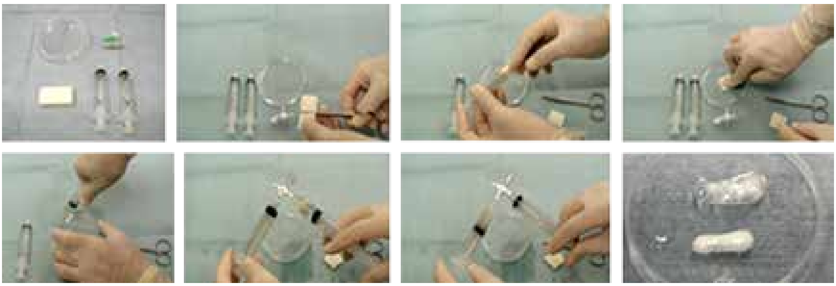


Figure 10: Gelatin sponge preparation for use in a pumping method. First, you need to cut the GS cube in half, then soak it in contrast and push it to remove the air (flip it over, and do that again) for about 20 seconds. The GS cube will become like "soft jelly". Pull out the plunger from the 10 mL syringe with lock, and put the "jelly like" half GS cube into the syringe from the back side. Then fill up the syringe with contrast (or 50% diluted contrast) to up to 5mL. Using a three-way stop cock and a 5 or 10mL syringe, pump and crush the jelly into particles.

Remarks:

» If some of the tips here feel too advanced, your feeling is probably correct. Some of these methods need advanced training and experience.

Coils: In general, coil embolization takes longer to perform than when liquid material is used. You will deploy the coil to make sure it forms tightly in the vessel. Coils do not work well in coagulopathy, but you can embolize in an accurate vessel position. The method is usually considered good for gastro-intestinal bleedings, isolation of pseudo-aneurysm, and pinpoint embolization. If the coils do not occlude flow, small amounts of GS or liquid agents can be added, combined with the coils. In life-threatening condition, you will need to choose the fastest and most effective embolic method. There are now available micro coils that are pushable, detachable, and many different types with different characteristics.

Tips:

» Check what items are available within your institution and get to know how to use them.

New coils are constantly being designed and put on the market. Pushable coils have been standard, conventional and cheap. However, once you put the coil in the catheter, you can only push it forward. Even if your coil will not form tightly, or is not optimal (under or oversized for the vessel), or is placed in an undesired position, you cannot pull it back. A migrated or displaced coil can cause unwanted embolization and disaster. If you use a detachable coil, you can pull it back or remove it, and start over again. Selection of best coils size that fits target vessels is an art to be learned. Undersized coils lead to distal migration, and oversized coils will not form

Figure 11.1

Figure 11.2

Figure 11 1-3: Coils (Courtesy of Cook Medical). There are many types of coils with different characteristics. We will not get into details here about the different types of coils.

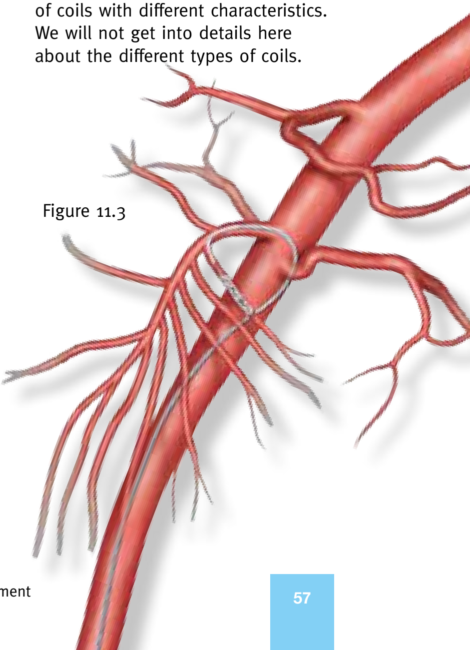


Figure 11.3

tightly in the vessel. A tip for determining coil size lies in the "+3 rule". You can measure vessel size in the DSA image calibrated with the catheter size (or in the CTA you did before). You may have a wide variety of sizes, i.e. diameters and lengths. Adding "3" to the vessel diameter gives the proper diameter. If the diameter of the splenic artery is 5.2mm, choose a 8mm diameter. Even if you do make the wrong choice, retractable coils will give you and the patient safety and security. Device development is rapid, so speak to your friends in the IR department. It's all about collaboration.

Tips:

» For selective and super selective coil embolization, use microcatheters. A coil-pusher is recommended.

» You have to choose coils of an appropriate size not only for the catheter but also for the vessel to be treated! Look at the package to find out what size of catheter is needed (or ask someone who knows!). Choose coils that are somewhat bigger than the vessel.

» If coil placement has to be accurate or the catheter is in an unstable position, use detachable coils.

Vascular plugs

A vascular plug consists of a tight nitinol mesh and its delivery mechanism is controllable. The plugs are suitable for large and high-flow arteries, like the splenic and the hypogastric arteries. In hemodynamically unstable, high grade splenic injury patients, proximal splenic embolization is acceptable. If you cannot use NBCA or Onyx for coagulopathic pelvic fracture, a plug might be helpful (practically, combined with GS). An Amplatzer vascular plug cannot be delivered through a micro catheter. If you fail to advance the catheter to the target region for any technical or anatomical reason, you cannot use it. Vascular plugs are delivered through a catheter or guiding catheter. The delivery sheath varies in size depending on the size of the plug. The effect of vascular plugs is, as with coils, dependent on whether the patient has coagulopathy. In a trauma setting, **you have to consider procedure time**. New micro-plugs (3-5-7mm, by Medtronic) can be delivered through micro catheters, and may be very useful as they can be inserted into smaller vessels and plug them fast and effectively.

NBCA + lipiodol

N-butyl-2-cyanoacrylate (NBCA) is a liquid and permanent embolic agent. This is the original "super glue", approved for skin wounds and esophageal varices. Injected into the vessel mixed with lipiodol – lipid contrast – you can embolize even under coagulopathy since its embolization capacity is independent of coagulation status. You can extend the reactive time by increasing the lipiodol part of the mixture, then you will embolize more distally and slowly. So, in other words, this is a fluid to inject. It will go downstream and block the bleeding focus. This is a great tool for coagulopathic patients, and essential for damage control interventional radiology in some centers. However, it is difficult to control the embolized area and length. To visualize clearly, DSA images during fluoroscopy during injection helps to establish when to stop the injection. Your catheter tip might be dipped in the cast. An "NBCA package" will help you in urgent situations. The package would contain a 1mL locked syringe (for final injection), a 2.5mL locked syringe (for aspiration of NBCA first, and then for glucose injection), a 5mL locked syringe (for lipiodol and mixing), a 20mL locked syringe (for glucose), an 18 gauge needle (for glucose and lipiodol), a 3-way stopcock (for mixing and injection), and usually a syringe set for angioembolization (e.g., 10mL locked, 5mL locked, 2.5mL locked).

Figure 12.1

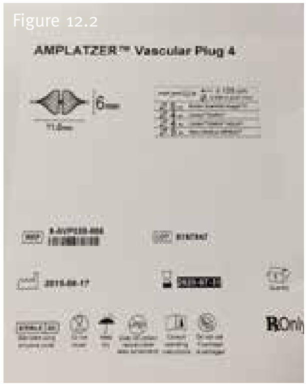


Figure 12.2

Figure 12 1-2: An Amplatser Vascular plug. There are different sizes to fit target vessels and sheaths. This information is on the package, which includes delivery system information (size).

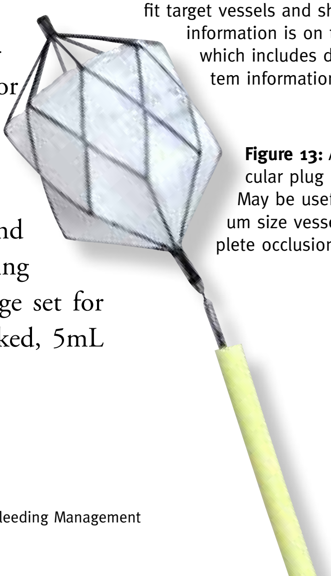


Figure 13: A micro-vascular plug (Medtronic). May be useful for medium size vessels for complete occlusion.

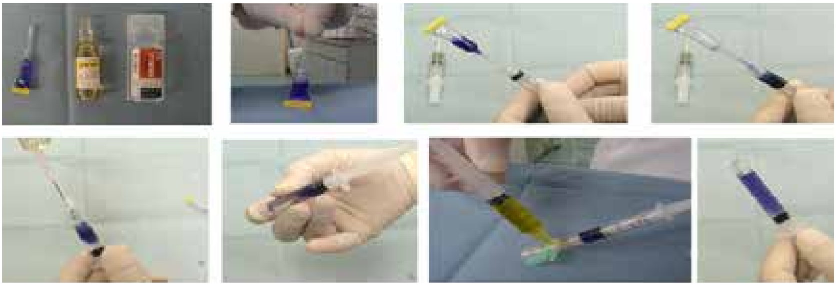


Figure 14: N-butyl cyanoacrylate (NBCA) preparation. You need NBCA, lipiodol and 5% glucose. Cut off the plastic tip of the NBCA bottle, then put it into a locked 2.5mL syringe, and aspirate the blue glue (0.5mL NBCA). Lipiodol sets in the 20mL syringe, and inject the appropriate volume needed (If you want to make 1:4 NBCA/Lipiodol, you inject 2mL lipiodol). Mix it by inversion or pumping with 3-way stopcocks.

Tips:

- Most of us would consider this is a rather more advanced product that you have to know well for safe usage, but if you know the product well, it is very effective.
- Under coagulopathy or in most urgent situations, NBCA is a fast and reliable embolic agent. But NBCA is difficult to handle. Be aware of distal embolization and complications!
- Onyx works as well in coagulopathic patients (see below).
- Follow IFU!

Onyx

Onyx is a polymer that stiffens in contact with an ionic solution, i.e., blood. It contains tantalum to become visible during fluoroscopy. The substance is injected through macro or micro catheters (2.7–2.8Fr, e.g., Progreat, Terumo). The catheter **must be compatible** with Onyx (e.g., Bernstein catheter). To prevent Onyx polymer getting stiff in the catheter during injection (as should happen when in contact with liquid), the catheter lumen is filled with DMSO solution once the catheter has reached the target area. After the Onyx has been shaken for 20 minutes it is slowly (around 0.3 ml/min as a recommended rate) injected using a 1 ml syringe. As Onyx comes into contact with the blood, when it leaves the catheter tip, it will stiffen and thereby gradually fill and occlude the vessel lumen or pseudo aneurysm. It is important that the injection is done slowly; otherwise Onyx will go with the flow in fragments to more distal vessels “downstream”. Onyx, like glue, occludes flow even if coagulopathic, but the drawback is that is time-consuming, compared with, for example, GS and coils in patients in severe hypovolemic shock. One advantage, however is that it gradually fills the vessel in a distal direction, so it might reach areas a few cm from the catheter tip that are not reached by the catheter itself.

Tips:

- Check which catheters you have; are they compatible with Onyx?
- Slow injection of DMSO in conscious patients is recommended but might cause spasm and pain.
- Inject the onyx slowly when you are beyond the dead space of the catheter! It might migrate.
- Always consider the risk of embolization when removing your catheter.
- You can do control angiography via the macro catheter during the procedure (you will need a Y-connector)!
- Liquid embolic agents are not easy to use and you should not use them if you are not very experienced with embolization.

PHIL

A new embolization liquid that can be injected directly after DMSO, which is similar in this regard to Onyx, but without preparation time. It is currently being evaluated for bleeding control, so it is hard to give more information at the moment.

Figure 15.2

Figure 15.1

Figure 15.3

Figure 15 1-3: Onyx embolization agent (courtesy of Medtronic). Onyx injected during elective procedure.

Balloon catheter and micro-balloon catheters

Balloon catheters might give you strong support in bleeding control. Of course, you can use an aortic balloon occlusion catheter (REBOA) in refractory hemorrhagic shock patients. But long occlusion at Zone 1 might impose a catastrophic metabolic burden: Excessive ischemia and subsequent ischemic-reperfusion injury. If you can identify the bleeding point, change to a more selective balloon catheter (or micro balloon catheter). It will be safer and more effective. In patients with a hemodynamically stable high grade splenic injury, proximal embolization with a vascular plug is standard in some centers. At times, you cannot get as distal as you want and, while considering what to use or to do, you might have other solutions. Temporary balloon occlusion of the splenic artery may be an option. This may allow you to do open surgical repair with balloon bleeding control. Combined with REBOA or a balloon catheter, intraoperative bleeding might be reduced if patient requires surgery. If your patient has an abdominal blunt injury and catastrophic hemodynamics, emergency laparotomy under hemorrhage control with REBOA will reduce the bleeding amount and transfusion, and you can keep the surgical field dry. You may meet a patient with a subclavian artery injury. If you are familiar with catheterization of the subclavian artery, proximal control by balloon catheter might be useful during surgical repair. However, care must

Figure 16 1-2: Iliac balloon for proximal control in a bleeding femoral artery. A PTA (Cordis 16mm) balloon was used and for this an 8Fr sheath was inserted from the Left side. The balloon was inflated just some atmosphere to get bleeding control and open surgery performed (hybrid concept).

be taken regarding potential cerebral ischemic effects due to the subclavian supply to vertebral arteries and the right carotid artery. Balloon catheters can also be used to occlude a vessel during injection of an embolization agent and decrease distal migration as well. These are advanced methods that we will not be able to discuss in this manual. We will discuss balloons in non-aortic locations in a separate chapter.

So, in this chapter we tried to cover the issues of what to use and how in a basic matter. We do not recommand to use any of these methods without proper training and suggest good cooperation with your IR or vascular collouges. We should also mention here again that you should follow the IFU (Intructions for use). There are probably more tools to use, in different ways.

Think before using endovascular and hybrid tools, and be careful out there!

Notes

Chapter 3.1

How to think EVTM as a trauma surgeon

Some thoughts from trauma people with “blood on their hands” regarding EVTM

Lauri Handolin, Boris Kessel, Joe Love, Pantelis Vassiliu and George Oosthuizen

“Do or do not – there is no try” Yoda, the Empire Strikes Back.

Trauma surgery; the most challenging profession there is! Why? Because you often have to step out of your comfort zone, away from conventional thinking, and make rapid, immediately life-saving decisions. You need to stay cool and trust your training; who dares wins!

Major trauma impacts the body in two ways; it causes anatomical injuries such as bowel perforation and/or complicated orthopedic fractures, but more importantly, it causes major tsunami-like disturbances in the patient’s physiology. Elective surgeons who may be very comfortable with restoring anatomy in “physiologically stable” patients may quickly be overwhelmed in major trauma with low blood pressure, poor oxygenation and ventilation, disturbed coagulation, hypoperfused tissues, increased intra-cranial pressure, and decreased body temperature. There is no place for contemplating how an intra-articular proximal tibial fracture should be plated, or how much more familiar you are with the laparoscopic approach to surgery utilized in your elective practice. While there may be instances where your familiar approaches are comforting and applicable they can and should not be the limiting factor on whether the patient lives or dies. You need to focus on the immediate threat to life – control the damage caused by the anatomical injuries in such a way as to expedite the restoration of the physiology and do it quickly! Time is a major factor in trauma and bleeding patients.

If you don't work in a busy trauma center constantly confronted with major trauma, it may be difficult for you to change your elective mindset from developing a detailed work-up and elaborate management plan with all the time in the world to suddenly receiving a young Jon Doe with a mutilated face and chest, unstable pelvis with a distended abdomen. Oh and by the way, the patient has a systolic blood pressure of 80 mmHg and is struggling to breath. Now you need to step away from elective surgery and become a trauma surgeon.

Your first priority must be to address what is endangering the patient the most. Don't forget the basic ABC's of initial trauma evaluation. The lack of an effective airway can kill quickly – be prepared to deal with it by doing a surgical airway if endotracheal intubation fails. Breathing may be compromised by a significant pneumo- or hemothorax and may require a tube thoracostomy urgently. For circulation, all major external bleeding should be controlled with compression or tourniquet. Sometimes it doesn't work, so this is a time and place to use your fantasy improvisation. Even in the emergency room you may use massive packing of large bleeding surfaces. If possible, quickly closing the skin over the pads may enforce the tamponade effect. In a deep relatively small hole you may insert and inflate a urinary catheter balloon. For even bigger holes just for your knowledge, you also have the option of large 32 French Foley catheters which our urology friends use for urine bladder irrigation. In a massive bleeding neck or gluteal dump it will save life! Think and teach that even your youngest resident can do it. A pelvic binder may be required, and long bone fractures may benefit from prompt splinting. If the patient fails to respond rapidly to the ABC's of initial trauma evaluation, there is an obvious need to do something quickly. Is it bleeding that is causing the circulatory compromise? Our answer will be "yes", our patient is in hemorrhagic shock, until proven otherwise. However, when you rapidly search the major source of bleeding, still keep in your mind in the course of your initial trauma evaluation, have you effectively ruled out an A and B problem as the cause? Is there a pericardial effusion? Does the negative FAST exam still suggest bleeding into the abdomen? How portable pelvic x-ray may be helpful in your decision-making process? What if the pelvic x-ray indicates an unstable pelvic ring fracture? The findings should cause you to consider major extraperitoneal bleeding until proven otherwise! The patient remains a transient responder to your blood product resuscitation while you work rapidly through the algorithm of possible sources. Time to do something… NOW!!!

After likely sources are identified, you need to promptly control the bleeding. To do something means to control major bleeding. If the patient is still relatively stable, maybe the first stop is the angiography suite for possible embolization. However, most probably you should take the patient directly to the OR, open the abdomen, stop the hemorrhage and leave the abdomen packed and open. In case of unstable pelvic fractures think about preperitoneal packing before explorative laparotomy! **Or** do you land at zone 3 with a REBOA you put in place in ER, and stay ready to proceed to zone 1 if no hemodynamic response is seen after the balloon occlusion? With resuscitation in progress, it takes only a few minutes to insert the REBOA. The patient now needs extra pelvic packing and laparotomy for sure, but it is much more expedient for you to start operating when you have in-line proximal bleeding control in place. Deflate the balloon partially and see what happens (see the REBOA chapter); does the patient tolerate it? If prominent significant bleeding restarts again, refill the balloon and do your damage control maneuvers. If your patient tolerates partial deflation, see what happens if you deflate the balloon completely. Look for physiological responses and play the game. Let the ultimate goal, prompt stabilization of the physiology, lead your decisions, not the need to correct the anatomy.

Comment:

- Don't forget that REBOA is just one tool and it's not clear yet who has most benefit of it. Always have in mind other tools of trauma surgery. Always have plan B and plan C!

In case of a fast track whole body CT-protocol, insert the balloon and scan the patient immediately if the patient's physiology will allow. The CT scanner can be the loneliest place on the planet when this decision is made in haste and the patient actually belongs in the operating room. However, there may be no absolute indication to perform a laparotomy at this time, and it may not be needed at all if abdominal bleeding turns out to be minor or controlled by endovascular techniques. Prevention of unnecessarily opening of a body cavity may avoid escalating hypothermia, the need for additional fluid requirements and the possibility of worsening coagulopathy. What if you find on CT that your patient also has a significant injury of the left subclavian artery and a blush in the liver? Continue resuscitation and consider where the patient needs to go. Are they better suited for some additional resuscitation in the ED or ICU before intervention? Do you have access to a hybrid suite that can facilitate combined open and endovascular procedures? If not, should they go to the interventional suite first, and then the operating room…or the other way around. Every patient will be different and a fluid thought process is mandatory. But even you have decided to go to your super fashioned hybrid room, please continue to think as a trauma surgeon. If you do any endovascular procedure after completion of thoracotomy or laparotomy, you just continue your case. Still remember, that physiology is the first priority. In fact, an endovascular procedure may be much longer than a surgical one!

Comments:

» CT, as all imaging, must be considered carefully: What am I looking for and what would be the next stage after the examination? Put up a plans. Both plane A and plane B!

Can endovascular management (as part of the EVTM) help with management of the patient in front of you? In most instances the answer is likely "yes", but you need to consider when / where and how to employ this skills set. You need to understand the possibilities and limitations of endo tools. When it comes down to bleeding, you generally follow the principle "proximal and distal control – then fix what is in the middle", or you amputate distal to uncontrolled bleeding in the unstable patient if it is feasible. These decisions require a comprehensive understanding of anatomy and physiology – as well as the tools that you can bring to the fight and salvage a patient in need of help. The EVTM thought process require thinking outside of "the lesion" alone. The elective endovascular thought processes are important, but can lead you astray. Crossing the lesion with a wire may save the day – but it also might take too long in an unstable patient. Maybe embolization is a better answer in certain situations? Even if you can cross the injury effectively and deploy a covered stent to repair an injured blood vessel – is this a "definitive" solution, or is it damage control? Is it wiser to replace a stent graft with a vein conduit for long term patency in a 20-year-old patient? Could you place a temporary vascular shunt and allow for reperfusion while additional maneuvers are undertaken? What about anti-coagulation? Should you give it in the midst of the procedure despite a liver injury? What represents a greater risk to the patient in front of you – liver hemorrhage or arterial repair thrombosis?

Comment:

» The EVTM concept deals with these considerations and helps you decide if endo tools can help you now. It does not exclude open surgery! Moreover, keep this option always available!

These decisions are not easy. They are often made in a hurry – and they may fly counter to everything you have been used to doing in your elective practice. The best in this situation may be something different from what you are normally comfortable with. If it was easy… everyone would be doing it. Embrace the challenge!

Final tips:

» Forget elective surgery principles if patient is dying in front of you; there is no time for waiting, slow proper sterile draping and strict anatomical dissections. React and put all efforts on the patient.

» Consider always open surgery to solve problems, don't get locked on endo.

» You are not finished until the patient shows signs of getting better. The ICU is not the end of surgery; it's the beginning of a very important journey. Be there!

» You just did a REBOA and packing and the patient is stable? In some hours or days, he might develop multiple organ failure. Work actively to prevent that.

Chapter 3.2

Endovascular Resuscitation in the Emergency Department

Thoughts of emergency medicine doctors with REBOA and EVTM interest

Lisa Hile, MD and James Daley, MD

A significant member of the trauma team both in the pre-hospital setting as well as in the trauma bay in the emergency department is the emergency physician. Traditionally the role of the emergency physician is to resuscitate and stabilize the patient while working with the surgical trauma team to decide whether or not the patient needs surgical repair for his injuries. Part of the decision making tree for an EM physician is to also work with the attending surgeon to manage where the patient should ultimately go for definitive treatment. This may include transferring a patient to a higher level of care which in some circumstances can be risky for both the patient and the EMS crew. In the setting of a trauma centre with an in house trauma team, the most efficient management is for the emergency and physician and surgeon to work together as a team. In the new era of trauma management, fewer patients are going directly to the operating room for the traditional laparotomy. This new push is a result of better imaging technology, research in trauma management, the surge of interventional radiology, and the new role of EVTM. The skills set of the emergency physician is constantly evolving and expanding. EVTM will become paramount for the emergency physician to not only understand, but to also learn and utilize in the emergency department as part of modern management of the hemorrhaging trauma patient. Given the new research and advances with the partial occlusion REBOA catheter, longer transport times with a REBOA catheter in place is now feasible.

For example, a victim of blunt trauma from a high speed motor vehicle collision will more likely end up initially in a level II, III, or IV trauma center (no 24/7 trauma surgeon,IR or vascular surgeon on call). In the setting of an unstable pelvic fracture that needs to be transferred to a higher level of care for definitive management, the emergency physician this patient will be skillful at placing an ultrasound guided introducer catheter and endovascular occlusion device (REBOA) that can be used for a temporary hemorrhage control while also resuscitating with blood products and then transferring the patient. This can be done by any emergency physician, and has the potential to save lives when hemorrhaging patients present to more rural emergency departments with long transport times.

When considering EVTM as an adjunct or temporary measure for the hemorrhaging patient, the emergency physician is considered an integral member of the team, and **should be trained in basic EVTM**. Currently emergency physicians are on the forefront of using the new US FDA approved ER REBOA (Prytime) for non-compressible hemorrhage of the torso. Most recently, the ER REBOA catheter was used successfully by both a U.S. emergency physician and a surgeon in the battlefield in the Middle East. As new technology is brought into play with the use of catheters that can measure "partial" occlusion, the REBOA catheter might play an important role as a temporizing measure to get hemorrhaging patients transferred from a community hospital to a level 1 trauma center. Due to its ease of use, it also has a promising role in the pre-hospital setting. Its use at smaller institutions without surgical support and in the field makes it a crucial part of the developing skillset of the emergency physician.

The use of focused bedside ultrasound has been rapidly integrated into emergency medicine training programs across the United States and proficiency is now a requirement for all trainees. The importance of ultrasound extends far beyond the focused assessment with sonography in trauma (FAST) exam. Ultrasound can assist in the diagnosis of a traumatic condition requiring or excluding EVTM, attaining **vascular access** for EVTM, and confirm-

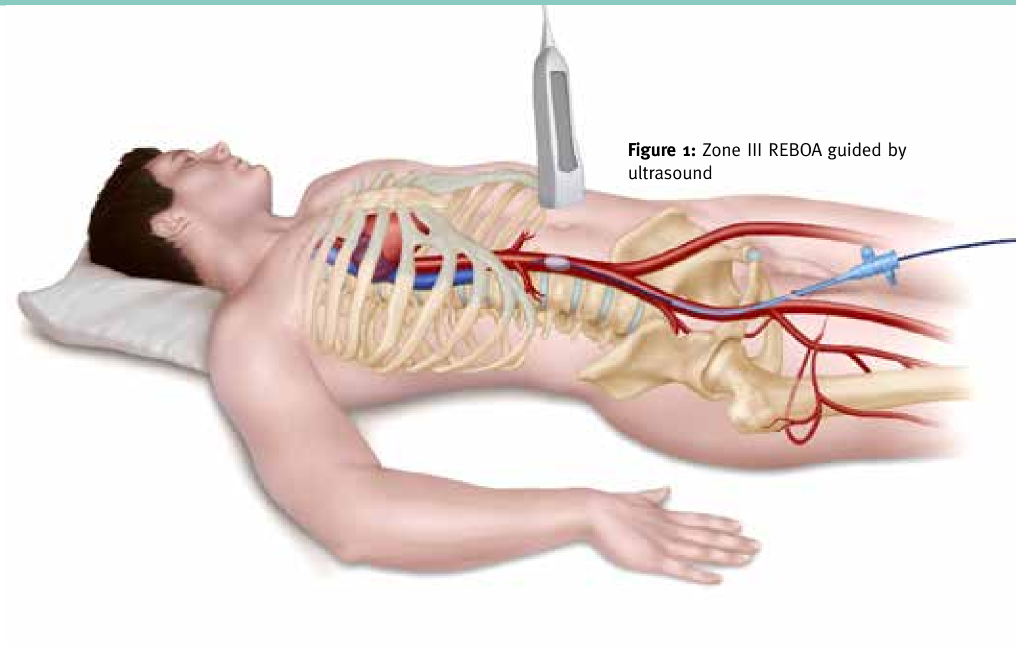


Figure 1: Zone III REBOA guided by ultrasound

ing placement of EVTM devices. Its portability allows the technology to travel with the physician, making it extremely useful in both the pre-hospital and battlefield settings.

A critically ill patient often cannot be transported from the trauma bay to the radiology department for definitive imaging and thus a diagnostic methodology that can be employed at the bedside is invaluable. The FAST exam allows the efficient identification of a non-compressible hemorrhage that may be amenable to EVTM in the shocked patient. While its use in the abdomen has been popularized, emergency physicians are capable of using ultrasound to check for thoracic and vascular injuries that may preclude the use of EVTM techniques such as REBOA. Ultrasound can readily identify a pericardial effusion, hemothorax, pulmonary contusion or hemorrhage, and can be used to assess the thoracic and abdominal aorta for signs of injury. Bedside ultrasound has enabled emergency physicians to become leaders in vascular access and its use has been consistently demonstrated to be superior to blind approaches concerning both venous and arterial access. Ultrasound is utilized for central venous access at the femoral vein, the subclavian (both infra-clavicular and supra-clavicular approaches), and the internal jugular, while it also improves femoral and radial artery cannulation success. In regards to femoral arterial access, not only does it improve time to cannulation, but it also improves first time success rate and decreases accidental venous cannulation. This skill becomes even more critical in the shocked or cardiac arrest patient with collapsed vessels.

Historically, EVTM techniques such as REBOA have required fluoroscopy for confirmation of proper placement, however ultrasound is now beginning to play a major role in this area as well. By inflating vascular balloons with contrast dye, ultrasound can readily identify their position within the aorta. With the deployment of REBOA and other EVTM techniques in the pre-hospital and battlefield setting, ultrasound has become the most practical imaging modality for the confirmation of device placement.

The use of EVTM by emergency physicians may allow for the dissemination of these techniques into other non-surgical areas of medicine, most notably in medical cardiac arrest. Through the cessation of distal flow, one can effectively cause the selective perfusion of the heart and brain. During a low flow state such as cardiac arrest, balloon occlusion of the aorta redistributes cardiac output and increases flow to these critical organs. Increased coronary flow improves the chances of return of spontaneous circulation while increased cerebral flow helps maintain neurologic preservation during resuscitation. The use of balloon occlusion during non-traumatic cardiac arrest is supported by a multitude of animal studies, limited case reports in humans, and is currently undergoing prospective trial development in humans.

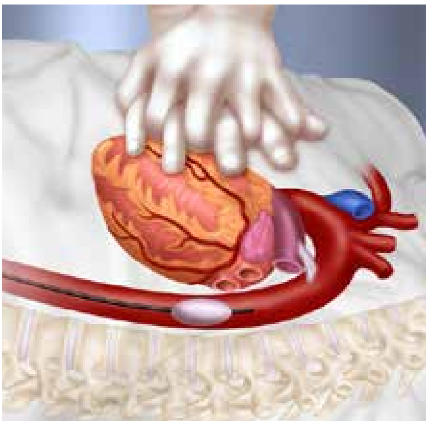


Figure 2: CPR with Zone I REBOA in place.

