Chapter 1
The 3-D Trauma Surgeon

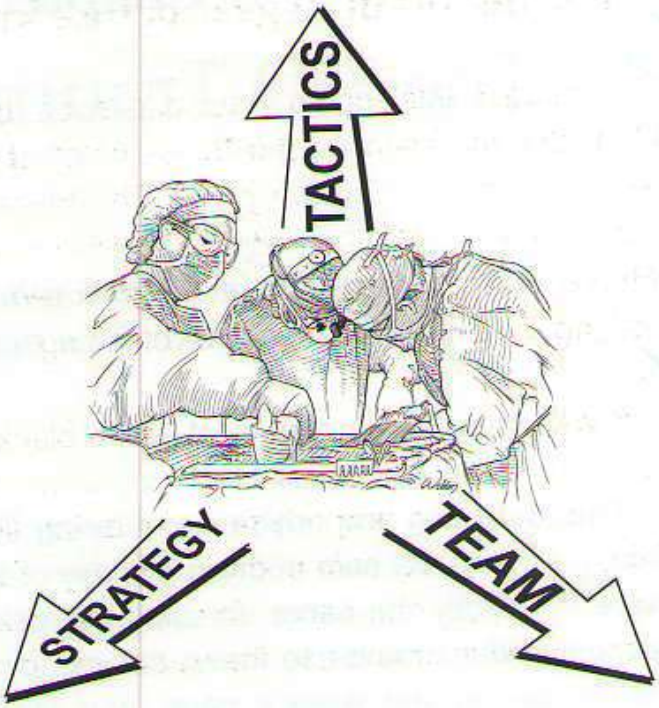
An expert is a man who has made all possible mistakes in a very narrow field.

~ Neils Bohr

The first thing you notice on entering the peritoneal cavity is bleeding from a large nasty hole in the right lobe of the liver. Strangely enough, you were in exactly the same situation a week ago. You don't even have to glance at the monitor to know the systolic pressure is going to be 60. Remembering last week's case, you rapidly pack the liver to stop the bleeding. However, this time the injured liver continues to bleed through the packs. It was supposed to stop. It did last week. What's wrong? What's different? You do a Pringle maneuver, but it doesn't help much. The metallic voice of the anesthesiologist alerts you that the patient's systolic pressure is now unobtainable. He is dying. What is going on? What do you do now?

You remain surprisingly calm for a surgical resident with only three or four years of training. The reason is simple: you know exactly what comes next. Soon the lights in the Surgical Virtual Reality Lab will be turned on and the simulation will pause. Using a revolving hologram of the injured liver and retrohepatic veins, your instructor will explain what went wrong and why. This "dry clogs" approach to teaching surgery is rapidly becoming a major part of surgical training. A simulator can help you learn to operate, yet something fundamental is missing.

When you work on a simulator, operate in a large animal lab, or work in the OR with a good teaching assistant, you learn the tactical dimension of the operation. You learn to select from several technical options and execute your choice in specific operative circumstances. You spend most of your surgical training focused on operative tactics in elective and emergency procedures. Only when you begin operating on your own do you become aware of the other two dimensions of every operation: strategy and team leadership.



The strategic dimension of an operation is the broad consideration of goals, means, and alternatives. When you operate with a teaching assistant, your teacher usually handles the strategic dimension for you. While you are absorbed in mobilizing the splenic flexure, your teacher is already weighing the options of a rapid damage control laparotomy against a time-consuming definitive repair. When you are working on your own, the strategic dimension suddenly falls on your shoulders. You can no longer focus exclusively on the holes in the colon, but must also consider the "Big Picture."

The third dimension of every operation is team leadership. Being a surgeon means making sure that the efforts of the OR team members are coordinated and focused on the same goals. You cannot assume your scrub tech knows what to do next just because he or she is smart and experienced. You must clearly communicate your plan. Similarly, the anesthesiologist does not have extrasensory perception and cannot guess your plan unless you share it. Mishandling the team dimension during a trauma operation is one of the worst mistakes you can make.

To operate effectively on wounded patients, you must train yourself to be a 3-dimensional surgeon who constantly zooms in and out of the tactical, strategic, and team dimensions, monitoring progress and reassessing options in each.

Putting brain in gear before knife in motion

Strategic thinking is essential even before you make the incision. Consider, for example, the "black hole" of surgery, a term you have never heard yet encounter every day. The black hole is the time between the patient's entry into the OR and the skin incision. It is an obligatory logistic interval during which the patient is moved, positioned, and prepared, but nothing is done to stop internal bleeding.