Notes

Chapter 4

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

Jonny Morrison, Viktor Reva, Lars Lönn, Junichi Matsumoto, Yosouke Matsumara, John Holcomb, Koji Idoguchi, Tal Hörer and Joe DuBose

Picture the scene, you are the Trauma Surgeon on-call for your hospital and word has been received that paramedics are minutes away with a pedestrian hit by a car. Nothing about this sounds good – the patient is profoundly hypotensive and unconscious with a disfigured pelvis. What goes through your mind?

Your patient is almost certainly about to bleed to death, but what other injuries does he have – a traumatic brain injury, long bone fractures? Where is the bleeding focus – pelvis, solid abdominal organs, chest, or all of these? What clinical capabilities do you have and do you need to report them now?

The patient arrives and looks terrible – pale, clammy, moribund. Your team gets to work – high-flow oxygen by mask, pelvic binder applied, large-bore venous access, bloods away, and O-negative blood transfusion commenced. The primary survey reports no major chest injury on physical examination or x-ray, FAST scan positive, but the pelvic film shows disruption to the left sacro-iliac joint and pubic rami anteriorly. The last blood pressure recorded was 60/40mmHg, despite the first unit of blood already in, and the pelvic binder correctly positioned and secured. Your team looks to you – what is the plan now? Let us pause for a moment and consider the options. Your

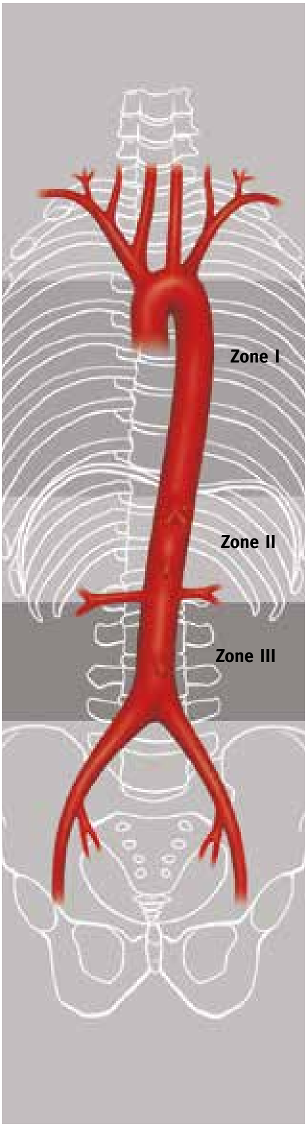


Figure 1: Illustration of Aortic zones. Zone I supra-celiac (descending aorta), Zone II para-viceral, Zone III infra-renal.

patient is bleeding to death from somewhere in his abdomen and/or pelvis. You need to stop this process as quickly as possible. The "ideal" solution is immediate Damage Control Surgery (DCS, e.g., trauma laparotomy and pelvic fixation followed by pre-peritoneal packing) as part of your ongoing damage control resuscitation. This would preferably be done in a hybrid operating room (OR) with endovascular embolization capability. If you are lucky enough to have that facility – use it! However, life is rarely ideal. The OR may be 10 minutes and two elevator rides away. The OR might have another critical case on the table and may need to call in a second team. Your patient may have a difficult airway, and the anesthesiologist needs specialist equipment. You do not know if your patient is going to last that long – you need a bridge that will support the patient until you can get to somewhere where you can stop the bleeding.

Resuscitative Endovascular Balloon Occlusion of the Aorta (**REBOA**), also called Aorta Balloon Occlusion (**ABO**), may be the solution to your problem. By occluding the aorta with an appropriately sized compliant balloon, you can achieve several beneficial effects. The increase in afterload will raise central pressure, improving cerebral and myocardium perfusion. The reduction in blood flow beyond the balloon will also reduce perfusion to the hemorrhagic focus. Thoracic aortic occlusion (Zone I) is useful in controlling bleeding from an abdominal focus, whereas infra-renal occlusion (Zone III) can control pelvic hemorrhage. Zone II lies between

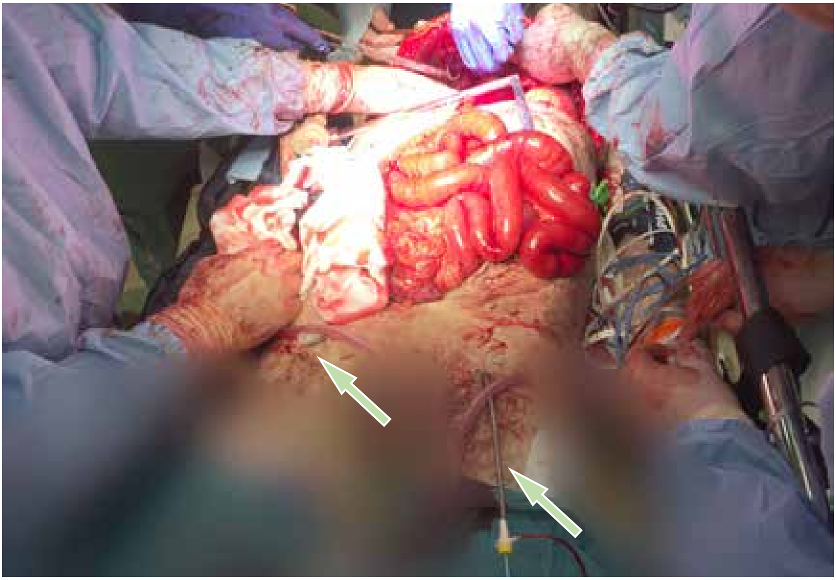


Figure 2: Usage of REBOA in a trauma patient with clampshell thoracotomy, laparotomy and REBOA in the left groin. Note also the 5Fr sheath in the right groin. Some advanced methods as Zone I intermittent REBOA (iREBOA) and partial REBOA (pREBOA) where used. The 5Fr sheath could be used for pREBOA monitoring.

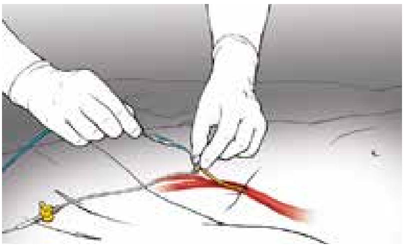
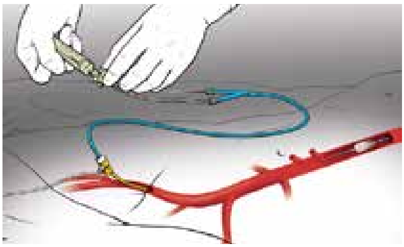


Figure 2.2:



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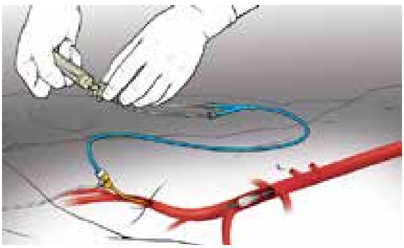


Figure 2.4:

Figure 2. 2-4: Balloon insertion to the sheath and REBOA in zone I and III.

these zones and is where the visceral arteries supplying the GI tract, liver and kidneys originate, which must be considered when doing REBOA.

Although REBOA can be a wonderful tool in the right situation, it is important to note that it might be associated with some **potential severe risks.** REBOA effectively cuts off the blood supply to the lower body, at the level of either the diaphragm or the pelvis. Every minute, more ischemic "debt" accumulates, which will eventually have to be paid back by your patient once the balloon is deflated. Occlusion at or above the visceral arteries (Zone I or II) is tolerated least well, due to the burden of visceral ischemia. In theory, Zone-I occlusion still permits "some" collateral or retrograde perfusion of the abdominal viscera, so Zone-II occlusion is discouraged. To mitigate this burden, another option is to use periodic inflation (or intermittent REBOA), which we will discuss later in this section.

Remarks:

- REBOA is a less invasive procedure than thoracotomy, and permits aortic occlusion at different levels and in different ways, depending on clinical need.
- REBOA is a bridge to definitive repair, not a solution!

In general terms, if you do use balloon occlusion, you want to have the shortest time possible. For Zone-I occlusion, under 30 mins is optimal, but over 60 mins is very dangerous, due to ischemic insult and consequent reperfusion injury. For Zone-III occlusion, up to two-three hours can be tolerated (it has been used for up to 5-6 hours, but this is not recommended), but fewer than two is preferable. Remember, once the balloon is up, it is a race against time to get it down again! If you use Zone-II occlusion, a very short occlusion time of minutes maybe the only way to use it.

Advanced Tips:

- Once familiar with the anatomy of aortic zones, there are several advanced maneuvers to consider – intermittent and partial inflation. Consider using them if possible.
- REBOA is not an "inflate it and forget it" technique. Inflation may keep your patient alive, but prolonged use beyond what is necessary can cause severe organ damage. It might also migrate!
- **Have someone assigned to monitor the balloon** and keep its usage limited to the time needed (bridge to surgery). Ask anesthesia to record the inflation time.

Stages of REBOA Deployment

Arterial Access: REBOA is all about access – see Chapter 1&2. An arterial access sheath can also be transduced via the side arm or contralateral CFA to measure invasive blood pressure and provide samples for blood-gas chemistry. Early access in the form of a small sheath can be used for monitoring, with the option of "up-sizing" to a larger access sheath for interventions such as REBOA. Importantly, your access sheath must be of an appropriate size (at least 5Fr) to accommodate whatever you plan to deploy through the sheath. As mentioned above, this is the limiting stage of REBOA, and access in hypotensive patients might be challenging!

Advanced Tip:

- In elderly patients with vascular disease, beware of calcified arteries. You can use micro-set to get in, and use ultrasound if possible.
- If you fail, leave the sheath in place for now. Take it out later on, as it might bleed.
- Calling a colleague to assist with REBOA is not a sign of weakness. It is often a sign of sound judgement in challenging cases. **Work as a team** around the patient with an EVTM mind-set.
- Use both femoral arteries for access, if possible, as the contralateral side can be used for arterial pressure and have a modifying partial REBOA effect. It is easier to insert the sheath before commencing occlusion, so do that expeditiously.
- While you are working to establish femoral artery access for potential REBOA, also consider using the common femoral vein as a site for central venous access and fluid resuscitation – your anesthesiologist will thank you!

Catheters are "rated" according to the sheath size required; e.g., a 14Fr Cook Coda balloon will fit in a 14Fr sheath. Although there are exceptions, like the smaller Coda balloon (30mm, which needs 9Fr). The Medtronic Reliant balloon catheter can fit in an 11Fr sheath, as can the Boston Scientific Equalizer, but such fittings are "off-label" or outside the "instructions for use" (IFU) for these devices. In addition, when using a narrower sheath for the devices, they become difficult to manipulate, as there is not enough space in the sheath for the device. On occasions, it is useful deliberately to use a larger sheath size to permit easier flushing – a good habit, especially when not anti-coagulating the patient. We should mention that there are some 10Fr REBOA catheters as well as Fogarty balloons in different sizes. The Rescue

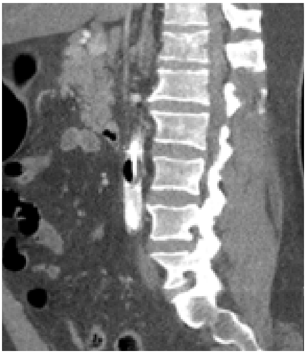


Figure 3.1

Figure 3.2

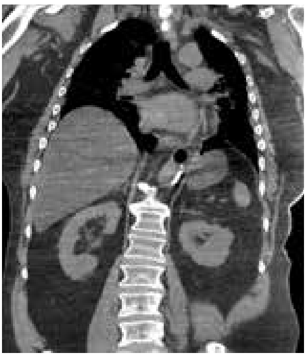


Figure 3.3

Figure 3 1-3: Some examples of REBOA in place on CT

Balloon (Tokai, Japan) and ER-REBOA (Prytime, USA) use a 7Fr introducer and are in early clinical usage; we will discuss them in greater detail below.

The optimal arrangement is to have a "REBOA set" prepared, which includes a sheath, balloon catheter, wire, and a bottle of contrast medium. Some of us have two sets as mentioned before: ACCESS kit and REBOA kit (or a combined set). If not available, then it may be best to postpone this bold maneuver for the next exsanguinating patient. Always have at least 2-3 sets for REBOA, as various items from a set may accidentally fall out of the sterile field during the inevitable controlled chaos of serious trauma resuscitation, or the balloon may rupture during insertion. The key elements of access are better outlined in the dedicated "It's all about vascular access" chapter in this text.

Balloon Selection and Positioning: Your choice of balloon obviously depends upon what you have at hand. The most common types of balloons use a conventional "over-the-wire" system, such as the Cook Coda (14Fr) and the Medtronic Reliant (12Fr) or Equalizer balloon, (14Fr) which are primarily designed for use with aortic stent-grafts. In general, these balloons can inflate to large diameters (40 to 46mm), but will fit in any size of "healthy" thoracic and abdominal aorta. As these catheters are designed to be deployed under fluoroscopic guidance, the shafts contain no distance markers, which can make you a bit nervous if imaging is unavailable. They also do not have clear marking, and a diluted contrast media should preferably be used when you inflate the balloons. In smaller centers where stent-grafting is not a routine procedure, you can find a large angioplasty balloon, such as Cordis Maxi LD (12Fr), which can expand to 25mm diameter. The CODA LP balloon is a 9Fr system (30 mm) and can be also used for REBOA. In healthy and young patients, these diameters should be sufficient. Remember that the standard angioplasty balloon is a high-pressure balloon usually blown up using an inflation device. The device is designed for balloon expansion to reach the desired diameter in the atherosclerotic arterial lesions by rupturing the plaques under high pressure. In a normal vessel, it can lead to intimal tear and dissection. This effect should certainly be avoided; hence, if you have only such a high-pressure balloon, inflate it by hand (it can reach up to 8ATM but not more). While the use of the above-mentioned balloons in “traumatic hemorrhage” is an extension of their initially conceived usage, several low-profile (7Fr) devices, specifically designed for trauma, are available, and their use is expanding. Low-profile devices have advantages, since they reduce the need for large sheath sizes and their associated complications – plus closure becomes easier. Examples include, as previously mentioned, the Tokai Rescue balloon (RB) and Prytime ER-REBOA catheter. The latter is a novel wireless system, which incorporates a wire in the shaft,

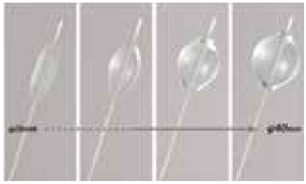


Figure 4.1

Figure 4.2

Figure 4 1-2: Rescue Balloon by Tokai (With permission).

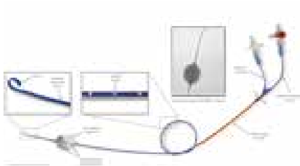


Figure 5.1

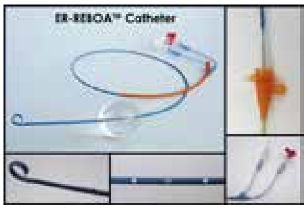


Figure 5.2

Figure 5 1-2: ER REBOA by Prytime (With permission).

eliminating the need to pre-place the wire. The RB has been in use for some years now in Japan, and also has been used without a wire (but this practice is "off label"/outside the IFU for the device). It has the advantage of possible usage up in the neck vessels and not only the aorta.

The first step is to choose an appropriate wire over which to deploy the balloon. It needs to be stiff enough to support the REBOA catheter, but not so stiff as to risk perforating the patient's arterial wall. To reduce this risk, a wire should have a tight atraumatic J-tip, as, for example, the Rosen wire. A floppy-tip Amplatz or Lunderquist are other options commonly employed in some centers. The wire also needs to be long enough to permit deployment inside the patient, while having a sufficient length outside on which to mount the REBOA catheter. Finally, it must be of an appropriate diameter to fit the central channel of the catheter; for example, a Coda balloon uses a 0.035inch diameter wire and a Reliant 0.038inch wire, whereas a Rescue balloon uses an 0.025inch wire. Remember, you can use a smaller wire than recommended, but not a larger one!

General Tip:

» Know your equipment before starting to use it!

Introduce the wire into the sheath and advance it slowly. Provided there is no resistance, delivery of the wire can be speeded up. Ideally, the wire should be inserted under fluoroscopic imaging to ensure that it maintains aortic travel and does not enter a side branch. Other options for imaging include the use of plain radiology and ultrasound to assess intraluminal wire position.

It is also helpful to have measured the wire against the patient's torso in order to get a sense of the length that is required. If you have ultrasonography available in the ER, just place the probe on the abdomen and look at the aorta shadow. Can you see a white line (the wire) in it? Remember that bowel gas and patient body habitus can make seeing the wire in the aorta with ultrasound a significant challenge. If the images are not clear, do not dwell on getting a perfect picture.

The ideal wire position is in the proximal descending thoracic aorta, which will permit deployment of the balloon catheter in the thoracic aortic or infra-renal aorta depending on the desired clinical effect. It is important that the

Figure 5.3: REBOA insertion in a trauma patient with positive DPL.

wire does not migrate proximally too much, as the wire can disrupt the aortic valve, or perforate the left ventricle, or migrate into the carotid or vertebral arteries. Introducing a wire into the arterial system is not a benign procedure. We just mentioned that the wire might perforate other vessels or go directly into the carotid artery, so always use the soft end of the wire first. Once the wire is in situ, the balloon catheter can be delivered over the wire by loading the catheter onto the wire, securing the end (usually done by an assistant) and advancing the catheter into position, using the same method as for the wire. Again, you are using the Seldinger over-the-wire method, as mentioned in the access chapter. If you use the ER-REBOA, no wire is needed and you will push the catheter into the sheath and advance to your target location. That we will discuss now.

A variety of means adequately to position the REBOA balloon into aortic Zone I have been described and may prove useful. Particularly useful when imaging is not available, you can measure the appropriate distance between the sheath and the patient's xiphoid process, and then apply a marker (finger or steri-strip) to the shaft of the catheter that represents this distance. In order to position the balloon in aortic Zone III, a rule of "5x6" has been proposed, where you advance approximately 5 cm of a balloon catheter into a sheath 6 times in diameter. This approach will likely land the balloon reliably above the aortic bifurcation. An alternative for Zone-3 positioning is to measure externally to the approximate length required using the umbilicus. As the aortic bifurcation is most commonly at the level of the umbilicus, measuring the length required to be just above this external landmark should be safe and practical in the vast majority of cases. Remember that when using an "over-the-wire" technique, the wire should always remain inside the catheter to help maintain a stable catheter position.

Warning

» Do you feel resistance when advancing the wire or balloon? You might have a problem. In young patients, the REBOA should go in smoothly. Unsure? Stop and reconsider! Change strategy!

Despite the stress of the moment you must confirm a balloon's position before complete inflation at least once, by FAST or mobile x-ray if possible. Although Zone II is much shorter then Zone I or Zone III, you can easily position the balloon right there, between the celiac artery and the lowest renal artery. You do not know exactly where these "undesirable" arteries are located in a particular patient, so just avoid positioning at the level between the Th12 and L2 vertebrae.

Advanced Tip:

» It is a basic tenet of endovascular intervention that maneuvers are performed over a wire; however, in a crisis, with a flat-lining patient, corners can be cut to expedite placement. The wire and balloon catheters can be deployed together, provided there is 15-20 cm of wire protruding ahead of the catheter. This is a more advanced technique, best performed by someone who has substantial REBOA experience. There are different methods and different products to do this.

» Train with dummies, autopsies and simulators before you do blind insertion. You will learn to feel the correct resistance.

» In hyper acute situations like 0 pressure or CPR, do the insertion blindly, but be aware of the risks. The procedure is highly dependent on whether you have a sheath in place.

» Some experienced providers have described the pre-placement of the REBOA catheter without inflation, if the patient is relative stable but is perceived to have a significant risk for decompensation. In this sense, you can think of this approach as similar to putting a monitoring arterial catheter in the aorta – with the option rapidly to convert to REBOA inflation as the situation dictates. The technique may prove useful in specific cases, but does carry some potential risk (to be discussed below).

Balloon Inflation: This must be performed using a fluid, as the use of room air can result in an air-embolus should the balloon rupture (and some do rupture!). An ideal fluid is a 50:50 mix of 0.9% saline solution and an x-ray contrast agent. This enables the balloon position to be assessed radiologically once inflated. In acute situations this might be challenging (takes time to prepare), so straight saline is utilized at most centers with robust REBOA practices in ER settings. We look at the balloon markers, feel the resistance and follow invasive blood pressure, which should rise.

The inflation medium should be drawn into a 20cc or 30cc syringe and attached to the balloon port via a connector with a stop-cock. The stop-cock is important, as once balloon inflation is complete, the tap can be turned off to maintain inflation. If you are unfamiliar or have forgotten how to use a three-way stop-cock, just make a 45-degree rotation and it is completely blocked. Some of us use as routine a 2x20cc syringe attached to the stop-cock. In young patients, 10-15ml might do. It depends on your REBOA system and its dead space and capacity.

General Tip:

» Don't forget the stop-cock – otherwise, you will stand there with the REBOA syringe and not be able to do anything else as the balloon will collapse if you leave it.

Inflation should start slowly in a controlled fashion, ideally while watching an invasive arm BP trace under fluoroscopy. Inflation should stop once resistance is felt within the syringe; however, this can be subtle, so it is important to have been trained appropriately to detect the tactile difference. Fluoroscopy should demonstrate the balloon "mushrooming" into the shape of the vessel. Where fluoroscopy is unavailable, BP monitoring and various clinical examination findings can be used as adjuncts to confirm position.

If BP monitoring is being performed from the femoral artery, the biphasic waveform below the balloon should be lost following complete occlusion, and any blood pressure measured above the balloon should rise. When invasive monitoring is not in place, loss of a palpable femoral pulse is another useful clinical indicator. The loss of a left brachial pulse suggests placement is too proximal (i.e., the balloon has insufflated proximal to the left subclavian).

Figure 6: Holding pREBOA without a stop-cock in a pREBOA case. Note that one hand is on the catheter and sheath together, the other on the syringe, adjusting it to maintain SBP.

Figure 7: Holding a REBOA in place. With built-in stopcock and syringe attached. Some of us strongly believe that **you should always hold the catheter in your hands, at all times.**

For blind Zone-III occlusion, after insertion of at least 30 cm of a catheter into a sheath, inflate a balloon inside the aorta until resistance is felt, withdraw a few centimeters to allow the balloon to move up and down freely, and then pull out the balloon catheter slowly until it presses against the origin of the common iliac artery. You are in the right place now! Just advance the catheter a couple of centimeters back into the aorta, inflate completely, and secure.

Advanced Tip:

» US imaging can also be useful, although body habitus and bowel gas can obscure a good image. For Zone-1 placement, a subxiphoid window through the left lobe of the liver can demonstrate the aorta at the level of the diaphragm, and the operator can observe the wire and catheter traveling into the thoracic aorta. For Zone III, a transverse view just above the umbilicus will yield a view of the infra-renal aorta. You might see the balloon shadow.

» This technique is highly operator-dependent and should not be undertaken unless you are appropriately trained and experienced. Microbubbles or carbon dioxide gas can be used as an inflation medium to improve ultrasound imaging of the balloon, but this depends on the clinical scenario.

Once the balloon is inflated, especially in Zone I, it is imperative that you keep a close eye on the secured catheter as there is a risk of distal migration. Systolic blood pressure above the balloon might suddenly rocket by 50 mm Hg or more. This can push the balloon back, bit by bit, especially if a short sheath and/or a soft wire is used. If the balloon is not well secured, in a few seconds the balloon may abut the aortic bifurcation. It is not uncommon to see the shaft of the balloon bend and even dislocate upside-down in the aorta. We would recommend that you or a specifically assigned team member **hold the REBOA and sheath and control it at ALL TIMES**. After full insufflation of the balloon or during inflation, you can proceed to pREBOA (partial REBOA) as soon as possible, using the proximal systolic blood pressure (above the balloon) as a guide to dictate its effective use. A suggested target systolic blood pressure above the balloon is around 80-90mmHg (maybe a bit higher in cases of suspected brain injury, but this is unknown and based on “gut-feeling”).

General Tip:

» **Communicate** with your ICU partner, the anesthesiologist and all members of the treatment team during REBOA use – let everyone know when the balloon is inflated, coming down, going up, etc.

» Hold the REBOA and introducer in your left hand, and the stop-cock/syringe in your right hand to allow total control and modification.

Remember that during transportation eny line can be accidentally withdrawn. Fix the sheath and decide whether to keep holding the REBOA catheter, considering migration and displacement! To avoid this, you should use proper fixing on the REBOA – reliably securing all external parts of the “balloon set”; a silk suture is best for securing both the sheath and the catheter. However, remember to have a spare scalpel and replacement suture at hand in case urgent re-positioning is required. If you can, have one person (or you) holding the REBOA during transportation aimed at pREBOA. This will minimize ischemia time.

Balloon Deflation: This can be required for several reasons – to reposition the balloon, to test for bleeding foci inter-operatively, to permit transient reperfusion, or for final removal. The main rule here is **very slow deflation**. Don’t panic! Stay calm! The bleeding is controlled and the patient is alive – but fast deflation will inevitably result in circulatory collapse. Withdrawing 1-2cc from the balloon every 30 sec is a reasonable rate of deflation. However, be aware that due to the compliance in the balloon, the last few (2-4) ml will have the greatest effect on the balloon diameter. Do not rush at the end!

Figure 8.1

Figure 8.2

Figure 8.3

Figure 8.4

Figure 8.5

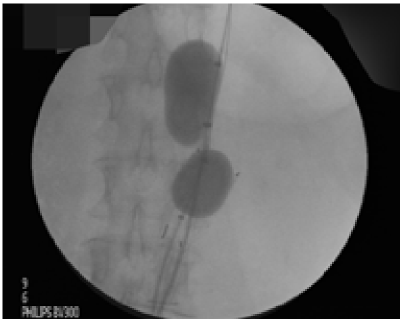


Figure 8.6

Figure 8 1-6: Some more REBOA images in trauma cases as seen on plane x-ray and CT. Double REBOA in a rAAA case.

Prior to any deflation maneuver, the anesthetic team must prepare the patient for reperfusion injury. This generally involves ensuring that the patient is suitably resuscitated with blood products, sufficient to maintain a "good" BP. On rare occasions, vasopressors will be required to maintain BP, but only after intravascular volume is restored and further bleeding has been excluded. Good communication between the surgical and anesthetic teams is crucial, especially as expeditious re-inflation may be required in the case of a precipitous cardiovascular collapse. The anesthetic team should also be prepared to treat electrolyte disturbances associated with reperfusion, such as hyperkaliemia. Remember that reperfusion injury will come in the first hours after REBOA. It will come, so **be prepared**!

Once the balloon is deflated and inflation is not needed anymore, the balloon should be taken out as soon as possible. Legs have had to be amputated in the past due to the presence of a balloon catheter long after it was needed. So, consider the situation now. Should we take out the REBOA? Should we leave the introducer? What should we do with it? We would recommend, if keeping the introducer in place, flushing it with 10-20ml saline solution per minute. Check distal status hourly!

Figure 9: Dissection in the aorta after using REBOA in trauma. Successful treatment in this case.

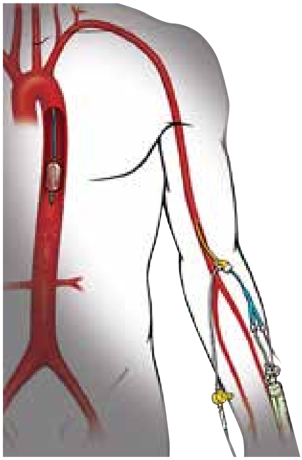


Figure 10: REBOA via brachial artery access. The majority of authors do not use this method as the preferred REBOA method but can be done (and has been done). Due to anatomy and risk of blind insertion, might be challenging in trauma cases but has been used. More information on this access route you can find in other places in this manual.

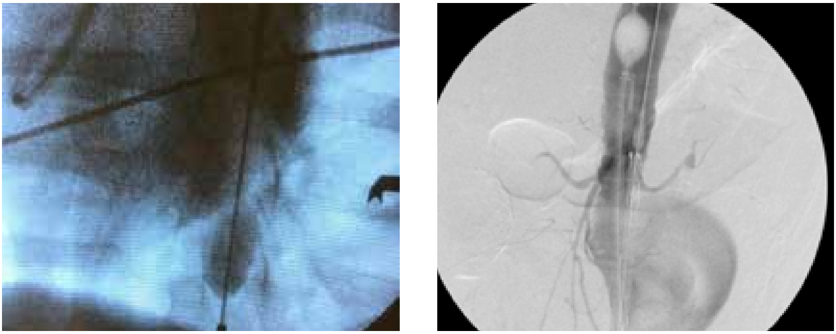


Figure 11 1-2: pREBOA (on animal CPR REBOA model)(left). pREBOA in rAAA patient (right).

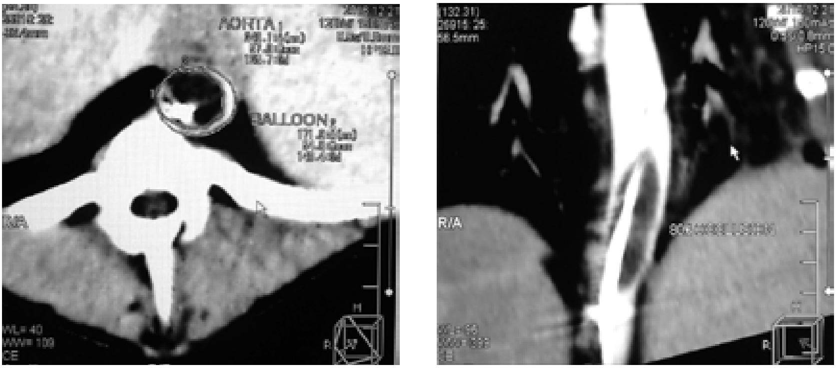


FIgure 11. 3-4: pREBOA (80%) on animal CT.

Figure 12 1-2: Extra-corporal measurement of REBOA in filed military REBOA training (left), and in a patient during CPR (right).

Figure 13: REBOA in place at the end of surgery (non-trauma). Deflated (dREBOA) at that time.

Advanced Tip:

» Total REBOA (tREBOA) is where the balloon is inflated with out the intention to deflate until hemorrhage control is achieved. There are other options susch as pREBOA or iREBOA, but these can induce cardiovascular instability, so need to be used with caution. Equally, these techniques can help reduce the ischemic insult, so be brave!

Intermittent Occlusion (iREBOA): This is where the balloon is deliberately deflated in order to provide a degree of reperfusion, and to help the surgeon or radiologist locate the focus of bleeding in a controlled manner. The emphasis is on "controlled", where ideally a hemostatic maneuver is ready to be delivered, and the operator needs the balloon down just to locate the bleeding. Another scenario is when the patient become stable and the REBOA is deflated, but inflated again when the patient becomes unstable during the operative procedure (we have experienced patients with some iREBOAs during surgery).

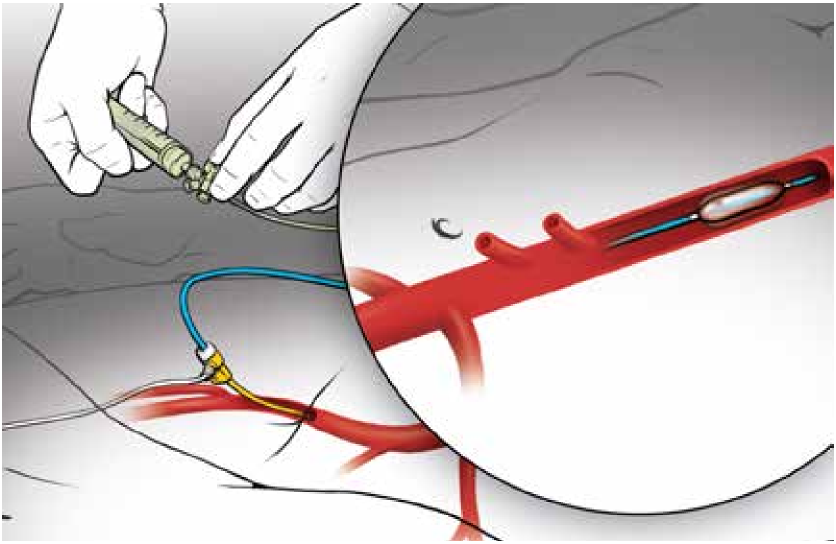


Figure 14: Illustration of tREBOA and pREBOA. You can find som animations on www.jevtm.com.

Partial Occlusion (pREBOA): This is where the balloon volume is titrated against the patient's blood pressure. In essence, the balloon is partially deflated to permit some blood to pass the balloon, permitting a degree of distal perfusion, accepting that some blood will be lost at the injury focus. You can do pREBOA gradually and see if the patient becomes more stable, thus avoiding total occlusion in some cases. The goal would be to elevate the systolic blood pressure to around 80-90mmHg until you solve the bleeding problem. If you have a contralateral 5Fr sheath in place, you can follow the appearance of blood pressure and then you know for sure that you have a pREBOA. Probably, this is the way REBOA should be done if possible.

Deflated REBOA or dREBOA is the use of an in situ catheter without inflation, as hemodynamic stability is achieved or has not deteriorated.

Remark:

» Remember that vascular access in patients with shock is not the same as elective angiography. Follow the patient's clinical status carefully after sheath removal.

» The vessel diameter of young patients in shock is small and your sheath will block the flow. Take this into consideration when you examine the patient after your successful REBOA....

Remark:

» Is the balloon still inflated? Totaly deflated? Remember that you are doing an endovascular procedure and might miss invisible details! You must have balloon control at all times!

Sheath Removal: A large-diameter sheath should be removed after the procedure as it can induce thrombosis and reduce perfusion to the extremities. In a large trauma center you can seek assistance from a vascular surgeon once you have inflated the balloon. The best option for removal of a large sheath (8Fr or greater) is open surgical exploration followed by lateral suture of the femoral artery, or round serosa suture if you are familiar with this. Manual compression is not appropriate in a coagulopathic patient but has been done. You have to know that it will not bleed in the ICU when the patient is warmed up and is covered…

For smaller sheath sizes (7Fr or less), several vascular closure devices are available (e.g., the Abbott Perclose Proglide). At the end of the procedure, the presence of a pedal pulse in the extremity should be confirmed by manual palpation and Doppler ultrasound. US examination might give you some data but you can't see the flow the whole way. **If you are not absolutely certain that distal perfusion is normal, perform angiography** or even thrombectomy directly. Some experienced providers advocate the routine use of extremity angiography after REBOA – particularly soon after your experience with this modality.

Contra-indications

Finally, a word about contra-indications. Be aware that a balloon can also make the situation dramatically worse. The use of REBOA in the setting of chest trauma can theoretically exacerbate bleeding in the chest, neck, upper extremities, and head. It only makes sense if you have a source of arterial bleeding ABOVE the REBOA balloon. Insufflation will increase the pressure and subsequently the speed of hemorrhage. For this reason, **known injuries to the heart, aortic arch, as well as to the arterial structures of the neck and lungs, are probably contra-indications for tREBOA.** Patients with these injuries might, however, tolerate pREBOA as a lifesaving maneuver in selected situations where other options are not immediately available.

Caution:

» Be aware that REBOA has the potenial to make some injuries worse...

The potential of REBOA dangerously to elevate intracranial pressure in patients with traumatic brain injury is also an important theoretical concern. However, the impact of REBOA use in this setting is largely unknown at present and remains a matter of active investigation.

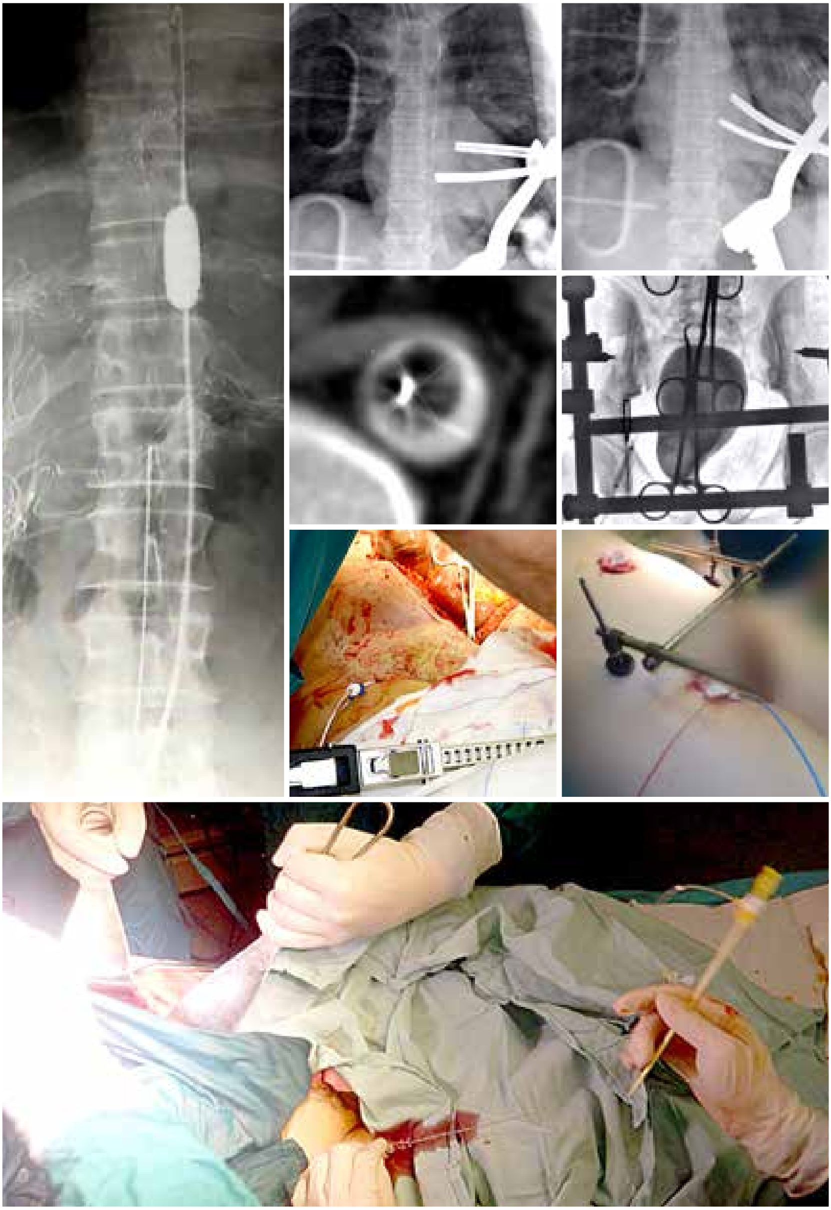
A specific catastrophe to be aware of is concerned with the setting of severe chest trauma with multiple-rib fractures (especially, 1st and 2nd ribs), scapula fractures, or a widened mediastinum. REBOA has the potential to convert a stable aortic pseudoaneurysm into an uncontained aortic rupture. For these reasons, bear in mind as a team leader that information is all important. Obtain as much knowledge of your patient's injuries as you can before committing to a major intervention, such as REBOA.

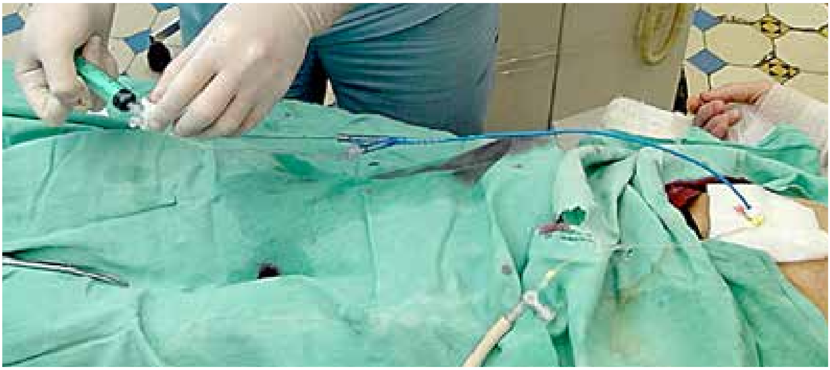
Do not forget the risk of complications, such as femoral and iliac artery dissections (and aorta dissection), thrombus formation (and ischemia), vessel perforation, and bleeding at the insertion site. So, this is a risky business. Be aware!

Remember, **REBOA is a "living entity" and NEVER a definitive solution**. Respect it and THINK BEFORE USING IT!

Good luck!

REBOA in trauma patients





Notes

Chapter 5

EVTM and REBOA in pre-hospital, transfer and military settings

Thoughts, possibilities and limitations

Tal Hörer, Viktor Reva, John Holcomb and Joe DuBose

The tendency with any new life saving technology is to explore the range in which it can or should be employed. Endovascular principles, and in particular REBOA, are no exception. If a significant portion of deaths after trauma are the result of significant hemorrhage at non-compressible sites (i.e. a place you can't put a tourniquet on or compress effectively to stop the bleeding) – then it makes sense that consideration should be given to moving technologies that can assist in control of these hemorrhage sources as close to the point of injury as feasible and appropriate. What is "appropriate" in this context? This remains a matter of active study. It is clear, however, that there is potential for REBOA to be utilized in pre-hospital settings for patients who would otherwise likely bleed to death before reaching an environment where surgical control of non-compressible hemorrhage (in most cases by an emergent thoracic or abdominal surgery) can be achieved. There are some key questions that need to be answered before we can say anything definitive about the optimal role of REBOA in the pre-hospital setting. What patients need REBOA before transfer to a surgical capability? How do we identify them? What impact does the estimated time of transfer have on the choice to use REBOA in these environments? Who should be doing the REBOA in this setting? What training do these providers need? While we don't have the answers to these questions as of yet – we can identify and discuss a few situations in which EVTM approaches, including REBOA, may prove useful as experience accumulates. So, let us speculate and discuss our thoughts.

Transfer REBOA

We discuss elsewhere in this text the potential for REBOA use in the Emergency Department to prolong the survival of the patient long enough to reach the operating room for definitive surgical control of bleeding. What if the patient presents initially to an emergency room or small medical facility that does not have an operating room readily available? What if, instead of rolling the patients gurney down the hall into a ready operating room, you need to put them in an ambulance and drive them down the road to get to such a facility? The reality of trauma care, even in countries with advanced civilian trauma systems, is that there is not an advanced trauma center with a surgeon on site at every corner. While a good system optimizes the chance that a severely injured patient is delivered from the scene of injury to a center with immediate surgical capability, in practice this is not always the case. Even with expedient transfer practices and mature trauma systems, patients die every year in every country while being transported rapidly from a smaller medical facility without immediate surgical care to a larger one with a ready operating room. Could a rural provider at a small medical center emergency department be trained to place a REBOA device? Yes. Could REBOA keep a patient how is likely to bleed to death quickly alive long enough to survive transfer to a facility capable of immediate surgical hemorrhage control? It is definitely possible for some patients. Could inappropriate REBOA inflation make the patient worse? Yes! There are a myriad of factors that come into consideration – including time of transport – but the feasibility of rural REBOA use is not difficult to conceive.

We outline very well in other areas in this text the specific technique of both REBOA and pREBOA. These would be the mainstays of approaches that could be utilized to facilitate transfer of severely ill patients with ongoing non-compressible hemorrhage. What needs to be better addressed to make this practice optimally feasible in an existing trauma system would be a cohesive arrangement of transfer policies and communication between transferring and receiving centers. Only if all providers are on the same page across a trauma system would this work effectively.

Some degree of common sense would also have to prevail. A patient with a zone I REBOA full occlusion of the aorta for an extended period of time is not likely to survive no matter what is done. While it is not yet known what the "magic time interval" beyond which total aortic occlusion is futile – is stands to reason that the transport time would need to be extremely short (30-45 minutes) in order to optimize outcomes. **pREBOA** might play an important role here, but again, we speculate.

There are a lot of issues to be addressed to make transfer REBOA a common reality of trauma system care – but it is an important discussion to start. There are other pre- surgical / pre-hospital scenarios where EVTM and REBOA might also prove applicability – and has even already been used with some limited success. Let's examine these scenarios next.

Pre-Hospital REBOA

EVTM, in particular REBOA, has long been discussed for use in select pre-hospital environments. The London air ambulance experience has demonstrated that a capable provider can be delivered to the scene of injury and place a REBOA effectively and rapidly in this setting. This experience has been instructive, but raises questions about optimal pre-hospital use that must be better examined. Optimally, REBOA in the pre-hospital setting would be reserved for patients who are deemed not likely to survive to reach the hospital without it. But how do we identify these patients most accurately? Ultrasound (FAST) identification of hemorrhage in the abdomen on the scene? Identification of unstable vital signs and an appropriate mechanism? How does one make sure there is no substantial bleeding in the chest? What training level should the provider making this determination and placing a REBOA ideally have? The London experience suggests that capable physicians can accomplish this goal, but can that experience be extrapolated to other environments of care?

The use of REBOA at the scene of injury also must be considered in the context that a severely injured patient with active non-compressible bleeding requires surgical intervention for definitive control. How long should time on scene be extended to facilitate REBOA for most patients? It is likely that the use of EVTM will evolve from an on-scene skill to an "in transit" skillset – with the appropriate provider establishing arterial access and / or REBOA in a helicopter or an ambulance during transfer. In this scenario, no time is lost in moving the patient towards surgical intervention – even as EVTM principles are being used during travel in an effort to promote his or her survival to make it to the operating room or endovascular suite.

Remark:

» Attempts at arterial access might take more time than you think – if attempting to obtain arterial access in the pre-hospital setting – avoid lingering on the scene to do so. If you are not successful don't delay getting to the hospital. **Never stop the evacuation for any heroic REBOA maneuver.** Explore and rehearse options for obtaining access en route.

Battlefield / Military applications

The considerations for battlefield use of EVTM and REBOA are in many ways similar to those of the civilian sector – with several unique considerations. In both settings the providers performing REBOA must be appropriately trained. They must consider if REBOA is likely to be beneficial – or if its use warrants a potential delay in transfer. Could REBOA make the patient worse?

The differences in the two settings, however, are dramatic. Military settings are often associated with the "tyranny of distance" – meaning that the transfer times to a surgery-able setting may be more prolonged. The time on scene may also be affected by other factors unique to the military setting – namely, do the local conditions even permit evacuation of the casualty immediately? If active fighting is still ongoing, the medical team may be called upon to issue prolonged field care until casualty evacuation can be safely undertaken. There is also data to suggest that the majority of potentially preventable deaths occurring after modern combat injury are the result of hemorrhage from non-compressible locations – a scenario perhaps ideally suited to REBOA utilization. These considerations – the preponderance of death due to non-compressible hemorrhage and the challenges of casualty evacuation – make REBOA a significant **potential tool** for military use. How might pre-hospital REBOA beused in the military setting work? Let's look at a potential scenario that serves to outline important considerations in this setting:

Here is the hypothetical situation. You are on a military mission as part of a front line medical support unit. Suddenly you are called forward to care for a wounded soldier who has sustained major blast injuries. When you get to the wounded soldier, he is still conscious. Obvious bleeding sites are controlled – including tourniquet placement on both severely injured lower extremities. Clinically you can determine that his blood pressure is likely getting low – as he has weak pulses, appears pale and clammy and is becoming confused and somnolent. A number of fragmentation wounds on his torso suggest that he probably has ongoing hemorrhage within his abdomen or perhaps chest – although his lung sound is clear bilaterally and you have already performed bilateral needle decompressions to exclude tension pneumothorax as a cause. He needs evacuation – but you are told that there are enemy identified in the area and that it is not safe to move the casualty at this time. You prepare to do the best you can – administer fluids and tolerate some degree of hypotensive resuscitation – but the patient continues to appear in an advanced level of shock.

Sounds like a situation in which REBOA might buy a little more time? Maybe the use of this technology could help you keep the patient alive long enough to get him out of the zone of active combat and to a location that can better deal with his non-compressible hemorrhage by surgical means. The principles of REBOA in this setting are similar to those of the in-hospital setting – but the situation is dramatically different. Sterility is compromised, as may be visibility – there may even be mortar rounds or gunshots landing nearby.

One of the challenges in this setting, similar to that of the civilian pre-hospital setting, is to define what you might need to do REBOA in this setting. Weight is an issue – as you most likely brought all the medical supplies you could in a pack on your back. You won't be able to fit a fluoroscopy machine in there!! An ultrasound? That technology is certainly getting more compact, lighter and more portable. Durable small ultrasound machines are already in use in military field hospitals and among elite medical units of the military of multiple countries. You may not have this capability either…in which case anatomic landmarks or a femoral cutdown will be required –these approaches are discussed in earlier chapters in this text – but require appropriate training to complete. The key here is that the use of REBOA is possible in this setting – given appropriate training, equipment and system-wide planning. One positive thing (and the only one) is that in young, well trained soldiers, your landmarks are easier to find compared to a 75 year old man with calcifications and round belly…

The reality is that REBOA is already a capability of select medical units of various militaries and that experience with this adjunct is emerging. It can be employed by an advance surgical team far forward of a true hospital envi-

Figure 1.1

Figure 1.2

Figure 1 1-2: Military training on REBOA. Sheath and balloon marked with arrows.

ronment, or even during military casualty evacuation by advanced capability air platforms such as the UK Medical Emergency Response Team (MERT) – whose medical providers have advanced clinical training and appropriate equipment for many en-route interventions. Modern large-body helicopters, such as CH-47 Chinook, have sufficiently large interior space what allows gaining good access to the patient and facilitate environments capable of these interventions.

The full spectrum of EVTM and REBOA utilization is perhaps most extreme when considered directly at the scene of injury or during initial casualty evacuation…but these technologies are also becoming a critical part of military combat support hospitals, also known as Role 2 or Role 3 environments of care. As the casualty moves further along the evacuation chain, increasing EVTM capabilities can be brought effectively to bear in combating the sequelae of injury. Recent experience by US military medical systems has demonstrated that fluoroscopy capabilities at Role 3 facilities can afford the endovascular treatment of a variety of traumatic pathologies – including the formal angiography, the use of angioembolization and even endograft coverage of injuries.

With advancing time and experience, technologies will become more facile and portable. These advances will likely bring EVTM capabilities further forward in the treatment of the critically injured – in both civilian and military settings. In the interim, other challenges will need to be overcome – including the optimal identification of patients likely to benefit from EVTM in these settings, protocols for cohesive EVTM use across civilian and military trauma centers and determining the appropriate training required for their employment. Through increasing experience and study – EVTM applications may transit from the realm of theory to that of routine practice in the coming years.

Warning

» We are strong believeres in REBOA, but as this is an evolving issue, one must stop and think- Can REBOA save life in these settings? When should it not be used. More clinical data is needed before we can recommend the usage of REBOA in the field.

Notes

Chapter 6

The hybrid OR and hybrid options for trauma and bleeding patients

Tal Hörer, Melenie Hoehn, Megan Brenner, Artai Pirouzram and Thomas Scalea

A hybrid operating suite might be the ideal location to treat hemorrhaging patients. It consists of much more than just a table amenable to fluoroscopy. It is a room modified to treat hemorrhage utilizing advanced technology, integrating both open surgical and advanced endovascular techniques. We will discuss some options and give some examples of the usage of hybrid suite and hybrid "set of mind", as part of the EVTM concept.

The hybrid angiography suite allows the team to perform multiple procedures simultaneously, such as laparotomy and an extremity angiogram, without change in location or time delay. Preferably, it is stocked with modern devices, with immediately available experienced 24/7 staff in close proximity to the receiving unit or even door-to-door to the trauma bay. Until recently, few places had this capability, but the advancement of endovascular techniques for vascular surgeons has led to a rapid increase in the availability of hybrid suites.

Remark:

» The availability of angiography/endo, the hybrid suite and other resources is highly dependent on your institution. What will work best **in your environment**? In some centers the vascular surgeons will be called in initially, in some the interventional radiologists, and in some others, the trauma (or general) surgeon is alone. Conditions are highly variable, so **tailor our comments and information to fit your center and your needs**.

A variety of imaging systems are utilized in hybrid rooms, each with different advantages and all with excellent imaging quality. The hybrid suite in Örebro Sweden is made by Philips and used extensively for hybrid surgical procedures, but, as for now, not for unstable trauma patients (location and logistics). Toshiba also has a similar system as do some other companies. The Artis Zeego (RA Cowley Shock Trauma, Baltimore) by Siemens combines high-resolution angiography with CT fluoroscopy. This advance in technology allows the acquisition of a CT scan while on the table. This "CT" is not as sensitive as the 64 slice or more helical CT but can give excellent-quality 3-dimensional views to supplement 2-dimensional angiography. The advantage for trauma patients is significant. It allows for additional imaging without the travel, delay and additional contrast usually associated with CT scans. Additionally, it can identify associated injuries, such as intracranial hemorrhage that might significantly alter the treatment algorithm. Just a simple thing like a C-arm for chest x-ray or fracture identification is very practical. Monitors, lights, anesthesia, surgical and endovascular supplies are obviously essential for a functional hybrid suite. Additional instruments, such as a duplex ultrasound, intra-vascular ultrasound (IVUS) and a transesophageal echo (TEE), should be available as well. The ability to utilize cardiopulmonary bypass, ECMO, and CVVHD in difficult situations is ideal. The full potential of these suites is still unclear as there are not so many up and running and the long-time experience with them is somewhat limited.

The technology for a hybrid OR is costly, approximately $3-9 million total for the room, and 1.5-5 million for just the fluoroscopic equipment (US calculations, 2016).

Another major challenge is the design of the hybrid suite. Serious consideration should be given to the location of the angiography arms, and how they relate to the monitors and the anesthesia equipment, to maximize flexibility. A major factor impacting utilization is location. Optimally, this is in the OR, near the trauma bay and/or the emergency room.

Difficulties may arise surrounding utilization of the room. Should it be on stand-by for acute cases or be used for elective surgery? Who should work there during off hours? Should a specialized scrub/radiology team be utilized? Lots of operational issues around hybrid suites function depend on local routines. To the best of our knowledge, there are now only a few centers with the capacity but it is expanding.

Tips:

» When planning the room, make sure it is **designed for acute situations**: from the position and size of the doors, ventilators, arms, ultrasound and monitors to storage for surgical and endo equipment. All personnel must know where the equipment is, including blood products, cell saver, etc. This is crucial for good function in stressful trauma situations. Decide who should work in the room and how to work there at night time and weekends. These questions will come up and you need to be prepared for them.

Appropriate staffing of the rooms is essential. The equipment and techniques are new to traditional surgical scrubs and nurses, and training is mandatory. The OR staff need to be comfortable with the acquisition, preparation, and billing of endovascular devices. A competent radiation technologist is essential to help provide images critical to decision-making and treatment (this function is less common in Europe). Radiation safety should also be practiced with vigilance. Essential staff needs to be present at all times, and depending on the acuity of the situation, the interventionist must be readily available. Waiting one to two hours to mobilize a team from home is obviously not ideal for a patient in extremis.

In addition, it is vital that the person leading the hemostasis team is familiar with trauma/surgery and has extensive experience in the management of injured patients. In most institutions, catheter techniques are performed by interventional radiologists who are usually not in-house at night; however, this varies significantly depending on the institution. These individuals are usually skilled with catheters, wires, coils and stents. They, however, often have little understanding (no offence, guys) of the dynamic nature of a multi-trauma patient, particularly one who is actively bleeding. Endovascular surgeons are performing these procedures with increasing frequency, although their experience with the management of these situations varies significantly. It is essential that trauma surgeons have an understanding of embolization techniques to help guide the procedurals who lack the experience to make decisions. They are performing (at least in the USA) an increasing number of endovascular procedures themselves, with on-table angiography and REBOA both well within their scope of practice. Exactly what procedures trauma surgeons are capable of safely performing without advanced training remains unknown.

CTA is a useful tool for the critically injured patient. REBOA can help stabilize the patient, but even in experienced hands or in a hybrid suite, **localization of bleeding with selective angiography is very time consuming.** A CTA head-thorax-abdomen-pelvis offers huge assistance and is has a key role in EVTM. With the correct protocol (head first, as the contrast is injecting, continuing down through the pelvis as well as a 100 sec delay for the venous phase), the scan only takes about 3 mins (there are many different protocols). A "super acute CT" scan on the way to the hybrid room or OR may give valuable information and should be considered. The CT can be reviewed while colleagues continue treatment, and may be viewed "online" by senior colleagues. This may free the treating surgeon to direct all attention to the patient. The new generations of CTs are very fast, and can be placed nearby, in the ER or hybrid suite. "CT on rails" is a new technology that is spreading fast, and some of the equipment has the quality of a standard modern CT. If CT is used correctly, fear of the "tunnel of death" might be a part of the past. Train with the staff, make sure that the protocol works, and do a risk-benefit calculation for obtaining further imaging. The main problem with CT is transfer of the patient to and from the CT, and is a critical point in the chain of care for these patients.

Back to the hybrid suite issues. For treatment of an unstable multi-trauma patient, the hybrid room must be prepared for both open and endovascular procedures. As mentioned before, this might be the ideal location for

Figure 1 1-5: Transfer of trauma patient into the CT. Note a REBOA and sheath during transfer.

critical patients with multiple injuries, and also for hemodynamically unstable patients. The hybrid angiography suite will allow the team to perform multiple procedures almost simultaneously, for example, a laparotomy and an extremity angiogram without change in location or time delay. This is being recognized now in trauma and bleeding patients, as the concept of hybrid procedures can be applied in a standard surgical environment. A C-arm and a sliding angiography table is a reasonable alternative, and all trauma patients should, in our view, be placed on an angiography compatible table. Basic endovascular stock can be stored in the room or on a trolley and taken to multiple locations as necessary (your friends in surgery have an iatrogenic bleeding and need REBOA?). An ultrasound/FAST should be readily available. In addition to angiography, the imaging equipment can be used for many functions, including cystography and head CT, or just to get plain films for pneumothorax or fractures. So, lots of options, but you need to know how to use them.

Here is a list of procedures that, in our view, can be performed in the hybrid OR:

- General anesthesia
- TEE
- Resuscitation; Lines
- REBOA, Arterial and venous balloon occlusions
- Pelvic packing
- Cardiopulmonary bypass, Continuous renal replacement therapy, ECMO
- Exploratory laparotomy, Thoracotomy, Thoracostomy
- Rib fixation
- Stent grafts of major vessels
- Esophagogastroduodenoscopy/PEG/Tracheostomy
- Orthopedic stabilization, External fixation/Extremity fixation
- Amputation
- Extremity revascularization/Shunts/Vascular repairs, Angiography
- Angioembolization
- Cystogram
- CT head

And probably some more...

Figure 2 1-2: Shock & Trauma Baltimore hybrid suite

Figure 3 1-3: REBOA in different patients as part of hybrid procedures.

Figure 4.1: Intra-cranial hemorrhage imaging by hybrid suite C-arm. This might be highly relevant for the decision making process in this patient.

Figure 4.2: Patient in hybrid suite ready for TEVAR. Notice left arm scrubbed for potential brachial or axillary access.