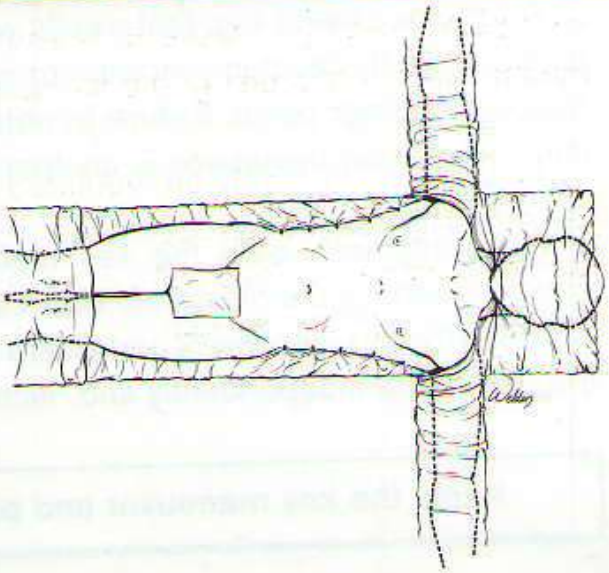
If you choose to spend most of the black hole interval at the scrub sink, you may end up with clean fingernails, but when you enter the OR you will find the patient improperly positioned, the scrub nurse prepping the wrong field, and the OR team effort in disarray. You may well have lost the battle before firing your first shot. To avoid this, stay with your patient until the last possible moment and use the black hole for effective preparations.

Is the patient positioned properly? Does the OR team know which operative field to prepare and which instrument sets to deploy? Does the anesthesia team need help with lines? You cannot address these questions from the scrub sink. Go and scrub only when you are sure that everything is set up and ready.

If the patient is in shock, don't waste time on scrubbing. Every second counts. Just get a gown and gloves, grab a knife, and rapidly dive into the chest or abdomen.

Sterility is a luxury in severe hemorrhagic shock

The way you position the patient and define the operative field are other indicators of your strategic vision. Always prepare for a worst-case scenario. In torso trauma, this typically involves access to both sides of the diaphragm and to the groins. Your worst-case operative field extends from the chin to above the knees,



between the posterior axillary lines. Abduct both arms to allow the anesthesiology team full access to the upper extremities.

For isolated extremity trauma, include the entire injured extremity in the field to facilitate manipulation, and prepare an uninjured lower extremity for saphenous vein harvesting. For a neck exploration, prepare the entire chest, since the upper mediastinum is a continuation of the neck.

Always prep for a worst-case scenario

ABC of tactical thinking

Train yourself to think of every operation as a sequence of well-defined steps, but memorizing the steps is not enough. You must gain insight into the procedure by learning the key maneuver and the pitfall in every step.

A *key maneuver* is the single most important technical act in an operative step. The key maneuver in mobilizing an injured spleen is incising the splenorenal ligament and entering the correct plane between the spleen and the kidney. Often, a key maneuver is identifying a gatekeeper, a structure that serves as a guide to dissection or opens the correct tissue plane. The gatekeeper of the carotid artery in the neck is the common facial vein. Identifying and dividing it is the key maneuver. When mobilizing the hepatic flexure of the colon, the key maneuver is finding the plane between the right side of the transverse colon and the duodenum.

A *pitfall* is a major trap that awaits you in every operative step. Choosing an incorrect thoracotomy incision or performing it at the wrong intercostal space is a major pitfall. Failure to obtain proximal control before plunging into a contained hematoma is another classic trap.

Familiarity with both the key maneuver and classic pitfall of every operative step is the difference between the trauma pro and the wannabe. Knowing the key maneuvers and pitfalls of a procedure allows you to perform the procedure independently and, with experience, teach it to others.

Know the key maneuver and pitfall in every operative step

A common tactical dilemma

Have you ever heard of flailing? Flailing is repetitive, ineffective action. It is one of the most common tactical errors of the inexperienced. For example, imagine yourself trying to control a bleeder with a hemostatic stitch. You insert the suture and tie it, but bleeding continues. You try again. It still doesn't work. You try again; maybe it will work this time. We can tell you without being there that it probably won't - you are flailing. Very often, flailing will be more obvious to the OR team than to you. How can you avoid it?