How to think hybrid

As previously mentioned, hybrid surgery has been practiced in vascular surgery for the last 20 years with excellent outcomes. The idea is simple: You can combine endovascular tools with open surgery to control life-threatening hemorrhage. While simple in theory, the techniques are more advanced. Surgeons must make an effort to obtain wire and catheter skills in order to fully utilize advancing technology. Collaboration with colleagues is essential and is an essential part of the EVTM concept. A lot can be learned from other specialties and the techniques can be useful in difficult clinical scenarios. Remember that even if all these options are available, **you must decide what are the priorities** – What injury to be treated and when? What resources to use and how? This is highly dependent on your experience but the first rule in hybrid thinking is still the first rule of trauma: **When it is bleeding, stop the bleeding!** How to do it with endo or hybrid tools depends on many factors that we discuss later on.

Obviously, you can use a standard surgical suite and convert it into a semi-hybrid suite as seen in these photos.

Figure 5: A surgical suite converted easily into a hybrid suite (Semi-hybrid suite). C-arm on the left side, patient on a sliding (angiography) table. In this case, major liver and brain penetrating trauma in a hemodynamic unstable patient. Simultaneous laparotomy packing and craniotomy.

Tips and some words of caution:

- All these fancy things...**But what do I have in my hospital?** That's the only important thing! Calculate the risk and benefit. Is it reasonable to do CT? If you don't have the time, take the patient to the hybrid OR.
- Transfer time is the real time of CT, not just the scan itself.
- Hybrid or endo solutions are frequently useful but **should not replace good surgical solutions**. Sometimes, minimally invasive methods unnecessarily complicate things and a good surgical exposure might be the easiest and simplest solution. It's a delicate balance.

Figure 6: Surgical suite in hybrid configuration (semi-hybrid). The size of the room is a limiting factor in trauma and bleeding surgery.

» **Tip:** Place bleeders (trauma or not trauma) on a sliding angiography table.

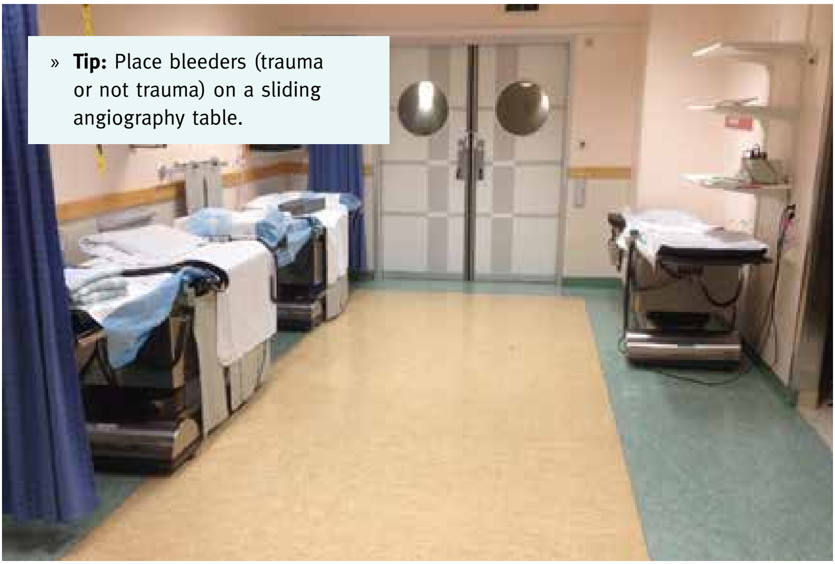


Figure 7: Sliding tables in the entrance to the surgical division in Örebro, Sweden (three tables available 24/7). All bleeders as well as all trauma cases are placed on these tables.

Figure 8.1

Figure 8.2

Figure 8 1-2: After pREBOA, Laparotomy, Exfix, Preperitoneal packing. Intracranial pressure monitoring (ICP), Extremity fixation and fasciotomy in the same semi-hybrid suite.

So, with a hybrid and endo state of mind, whenever possible, common femoral arterial access should be established already in the resuscitation area. It is one of the principles of EVTM. Blind puncture, ultrasound guided puncture and cut-down are all acceptable approaches. The access can be easily upsized for a larger sheath for REBOA or angiography if needed. There are many situations where a hybrid approach has its advantages. A deflated balloon (dREBOA) can be placed prior to abdominal exploration in certain situations, to be inflated if necessary. This may be useful in patients with previous abdominal surgery, when adhesions make timely exploration difficult. Again, the majority of experienced surgeons will easily get to the bleeding kidney in minutes, but is it so easy with dense adhesions or morbid obese/fetma patients? The risk of having a deflated catheter in the aorta for a limited, short time is RELATIVELY low. The same concept might be applied to the arch vessels as well (we are not talking about REBOA now). For upper chest injuries, you can get a brachial or axillary arterial access. A PTA balloon can be used in a major vessel for proximal control while your colleagues approach surgically. Again, the risk of wire placement is relatively low, and a procedure can then be carried out quickly. In some centers, a wire will be placed in the target organ vessel whenever possible and the decision whether to use it will be taken later on. This can also be done simultaneously in some cases, especially if you are working in a hybrid suite.

Endovascular treatment of hemorrhage can be performed as a temporary bridge or definitive therapy. For vessels that are difficult to access, such as the subclavian, a stent-graft is a great option particularly in a large patient who is unstable. Occlusion balloons can be used for proximal control of great vessels prior to exploration (subclavian, innominate, carotid but also iliac, femoral and

Figure 9: Hybrid Procedure (Iliac retroperitoneal approach and Axillary approach) in an elective endovascular procedure. Done here in a surgical suite with a mobile C-arm.

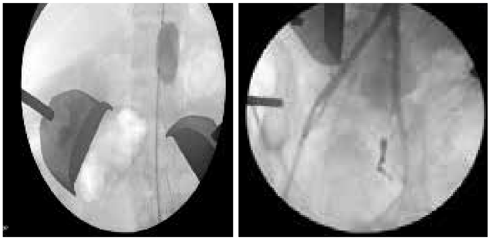


Figure 10 1-2: Embolization as part of the hybrid concept. REBOA during CPR, preperitoneal packing and ex-fix with angioembolization. Done with a mobile C-arm in a semi-hybrid surgical suite.

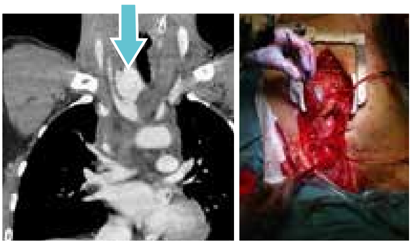


Figure 11 1-2: Innominate artery exposure and patch repair with PTA 14mm balloon in place for bleeding control via right axillary approach in blunt trauma (not seen in this photo).

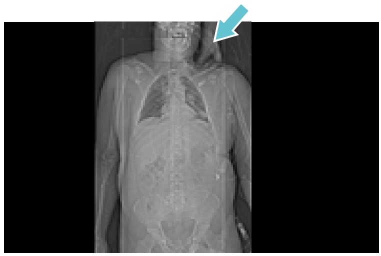


Figure 12: CTA with hybrid set of mind. Manual compression of zone I neck bleeding during CTA to exclude thoracic vessel or parenchyma injuries. Open repair followed. This photo demonstrates that sometimes you can do CTA and get more critical information if your CTA is next door. At time it can be a very unwise (or even stupid) idea! Use these resources wisely.

Figure 13: Hybrid procedure for massive iatrogenic CFA bleeding. Notice 8Fr sheath on the patients left side, used for contralateral iliac balloon occlusion (ABO).

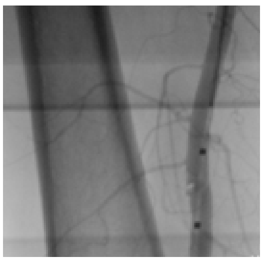


Figure 14: SFA injury and proximal balloon control as part of hybrid procedure.

Figure 15: Clinical photo of the patient.

obviously, REBOA). Care should be taken when instrumenting around the arch in patients who cannot be heparinized. Stent-grafts in the extremities (e.g., SFA) can also be used to control hemorrhage in patients with challenging anatomy. These can be removed if definitive interposition grafting is felt to be the best long-term option, and performed once the patient has stabilized and orthopedic injuries have been addressed.

We might suggest the following in the ENDO trolley (see also the other “What to use” text in the manual). This is only an example of the content.

Endo Trolley

- » Puncture sets (multiple) – 18G needles and Micro-puncture sets
- » 5-7Fr Sheaths, 11-24Fr Sheaths (depends on your needs, e.g., TEVAR?)
- » Soft wires (e.g., Terumo). Short and long.
- » Stiff wires (e.g., Lundeqvist, Amplatz, Back-up Meier)
- » Contrast medium, 10-20ml Syringe, Sterile saline
- » Aortic balloon/REBOA
- » 8-14mm PTA balloons (e.g., ‚Cordis PTA balloon)
- » Birenstein catheter, Bolia catheter
- » Some other catheters (depends on your skills and your needs)

In this chapter, we tried to cover some issues regarding hybrid set of mind and some issues will be presented in other chapters. We want again to remind you that these are our thoughts and based on the experience of the authors but there is no right or wrong here. We believe that there are many options with a hybrid state of mind – from access to surgical maneuvers that can be performed in a hybrid suite or semi-hybrid room.

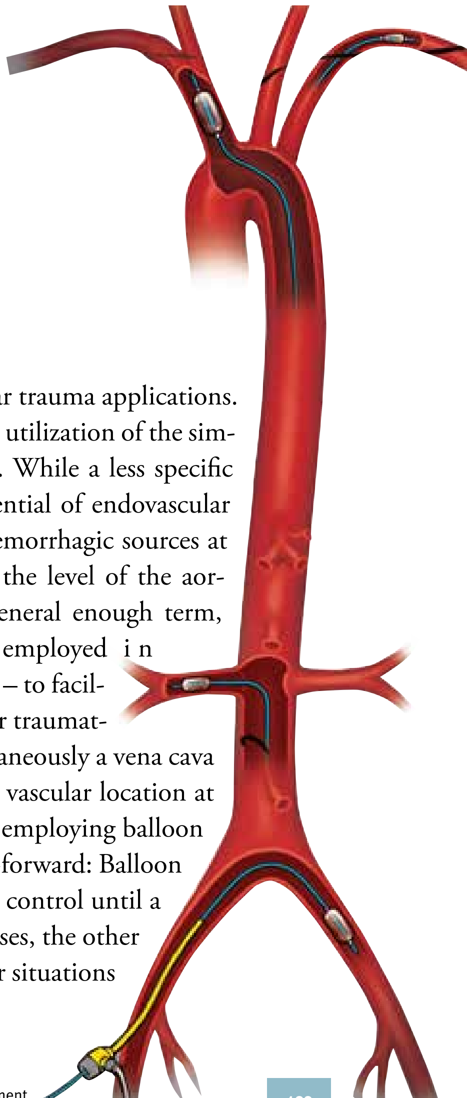
Let us repeat a word of caution: While hybrid and endovascular solutions sometimes have advantages, it is important not to delay hemostasis. An open surgical approach is frequently a reasonable and preferred approach, and the risks and benefits of each technique should be considered.
So, **think before using it!**

Notes

Chapter 7

Balloon occlusion and EVTM at Non-Aortic locations

Tal Hörer, Viktor Reva, Artai Pirouzram and Joe DuBose



REBOA has become a hot term in endovascular trauma applications. Some leading experts, however, have advocated utilization of the simple term "Arterial Balloon Occlusion" (ABO). While a less specific acronym, ABO appropriately reflects the potential of endovascular balloon occlusion to be utilized to control haemorrhagic sources at a variety of anatomic locations – not just at the level of the aorta. To be fair, even ABO is perhaps not a general enough term, since balloon occlusion can also be effectively employed in larger venous structures – such as the vena cava – to facilitate control of bleeding. We are aware of a liver traumatic-bleeding case treated by REBOA and simultaneously a vena cava balloon occlusion (surviver). Regardless of the vascular location at which they are employed, the basic benefits of employing balloon occlusion using endovascular means is straight-forward: Balloon occlusion affords proximal (and/or distal) flow control until a definitive solution can be provided. In some cases, the other end of the "bridge" will be open repair, in other situations

Figure 1: Neck penetrating injury Zone I

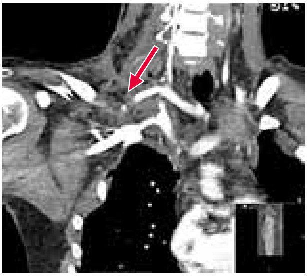


Figure 2.1

Figure 2.2

Figure 2 1-2: CTA imaging with reconstruction demonstrating a right subclavian injury resulting in occlusion. Open or/and endo methods can be used to solve the problem. If extravasation, balloon proximal occlusion might help.

it might prove to be endovascular stentgraft deployment. In selected cases, it might allow more limited tissue exploration, and exposure as well.

Remarks:

- Balloon occlusion, in any vessel, is only a **temporary solution**. Once occlusive control is achieved (and all other haemorrhagic sources are addressed) – take a deep breath – let anaesthesia catch up with resuscitation as needed, and develop a sound plan for definitive treatment of the injury.
- Always think of possible organ ischemia when using ABO.

Here is a case to illustrate the potential utility of balloon occlusion at non-aortic locations: A young man arrives at the emergency room with a penetrating wound in the right side of the lower neck just above the clavicle (Zone I neck injury). He is conscious and alert. A medic has been holding a hand over the wound, but when the hand is removed, no ongoing bleeding from the wound is noted. The situation could certainly be worse – right? You may well have treated patients with torrential bleeding from wounds at this location before – definitely a more challenging situation. This stability of this particular patient, thankfully allows us to proceed deliberately in our evaluation. What was the mechanism (knife, gunshot)? Are there other wounds or injuries? Given that he is stable, some imaging is probably appropriate – but what kind?

Advanced Trauma Life Support (ATLS)

principles are paramount here. ABCs are effective principles for a reason – they work. Address airway, breathing and hemorrhage control just as you should for any trauma patient. As you get through your primary and secondary survey with no other findings – make sure you incorporate a focused ultrasound sonography for trauma (FAST) and plain radiography (in this particular case, a chest X-ray). All indications in these evaluation in this particular patient were negative, except for a possibly diminished radial pulse on the right. Obviously, you must communicate with your aneasthiologist during this process while considering when to intubate the patient and how to proceed.

What now? A computed tomographic angiographic (CTA) exam, or a CT with protocolized angiographic contrast, is a very appropriate choice here. A CTA answers a lot of questions with high fidelity and will exclude also pneumothorax/hemothorax. The CT should be done with IV contrast, at **both the artery and late (vein) phases,** to improve detection of injuries to both arterial and venous structures. See the figures here that illustratedifferent injuries patterns. CTA imaging here allows you not only to identify the injury and exclude active hemorrhage (no extravasation), but also to afford measurement of the proximal artery for determination of optimal balloon and/or stent graft sizing. Don't forget to include both the entire neck and the chest in the scanned field, particularly for gunshot wounds. Just because the wound is located in

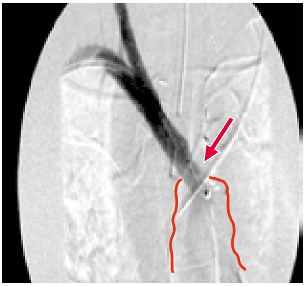


Figure 3: BCT (Brachio-cephalic-trunck) injury with extravasation. PTA balloon in place before open exploration. Balloon control can be accomplished via either femoral artery access or brachial/axillary artery access. The aortic arch is marked.

Figure 4.1

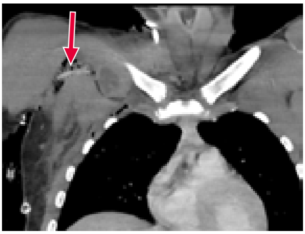


Figure 4.2

Figure 4 1-2: Multitrauma CT with occlusion of the right subclavian artery. This imaging demonstrated occlusion and no active extravasation. Open arterial reconstruction was performed. Endovascular recanalization can also be performed in selected pateints. There was no need for balloon occlusion in this case.

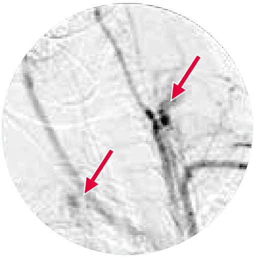


Figure 5: Knife left carotid injury Zone II injury patient's right side. Note extravasation from the BCT (right) as the knife penetrated the neck down towards the chest. Balloon occlusion and open exploration might be useful here!

Zone 1 of the neck, does not exclude injury to an important structure higher or lower than this internally.

It is key here to remember that sending the patient to the CT scanner requires appropriate caution. Always consider what you will do if the patient suddenly decompensates. It may be a better course of action in such instances to abort the scan and proceed to the OR. This depends also on whether you have a CT in the ER (even in the trauma bay/CT on rails) or it is somewhere else in the darkness of the radiology department. If you plan for the worst mentally, and develop what your response to a decompensation will be, you will be prepared. Verbally communicate this plan to the entire team – so that they are on the same page and are alert to the concerns that you have. As mentioned, there are now some new "CT on rails" that can be used in the trauma bay, which might make it easier to do the scan.

Word of advice:

» Plan the CT examination: Do you have all you need? Is it safe to proceed with CT?

» Always have a "plan B".

Back to the basics and the EVTM concept; if you are concerned the patient may decompensate or may potentially benefit from the use of endovascular trauma adjuncts (balloons, angiography, stent grafts, etc.), consider rapid placement of a femoral arterial line prior to movement to the scanner or OR. Arterial access is far easier to accomplish in a patient who is stable, and can prove exceptionally challenging after they decompensate. Even small caliber access (a standard femoral arterial monitoring line, around 4Fr) is easier to upsize rapidly than to establish de novo access when a patient decompensates. Follow the principles outlined in the access chapter of this text.

So, for the particular patient discussed above, let us say that a BCT injury is identified on CTA. The patient is still quite stable – normal blood pressure, normal heart rate, no breathing difficulties, alert and oriented. What to do now?

This injury clearly requires repair – and does remain potentially life threatening. It will need some form of definitive surgical repair, either endovascular or open. At this stage, it would be wise to activate the proper resources. Notify the operating room staff – and let them know that endovascular capabilities (C-arm, hybrid suite) should be included in their preparation for urgent operation. Prepare a radiolucent table (angiography or sliding table if possible). Would additional technical expertise prove useful? Now is the time to muster the providers with the right skillsets to be of use at your specific facility (interventional radiologist, vascular surgeon, cardiovascular surgeon). This is highely dependent on where you are and your assets. Get every aspect of care moving expeditiously but smoothly towards getting the patient to definitive care.

What are the repair options for this BCT injury patient? From an open perspective, a midline extended sternotomy would probably be the gold standard exposure for repair, but opening the chest near a vessel with active extravasation (near the aortic arch) is likely to invite torrential bleeding. It might be manageable with your great surgical hands and experienced aneasthesiologits, but you will probably need massive transfusions and more. Endovascular stent graft coverage may be an option, but that would require traversing the region with a wire, which may disrupt any semblance of clot formation near the vessel or even worsen the arterial injury itself while trying to cross the injury. Regardless of open or endovascular repair selection, proximal control before getting too far would be ideal in lowering the risk of significant bleeding or death. It sounds like a balloon occlusion option would, indeed, be useful to accomplish this objective.

Remark:

- As you noticed, we used the word “option” – **it’s a tool to consider**. Think before making any decision and do not hesitate to use the best tools you have.
- Balloons are only a bridge to definitive treatment.

In the particular BCT injury case demonstrated here, common femoral artery access provides passage of a wire into the aortic arch. The wire can then be carefully directed across the area of injury – using a variety of different guide catheters or long sheaths as needed (in this particular case, time of vascular access to wire in place took around 1 minute). Once you have a wire across the injury, it is a simple matter of selecting the correct balloon shaft length and balloon diameter to cover the arterial injury (remember the CTA we got – you already know the balloon size needed if you took some seconds to measure arterial diameter just proximal to the arterial injury. If you do not have prior imaging to delineate the size of the vessel, you must rely on known estimated diameters of the vessel being occluded. "Phone a friend" if need be – many experience endovascular providers commonly have a reasonable starting range for each particular vessel in their head from past experience. Remember that this access route is used for carotid stent grafts in elective surgery.

In the case of the brachiocephalic artery, the normal diameter is around 8-12mm in men, and somewhat samller in woman (age dependent!). That gives you diameter, what about length of the balloon? Use shorter as a start – remember initially you may only need proximal occlusion, not a balloon that extends the whole length of the injury. A longer balloon (40-60mm)may be nice to have, but is harder to fit in the space needed – which may not be clear on the basis of pre-operative imaging (if you even have it).

What about the type of balloon to utilize? Compliant or non-compliant? Which manufacturer? Does it need a special coating? In the context of trauma and emergent hemorrhage control, keep it simple. Use a percutaneous transluminal angioplasty (PTA) balloon of the most common variety on your shelf that fits the dimensions you need. You might be able to use any other elastic balloon, but there is limited experience with that. No need for anything fancy – just something that works. Don't get bogged down in the vast number of options available.

Word of caution:

- Aggressive oversizing or over-inflation of the balloon might cause further injuries to the vessel. **Inflation and deflation should be done slowly**, and using tactile sensation. Try to "feel" the arterial wall resistance as the balloon inflates to touch the arterial walls – stop at the very first sensation of any resistance. You don't need to get more than 4-6mmHg to get most of the balloons inflated to fill the artery luman.
- Consider using manual hand-syringe inflation and not using an inflation device (Manometer) if you are not experienced with that. Manual inflation will allow you to "feel" the resistance of the artery. Use always Stop-Cock/Luer-Lock.

Back to our BCT injury patient, introduction of a balloon into the brachiocephalic origin afforded safe control of a major arterial injury and facilitated open repair. You are likely to have encountered a patient where such an approach may also have been useful. If not, the fact that you are reading this text suggests that it might cross your mind in the future. It is not hard to consider that the basic principles of balloon occlusion can be afforded at a wide variety of locations in the vasculature – it is a key tool to have in the potential "trauma tool kit" of any capable provider. Remember – while the balloon does buy you time and provides an opportunity to take a breath and allow resuscitation to "catch up" as needed – don't spend toomuch time patting yourself on the back. You should be moving expeditiously to plan the next step. What other injuries might need to be addressed before repair of the injured vessel? Are there other bleeding sources that need to be stopped? What type of repair are you going to select? Open or endovascular? Other chapters in this text will help you with some of the thought processes that might define the applicability of endovascular definitive repair options – but for the purpose of moving forward after balloon occlusion of any vessel – you need to do so purposefully.

Also important to consider here is that any occlusion results in downstream ischemia. At some locations, where collateral flow is redundant and robust, this may not be a big issue. At others, for example the carotid arteries or a variety of visceral end arteries (renal, hepatic, mesenteric), **once occlusion is initiated a desperate race against the clock to restore perfusion has been started**. Get flow back to anatomical norms as quickly as possible if that is the ultimate plan. Often forgotten in this context are the effects of a long balloon on side branches. For instance, in the brachiocephalic artery coverage patient described in our example, the balloon covering the BCT injury may also cover the right carotid artery (or at least impede flow in this vessel). This will probably be tolerated well by the majority of patients with otherwise normal cerebrovascular collaterals and may be a "necessary evil" in an emergent setting, but should be considered when moving quickly to restore normal flow patterns and avoid potential ischemic stroke.

The described example is of a brachiocephalic artery injury, but can the same principles be employed for injuries at other locations? Absolutely!!! The figures below demonstrate effective utilization of balloon occlusion principles

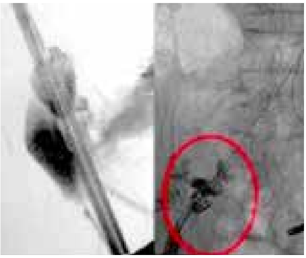


Figure 6: Iliac bleeding with contrast extravasation in two cases.

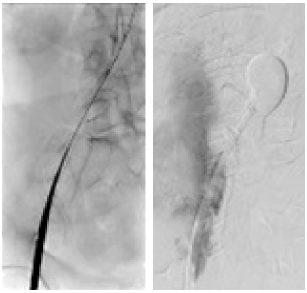


Figure 7: Sheath and wire in place to facilitate artery treatment. REBOA has been used in Aortic Zone 3 (the aortic bifurcation) to facilitate control of hemorrhage. Note the large contrast blush on angiography consistent with a significant bleeding source. Non-trauma case.

following an iliac artery injury. Here there is vast experience from endovascular surgery but more limited experience in trauma.

Similar principles can be utilized to approach injuries to peripheral arteries, visceral arteries, or even significant solid organ injury. These may be of particular utility at locations that represent significant challenges for open exposure or open control. If you can cross an arterial injury or place a wire in a proximal feeder artery, then you can place an occlusive balloon to facilitate control. You must understand though, that catheter or wire access to visceral organs might **take some time** and this has to be taken into account when planning the overall management.

It is important to note (again) here that endovascular tools are just that – tools.

Don't forget and use you surgical approach as needed and don't rely on "just endo methdos".

As with any tool, you have to use the device that makes sense. Why take the time to walk next door to ask your neighbour if you can borrow their power tools when you have a good old fashioned screwdriver that will do the same job with two turns of a hand and is sitting within arms reach? In the same way, be smart about endovascular utilization. Sometimes open surgery is both more expedient and smarter. Endovascular approaches can take more time and resources to utilize. Conversely, however, endovascular tools often give an elegant solution in situations when time permits and open alternatives are more challenging. One example would be patients with previous multiple laparotomies, and just doing open hemmoragic control is usually very time-consuming as well as very demanding. You get the point. You can see some elegant solutions in the figures below. So, proximal balloon occlusion is generally a very useful tool to have at your disposal for the management of vascular injury. It is not the perfect tool for every instance, but can certainly make a tremendous difference in specific patients. We will further discuss more possibilities in other chapters in this manual.

Figure 8.1

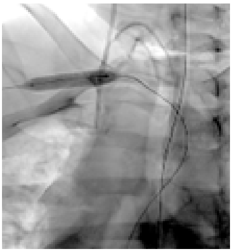


Figure 8.3

Figure 8.2

Figure 8 1-3: PTA balloon utilization and stentgraft repair of the left subclavian in an extreme obese patient (non trauma). Note the wire position and sizing of the balloon. Balloon occlusion in this instance can be utilized as a temporary bridge to definitive treatment. Completion angio (right side) with stentgraft in place.

Figure 9.1

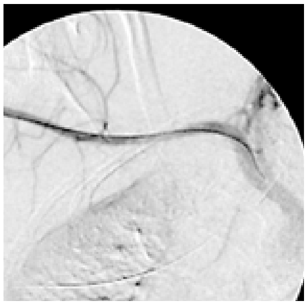


Figure 9.2

Figure 9 1-2: Angiography with extravasation from an injury of the left subclavian artery. Stentgraft in place and completion angio on the right. Balloon occlusion may be useful for proximal control, but careful deployment is required. Over-inflation can make arterial injuries worse.

Here you can see some illustrations of access to the axillar and brachial arteries for angiography and/or balloon occlusion.

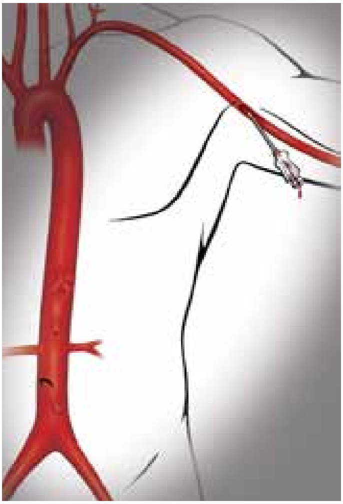


Figure 10.1

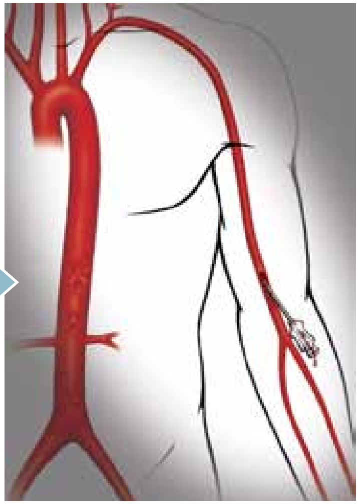


Figure 10.2

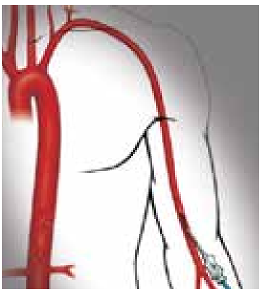


Figure 10.3

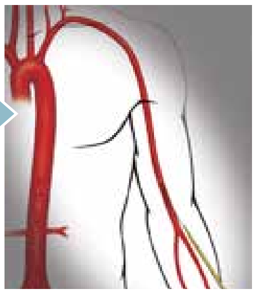


Figure 10.4

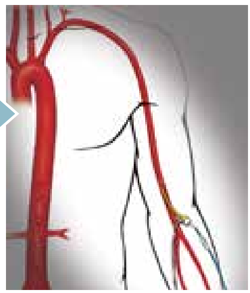


Figure 10.5

Figure 10 1-5: Access to the artery, guide wire and sheath insertion. If you know your wire corssed the lesion (and sure about it using angiography and contrast), you might be able to use a balloon or stent-graft. See also other relevant chapters.

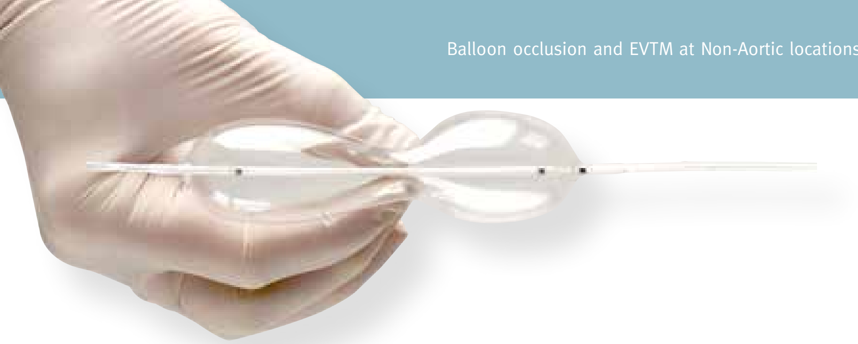


Figure 11.2

Figure 11.1

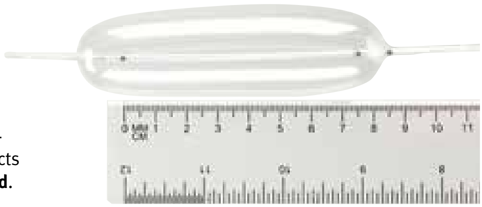


Figure 11 1-2: An example of a balloon that might be usufule for bleeding control, especially the inferior vena cava. As in all products we mention or show, **IFU should be followed**. (Courtesy of Spectranetics).

As a way of reviewing and closing out this issue – some **key points** of emphasis for the use of balloon occlusion at non-aortic sites that you should always remember:

Open exploration and repair often remains the gold standard for a reason. If the patient is crashing, there may not be time to muster resources for an endovascular procedure or balloon occlusion.

You can't use endovascular techniques without having vascular access – consider establishing early arterial access for patients you think potentially need it.

Use your imaging if the patient's condition allows it. CTA can help identify the injury and determine if endovascular capabilities – including balloon occlusion or definitive repair – are useful adjuncts to employ.

When using a balloon – avoid oversizing or over-inflation. You can make a bad situation worse if you ignore resistance.

If heparin use is safe in the situation, use it. You will not regret it when employing endovascular techniques. Especially when dealing with BCT, carotid and visceral arteries.

Notes

Chapter 8

Stent Grafts for major cervical and truncal vessels: Who, Where and How?

Joe DuBose, Elias Brountzos, Timothy Williams, Tal Hörer and Thomas Larzon

Endovascular technologies continue to advance, with increasing utilization not only in the treatment of atherosclerotic and aneurysmal disease – but also for trauma. Recent literature suggests that these capabilities, including stent graft utilization, have become an integral part of modern care for patients with vascular injury. We think it is possible to take it further on to the integrated EVTM concept which means that endovascular tools can facilitate open surgery or replace it. In this chapter, we will discuss the basic principles of stent graft utilization for the aorta and its major branches, the brachio-cephalic trunk, carotids, subclavian, visceral and iliac arteries. Some of the information here might be discussed in other chapters and other authors but we think that this might give you some wider view of these developments. We will in not discuss specific devices detail, as local traditions are important for product selection and as from the aspect that product development in this area is so fast. The intent of this chapter, rather, is to highlight the basic principles and tips for the successful integration of endovascular stent grafts into the tool kit of EVTM. The principles we shall focus on are for the acute and sub-acute management of vascular injury – and will focus on expedient solutions to emergent problems.

Who? – Vessel and Patient Selection

Essentially every major named vessel in the human body can accommodate a stent graft. The evolution in endovascular applications in the elective setting has provided us with outstanding examples of the techniques that can be employed to this end. When considering the applications of endovascular techniques in trauma management, however, one must consider both whether endovascular approaches are applicable or feasible for the given situation. In other words, just because you CAN use a stent graft, does not mean you SHOULD in every case.

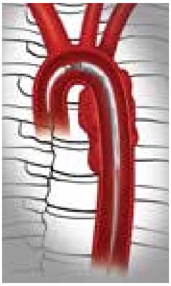


Figure 1.1

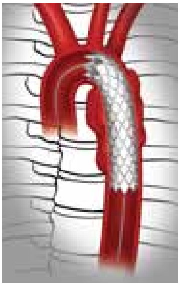


Figure 1.2


Figure 1.3

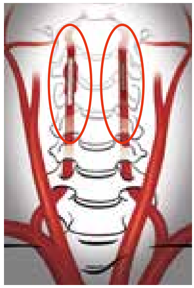


Figure 1.4

Figure 1 1-4: Some possibilites for endo-treatment seen here. TEVAR, vertebral artery balloon and stent graft.

There are several key questions that must be answered to define the applicability of EVTM to any specific injury or patient. Can the injury be treated by other endovascular modalities with an equivalent outcome? Will the use of a stent graft occlude critical arterial branches or compromise needed collaterals? Will a stent graft placed at a specific location have a high likelihood of occluding rapidly? Is the risk of embolization high at a specific location? Is there a better, more expedient open operative solution associated with fewer potential complications? If the answer to any of these questions is “Yes”, than strong consideration should be given to the chance that stent graft deployment is not an ideal solution for the issue at hand. **One must also consider the expertise and equipment available to safely apply endovascular methods and the EVTM approach**. No provider should intervene using a skillset that they have no experience in. Likewise, one often underestimates the time it might take to muster the required expertise, imaging and devices necessary to optimally utilize the EVTM approach. In a stable patient, these time limitations can be afforded. In a patient with more emergent needs, however, waiting on tools or expertise to arrive at the bedside may result in adverse outcome or even death.

All these things considered, there remain important challenges in vascular injury that might be more safely, rapidly and elegantly managed using endovascular approaches than open counterparts. While the optimal selection of patients for endovascular treatment remains to be investigated, it is becoming clear that EVTM may contribute to improved trauma outcomes after vascular injury in properly selected patients. Whether endo used alone, or in conjunction with open approaches in a hybrid fashion, will be the optimal solution must depend on the individual situation but having both modalities available for trauma providers will be a strength facing challenging management scenarios.

Remarks:

» EVTM is a whole concept. It does not mean "endovascular only"

» You should decide if your patient is a candidate for any endovascular option

» What are your time limits? Who can help me solve the problem? **What is the best option for THIS patient?** Consider these questions when deciding what to use.

Where and how?

The Thoracic Aorta

The treatment of Blunt Thoracic Aortic Injury (BTAI), in many ways, serves at the ultimate illustration of the potential utility of endovascular stent grafting in the setting of trauma. In the era prior to these capabilities, the repair of BTAI required major open thoracic incisions, often with the employment of cardiac bypass or distal aortic perfusion techniques. Thoracic Endovascular Aortic Repair (TEVAR) began to change the approach to these injuries in earnest, beginning in the first decade of the 21st century, and a wealth of data now supports TEVAR as the standard of care for BTAI in the majority of cases. Who should receive TEVAR after a BTAI? While a variety of grading system approaches have been proposed and employed effectively, the key point is that if the risk of rupture outweighs the risk of intervention then TEVAR should be performed. In the contemporary era, emergent or urgent TEVAR is most commonly utilized for pseudo-aneurysms and true transections of the thoracic aorta. Patient condition and the severity of the injury dictate the timing of this repair. Current data and experience supports the use of initial blood pressure control to minimize stress on the injured aorta, followed by delayed repair (> 24 hours) for patients not at risk of impending rupture.

The technique of TEVAR has been well described for both trauma and in the setting of treatment for aneurysmal disease or aortic dissection. There are several important concerns related specifically to trauma, however, that deserve mention. First among these is the use of anticoagulation for access and stent graft placement. In particular, the larger diameter sheaths required for TEVAR represent a significant risk for occlusion to the outflow of the leg, especially in a hypovolemic patient! So, if you are using a large sheath in a trauma patient, expect thromboembolic problems! In elective situations, this risk is mitigated with the liberal use of systemic heparinization which cannot be used in a bleeding patient. Among trauma patients with BTAI, however, associated contra-indications to systemic anticoagulation do not only occur – they can be quite common. Traumatic brain injury (TBI) and significant solid organ injury may often be the rule rather than the exception in these patients. This fact should play into the discussion process and planning of team caring for the patient. If the TEVAR must be done emergently in a patient with these contra-indications, then the procedure should be done without anticoagulation and the ischemic risk to the limb accepted. In these instances, it may be wise to do a completion angiography or ultrasound to assess patency of the femoral artery. If thrombosis is suspected a femoral cut-down embolectomy can be completed at the end of the procedure as needed. A percutaneous inserted large-bore introducer normally allows some blood flow while choosing an open femoral access normally requires banding of the artery (around the sheath) to avoid oozing. In that case the peripheral circulation might be totally blocked.

Remark:

» Take into consideration when doing urgent TEVAR that these big sheaths will occlude the flow in a patient that is hypovolemic! You don't just do TEVAR and go home...

In instances where the BTAI requires repair on a less urgent basis, delay of the procedure until after the risk of secondary hemorrhage from TBI or other trauma related sources has passed is advisable. A delay of as little as 48 hours may significantly decrease the risk of the brief systemic heparinization required for TEVAR, and can facilitate safe BTAI repair with a lower risk of associated thromboembolic events to a limb. Another issue that is commonly encountered in TEVAR for trauma is the need for left subclavian artery (LSCA) coverage. Current experience at large volume trauma centers suggests that this may be required in as much as 40% of trauma patients requiring TEVAR. The literature suggests, however, that in the typical trauma patient LSCA coverage is very well tolerated. Carotid-subclavian bypass, if needed, can be performed in a delayed fashion if symptoms of steal develop. As an aside, the risk of steal syndrome can sometimes be predicted by paying careful attention to pre-operative imaging obtained in the context of the trauma work-up. Careful review of the CTA images obtained can often be utilized to estimate the relative size of the left vertebral artery and the anatomy of the Circle of Willis. Dominance of the left vertebral artery or abnormalities of the Circle of Willis (a more common phenomena than most appreciate) may predict the need for increased vigilance and early carotid-subclavian bypass. Depending on the situation the bypass might be performed as the first step in the operation, prior to TEVAR but obviously, not in urgent surgery…

Tip:

» In the majority of cases, probably you can do TEVAR and wait with the open bypass. Asses clinically your patient after surgery and see if bypass is needed!

An additional concern regarding coverage of LSCA is the increased risk of paraplegia; it is now accepted that carotid-subclavian bypass performed prior to TEVAR reduces this risk in elective cases. This is mostly relevant in long cover of the aorta (more than 15-20cm probably). However, in emergent cases whenever TEVAR should be performed without prior LSCA patency preservation, if paraplegia develops, it should be managed with cerebrospinal fluid drainage. With the advancement of endovascular technologies, including more common utilization of branched grafts in the thoracic aorta, coverage of the LSCA may shortly become an antiquated concern. Spinal drainage might also be problematic in trauma and hypocoagulative patients due to the risk of spinal puncture and hematoma.

There are also other novel approaches that can be utilized to provide for early LSCA perfusion. There is an expanding experience with the use of parallel grafts (e.g., chimneys, periscopes) in treatment of complex thoracic aortic disease. Parallel grafts are now widely used in the subclavian and carotid arteries as an adjunct technique in treatment of aneurysm with extension into the aortic arch and has been especially valuable as an endovascular tool in emergent aortic abdominal repair where off-the shelf systems are not available (as fenestrated stent grafts). Such approaches could also be utilized to preserve other branches while covering injured arterial segments in the aorta and a variety of other locations. Off the shelf fenestrated TEVAR grafts are coming into the market and there might be place for them in these settings. They might be also very useful in sub-acute situations where you have time to plan the procedure and use highly experienced collogues.

The key element to consider in the use of any complex attempt to re-vascularize the LSCA, however, remains the **time** required for procedure completion. For many trauma patients with BTAI, an expedient TEVAR with LSCA coverage affords the opportunity to rapidly transition the focus of care to more pressing associated injuries – thereby potentially improving outcome. It is important to note that more complex approaches to endovascular repair of BTAI are possible. In this sense, it would be wise and we advocate a

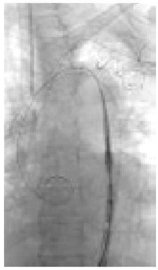


Figure 2.1

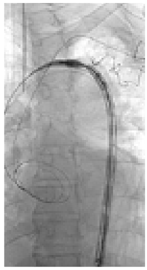


Figure 2.2


Figure 2.3


Figure 2.4

Figure 2 1-4: Stent graft deployment stages (non-trauma) from left to right. The stent graft is advanced to the area in the arch you want it to be. Angiography series will show you the takeoff vessels which is the major point here. Be aware that you have to rotate your C-arm so the aortic arch "opens up". Note angiography access from the brachial-subclavian artery.

multidisciplinary approach for these complexed interventions.

If you decide that your patient needs TEVAR, there are some things to think about. Among them: **Do I have the facilities? Do I have the knowledge/experience? Is this the best option for my patient?**

CTA studies are paramount for the estimation of 3 key factors which are important for successful TEVAR in BTAI: 1) the length of the proximal aortic "landing zone", 2) the true diameter of the aorta at the proximal and distal landing zones, and 3) the diameter and tortuosity of the access vessels (femoral and iliac arteries).

Practical Tips:

- Look at different CTA series and try to follow the injury pattern on the vessel- any other vessel injuries? Where is the aorta normal and what is the aorta diameter there?
- Look at you access ways (Femoral artery, iliac artery etc...): Can they contain a large sheath?
- Usually the length of the landing zone should be >15mm, while for adequate sealing the diameter of the stent graft should be oversized by 15-20%.
- In young patients with small diameter aortas the use of the commercially available stent grafts have diameters which are made for older patients and may be complicated by in-folding or collapse of the stent graft due to oversizing, so consider carefully if a stent graft is a good solution in a young patient- The aorta will change size and elasticity in time.
- Stent grafts can be also used as bridge to surgery but removing them might be a technical problem as well...

If a patient which has a bleeding from the descending thoracic aorta (i.e. knife wound), you might be able use REBOA (see the relevant chapter and contra-indications) to stabilize the hemodynamic situation using one femoral access to insert a stent graft and a contralateral femoral access to insert the occlusion balloon. You might need a third access route to perform an angiography, which can be achieved by a double puncture of the femoral artery, by using a larger introducer that accommodates both the occlusion balloon and the angiography catheter or by using a brachial or axillary access. You can use other advanced methods that are best to learn by training with experts before trying on your own.

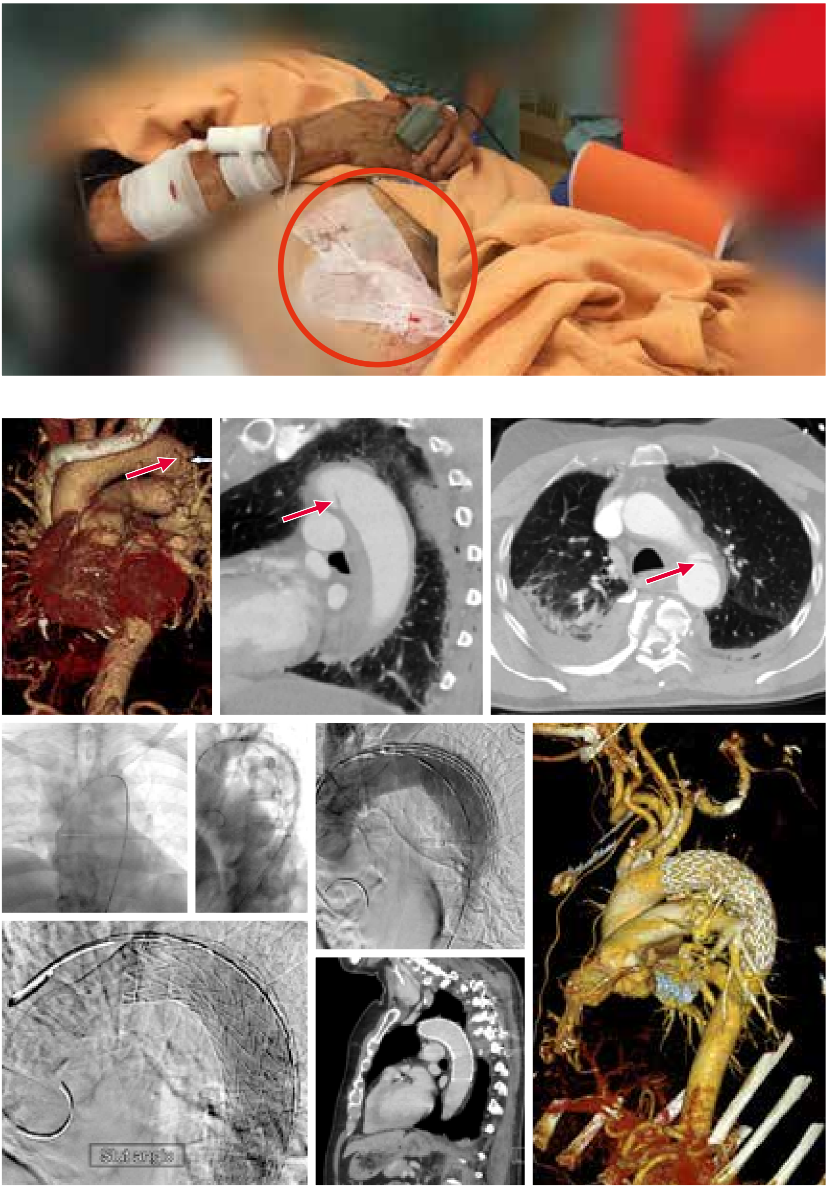


Figure 2 5-15: Patient with traumatic thoracic aorta transection treated by acute TEVAR. Wire and stent graft in place and deployed as well as control CTA. Note that the stent graft follows the great curvature of the aorta when deployed and covers the injury site well.

In the bleeding patient, think about solving the problem now: What is the best way? You can proceed later on to other solutions. Many of the lesions seen are stable, have some damage to the vessel and may not be bleeding at the moment. In these patients, you can do an endovascular repair with advanced technique with help of colleagues specialized in endovascular repair (interventional radiologists or vascular surgeons). But again, don't think only "we can do that". Think what the best option for your patient is instead. Don't go away from open surgery as you might need it! Think instead how an endovascular solution can help the patient now". This is what the EVTM is all about…

Practical tips:

» If your patient has a bleeding from the descending thoracic aorta you might be able to use REBOA to stabilize the patient before inserting a stent graft from the contralateral side.

» And no, some of us do not think that REBOA is contraindicated in thorax trauma. Not if you use it correctly as part of the whole EVTM concept and think before using it!

» You might need a third access for angiography but this can be done by double puncture of the femoral artery, by two catheters in the same introducer or by using a descending angiography catheter by brachial or axillary access.

» Consider open surgery. Any other organs at risk? What is best for the patient now? Don't avoid surgery just because you have the endo capacities.

Figure 3.1

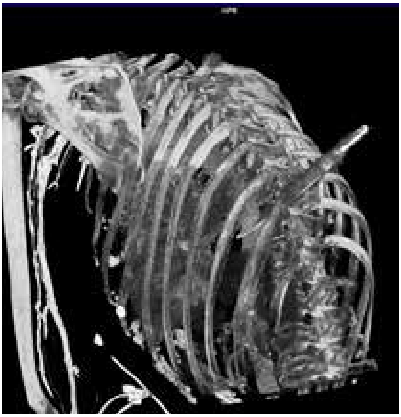


Figure 3.2

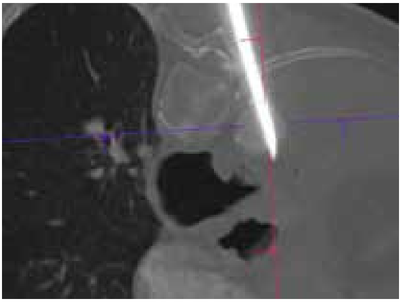


Figure 3.3

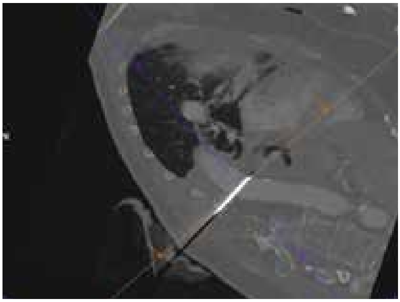


Figure 3.4

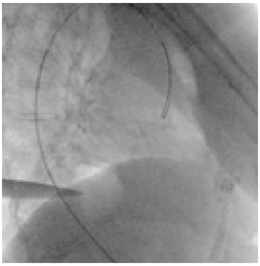


Figure 3.5

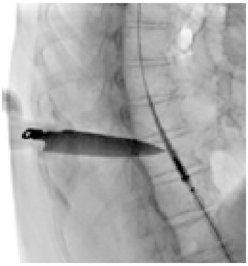


Figure 3.6

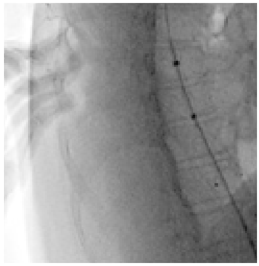


Figure 3.7

Figure 3 1-7: Penetrating knife injury to the back with direct aorta penetration, with successful stent graft deployment. CT reconstructions followed (3.2–3.4) by C-arm photos of the stages of deployment (3.5–3.7) (Courtesy of Manne Andersson, Håkan Åstrand, Werner Puskar, Jönköping hospital, Sweden).

Practical tip:

- Get a femoral access and upgrade to the sheath needed (usually 18-24Fr) on a stiff wire. Advance a catheter with a slightly angulated tip (e.g., Bernstein) on a soft wire (e.g., Terumo) and change to an angiography catheter with cm marks (measurement catheter) up to the ascending aorta from a contralateral access. Sometimes an angiography catheter can be used directly.
- Advance your stent graft on a stiff wire (e.g. Lunderquist) and advance beyond the lesion and the landing zone. Then, retrieve it to the proximal landing zone and do angiography to check the location. Don't forget to angulate your C-arm laterally (LAO) at around 40-50 degrees to see the arch (depends on the CT imaging).
- The ventilator tube normally corresponds well to the origin of the left common carotid artery
- The deployment depends on the type of stent graft as the mechanism and the way the stent grafts opens are different in every system. So, know your system before using it!
- Do always a completion angiography to see that you graft is in place without any endo-leak and the side branches are open!

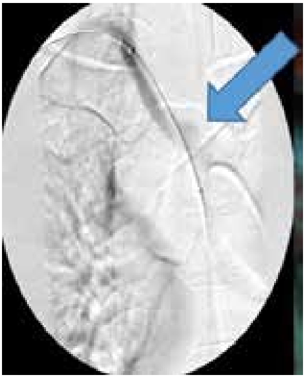


Figure 4: We showed this before but it's here again to demonstrate that stent graft can be used here. Depends on the location, access and clinical judgment!

Axillo-subclavian arteries

The axillo-subclavian arteries represent another ideal location for potential endovascular stent graft utilization. The density of relationship of important anatomical structures in this area represents a challenge in the setting of trauma intervention, particularly when the field is obscured further by hematoma and soft tissue disruption. This is commonly the case with both penetrating injuries and with significant stretch/distraction injuries. The vessels might be deep and vascular control might be challenging, especially in obese and short neck patients. There is an increasing wealth of experience with stent graft utilization in this context. The use of a stent graft at this location has some significant potential benefit in avoiding additional injury to the brachial plexus or lymphatic drainage pathways at the initial intervention.

The brachiocephalic trunk and even the ascending aorta are also regions of vascular injury where the application of stent grafts and EVTM approaches may prove useful. Particularly given that repair of arterial injuries in these areas most often requires cardiopulmonary bypass and complex thoracic approaches, endovascular utilization may augment care by providing either a definitive or temporizing damage control solution. A growing body of case reports on the use of endovascular stents for iatrogenic injuries to these areas has demonstrated significant potential in this regard.

Figure 5.1

Figure 5.2

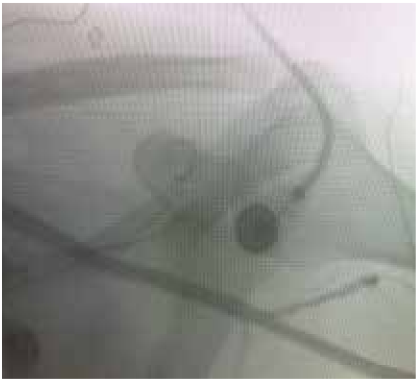


Figure 5.3

Figure 5.4

Figure 5 1-4: (left to right 1-4) Significant Axillo-subclavian artery disruption secondary to distraction injury. Employment of "Body-Floss" or "through and through" technique with use of brachial and femoral access and snared wire through disruption to obtain wire crossing of lesion. Completion angiogram after repair of traumatic axillo-subclavian arterial injury with endovascular stent graft. Passage of wire into the subclavian artery for possible stent graft placement might be possible in some cases.

Figure 4 is an example of how endo and open (hybrid) technique as part of EVTM, can help you in a challenging great vessel trauma.

Brachial access alone can often facilitate repair of these injuries, but in instances of significant disruption, alternative adjuncts may prove useful. In particular, "rendezvous" or "body floss" approaches using dual access from both the brachial and femoral arteries may prove paramount to success. This

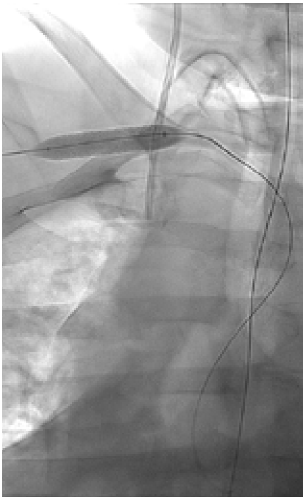


Figure 6.1

Figure 6.2

Figure 6 1-2: Stent graft deployment through a 5Fr sheath in the brachial artery under local anesthetics. Balloon expandable stent graft used in this case.

principle is outlined in greater detail later in this chapter but you can see here some examples. Some of us think that this might be time consuming and not a beginners move. There is also significant risk of damaging the artery during the procedure but it has been done and you should know about it.

Practical tips:

» Get access both on the brachial/axillary artery and the femoral artery. You can do that while your friends are working in the thorax/abdomen. Leave the upper extremity 40-60 degrees extended on a side arm so you can work on the access.

» Whith access gained, you will need to verify you guide wire location by fluoroscopy and will need space and some minutes for that. Communicate with your colleagues about it. Use a 7-9Fr introducer (yes, even in a brachial proximal artery) so you can get a PTA balloon in. You can place the wire over the injured segment (if you passed the injury with a wire), and then do surgery. Endo can help you here in case of major bleedings by taking in a PTA balloon (10-14mm should do well). Using a non-compliant balloon however has disadvantages as sizing is critical. An alternative option is to use elastic balloons if they are available and the size of the required introducer can be accepted. Traditional thrombectomy catheters over-the-wire can be a good option.

» Again, you have to consider if this is the correct line of treatment for your patient!

Carotid

Stent grafts have also been utilized effectively in the setting of carotid injuries, most commonly for injuries to the proximal or distal segments of the carotid. As with the axillo-subclavian arterial injury locations, these extremes of the carotid artery may represent considerable open exposure challenges in the setting of the severely injured patient. As with the endovascular treatment at other locations, the use of anticoagulation here represents an issue for careful consideration. The inability to utilize systemic anticoagulation in the treatment of the carotid represents significant risk for possible stroke. Distal embolic protection devices commonly utilized in the setting of atherosclerotic disease treatment at this location may be useful in select situations, but their routine use for trauma applications has not been very well established. Probably endo treatment might be of great value in sub-acute cases and patients with former neck surgery or radiation therapy. In general, zone II-III are surgically treated. In some situations, you might need proximal low carotid bleeding control and in these situations, a femoral access and PTA balloon in place might assist you. You might do angiography through this route as well. In general, if you can stop the bleeding by compression, the solution is open surgery. Stent grafts in the carotid is a controversial issue and it would be hard to get a consensus on this issue. Most of us belive that open surgical repair is indicated in most carotid injuries. It is usually safe and you need to evacuate the hematoma as well as inspect other possible injuries. Zone I injuries are difficult to manage and the endo-solutions advantage there is clear.

Figure 7.1

Figure 7.2

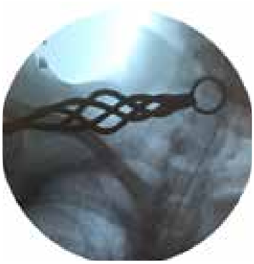


Figure 7.3

Figure 7.4

Figure 7.5

Figure 7 1-5: Penetrating injury to the axilla towards the R carotid. Metal body on the Carotid that could be removed by open dissection and retraction with manual compression of the jugular vein and carotid. Wire and Bernstein catheter left in the common carotid artery during the procedure for proximal control if needed and angiography. In this case angiography showed exact localization and open repair performed with wire in place. Note that CT examination was impossible to perform in this case due to position of the injury and abducted arm.

Practical tips:

- You might consider having a 0.038 or smaller wire in the carotid. The risk of it is minimal and you can use it for temporary control or for stent grafts. The treatment of carotid injury at zone II or III is, though, generally open surgery!
- Your catheter can give you also an option for completion angiography
- You opened the carotid and the injury is proximal at zone I? You might be able to use the wire and insert a balloon for temporary control. A PTA 6-8mm short balloon will do, but be careful, you might cause more damage with the balloon!

Abdominal Aorta

Abdominal aortic injuries are, fortunately, very rare. The majority of abdominal aorta direct injury patient with severe bleeding will die on the spot. There is very little experience with stent graft use for trauma at this location, but the utilization here makes sense in appropriately selected patients. The growing familiarity of endovascular providers with endovascular aortic repair (EVAR) for aneurysmal and atherosclerotic disease – even in the setting of aortic rupture – suggests that there is a clear potential role for EVAR in a very select subset of patients. The majority of these patients, after both penetrating and blunt mechanisms, are likely to have associated bowel injury. The use of EVAR may mitigate the subsequent risk of graft infection relative to open intervention. If utilized, the concerns regarding anticoagulation and risk of limb ischemia associated with larger delivery sheath sizes for EVAR are of importance as these patients are coagulopathic but you can read about this issue in the other chapters.

You might be able to use stent graft for isolated lesions or pseudo-aneurysms and always consider other injuries. Other options include a wire and REBOA in place for proximal control. So, while working on the patient, get a good femoral arterial access (see the first chapters in this manual) and work parallel with your other collogues. As in everything with the EVTM concept-use the mobile hybrid suite concept by putting the patient on a sliding table and have a C-arm ready in the suite. You might need it!

In cases with penetrating injury to the aorta REBOA, you can be prepared by having the balloon in place during open dissection and suture of the aorta. Temporary balloon inflation can be performed if deemed necessary. If the injury in the abdominal aorta and there is no ongoing extravasation (low grade wall injury or pseudo-aneurysm), you might consider doing the repair in day time either by open or endovascular methods, and then use advanced endo methods. There is always a risk for infection in whatever graft you use in the abdomen but EVAR solutions have been used for trauma patients. So, you can use for example a straight abdominal graft for repair, but you always have to consider other injuries (bowels?) and what is the best solution for your patient. The age of the patient, mechanism of injury, previous abdominal surgery and type of aorta injury all play major roles in the decision making here.

Figure 8 1-2: Examples of aorta stent grafts (Courtesy of Cook Medical and Bolton). Consult your colleagues to know what is available in your hospital and what is appropriate to use in your patient. Deciding which graft to use in the Thorax or abdomen is not easy, especially in young patients.

Practical tips:

» Look at the CT- size of aorta? What to cover?

» Choose a bigger graft than what is recommended if the patient is in hemodynamic chock and plan it carefully. Ask someone to help you. These are challenging cases and you need all the help you can get. The majority would recommend over-sizing of 15-20% but there is no real evidence yet and this is based on relative small series and personal experience. It also depends highly on the age of the patient and hemodynamic status when measurements are done.

Viscerals

The mesenteric and renal arteries represent another location in which stent, stent graft or embolization technologies have the potential to be utilized. The specific technique of stent graft utilization after trauma does not differ considerably relative to atherosclerotic or aneurysmal disease indications. It is important to consider however, that these procedures may prove complex and take substantial time to complete in trauma patients. In a patient who is hypovolemic due to traumatic hemorrhage, the threshold for contrast complications may also be lowered. The specific impact of this lower threshold on the kidneys is difficult to quantify in what can be a heterogeneous group, but it must be acknowledged. Given these risks and the complexity of the required intervention there are situations where insertion of stents or stent grafts will be a good alternative as dissected arteries or when a pseudo-aneurysm is present.

Practical tips:

- Remember that angiography might take time and you must consider that in applying these techniques. Cannulation of a visceral artery can be challenging but might be very useful if you suspect dissection. It can be used also to cover pseudo aneurysm or even bleedings (renal arteries, celiac and even SMA).
- Crucial to have a CTA before so you will know where the injury is and what is the segment/size. You will need to work with a sheath catheter (long introducers) and might want to pick a 10% or bigger stent graft. Might be challenging- ask someone who has done that before to help you!

Iliac vessels

The iliac vessels represent a location where, as with axillo-subclavian injuries, endovascular stent graft utilization has been well described. In a similar fashion to the axillo-subclavian location, anatomic challenges and difficult surgical exposures are legitimate concerns. Anticoagulation use is also a specific issue here, as with all other locations. A key difference between the iliac and the thoracic inlet is the higher association with bowel injury and concerns for subsequent contamination of open repair attempts. In this fashion, the iliac artery may represent an ideal location for stent graft use after trauma in properly selected patients. In cases of significant disruption, the "rendezvous" or "body floss" technique (described below) can also be helpful.

In general, open surgery is a great solution, but imagine an obese patient with multiple abdominal surgeries in the past (adhesions). You can get a femoral access and even work while manual compression or REBOA from a contralateral access. Getting a wire through the vessel will give you the ability to deploy a stent graft. Some of us did this under vision with a finger on the injured iliac vessel. Remember to get a stent graft that is 10-15% bigger than the estimated iliac diameter which is around 12mm in men and 10mm in women but individual variations are large. The length depends on the lesion. You can also cover the internal iliac artery in these situations if you don't have a choice. If the internal iliac artery is involved in the injury, back-bleeding from that segment can cause problems even if the origin is covered. This might require embolization of the internal iliac artery before covering it. Remember to cover the artery/graft with peritoneal fat if you did a hybrid procedure (think about possible infection). This can be also done as a bridge to open surgery. This procedure takes some minutes in experienced hands in acute situations if you have the vascular access and managed to pass the wire. This is not an elective case and the risk of contamination and infection are usually high. Depends of course on the scenario and injury.

Practical tips:

» Know your sizes: The iliac size in a man would be around 12mm and 10-20% smaller in a woman (but individual variations are large). In young people they are straight but angulated in older people.

» Preserve the internal iliac if you can. In emergency situations, cover it!

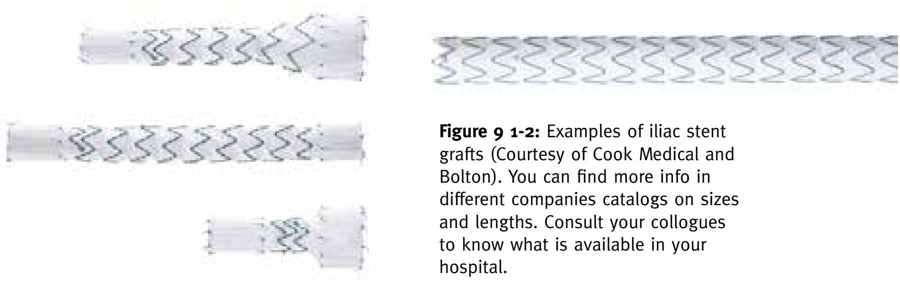


Figure 9 1-2: Examples of iliac stent grafts (Courtesy of Cook Medical and Bolton). You can find more info in different companies catalogs on sizes and lengths. Consult your collogues to know what is available in your hospital.

How – some General Principles

Access planning

The general principles of access are outlined very effectively elsewhere in this text. Specific to trauma situations, specific consideration should be given to the use of large delivery sheaths and the associated risk of distal thromboembolic complications when anticoagulation is contra-indicated. Particularly in young or small trauma patients with large vessel injury, the size of delivery sheath required to deliver the required balloons or stent-grafts for endovascular approaches may be near or totally occlusive to the distal limb in which access is achieved. One approach that can be utilized to mitigate this risk is to obtain distal antegrade access through which perfusion can be maintained. This can be done through a variety of means, including connecting tubing from the larger sheath to a smaller distal antegrade sheath, or even through an extracorporeal pump or circuit. This may though be time consuming. Consideration for such alternatives should be discussed whenever it is anticipated that total vessel occlusion with large working sheaths will be required.

Access is often the most challenging part of EVTM approaches, for a variety of reasons. The greatest advice that can be given to providers who are considering EVTM utilization for a patient is to obtain arterial access EARLY. Even if this access is obtained with a small diameter sheath initially, it can be rapidly upsized to facilitate either balloon occlusion of hemorrhage and definitive treatment. The most common mistake in the severely injured patient is to consider arterial access too late. It's much easier to get femoral access in a stable patient. Look at the "how to get a vascular access" chapter again!

Another general tip:

» Always consider when intending to use a large vessel stent graft – what is my bailout option? Is it endovascular? Is it open? Does it require help from other specialties (for example – cardiopulmonary arrest via cardiac surgeon). Who can help me and, again, what is best for THIS patient?

"Rendezvous" / "Body Floss" / Through and though technique

The initial challenge of endovascular treatment at a variety of locations is the same– wire passage. The basic tenet of – "If you can cross it, you can boss it" predominates. In other words, if you can get a wire across the injury site, you

Figure 10.1

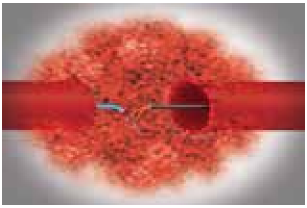


Figure 10.2

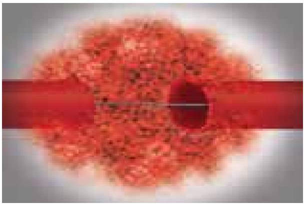


Figure 10.3

Figure 10 1-3: "through and through wire" or "Body Floss" technique.

Figure 11 1-2: Viabahn stent graft (or other products) might be useful in these type of injuries. Courtesy of W.L Gore.

can control it and treat it. You might still need to open and evacuate a hematoma, or do open reconstruction, but it's another tool that might be helpful. This is not infrequently a challenge in the setting of significant vessel disruption. When antegrade or retrograde approaches alone fail to cross the lesion, the "Rendezvous" or "Body Floss" technique can be particularly useful.

Significant axillo-subclavian disruption serves as a good example of the specific utility of this technique. While lesion crossing at this location can often be accomplished in the emergent setting through brachial access alone, in some instances of complete disruption the thrombosed ends of the vessel may sit in a contained hematoma through which the wire refuses to traverse. In this setting, an alternative approach termed "rendezvous" or "body floss" can be employed. This is accomplished by brachial access and the introduction of the tip of a long hydrophilic wire into the disruption area. Access from the common femoral artery is then utilized to place a snare into the disruption. The wire snared, and the end of the wire brought out through the femoral sheath. At the completion of this maneuver wire is then crossing the injury with the ends of the wire outside the body at the femoral and access brachial access sites – hence the term "body floss". This wire now provides a stable rail upon which to position and deploy a reparative stent graft.

A similar approach can be utilized for any vascular injury location where antegrade and retrograde access can be obtained on either side of the injury. The use of "body floss" in this fashion can be particularly useful. To expand upon the basic tenet of endovascular vascular injury management: "If you can cross it, you can boss it – but you might have to floss it".

Venous applications?

It is important to remember that the principles of stent graft utilization for endovascular trauma management also have the potential to be employed for major venous injuries. Stent graft repair of vena cava injuries has been discussed, but not widely utilized. In select settings, however, stent graft utilization may afford valuable expedient control of significant major venous bleeding. If you have a bleeding from the inferior vena cava or the iliac vein. You can puncture the femoral vein, get a vascular access with a larger sheath (10-12Fr), and advance a wire up. There are today vein stent graft that can be used in the vena cava or in the iliac veins. The problem might be related to slow flow and coagulation that might lead to stent graft occlusion. The experience in trauma patients is limited.

Damage control or definitive?

Controversies regarding the use of endovascular stent grafts do exist. A primary central theme in many of these discussions is uncertainty about the long-term outcomes of stent grafts placed in younger trauma patients. The use of endovascular stent grafts for diseases associated with more advanced age, such as atherosclerosis, has accumulated considerable follow up data. Comparatively less is known, however, about the natural history of these devices over the more lengthy possible lifespan of a 25-year-old trauma patient. Long term data regarding durability corresponding to the expected survival for the young patient group is non-existent nor is it known what effects a relatively more and more undersized stent graft will cause in a patient who is growing. What is the optimal surveillance for a younger patient after placement of these devices for trauma? Should they be on anti-platelet or anticoagulation therapy for life? If so, what regimen? These questions are difficult to answer at this stage in the evolution of endovascular trauma management.

An often-overlooked perspective, however, is that the use of an endovascular stent does not have to be considered a definitive intervention in every case. The potential utility of stent grafts in the emergent setting is apparent, as discussed above. The uncertain long-term risks, however, should necessitate an informed discussion with the patient after they have recovered from their injuries. The potential for long-term antiplatelet or anticoagulation utilization should be outlined. Uncertain long-term patency or device durability over the entire lifespan of a young patient should be discussed. These risks and uncertainties must be weighted with the patient against the risk of conversion to open bypass revision. To balance this, you can look at the experienced gained form EVAR and ruptured abdominal aneurysm (rEVAR) as well as TEVAR and rTEVAR which show very good results as well as long term patency. Obviously, this data is not equivalent to trauma patients, but it is of great interest and should be investigated.

In some instances, there may be other confounding factors that impact this discussion. Take the case of the axillo-subclavian distraction, for instance. In some cases of clinically apparent brachial plexus injury, interval attempt at nerve repair may be undertaken in a delayed fashion after other injury issues have resolved. If the subclavian artery had previously been repaired by stent graft, the delayed neurological surgery intervention represents an opportunity to replace the stent graft with an open bypass using the same exposure. Such an opportunity should be discussed at length with the patient.

While a variety of unique scenarios could be considered in a similar fashion, the "take-home" massage is that endovascular stent grafts can be considered as either "damage control" adjuncts or definitive therapy – Depending upon the individual situation. By expanding our thought processes in this fashion we promote the innovative and effective utilization of endovascular trauma management techniques.

Notes on tunnel vision and the endo mindset

One of the greatest early dangers in attempting to employ stent grafting for the treatment of vascular interventions is the onset of "tunnel vision". Providers should be cautious to avoid excessive focus on making stent graft utilization fit the situation… instead focusing on treating the situation with their full understanding of endovascular capabilities. In this fashion, it is important in any vessel to consider when to change from the thought of stent graft utilization to balloon occlusion or embolization. Particularly in the significantly bleeding patient, struggling with challenging stent graft sizing, positioning and deployment may not make as much sense as simple balloon occlusion or even embolization. These latter two modalities afford expedient control of hemorrhage and give the endo operator a chance to “catch their breath” – not to mention permitting needed resuscitation of the patient. In this reconsideration of the problem in front of them, the provider may find that it makes more sense to convert to open intervention – but now has the opportunity to do so in the setting of controlled bleeding.

It is important to utilize the full range of endovascular considerations in addressing issues in the visceral arteries, or any of those vessel groups in this chapter. While these concepts are addressed elsewhere in greater detail in this text, we cannot emphasize enough the development of an “endo mindset” that is nimble and effective at switching strategies to most effectively and safely address the particular issue at hand. We emphasize here again that EVTM is not endovascular treatment but a tool box that might facilitate you in your struggle to save the patient.

Some words of advice

Great vessels might become huge problems. Endovascular solutions are great tools but should be used carefully. So, don’t experiment on the patient. Ask someone that know the area to help you. You will do great cases together and the patient will benefit!

Closing remarks for this chapter

Stent grafts are increasingly being utilized to control and treat vascular injury, particularly at anatomic locations associated with challenging and time consuming exposures by open means. While the long-term outcomes of stent grafts in this setting are uncertain, preliminary experience suggests that there is a potentially significant role for these adjuncts in the trauma setting. The continued evolution of endovascular trauma management promises to expand the tools available for the care of the trauma patient with vascular injuries and a EVTM mindset will help you choose the correct way for THIS patient.

Notes

Chapter 9

Some more basic issues to consider about EVTM and embolization

Yosuke Matsumura, Junichi Matsumoto, Per Skoog, Lars Lönn and Tal Hörer

We wanted first to write about "What to do when you are inexperienced" or "What to do when back up has not yet arrived?". We realized that in the bleeding patient, if you are not experienced, you will need back up even on patient arrival. Thus, the following text is built so you can make some choices and understand what can be done. You have a bleeder! You are not highly experienced! Call for backup and activate a multidisciplinary approach.

Endovascular techniques are being introduced in trauma surgery. The more tools you have, the more you can do! Is it so? Well, we know that at times you need just very basic tools, and the fact that you have many options might complicate the situation. The art of modern trauma and bleeding surgery is to know **when to use which tool and on what patient**. Your main problem is to **find the damn bleeding and stop it**! You stand there and know that the hypotensive patient is bleeding – but where? Some of us think that blunt trauma is more frightening than the knife in the belly that can "obviously" guide you to the bleeding source.

We will go through some basic methods and thoughts that might help you. Again, this is based on personal experience and opinion, so you choose what suits you. Do you suspect massive bleeding, and that the patient's life will fly out of your hands? Take the patient to the safest place **where you can**

stop the bleeding. Don't go to the CT if you are inexperienced or not sure what to do. Unstable patients require very fast decision-making and skilled hands. You will not have these in the CT unless there is a clear plan and nearby surgical suite, and also VERY skilled people with you. CT (or CTA!) is a very powerful tool **but it does not stop the bleeding!** So, you need to do something, now! There are some tools that are bridges to surgery, and one of them is REBOA (as you saw in the other chapters). REBOA may help you **win some times until you get to a place where you can stop the bleeding**. In order to do a REBOA, you will need a **femoral arterial access**. Then, you must think whether REBOA is the correct tool for this patient. This is discussed in the other chapters.

> Don't do "non-selective" angiography. You must know **where** to look for the bleeding focus.

IF the patient is stable, or if the abdomen is opened and already packed, and the pelvis is tightened, but the patient is still not stable, consider improved diagnostics and embolization. The alternative is if you had time for a **CTA on arrival**. You have identified a source of bleeding that is not easily accessible for open surgery, and the patient crashes. You might consider embolization, but remember that embolization takes some time. This time is highly dependent on where you are and, again, your skills. Internal iliac artery embolization can be done within 10 minutes by an experienced IR or endovascular surgeon but **transfer and preparation might take much longer**. Another option is to think hybrid (EVTM), and work on packing the abdomen while embolization starts (get a vascular femoral access if that's not yet done), or a REBOA in place with pREBOA or iREBOA (see the relevant chapter). In other words, while performing laparotomy (if not done before), someone else can do the femoral access and insert the REBOA (if not done before). Remember also that we need teamwork here; someone has to take care of the REBOA while you look for the bleeder or pack. If you don't know exactly where the bleeding source is, your heroic embolization efforts will not turn out well. If you, on the other hand, have a good idea of where the bleeding is, and use the EVTM set of mind as we described before, embolization might be a good solution. There are some scenarios where you can hold a patient at an acceptable systolic blood pressure with pREBOA until help comes or your surgical suite is ready. Whatever you do, don't just leave a REBOA in place without planning the next step. Hold it, use pREBOA, and call for help!

To counter all this, we should mention that the majority of trauma patients are hemodynamically stable and you might consider embolization or stent-graft deployment. But you will need a CTA to localize the problem, except in the case of hemodynamically unstable isolated pelvic injury. CTA will show you the extravasation location, will give you the "map" on how to get there, and, of course, will show associated injuries. A minor bleeding in the pelvis with an intracranial hematoma might make you change your priority, i.e., of what to do first.

What do you need if you want to embolize and have never been there before? Well, **you need someone with experience beside you!** But, anyway, some tips on what is commonly used for embolization:

Macro catheter	5Fr or more (more options than 4Fr)
Micro catheter	Smaller catheters (often carry a 0.018 inch wire)
Selective catheter	A catheter with some kind of bend or hook
Hydrophilic catheter	Helps you get through angulations and change wires
Coils	Small metal spiral forms
Vascular plugs	Forms for bigger vessels
Liquid agents	Effective but tricky to manage, instant hemostasis if deposited in the right place and not dependent on coagulation status
Gelatin sponge	Water insoluble gelatin, good for in peripheral diffuse bleedings

Let us assume that you have basic endo-training and focus here on some basic embolization skills.

Access is always the first priority for EVTM

(see also the chapter "It's all about the access")

If you want to do REBOA, arterial balloon occlusion, or embolization, or deploy a stent graft, you need a functional vascular access. We mentioned before that it should be already considered during the primary survey (AABCDE), but this is not yet anchored in any guidelines. Establishing a vascular access in an unstable patient is not easy, and if your patient is stable, consider doing it **now**. This will help you in ten minutes when the SBP is 60mmHg. Use a small sheath (5Fr), and you will probably not cause damage if you do it correctly. We are assuming and encouraging you to get some training on this before doing it the first time. Don't go around and do things you are not trained in!

Over-the-wire technique, tips and tricks

To avoid iatrogenic vascular injury, you should advance your catheters using the "over the wire" technique. The catheter tip might be stiff enough to injure the vessel wall if you push it without a wire, so never use just a catheter without a wire. Grab the catheter end in your left hand and the guidewire tip is in your right hand, and insert it into the catheter.

Probably you are using your favorite catheter (or the one your boss has decided is your favorite catheter). Advance the wire with a constant stroke length and count the strokes. You will, with experience, get to know when to stop the wire just before the tip arrives at the catheter tip. The moment the guidewire tip enters the vessel lumen is crucial, especially if the vessel contains a plaque. The wire might penetrate the vessel intima, causing a dissection. You should stop the wire completely, take a deep breath, and then advance the wire slowly with maximum care under fluoroscopy vision. Once the wire tip is inside the true lumen, you will feel almost no resistance to advancing. After placing the wire in the target position, you should hold the guide wire end in your right hand and move the catheter further with your left hand (the catheter will follow the wire). If you don't grab the wire end, it might migrate upwards. An important basic tip is that you need to use at least twice the length of guidewire for the catheter when you exchange the catheter using the guidewire. If you use an 80cm catheter, guide wire length should be 180cm (not 150cm). Exchanging the catheter in the aorta is less stressful than in a selected artery, but the basic procedure is the same.

After embolization (discussed separately) in pelvic fracture patients, you will confirm remaining bleeding (such as from the lumbar artery, branch of external iliac artery) by pelvic angiography. You will need a pig-tail (angiography catheter).

Angiography – contrast injection issues

After cannulating the target artery, the first thing you should do is to confirm backflow of blood. Inject some milliliters of sterile water. Contrast media injection testing should be done softly. Stop injection if you feel extraordinary resistance or see any vessel flow, since you might be in a dissection. A power injector can make beautiful images through mechanical constantly powerful injection. However, it takes some minutes to connect and is not always available. Most of us believe that manual injection through a macro catheter can achieve good quality images. You can easily inject 8–10mL/1–2sec manually. Most micro catheters can only allow 1.5 to 2.5mL/sec due to their pressure limit. Think about the diameter of the catheter when injecting.

Pelvic fracture related embolization tips

A pelvic fracture is a good example since the procedure might be straight-forward. Remember that a significant number of pelvic injuries give venous bleeding and are more challenging to embolize if needed.

Tighten first the pelvis binder and reevaluate hemostasis. Venous bleeding is best treated with external pelvic banding, primarily, external fixation, or extra-peritoneal packing. Arterial embolization will contribute to reducing inflow into the pelvic region, and might reduce venous bleeding. **Before starting angiography**, **decide which vessel you are treating!** Most IR people will choose the contralateral side for femoral access. So, if it is bleeding on the left side, puncture the right CFA and get in with a 5Fr sheath. If you have a REBOA on that side, you can do a parallel puncture or use the ipsilateral side. In young people with a sharply angled aortic bifurcation, some of us would advocate ipsilateral access if possible. In some patients, you will need to do bilateral embolization. This depends on your local routines.

What catheter to use? Find a favorite one that you can work with. Cobra, Shepherd, there are plenty. Do a pelvic angiography to map the aortic bifurcation! Inject 10mL contrast using RAO 20–40 degrees just to identify the Internal Iliac Artery (IIA) and its branches (the C arm angulated to the patient's right side). The oblique view will show the bifurcation. Thus, this is both a diagnostic angiography and a mapping of the iliac bifurcation. Then, you direct the guidewire into the IIA. Embolization can start there or more selectively. This is starting to be a part of a more advanced methodology, and we will not go into detail here.

Some more words on embolization agents in the pelvis

The choice of embolization material is determined by the injury pattern and your own experience. In a proximal major vessel injury like in the IIA main branches, stent-graft deployment isn't an option, but a vascular plug in combination with coils might be helpful. Plug embolization gives rapid bleeding control but also has some risk of distal ischemia for the plug. If it is 1st or 2nd branches to the IIA that are injured, both coils and bigger gelfoam particles can be used as well as liquid polymer agents. Gelfoam particles (2–4mm) are easy to prepare quickly and have a temporary embolic effect. Inject the gelatin sponge slowly and non-selectively (from your catheter in the proximal IIA). In hemodynamically unstable pelvic-fracture patients we advise that you do not try to do super-selective embolization! The large gelatin sponge won't go distal and migrate the fastest way, downstream. Gelatin sponge and contrast saline can be injected alternately. Embolize until the gelatin sponge fills up to the catheter. Then pull back the catheter to CIA, aspirate if needed and inject contrast as post-embolization study. If you cannot aspirate the gelatin sponge out of catheter lumen after embolization, you may remove the catheter and flush it outside the body. But remember that you might need to get back there and continue, and re-entering the same place takes time! Coils require intense packing to have an instant effect and are easier to identify while you are performing the embolization (you can see them on the x-ray). However, they might not work as well due to coagulopathy. In peripheral and diffuse bleedings, a gelfoam-saline-contrast mixture (see recipe below) can be injected non-selectively. A non-reversible alternative is a liquid polymer embolization agent like Onyx or NBCA that works regardless of coagulation status. Onyx might be very useful as it will go downstream and block the "back door" of the bleeding from feeding arteries.

The anterior pelvic portion has collateral flow from the contralateral side, so here injuries MIGHT require bilateral embolization. If you have bilateral access and prefer a contralateral approach, you can go to right IIA from left sheath and vice-versa, a so-called "symmetrical procedure". If you have only one sheath, you will need to access ipsilateral IIA from your femoral access.

At the end of the procedure perform a distal aortogram. Your aim is to identify remaining extravasation. In unstable pelvic fracture patients, one might consider bilateral non-selective gelatin sponge embolization as a rescue procedure. Some centres are doing this routinely.

Your pitfalls in the pelvis:

- You can't get a vascular access.
- It takes time to cross over and get into the IIA.
- An unstable catheter in place.
- You cannot identify the bleeding focus.
- Coiling does not stop the bleeding and time is running out.

Renal embolization issues

In most cases a femoral access is the easiest way, but you can take the brachial or axillary artery approach (It's trickier. You need experience here). Start the procedure by doing a high dose, high flow (15ml/s, 20-30ml) aortogram with angiography catheters in the Th12-L1 area. Here, you look for the main renal arteries. Catheterize the renal artery with a selective catheter (something with a hook or 90-degree angulation usually works). When you are inside, perform a hand-injected series and seek for extravasation. Placing a macro-catheter in the renal artery and use of coiling is the fastest way to stop the bleeding in, for example, transections of the main artery. Vascular plugging is an alternative. A better choice is a selective or super-selective branch embolization if possible. It might be wise to have a guiding sheath (6-7Fr) in the renal artery hilum and work with a macro catheter (4-5Fr) and micro-catheters in the branches. This will give you the opportunity to do contrast angiography control and be more selective with micro coils or embolization liquid. If you encounter renal vascular pedicle injury,s renal artery stent can be an option. These methods are not a beginner's maneuvers!

Pitfalls:

- You can't get access to the arteries, or have unstable catheters so you can't enter the arteries. Consider another approach/access.
- Wire perforation of the kidney/vessels. Consider embolisation.
- Unintentional complete embolization of a kidney, with its consequences. No easy solution.

Splenic embolization

With a selective catheter, you catheterize the coeliac trunk and often end up in the hepatic artery. Here, a stable catheter position might be a bit tricky to achieve. Consider using a guide catheter or sheath at the celiac artery (6-7Fr). Do an angiogram and continue to the splenic artery. You will need to change the C-arm position to see the celiac artery going anteriorly. Decide if the bleeding requires a proximal embolization (vascular plug or coils) or a peripheral selective embolization using a micro system. Even if you decide to put your devices proximally, the spleen will have collateral blood supply (from the proximal splenic artery, but beyond the dorsal pancreatic artery), but you will probably lower the perfusion pressure and make the patient stable. Liquid embolization agents might also be used here. Embolization here might take time. There are no magic tricks and you need experience (or a friendly experienced collogue to take over). Balloon occlusion of the splenic artery is another effective temporary solution for splenic injury.

Pitfalls:

- Failure to enter the celiac artery and stay there. Consider another approach/access.
- High flow in the artery with migration of the coils. Change coils. Another approach.
- Re-bleeding due to collaterals or “back-door” bleeding. Change approach. Liquid embolisation?

Hepatic issues

Catheterize the celiac artery with a hooked catheter. Again, this position can be unstable so you might need a guide catheter sheath. Hand inject 10ml contrast and try to understand the anatomy and find the source of bleeding. Use multiple projections. Then, use a macro catheter and a hydrophilic 0.035 inch wire and advance as close as possible to the bleeding area (blush). Might be beneficial to use a micro catheter. In the liver, it is particularly important to close the back door of the bleeding. It depends on the situation, but it might be enough to decrease perfusion pressure by proximal bleeding vessel coils. Gelatin sponge can go into the systemic circulatory system through AV shunting, and may result in iatrogenic pulmonary embolism. **Embolize as selectively as possible!**

Figure 1.

Figure 2.

Figure 1-2: Arterial phase followed by venous (late) phase CTA. Note the extravasation. CTA at both the early and late phases can give lots of information.

Pitfalls might be:

» An unstable catheter.

» Wire perforation and more damage.

» You can't find the bleeding vessel/area. Change approach.

» Unintentional pulmonary migration of the embolic agent due to AV shunting. No easy solution.

Some take home massages:

- Get some training in basic techniques before you do any endo procedure.
- Get more training and help from your collogues, and don't play around with unstable patients!
- Know the material and how to use it.
- Think before using it!

Good luck!

Notes

Chapter 10

Organ by Organ

the possibilities and practical solutions –some further thoughts, tips and tricks

Lauri Handolin, Joe DuBose, Viktor Reva, Lars Lönn, Per Skoog, Junichi Matsumoto and Tal Hörer

Bleeding after trauma comes in many forms. While all bleeding should be taken seriously, all surgeons would agree that there is a difference between annoying blood loss that takes time to control but is tolerated by the patient's physiology and the audible exsanguination that spells immediate doom. As trauma surgeons, however, it is our calling not only to address each and every cause of bleeding correctly, but also to determine how and when to do so. Is there time or need for definitive repair? Or is it wiser in a particular situation to buy some time with temporary damage control maneuvers? **You need to make the call**! Everybody on the team is waiting for your decision.

When managing bleeding sources after trauma, it is important to remember that airway and breathing problems tend to kill more quickly than hemorrhage. Don't forget your ABCs. You must also appreciate that exsanguination is not the only way in which bleeding can kill. Even small amounts of blood in the wrong location – say, the pericardium or the skull – can have catastrophic consequences due to increased pressure on surrounding structures. These sources of hemorrhage, though smaller in volume, often require more emergency treatment. In examples like the skull and pericardium, there are no "EVTM solutions", so we will not address them here, but they may be highly relevant to the patient you meet and treat using EVTM principles…

It is also important to appreciate that vessel injury can be harmful even when it does not result in active bleeding. A partial occlusion can result in an embolism in a critical end organ, such as the brain. It might develop into a total occlusion of an end artery supplying a critical organ, such as a kidney. So, interpreting the patient and signs, and making decisions on management, have to be based on a good understanding of the situation and good clinical judgment. You need to use all your expertise and best judgment to optimize the outcome. The organs are different by nature and in terms of importance for survival. Access routes and management options for each organ represent unique challenges and there are different solution options. Let's have a look where you may find yourself next time on call – and consider the **options for each individual organ** that may challenge you. We will try to think "EVTM" here and see what we can come up with.

Pelvis

Pelvic ring and acetabular fractures are caused by blunt trauma. Ring fractures have mainly two possible directions of instability: horizontal (lateral compression and open book) and vertical (completely unstable pelvic ring). Pelvic ring fracture-related bleeding originates from fractured bone surfaces, soft tissues, and sheared veins and arteries. The most important and greatest impact on hemodynamic compromise is caused by posteriorly located major arteries and their branches (the internal iliac and superior gluteal arteries). Such bleeding is more often related to completely unstable pelvic ring fractures.

It is a busy Saturday evening in the hospital and Emergency Services are bringing in a hemodynamically compromised young suicide jumper. Your team intubates the patient and rules out breathing problems. FAST is negative for the abdomen, but clinically you find an unstable pelvic ring. The patient is bleeding and he is very likely bleeding from the pelvis. What do you do?

The first step is to apply pelvic binder and continue with a massive transfusion protocol. If hemodynamics are grossly compromised or the patient has a trend of continuous deterioration, you need something else, and you need it fast. You need proximal control of the bleeding and may start thinking of thoracic aortic clamping before you pack the pelvis. Stop for a moment. Let us challenge the traditional protocol and claim: There is no need for thoracotomy! It is more feasible to occlude the abdominal aorta at Zone 3 rather than to crack the patient's chest. You can cause damage by thoracotomy, not to mention the consequent morbidity. We have met some young people for whom we could avoid thoracotomy successfully and it was worth it! Think about this young girl or boy in front of you. Thoracotomy might have other consequences further on in her life. It's a thought…

Remark:

» As you understand, thoracotomy can be the correct treatment and we are not suggesting not to do it if indicated. We want in this manual to promote other tools that can be incorporated as part of the EVTM concept. So do what you are best at to save the patient.

Let's continue. Next, you need femoral arterial access to get in with REBOA, but you realize having the pelvic binder just in the groin area is preventing you from establishing it. **Do not open the binder** yet. Place another binder just below the original one, and open the original one only after the second binder is applied. Now, you have access to the groin area and you are still keeping the pelvis stable. Do the puncture and get the sheath in, either guided by ultrasound or via open exposure if needed. Push the REBOA catheter in and land in Zone 3. At this point, it does not matter which side, right or left, you go in, just go in. A right landing zone can be assured by fluoroscopy or US, but you can also find Zone 3 in a blind manner. Place the catheter on top of the patient's belly so that the balloon is just above the umbilicus, and check the site of the proximal end of the catheter. This will be your starting point. Push the catheter in just to the depth you defined at the first point. Start filling up the balloon slowly while pushing and pulling the catheter in and out with slow 5 cm movements until you feel resistance due to the balloon expanding against the aortic wall. With good resistance but with the catheter still moving, stop filling the balloon, pull the catheter out until it stops, and finalize the filling with two more ml of saline. Your balloon has very likely stopped at the aortic bifurcation due to the diameter difference between the aorta and iliac arteries. You can read the REBOA chapter, and do pREBOA here, as you monitor blood pressure if possible.

Now you have established proximal control of bleeding with REBOA in place. But, that only gave you some ten minutes, and you need something to continue with in terms of controlling the bleeding. The <u>next step depends on the patient's condition and the capabilities of your particular hospital</u>, how trauma care is organized. If the patient is relatively stable and you have an interventional radiologist (or endovascular surgeon) readily available, transport the patient to an angio suite for immediate angioembolization. Even at midnight with a crossly compromised patient, if you have certain endovascular skills and a reliable team, you can “blindly” embolize internal iliac arteries using a mobile C-arm in the OR. Even formal pelvic angiography is not needed for such a procedure. Instead, you only need a basic set of wires, catheters and embolic materials (gelfoam, coils, NBCA, Onyx, plugs, or whatever you think appropriate). This is considered to be a bordeline basic/advanced procedure for an experienced trauma surgeon.

Remark:

» There is also the option of doing CTA, which will give you more information on other injuries (head? spine? etc.). This is highly dependent on where you are and your experience, but most importantly: **What is best for your patient now?** Some of us will always do CTA if possible.

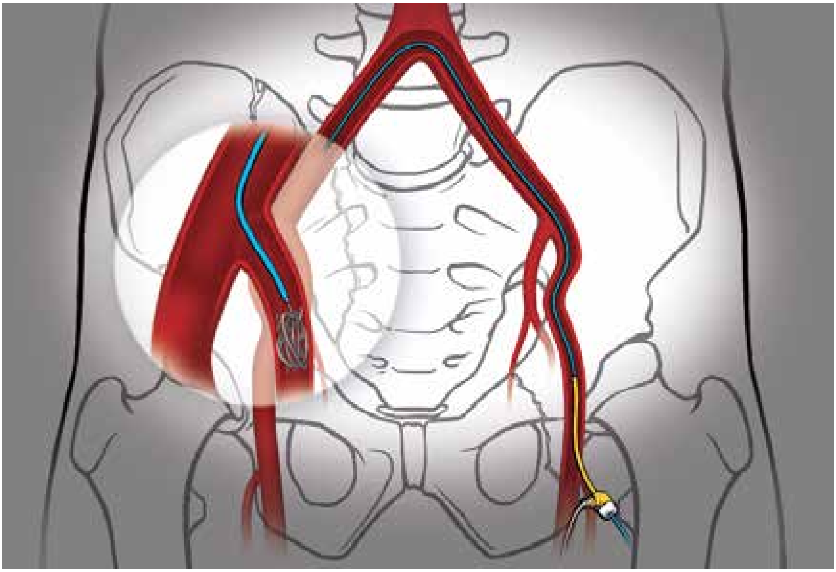


Figure 1: Pelvic embolisation of the internal iliac artery.

If you are not lucky enough to have the IRs available, a C-arm in the OR, you have no basic endovascular set, then you’d better proceed with a simple and very reliable maneuver – **preperitoneal pelvic packing**. You need to pack the pelvis and see if you can start slowly deflating the balloon. Your patient should be able to tolerate the slow and staged deflation if the packing was done properly. If the patient does not tolerate this, consider **partial occlusion** (pREBOA) with the balloon to restore some circulation in the lower extremities. The patient also needs, as said before, more detailed diagnostics with whole body CT. Those are things you need to get soon after the first lifesaving bleeding-control tricks. Don't fall into an "instant happiness" syndrome even though the blood pressure is stabilizing after the packing, but be aware that there also might be other injuries to deal with; at least you need to rule out hollow organ and intraperitoneal bladder injuries. You need to stay alert.

Leave the packs as they are, continuing with a secondary survey and let the patient stabilize. After 24 hours take the patient back to the angio suite, pull out the swabs one by one and check for arterial bleeding. Embolize the bleeders if seen in angio.

Spleen

In the case of hemodynamic instability and free fluid in the abdominal cavity, take the patient for laparotomy and splenectomy. If the patient is relatively stable, and you managed to get WBCT scanning and do not see any reason for laparotomy other than a bleeding spleen, **consider taking the patient for embolization,** which is the basis for non-operative management. You lose the opportunity of having great fun in taking the spleen out, but embolization is certainly more convenient

Figure 2.1

Figure 2.2

Figure 2.3

Figure 2 1-3: Extravasation on CTA with pelvic fracture. Angiography with extravasation and coils in place. REBOA was used in this case, while CPR. Patient survived.

Figure 3.1

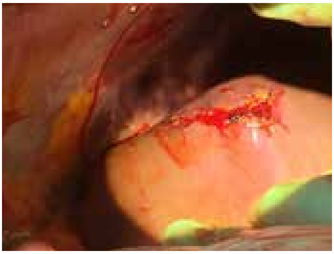


Figure 3.2

Figure 3.3

Figure 3.4

Figure 3 1-4: A penetrating liver injury. Blood around the liver. In this case, open surgery with packing was enough. dREBOA (deflated REBOA) might be an option for this case as laparatomy might reveal huge bleeding. With hemodynamic instabillity.

for the patient! Bear in mind how long it takes to get the patient to the angio suite, how quickly the embolization can be done, and if it can be risky. **You are in doubt? Get the patient to the OR**. Splenic artery catheterization is not as simple as embolization. Sometimes, it takes tens of minutes even in experienced hands to pass through the celiac trunk manipulating different catheters and wires. This maneuver is not for beginners.

The spleen gets its blood supply mainly from the splenic artery, but some blood also comes from the gastrosplenic ligament (vasa brevias). Thus, the risk of splenic ischemia and necrosis is relatively low after proximal (non-selective) occlusion of the splenic artery, which is the method of choice for acute bleeding. Only in stable-enough situations with no other major injuries, such as an intracranial injury, can a longer time be spent on selective segmental embolizations.

Splenic necrosis may occur after proximal embolization. The reason for this might be compromised gastrosplenic ligament vasculature due to primary trauma, leading to ischemia after blocking the inflow from the splenic artery. An ischemic spleen can be taken out after the patient has stabilized, but, fortunately, in most cases, splenic necrosis resolves itself spontaneously. Is there a need for vaccination after proximal embolization of the spleen as there is after splenectomy? Probably not, since if there is no total necrosis of the spleen, there will probably be enough spleen left to avoid this need.

Liver

There are three bleeding circulatory systems in the liver, two of them coming from a proximal direction (the hepatic artery and portal vein), and one filling in both from the liver and in a retrograde manner from the vena cava (hepatic veins). Roughly 75% of the blood entering the liver is venous blood from the portal vein, and the remaining 25% of the supply is arterial blood. In major hepatic bleeding all these three circulatory systems may be compromised. Thus, in most cases of major hemodynamic instability, the patient needs prompt laparotomy and packing of the liver. Temporary clamping of the hepatoduodenal ligament (Pringle's maneuver) stops effectively all the bleeding coming from the anterior direction (portal vein and hepatic artery), buying you time to deal with packing. Remember the 3P rule: Press, Pringle, Pack! On the other hand, when dealing with an unstable patient with positive FAST, you can start with REBOA and then go straightforwardly into the belly. When you struggle with uncontrolled bleeding from the retro-hepatic IVC, aside from Pringle's maneuver, you need to control IVC proximally and distally. To clamp suprarenal IVC, you just mobilize the duodenum using a Kocher maneuver, but clamping of the subdiaphragmatic or intrapericardial part of the IVC is a great challenge. You may use the same compliant balloon, brought from the femoral vein, for IVC temporary occlusion at the level of the hepatic veins. There is one known case of this being done with REBOA and a vena cava balloon (double REBOA) due to massive traumatic liver bleeding. We think this is a possible solution in selected cases.

In case of CTA revealing a blush in the liver, you need to make a decision.

Figure 4.1

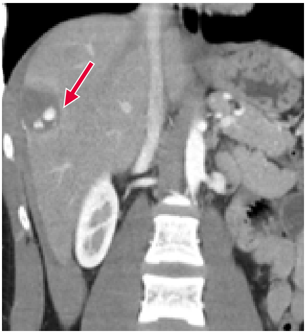


Figure 4.2

Figure 4.3

Figure 4 1-3: A liver penetrating injury with extravasation and coil embolization (not seen here).

Is there bleeding in some other place in the liver. The contrast blush is very likely to indicate arterial bleeding, but does not tell you much about the portal or hepatic veins.

Remark:

» As mentioned before, it would be good to have the CT done at both the arterial and venous phase.

Is the arterial bleeding taking place only inside the liver parenchyma (traumatic pseudoaneurysm) or is it also leaking freely into the abdominal cavity? Traumatic pseudoaneurysm does not result in hemodynamic instability but may cause problems later on. In such a case, let the resuscitation proceed, stabilize the patient, and deal with the pseudo-aneurysm by selective segmental embolization later on. In the case of arterial bleeding into the abdominal cavity, but no major hemodynamic instability, take the patient for immediate embolization.

Kidney

There are three kind of emergency problems related to kidney trauma; active bleeding, occluded renal artery with ischemic kidney, and leakage of the urea. Ureal leakage is due to deep injury to the kidney going down to the collection system or injury in the pelvic-ureteric junction area. The resulting leakage is not killing the patient in the first instance, but requires careful attention and treatment after the patient is hemodynamically stabilized. Troublesome bleeding in a kidney is usually arterial and related to severe blunt or penetrating injury. From the endovascular point of view, it is possible to occlude the renal artery to stop the bleeding. That should also stop the ureal leakage, since after renal artery occlusion there should be no more perfusion, and thus no discretion, taking place. However, there is great variation in the numbers, sizes and origins of renal arteries which may make endovascular treatment too challenging and time-consuming when treating the patient in an acute setting, especially in the case of hemodynamic instability.

You have probably already heard too much about REBOA. Proximal balloon occlusion might be useful in the case of a major renal artery injury causing critical instability. It allows you to perform a maneuver of visceral rotation to explore the renal hilum and to assess the injury pattern. Remember that an aortic zone between the celiac trunk and renal arteries is also called a "no-occlusion" zone, so care should be taken to reduce ischemic time as much as possible.

Remark:

» Here, also consider Zone I or II REBOA but with pREBOA if possible. It might give you some stability to continue with open repair.

There may be problems with elevated blood pressures later on if some, but decreased, perfusion remains in the injured kidney. Endovascular treatment is not the perfect solution for major kidney injury, but you need to consider nephrectomy if bleeding from the kidney is the reason for hemodynamic instability. However, in some cases, if feasible, and if the patient is in angio already, you can stop the kidney bleeding by endovascular means to stabilize the patient, and then finalize treatment with nephrectomy carried out at a second stage.

One more annoying remark:

» In patients with multiple previous abdominal surgery, these maneuvers can give you time for exposure…

In blunt trauma, you may sometimes see a completely dark kidney on CTA without any contrast perfusion. The reason for this is a blunt stretching injury to the renal artery, leading to thrombus and occlusion. Now, you will

Figure 5: Traumatic kidney injury. CTA is valuable to get information on injuries andendovascular or hybrid possibilities.

Figure 6.1

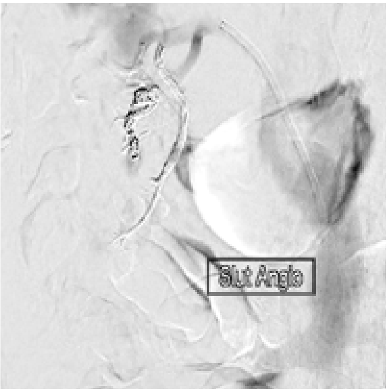


Figure 6.2

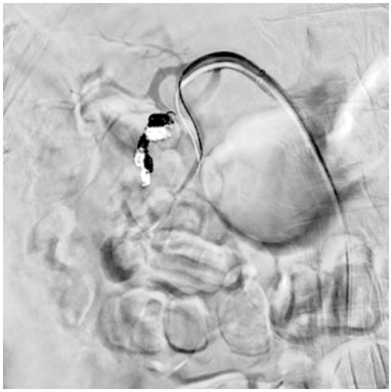


Figure 6.3

Figure 6 1-3: Kidney embolization using coils and Onyx.

obviously not have a bleeding problem, buy you may consider revascularization of the kidney by stenting the occluded artery open. The kidney tolerates warm ischemia poorly, and the revascularization should take place within the first hour after hospital admission. The result is not guaranteed, and the risk of future blood pressure problems is relevant, but in certain cases it is worth trying. You just need to get the diagnosis and stenting done promptly. So, EVTM might have a place for these patients.

Intercostal and lumbar arteries

Intercostal and lumbar-artery bleedings normally set spontaneously. In some cases you may have several arteries bleeding, especially in the presence of imminent coagulopathy, and you may find yourself evaluating the need for operative control of these nasty bleeders. The lumbar arteries are practically non-approachable. In severe bleeding cases, confirmed by prominent contrast blush on CTA and with the need for bleeding control, consider taking the patient into angio for endovascular embolization. Intercostals may bleed even more, since the chest wall and pleura are normally also injured, and there will be no counter-pressure due to free bleeding into the pleural cavity. Intercostal bleedings normally cease spontaneously, but especially in the case of compromised coagulation, you will have continuing blood drainage through the intercostal drain. At this point, you need to react. If you can't correct the coagulation very soon and the bleeding continues, **you have to intervene**. Embolization of such a bleeder can be only done by experienced hands. A few neighbouring intercostal arteries and an ipsilateral internal thoracic artery should be occluded to avoid rebleeding from collaterals. This usually takes time.

You must consider the pros and cons related to the endovascular and operative approaches. Thoracotomy is a large exposure but needs to be carried out if the patient is crushing, or for other reasons (associated lung injuries, cardiac injuries, evacuation of hematoma, lack of vascular access, and so on). In less unstable situation, endovascular embolization can be performed. However, it can take a long time to get into every single bleeding intercostal to occlude, compared with thoracotomy and putting the fingers on the top of bleeders for instant control. Also, both intercostals and lumbals will have some back flow after you have occluded the proximal site, and it may be impossible to control all the bleeding by endovascular means. Anyway, if you already happen to be carrying out endovascular treatment for some other reason, such as a bleeding pelvis, check the lumbals and control the prominent bleeders.

Tip:

» You might also consider liquid embolization to close the "back door" of the bleeder.

Extremities

Life-threatening bleeding from the extremities can be temporarily controlled immediately by using a tourniquet or manual compression. If bleeding is in the groin or axilla, you probably can control it by very hard pressure just above the inguinal ligament or high and medial up in the axilla. After primary control, you need to have proximal control of the bleeder. In the groin, you may need to expose the iliac fossa extraperitoneally and clamp the external iliac. This approach is relative simple and feasible. You open above the inguinal ligament and dissect down to the vessel, trying to avoid entering the peritoneum. However, it is a completely different and much more demanding ball game in the axilla compared with the groin. In axillary bleedings, surgery and repair require expertise that general surgeons seldom have. But, think of endovascular means. If you can just control the bleeding with local pressure or balloon catheters filled in the wound canal, take the patient for urgent endovascular balloon occlusion of the subclavian artery for proximal control. It may even be possible to deal with the arterial injury completely with a stent graft. At least you will have gained time for relatively time-consuming surgical exposure of the subclavian artery, to which the surgical team can proceed after the balloon occlusion. Another options used clinically in inguinal bleeding is ABO from the contralateral side or even from the SFA as we showed before.

Remark:

» See the other chapters for more tips and tricks on these issues.

Following the idea of EVTM damage control, you just need to do something from inside a vessel to restore arterial patency or to prevent further bleeding. You see a sharp "cut off" of the subclavian artery upon CTA. If you have stent grafts of appropriate diameters on a shelf, then you can try to recanalize the zone of injury followed by covered stent (stent graft) implantation. It may not be optimal right now, but the artery is patent and there is less threat to a limb. The type and success rate of such a procedure is operator dependent. Even through-and-through recanalization from femoral to brachial/radial artery can be achieved in difficult cases. Again, not a beginner's maneuver.

Said simply, there are two main types of extremity arteries: major and minor. In terms of EVTM, **minor arteries can be embolized** without any danger, and the **patency of major arteries has to be restored**. Bleeding branches, such as the deep femoral artery, circumflex arteries, the thoracoacromialis, should be embolized if possible. There is a temptation to stop peripheral bleeding, let's say, from the SFA or popliteal artery, by a simple endograft. Remember that a patient has to take anti-thrombotic medication for a long time after such procedures. You should give weight here to the age of the patient, compliance to treatment, the possibility of follow-up examinations, and so forth. **Might not be optimal for a young patient?**

If you consider endo is not optimal here, just set the balloon for proximal control and go straight to the bleeder. Lateral suture repair is not the worst thing in trauma surgery and works very nicely. Vein interposition grafting is a reliable solution, and should not be avoided if indicated!

Notes

Chapter 11

EVTM when you have limited resources

Viktor Reva and Tal Hörer

You have to be lucky to work at a level-one trauma centre. The trauma system is well organized, everybody knows what to do and how to do it, all the equipment is readily available. The system is stable.

A patient with severe chest trauma is admitted to your hospital. He has multiple rib fractures and a clavicle fracture. The left hand has a weak pulse, and there is a supraclavicular pulsatile mass. The patient is stable. CTA reveals partial injury of the first/second portion of the left subclavian artery with contrast extravasation. You go through with a 0.035 inch guidewire and put a covered stent inside the lesion. The problem is solved and a sternotomy or "book" thoracotomy is avoided.

But what do you do in your OR if you do not have a shelf full of numerous devices, stent grafts, catheters, etc.? You do not have an angio suite, and no interventional radiologist is on call. It is clear that extensive open proximal arterial control presents as an additional insult to the injured patient. You know it and want to change the usual practice of open trauma surgery. What do you need for it?

1. The will to provide the best possible care for your patient.
2. Appropriate training in both open and endovascular methods.
3. Fluoroscopy (any mobile C-arm).
4. Minimal equipment.

The first is indisputable. Until you follow entirely your hospital's old standard recommendations, you can easily say that no EVTM is indicated. Some patients tolerate big incisions well, some do not. But it is in your power to change the practice of your local hospital. You have to be appropriately trained in basic endovascular skills (see other places in this manual).

If you do not have a fluoroscopy machine, then your EVTM practice might be limited to REBOA only. Take any standard X-Ray machine, put a cassette under the patient's body and go in (see the REBOA Chapter). For any other procedure you have to use fluoroscopy. Although both wires and catheters can be seen well under ultrasound guidance, it is difficult to navigate them into the targeted vessel. But it can be done.

The EVTM techniques that you might adopt can be divided into two groups: "occlusive" or "closing" procedures, and "opening" procedures. You have a broad spectrum of possibilities in terms of the first procedures, but equipment limits the second set of procedures. That is reasonable because it is harder to build than to destroy. "Occlusive" procedures mean any kind of embolization. There are many different embolic materials available on the market, such as coils, Onyx, emboshperes, NBCA, etc., but they cost quite a lot of money. The only aim of this type of procedure is to occlude the vessel somehow. For any bleeders from minor arteries or bleeding arterial branches, you can prepare the coils *ex*

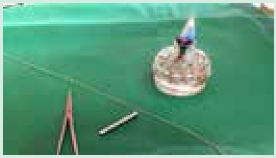


Figure 1

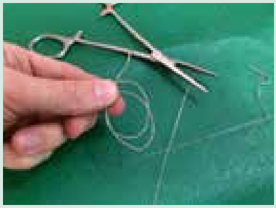


Figure 2: Remove the core from the wire and use the external winding to make coils. Than the core for straightening the colis before introducing them into the catheter.

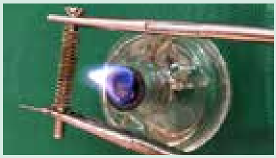


Figure 3: WInd the soft part of the wire around the screw and heat for some minutes. When the wire cools down, cut it to pieces. Use the guidewire core to straighten the colis.

Figure 4

Figure 5

Figure 1-5: Home-made coils using a wire.

Figure 6: Selectve embolisation of a gluteal artery after gunshot injury. Home-made coils used here.

Figure 7

Figure 8

Figure 7-8: Collagen sponge embolization.

tempore from a standard starting guidewire. It is not recommended but we will show it anyway. Maybe you will run out of wire in your fancy hybrid suite one day!

Another common approach is to use gelatin sponge or powder or even collagen sponge, which is much cheaper. Sponge injected selectively though a diagnostic catheter temporarily occludes a targeted vessel and provides excellent hemostasis in case of severe pelvic bleeding, splenic injuries, arterial branches, etc. See other places in this manual for further details.

The powder just needs to be diluted with a mixture of saline and contrast medium. While doing an angiography, you certainly get some blood out from the catheter, so when it is clotted you can use these sterile clots for embolization of the bleeder. It provides immediate but temporary hemorrhage control, and that is what you need in most cases, at least until transportation to another hospital. Another cheap embolic material is suture material. Just put a short piece of a surgical suture into a catheter's shaft and push it with a syringe. Repeat if necessary.

Now you know how to embolize a bleeder for free. All you need is just to cannulate the targeted artery with an angiographic catheter. Which type of catheter depends on the vessel and individual anatomy. There are a huge amount of different types of catheters, but in most cases just a few are enough: a Judkins Right catheter, a Simmons catheter, and a Cobra catheter. The difference between them is in the tips. So, you need a few catheters to make embolization possible. But if you have only one of them on the shelf, you can use a boiling kettle to soften a catheter's tip above the steam and reshape it as you wish. You can do the same with the tip of a guidewire, and no steam is needed. Just use a common needle and your fingers to modify the tip for better manipulation.

Of course, all these instruments are single-use items, but if your hospital does not buy equipment for them, theoretically, you can reserialize them in a plasma sterilizer. Note, that resterilization is not recommended, and it is completely your own responsibility. Obviously, we cannot recommend it in this manual!

Certainly, you cannot embolize an arterial injury in the way described above. So, you must use one of the "opening" procedures instead of a "closing" one. You have no stentgraft available for definitive hemorrhage control. But you can take any cheap non-compliant PTA balloon for proximal arterial control if no runoff is seen on angiography, or for topical control inside a zone of injury if the wire has passed through the lesion. Usually, we use an inflation device with a manometer for PTA balloon inflation, but here you just need gently to occlude the vessel and can use a standard Luer-Lock syringe with a three-way stopcock. When proximal control is achieved, go straightforwardly to the hematoma for open repair. Or you can even leave the inflated balloon in place as the endovascu-

Figure 9.1

Figure 9.2

Figure 9.3

Figure 9 1-3: Extravasation on CTA in a patient with pelvic fracture. Angiography with extravasation and coils in place. Can be done with a simple C arm and any material described above for embolization. It's your technical skills that matter, not the fancy equipment!

lar damage control option if the patient is critically unstable or if the patient is referred to another hospital. You can use this technique for most penetrating arterial trauma. An antegrade femoral puncture will allow control of any arterial lesion of an extremity. At the end of arterial reconstruction, you can do a completion angiography through the sheath placed in the femoral artery.

So, what do you need on your shelf to have the possibility adopting an EVTM approach?

» Puncture needle 18G
» Sheath 5-6Fr
» Long wire (straight tip)
» Diagnostic catheter
» Non-compliant balloon of large size (8-9 mm)
» REBOA balloon
» Gelatin or collagen sponge (or powder)

For appropriate use of these devices, be prepared mentally and practically. Train yourself and your team. And spend a bit of money to buy some very basic armamentarium, which might save your patient's life someday.

Notes

Chapter 12

Management of the REBOA patient in the Intensive care unit

Jan O. Jansen, Tal Hörer and Kristofer F. Nilsson

So your REBOA patient has made it off the table, and is being taken to the intensive care unit. With a bit of luck, things have gone well in the operating room, and the balloon has already been deflated. On the other hand, things may not be so rosy, and the balloon is still "up". What now? Those who like to base their practice on evidence will be disappointed. Current experience of REBOA is still limited, and reports of this experience are even fewer. In particular, there is no specific guidance on how to manage the REBOA patient in the intensive care unit (ICU). However, much can be inferred from the post-operative management of trauma patients in general, and that of patients who have undergone surgery for vascular disease. There is now even limited experienced with REBOA placed in the ICU due to circulatory collapse (not only in trauma).

What are the issues?

On arrival in the ICU, your patient will probably be cold, acidotic, coagulopathic, on vasopressors, anuric, and have associated injuries, which have not been fully evaluated or solved! Anything better than this, and you have lucked out. A good handover between the anaesthetic/surgical and ICU team should, in addition to the usual details, include information on when the balloon was inflated and, if applicable, deflated, ischemia time or whether there had been trial deflations, or partial occlusion (pREBOA, iREBOA). Obviously, total time of occlusion is important as well as localisation (Zone I? Zone III?).

Resuscitation

Unless the anaesthetic and surgical teams have done an outstanding job, your patient will require further resuscitation, and repayment of the "ischaemic debt" (see text elsewhere in this manual). The quality of your resuscitation will be a key determinant of outcome. This applies particularly if the balloon is still inflated. Balloon deflation will result in redistribution of the blood volume, and unless the patient has been well resuscitated, will result in catastrophic haemodynamic deterioration. Balloon deflation should therefore be treated with the same respect as removal of the aortic cross-clamp, following abdominal aortic aneurysm repair.

Even if the balloon has been deflated successfully, it is likely that the patient will have ongoing resuscitation needs. In other words, having hemodynamic stability does not mean that the patient is well! The aim now should be to reverse hypothermia, acidosis, and coagulopathy, and to discontinue vasoactive drugs, as quickly as possible. The endpoints of resuscitation are a normal temperature, normal base deficit, normal lactate level, normal coagulation tests (whatever type you are using), the absence of vasopressor infusions, and – ideally – a good urine output. In addition, lower extremity circulation should be "normal". Remember that you have just accessed the patients femoral vessels…

Usually, the situation will require the infusion of further blood products. Haemoglobin concentration is not an endpoint of resuscitation – haemoglobin levels can be normal, despite profound blood loss. In the face of persistent metabolic derangement, haemostatic resuscitation, with packed red cells, plasma, platelets, and cryoprecipitate, should be continued, and continued quickly, as prolonged shock will exacerbate the systemic inflammatory response. A "1:1" ratio of units of packed red cell concentrate and thawed plasma is a reasonable strategy. Unless already in place, additional venous access may be required. The easiest way to achieve this is usually by means of a "Cordis", or pulmonary artery catheter introducer sheath, in the subclavian or internal jugular vein(s). You might want to use a femoral vein sheath as well (depends also on your local routines), and replace it by central-line later on.

The use of synthetic crystalloids should be minimised. These fluids contribute to hyperchloraemia, and therefore metabolic acidosis, and haemodilution. There is no place for synthetic colloids in trauma resuscitation either. Buffering fluids (bicarbonates) should be considered, even though there is no clear evidence for their use.

Attention should be paid to electrolyte abnormalities: Hypocalcaemia is common, and can have profound effects on myocardial contractility and vascular responsiveness, and should be corrected by giving Calcium chloride or gluconate. Similarly, hyperkalaemia may results, as a consequence of administering blood products and acute kidney injury or due to release of intracellular potassium. Acidosis may also cause hyperkalemia. Serum potassium concentration should therefore be checked regularly and, if necessary, treated with insulin and renal replacement therapy. Hypothermia should be prevented or, if it has already occurred, be proactively treated. Under-body devices, such as heated mattresses, are particularly useful. On-the-body, forced-air devices, are less effective, but can be used in addition to under-body devices.

Monitoring

Unless there are comorbidities – in particular, cardiorespiratory disease – sophisticated cardiovascular monitoring is not required. The patient should have an arterial line, to allow the continuous monitoring of blood pressure, and to facilitate blood sampling. Some arterial access sheaths will permit pressure transduction. The patient should also have dependable venous access, which will often mean one or more central lines. However, these are used primarily for infusion, rather than monitoring. These is no value in measuring central venous pressure in trauma patients (or, indeed, any patient) – central venous pressure is not an endpoint of resuscitation. Advanced haemodynamic monitoring devices – such as PiCCO™, LiDCO™, CardioQ™, or Flotrac/Vigileo™ – also add relatively little during this phase. The diagnosis of haemorrhagic shock is usually obvious from other, more easily obtained parameters, and the resuscitation endpoints described above are more useful than calculated cardiovascular performance parameters. When there is genuine concern about cardiac dysfunction, whether chronic or as a result of injury, or indeed over-resuscitation, a bedside echocardiogram (if necessary repeated) is usually best at quantifying preload as well as contractility. Abdominal hypertension and abdominal compartment syndrome (ACS) may develop, and intravesical pressure should therefore be monitored. For this Foley manometer can be used with ease. Elevated pressure of more than 12mmHg is by definition abdominal hypertension (but might be effected by position, pain and other factors). A patient with elevated pressure more than 20-24mHg, or/and with signs of multiple organ failure (MOF) as decreasing urine output, is by definition ACS. These patients need aggressive treatment with different methods to decrease the pressure. If you don't take a pro-active approach, these patients will die. More on ACS and treatment can be found in other books or on the internet (e.g., world society of ACS).

AS we know on rAAA patients, even if your patient does well at on day 1, don't get to happy. Keep the patient in the ICU, see a bit more, see that all metabolic issues have been resolved and monitor REBOA patients carefully. You might meet some surprises on day 2, which leads us to the next issue…

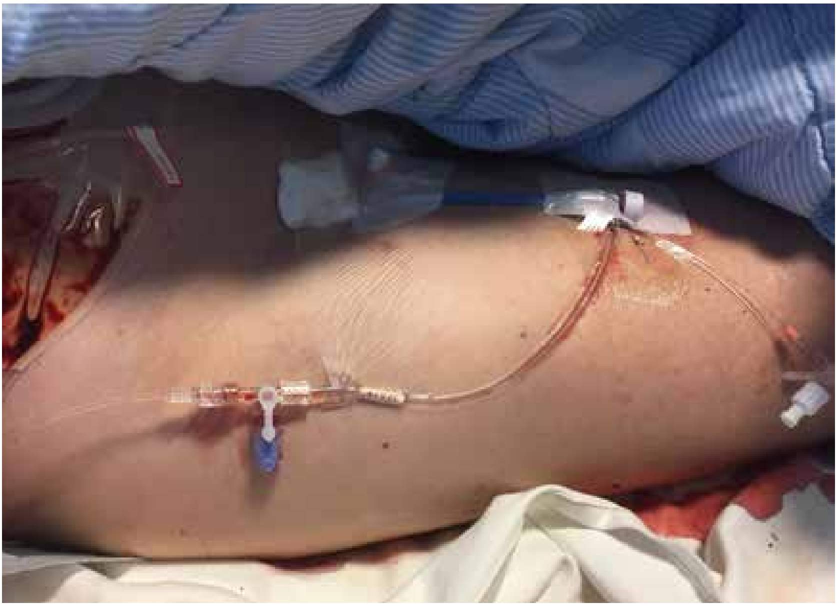


Figure 1: 12Fr sheath for REBOA used for blood pressure monitoring. Was used also during REBOA for pREBOA monitoring.

Post-reperfusion syndrome

REBOA, by design, gives rise to regional or indeed hemicorporeal ischaemia. (see the REBOA chapter) The magnitude of the insult is proportional to the completeness and duration of balloon inflation. Ischemia results in depletion of intracellular energy stores. When perfusion is restored, a post-reperfusion syndrome ensues, which involves a cascade of subsequent injuries, including activation and adhesion of leukocytes and platelets, generation of inflammatory mediators, calcium influx into cells, disruption of cellular membrane ion pumps, generation of free radicals, and cell death. Clinically, the syndrome is characterized by edema, further exacerbating intravascular volume depletion, and washout of myoglobin, potassium, lactate, and microthrombi into the systemic circulation, exacerbating hyperkalemia and hypocalcemia, and causing rhabdomyolysis and renal failure, ACS, and cardiac arrhythmias. All of these complications have to be anticipated and actively treated. Recognition can, however, be difficult when the sequelae of post-reperfusion syndrome are superimposed on the manifestations of hemorrhagic shock and hypoperfusion. In particular, when acute kidney injury has ensued, then using the resolution of metabolic acidosis as an endpoint of resuscitation is no longer possible. The situation requires experience and mature judgement.

Systematic inflammation

Injury, REBOA, operation, and post-reperfusion syndrome will all contribute to systemic inflammation. The systemic inflammatory response syndrome (SIRS) was first defined in 1991 at the American College of Chest Physicians/ Society of Critical Care Medicine Consensus Conference. SIRS is a physiological state, rather than a diagnosis. SIRS is commonly seen in trauma patients, as well as in patients undergoing abdominal aortic aneurysm repair. The treatment of SIRS is that of the underlying causes. Nevertheless, it is a useful concept, and both the duration and resolution of SIRS have been shown to be useful prognostic markers.

Anticipating complications

The use of REBOA is associated with a number of potential, and serious, complications. These may **relate to the access site** – bleeding is the most obvious, and relatively easily treated. The development of thrombosis, and subsequent acute limb ischaemia, may be more insidious, but can have devastating consequences. Repeated examination, and if necessary imaging, of the limbs is therefore essential.

The possibility of developing compartment syndromes has already been alluded to. These may occur in the limbs, necessitating early consideration of the need for fasciotomies, or in the abdomen. ACS which we mentioned before, may result from a combination of pelvic and retroperitoneal haematoma formation, as well as reperfusion-related edema, particularly of the gastrointestinal tract, even when not frankly ischemic. Frequent intravesical pressure measurements (the Foley manometer) may help in identifying the development of the syndrome.

Mesenteric and renal ischaemia and, if prolonged, thrombosis, are more likely to occur with intentional Zone I placement, or inadvertent Zone II positioning. Mesenteric vascular thrombosis would be a devastating complication which is, however, difficult to detect – particularly in the context of an established systemic inflammatory response. Deviation from the anticipated clinical course, whether characterised by an "excessive" inflammatory response, or lack of resolution, should prompt a search for possible causes. However, recognising such deviations from the expected course is exceedingly difficult and, once again, requires experience, judgement, and a high degree of suspicion.

Acute tubular necrosis, whether caused by Zone I balloon placement, or haemorrhage-related hypotension, perhaps exacerbated by the administration of contrast material, will occur in many patients who have been treated with REBOA. The metabolic consequences of acute kidney injury will complicate the assessment of shock, adequacy of resuscitation, and fluid management. Supervening renal failure will result in a non-lactic metabolic acidosis, by contrast with the lactic acidosis caused by hypoperfusion, and the measurement of lactate levels may help to distinguish between these two conditions. Anuria and hyperkalaemia will necessitate renal replacement therapy. As in other conditions, the choice of modality – haemofiltration, haemodiafiltration, or haemodialysis – is probably not important.

Associated injuries

Patients who required REBOA typically did not complete even the "primary survey" of assessment. Based on the ATLS "ABCDE" (Airway, Breathing, Circulation, Disability, Exposure) paradigm, these patients only advanced to the assessment and treatment of "C". If the more modern "<C>ABCDE" concept is considered, where "<C>" signifies the treatment of catastrophic haemorrhage, then assessment is even less complete. It is therefore imperative that patients undergo a thorough secondary survey as soon as they arrive in the ICU, and subsequently a tertiary survey. These assessments may involve additional imaging, which may have to be deferred until the patient's haemodynamic and metabolic status permits. Nevertheless, patients should be thoroughly examined, at the earliest possible opportunity, to identify other injuries requiring urgent treatment.

There are many other issues that you have to think about. For example, the need of antibiotics, the presence of synthetic materials used (grafts or endografts), any bowel perforation, and the manifestations of systemic inflammation and multiple organ dysfunction. What is the circulation to the target organs like? To the extremities? If this a healthy young patient or someone with multiple co-morbidities that complicate the situation? All of these factors and more should be considered when approaching patients who have been treated with REBOA or other EVTM treatments, as maybe is the case for all trauma and bleeding patients.

Comment:

» The role of ECHMO in trauma is not clear, but we might speculate that we will soon hear more on that issue.

Take-home points

Experience of managing REBOA patients in ICUs is limited. However, as with most ICU patients, outcomes are optimised by attention to detail, frequent re-evaluation, "doing simple things well", a high index of suspicion, and a healthy dose of good judgement. Endovascular tools can save time and patients, but there is a need for re-thinking and frequent re-evaluation in the ICU. **"It's not over until it's over!"**

Notes

Chapter 13

Some thoughts and remarks on endovascular and REBOA complications

Tal Hörer

We mentioned in different parts of this manual that you should anticipate problems and complications. When using endovascular methods, you should always have in the back of your mind thrombosis, dissection and vessel perforation as well as access vessel bleeding. Whenever you puncture a vessel, you are performing an invasive manoeuvre and disrupting the normal anatomy. In many cases, the damage is minimal, and if you manage the access site well, it will heal. When you puncture and when you bail-out, make sure the vessel is functional – by palpation, US, Doppler, or any other means. Always check the distal status of your access vessel and have a **high level of suspicion**. If you have a feeling that there is no flow in the femoral artery (thrombosis or dissection), go with your gut feeling and do what must be done (open exploration). Until recently, REBOA has meant using big sheaths (12Fr usually). In bleeders, the vessels are empty and the vessel lumen has probably been occluded for some time. This is a great location for thrombus formation. So, after every REBOA, you should think about these issues and be pro-active. Thrombus formation has been reported (personal communication) even with the low-profile systems that are coming up now.

Tips:

- You did a vessel puncture for access, didn't you? Think about complications like bleeding, thrombosis and dissection. Always keep strict control of your access site in the immediate postoperative period.
- Do you feel that there is something wrong, and the flow in the femoral artery (or any other access) is not ok? Act, investigate and repair. These patients have no margin of error.

When you perform a hybrid or endovascular treatment, bear in mind target organ perfusion as well as potential vessel injury due to balloons, endo-grafts or any other products. Control angiography, if possible, is always a good option. Did you deploy a stent graft? Did you use ABO? Do a control angiography and see with your own eyes the flow in the vessel on the screen infront of you!

Another way to check your endovascular repair is CTA. This will give you information on the vessels, target organ perfusion, bleeding, hematoma formation, and other injuries. Yes, with CTA you will inject 100–150cc of highly concentrated contrast media that might cause more damage to the kidneys. It is a problem, but think about what you need to know now and avoid more severe problems like vessel occlusion, perforation or other injuries.

We mentioned before that REBOA may cause ischemia and reperfusion injuries. So, when you are done in surgery, the problems are not over yet. "It's not over until it's over". Anticipate ACS, intestinal ischemia, leg ischemia, hypercalemia, acidosis etc. Intensive unit admission and a pro-active approach are

Figure 1

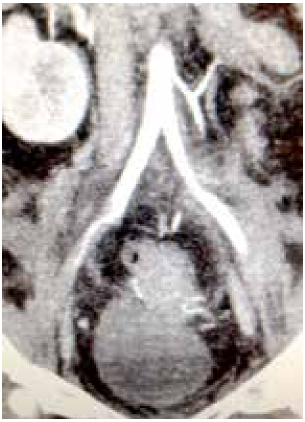


Figure 2

Figure 3

Figure 1: A trauma patient with severe atherosclerosis and stenosis of the iliac vessels. Any puncture and attempt at access in these patients may cause occlusion and increase the risk of ischemia.

Figure 2: Iliac thrombosis on the right side. Access may be challenging, and further steps should be taken to solve the problem.

Figure 3: Hematoma in the inguinal region after elective angiography. Needed open exploration to solve the problem.

highly recommended, at least for 24-48 hours. The majority of patients with a high injury score (ISS or other) will stay days in the ICU, but even if you have a patient with a fast-bleeding solution and fast recovery, let him or her stay in the ICU until you are sure that everything is under control. Strictly monitor the distal-extremities status, general status, all surgical wounds, intra-abdominal pressure, and access sites. Some of us perform control of the extremities hourly during the first 24 hours. Treating the patient with anticoagulation of different sorts might be beneficial but should be individualized.

Another issues in the puncture method for CFA access. Avoid high puncture and if you are not sure and the patient become hemodynamically unstable, act and exclude retroperitoneal bleeding.

We would recommend re-assessing your patient after any endo or hybrid procedure. At times, minimally invasive procedures may cause "invisible" problems. A high level of suspicion is needed as well as great clinical experience. Use all the tools you have and rely on your clinical judgment to confirm your results. Did you solve all the problems? Did you cause other problems? Did your REBOA cause intestinal ischemia? Is the SMA or iliac artery OK? Is the leg perfusion OK? Ischemia-reperfusion injury? You have just put great effort into stopping the bleeding. Make sure the patient is in the best postoperative place available, and make sure things are getting better. If you don't, you will get a call in one or two hours, or in the middle of the night, with the on-call doctor claiming (correctly) that the left leg is cold and there is no Doppler signal.

So, endo or hybrid procedures carry risks as well. Consider what to use and make sure you detect complications on time. Forget the words "it's ok"-

It's not over until it's over and the patients walk out of your hospital...

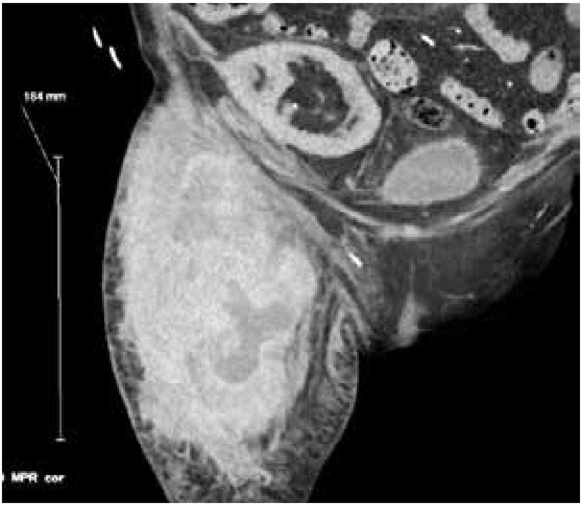


Figure 4: A huge hematoma 2-3 weeks after a simple endovascular heart procedure. Pseudo-aneurysm and rupture.

Figure 5: Removal of REBOA and sheath. Note thrombus on the balloon. Might cause some serious problems.

Notes

Chapter 14

How to perform, learn, and train

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In the past, endovascular techniques have predominantly been in the domain of interventional radiologists, with the majority of techniques focused on the treatment of non-urgent, age-related disease changes. Influenced by major developments in management of combat related trauma in Afghanistan and Iraq in the last 15 years, as well as the development of lower profile endovascular devices and techniques, application of endo-vascular methods in haemorrhage control has been experiencing a recent surge. Application of interventional techniques in trauma is growing and there is a parallel need for translating the basic endovascular skill set to non-IR practitioners such as trauma surgeons, and emergency physicians. **Endovascular management of trauma is in its infancy** and a lot is still to be accomplished in order to optimise training in this field.

This chapter aims to present some of the higher order issues in EVTM, such as the philosophy and learning that is required to effectively deliver this type of intervention. It also aims to present the various options for training in this evolving discipline.

EVTM Skills

Endovascular procedures are complex and require skills used mainly in an interventional radiological setting. EVTM demands fine manual dexterity, familiarity with devices used for access and haemorrhage control including sheaths, wires, catheters and embolization materials as well as knowledge of the exact procedural steps. These skills should be integrated into general trauma management and the overall institutional haemorrhage control paradigm – with awareness of both endo and hybrid approaches.

To deliver optimal care to a trauma patient using endovascular techniques, an operator needs to have basic trauma skills, and a range of endovascular skills including: vascular access, REBOA, catheterization of main aortic branches, embolization and stenting.

Remark:

» Sounds scary? Sounds like it takes long time to learn these things? You have a point there. This is a very serious matter and training is essential for using EVTM tools! Some can learn basic EVTM fast and for some this might take year!

Practitioners should have the capability of obtaining access using a variety of methods (cut-down, blind, ultrasound and fluoroscopy-guided puncture), interpret images obtained via CT, ultrasound and angiography and have a general understanding of radiation exposure and measures that should be implemented to maximise the safety of patients and staff in an IR or hybrid suite. An important difference between endovascular manoeuvres in routine IR practice and trauma is the **tempo** required by the operator performing the procedure on a hemodynamically compromised patient and need to quickly respond to changes in the patient's physiological signs and angiography findings.

A Team Philosophy

Whether a local endovascular care system is led by a trauma surgeon, interventionist or an emergency physician, successful implementation of EVTM requires a **multidisciplinary approach** and active involvement of trauma surgeons, interventional radiologists, and anaesthesiologists. Only a few centres enjoy the optimal model for endovascular trauma care delivery, where an interventional radiologist or an endovascular surgeon enjoys being an integral part of the trauma team. The involvement of such individuals occurs from the time of the patient's arrival in the emergency department, carrying the responsibility of the procedure whilst maintaining continuity of care. Although it is unlikely that such a model will be adopted worldwide anytime soon, but growing implementation of EVTM and likely eventual integration into routine emergency care highlight the need to develop a structured learning process for in-hospital trauma teams and practitioners.

Figure 1: A Simple illustration of team approach during REBOA procedure.

When it comes to endovascular intervention specifically, a successful team should be led by an operator who is cognizant of the extent and limitations of her skill set, but also of the capabilities of the rest of the team including scrub nurses and radiographers. Adequate **team based training** is crucial to developing a well-organized trauma team where every member has their place and contributes to the optimal care of the patient. This includes the scrub nurse being able to prepare the necessary equipment for each specific intervention, to the radiography technician who should aim to prevent unnecessary exposure to ionizing radiation. Team training can be enhanced with moulage scenarios where teamwork in emergency care can be practiced with improved realism.

In-depth familiarity with local facilities (IR suite, hybrid theatre etc.) and awareness of availability of specific endovascular devices

Figure 2

Figure 3

Figure 4

Figure 2-4: The EVTM workshop in Örebro, Sweden

through regular, periodic evaluation and an appropriately stocked inventory is an important adjunct to interventional team organization and is critical in saving time during critical moments of the procedure.

EVTM Training Courses

At the time of writing this publication, several courses are internationally known to be offering hands-on endovascular skills training to trauma surgeons and emergency physicians, interventional radiologists and intensivists involved in care of trauma patients.

The **EVTM workshop** is the only known European workshop organized biannually in Orebro, Sweden, aimed at teaching basic endovascular access skills, REBOA, basic embolization, and hybrid bleeding control methods. This two-day workshop uses a combination of seminars, group discussions and dry and wet lab hands-on training including endovascular virtual reality (VR) simulators, animals and cadavers. debates, discussions, cases, models and live tissue training. Vascular access and REBOA are just some of the key issues in this workshop. The EVTM workshop is a platform for sharing information and skills and aims at surgeons, intensivists and IR people from around the world. The Swedish residents trauma workshops (Örebro, Sweden) are also done yearly and is a mixture of both traditional trauma care and some basic endovascular methods as REBOA.

The **Endovascular Skills for Trauma and Resuscitative Surgery** (ESTARS) is a comprehensive 2-day course based in the USA, which utilizes lectures, endovascular VR simulators and live animal laboratories for training skills in femoral arterial access, proximal and distal arterial control techniques, angiography, coil embolization, REBOA, and shunt placement.

The Basic Endovascular Skills for Trauma (BEST™) course has been adopted by the American College of Surgeons Committee in Trauma (ACS COT). Originally developed in the University of Maryland's Shock Trauma Canter in Baltimore, there is planned expansion of the course to other locations around the USA. The one-day, concise and intensive curriculum focuses on training REBOA with the use of virtual reality endovascular simulation and models of pressurized cadaveric vasculature.

Another international training event is the **Diagnostic and Interventional Radiology in Emergency, Critical care, and Trauma** (DIRECT) course which has been developed in Japan and taught in Japanese. This 1-day event is aimed at emergency and medicine physicians as well as trauma surgeons and interventional radiologists and consists of didactic seminars and hands-on workshops with VR simulators and embolization materials.

There are new workshops and courses coming up in Europe (for example in London) and it appears that the interest in courses is huge.

Simulation

Endovascular procedures are characterised by the need to manoeuvre a wire within a three-dimensional vessel, whilst observing its position on a flat screen. In the trauma setting, in the presence of haemodynamic instability, the complexity of endovascular manoeuvres is further expanded by constant anticipation of changing physiology and the need for increased tempo to control bleeding in time to save the patient. The learning curve needed to obtain proficiency in endovascular trauma skills is steep and renders the traditional apprenticeship learning model inefficient. A range of simulation modalities allows trainees of a variety of backgrounds with different levels of experience learn and practice manual skills without compromising patient safety. With a variety of available simulation modalities, a trade-off between fidelity, access and cost exist. Whilst human and animal cadavers as well as VR simulators are more realistic, their use is usually limited to training more advanced endovascular techniques such as embolization and stenting, leaving more simple training devices to rehearse basic skills such as access and wire and catheter manipulation.

Synthetic models

A number of man-made trainers, phantoms and manikins are available, commercially depending on the particular skill needed to practice. These range from simple manikins with dyed liquid which can be used for ultrasound guided Seldinger technique vascular access, to more sophisticated phantoms with branched vessels and pressurised fluid. Simple trainers can be assembled at home using basic materials such as a segment of tubing fixed to a working table which serves as a blood vessel, allowing rehearsal of vascular access through cannulation and use of sheaths, catheters and wires. By connecting transparent plastic tubes at different angles to represent arterial branches, one can practice catheterizing those branches or even embolizing them with handmade coils. A few realistic artificial simulators allow puncturing a pulsating artery, but they are usually expensive. Depending on availability (usually limited to large centres), a pulsating pump can be connected to an artificial vessel in a simulator to allow more realistic representation of an artery. The more creative and determined trainees, might find that a home-made device composed of chicken thigh connected to a pulsating pump with liquid, provides a realistic training tool for US guided access of small vessels. There are now on the market 3D models that "real" anatomy (e.g., 3D Imprimo Ltd as well as well as other companies within the endovascular industry).

VR Simulators

While there is no replacement for live patient experience, with constantly improving technology, there is a growing access to sophisticated, high fidelity, digital software based, virtual reality simulators- which have been proven to safely aid development and assessment of advanced endovascular skills. Although they are expensive and access is limited, VR simulators can be used to train endo skills in an educationally oriented environment, without time constraints, risks to patient or ionizing radiation. Depending on software provided, VR trainers can be patient specific and use simulated fluoroscopic imaging allow training a variety of scenarios including internal hemorrhage control techniques and REBOA. VR simulators not only allow training but can also provide objective assessment of performance of technical skills, radiation exposure and contrast media use, and have been validated for their use. Despite their wide range of benefits VR simulators are expensive, require extensive setup and high maintenance due to frequent breakdowns. They are usually limited to large centres and training courses.

Live animal training

Anaesthetized arge animals (usually swine and sheep) provide an invaluable adjunct to improving manual endovascular skills due to their degree of realism, however they require specialist facilities. Animal models are expensive and are associated with ethical and legal issues limiting their access. In practical terms, the blood vessels in animal cadavers are thinner and smaller than those of humans, making vascular access more difficult. Animals also tend to lack atherosclerotic disease and cannot always reflect the obstacles met when cannulating human vessels with calcified plaques. Animal training can be done in different scenarios and recently, a pre-hospital REBOA helicopter/battlefield was performed on pigs. This, or a similar, model might be of interest for pre-hospital training.

Human cadavers

A human cadaveric model with artificially established pulsatile arterial flow following thrombolysis, provides a high-fidelity training too, allowing practicing vascular access techniques and REBOA within a full procedure setting from arterial access to closure. Similar to animal cadaveric models, there is limited availability due to high cost stemming from complex preservation and storage needs of the cadavers. There are now some perfusion cadaver models that are very realistic for endo training, and some under development.

Case reviews

Multi-disciplinary team meetings where cases are reviewed can be a great adjunct in EVTM training. Interdepartmental collaboration involving radiologists, orthopaedic surgeons, emergency physicians, and anaesthetists, where knowledge and experiences are shared, can enhance the educational experience. During these case reviews, two schools of thought are often discussed: *pro* endo and *pro* open surgery, as the nature of these meetings is usually retrospective the applied method of management as well as the outcome is known. Drawing a conclusion, a moderator might pay special attention to both methods of treatment focusing on advantages and disadvantages in every particular case. In case of lack of consensus on the appropriate treatment modality, the residents can be asked to prepare a presentation of a literature based review on the topic in question, in order to help resolve controversy.

Figure 5: Photo from a video. Video documentation of REBOA in the ER. **You can find more material on the www.jevtm.com**

Visual documentation

Visual documentation of cases (video recordings, radiology images) are a great adjunct to case reviews and provide an excellent learning tool for trauma surgeons. Video recordings ideally with a dialogue commentary by an operator can help a trainee improve their decision making skills with regards to specific steps of the procedure sequence. Similarly, recordings where a trainee is involved can be reviewed and used for constructive assessments of their skills once the procedure has been completed.

Training programs

Whilst most clinicians appreciate the importance of minimally invasive procedures in trauma, and there are some available training


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Figure 8


Figure 10


Figure 11


Figure 12


Figure 13


Figure 13

Figure 6-13: Training on different models for EVTM and REBOA.

aids in the form of training manuals and videos available pertaining to management of certain types of injuries. Despite available simulation modalities and courses a young trauma surgeon will be disadvantaged by limited skills development, unless they have an educational supervisor who oversees a structured EVTM training in their clinical practice. Well organised training programs and EVTM workshops are hard to come by. Only a few training programs in trauma surgery include a short block (up to 6 months) of interventional training in their curricula, and although currently considered optimal in terms of development of manual skills and "endovascular thinking", with growing prevalence of EVTM over the standard open approach in trauma surgery, the trauma surgery training needs will increasingly necessitate a review in resident training curricula. Developing a network with local/ national radiological and surgical societies is crucial in gaining support and optimising the quality of EVTM training.

Word of advice:

» We all highly recommend taking courses, workshops and other training forms in order to get at least basic training in EVTM issues before performing them on patients!

Here is a list of some of the major points of EVTM

- » AABCDE- it’s all about the vascular access- get one early
- » Working in a multidisciplinary manner- What do we have and who can help me?
- » REBOA if needed, as your bridge to definitive solution. Preferably pREBOA or iREBOA
- » Operate always bleeding or trauma patients on angiography table or sliding table
- » Are there any endo solutions for this bleeding? Are there any endo tools to help the procedure?
- » EVTM is a set of mind- endo and hybrid solutions
- » CTA if possible

But...

- » Endo is just a tool- Think how to use it on what patient, by whom?
- » Don’t just do Endo because you can- What does your patient need?
- » Forget your ego. Your patient needs excellent care now! Collaborate!

And, **endo is not instead of open surgery. Think EVTM!**

We tried to list here some EVTM issues. As this area is developing, you might find more information in the in the comming edtions and on our website: www.jevtm.com.

We will try to keep it updated with more exciting material related to EVTM and REBOA. The medical journal of EVTM (JEVTM) will provide scientific data on these issues.

Notes

The editor would like to express his thankfulness for family support in this as well as other projects (Joav, Adam, Sam and the one that can make things happen – Magdalena).

It's always an adrenaline kick when you get an unstable trauma patients to your emergency room. You stand there trying to understand what the major problem is and how to fix it.... Usually, you don't have a clue what is wrong when you see the patient but the truth is revealed within ten minutes...

Parallel to the endovascular revolution in vascular surgery, there is an ongoing revolution in trauma and bleeding management. We call it the EVTM- endovascular hybrid Trauma and bleeding Management. It's here to stay and might save your next patient.

In this manual, we gathered thoughts and ideas of many experts with only one aim: Try to put into text the new mind set of EVTM (including REBOA). This is a collection of very experienced people sharing their knowledge in a manual format combined with photos and illustrations. EVTM is evolving so fast that the text had to be changed during the writing process. We hope that you, the one that stands there when its chaotic and bleeding, will get some new information here and maybe can decide along the way- is EVTM something I can use for this patient?!

Written by experts within trauma, vascular surgery, general surgery, ICU and interventional radiologists with great passion for bleeding control and advanced trauma and bleeding care.

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