Get used to the idea that in the real world surgical maneuvers don't always work. Even the most technically gifted surgeon does not succeed in every move. You must learn to deal with technical failure effectively, not emotionally. When a maneuver doesn't work, don't take it as a personal failure. Pause and consider your options.

First, reconsider the need for the failed act. Is it really necessary? Does the bleeder require a suture? Perhaps it will stop with temporary pressure and patience.

Another option is to retreat and get help. If you are fortunate enough to have backup, use it. Someone more experienced often has a better chance of solving the problem. Recognizing the need for help and asking for it (whether you are a resident or seasoned trauma surgeon), is a sign of good judgment.

What if you are completely on your own and help is not an option? Then you must consider alternative techniques or a different approach to the problem. If your original solution doesn't work, you must come up with one that will.

How about trying again? As a rule, repeating an act or maneuver that has failed is worthwhile only if you have changed something in the tactical

environment: better exposure, an improved angle, a longer needle driver, a bigger needle, or a better assistant. Such a tactical change improves your chance to succeed in the next attempt. Identical repetition of an unsuccessful technical act is a mistake because it almost always fails. This is the very definition of flailing and exactly what you must avoid.

Remember these four options for dealing with technical failure. They are your tickets out of frustrating and dangerous situations. Effective surgeons don't take technical failure as a personal insult. They rapidly reassess the situation and come up with an alternative solution.

Avoid flailing; learn to deal with technical failure

Tactical flexibility

Regardless of your experience, you will find yourself in situations where your inventory of standard techniques simply will not solve the problem, forcing you to figure out a new solution. Tactical flexibility is the ability to devise new solutions to unusual operative situations. It is an acquired skill that you can develop by learning to think outside the box.

When facing an unfamiliar problem, ask yourself the following questions:

- Have I encountered a similar situation in another context? In elective surgery? In another injured organ or anatomical region?
- Can I modify or adapt a standard technique to the situation?
- How about solving part of the problem?
- Can I leave the problem unsolved for a while and come back later?
- What is the minimal acceptable option to deal with the problem? Will draining the injury (and creating a controlled fistula) be good enough? Can I ligate the vessel instead of repairing it?

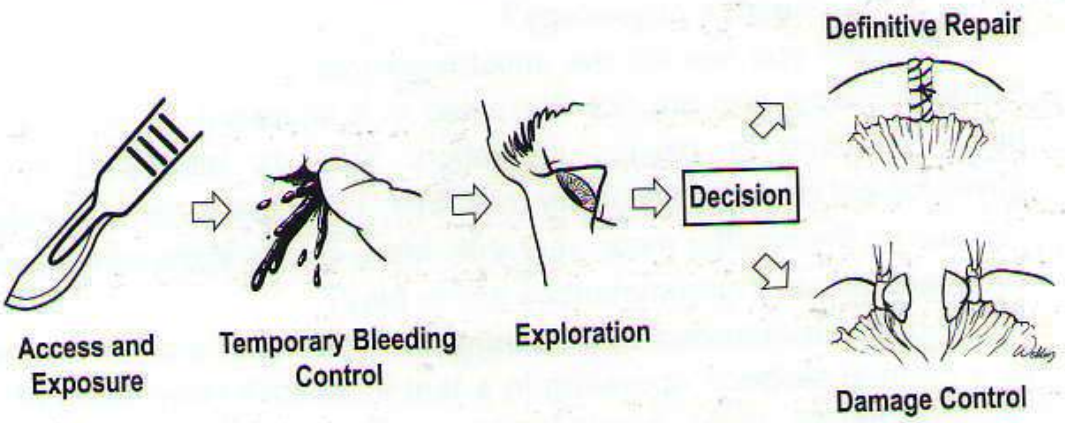
In a complex situation, always strive to simplify the problem. Assess the injuries and decide which injured organs must be fixed and which can be rapidly removed (or resected) and, thus, eliminated from the equation.

Make your reconstructions as simple as possible. The fewer suture lines you make, the better. In trauma surgery, simple solutions work; complex solutions often backfire on you.

Simplify complex tactical situations

The key strategic decision

Every trauma operation follows a generic sequence of reproducible steps. You gain access to the injured cavity, control bleeding and spillage using temporary measures, and then explore the cavity to define the injuries.



Now you face the key strategic decision of the operation, the choice between definitive repair and damage control. *Definitive repair* means resection or repair of the injured organs and formal closure of the cavity. *Damage control* means rapid bail out using temporary control measures and temporary closure of the cavity, with a planned return later under more favorable circumstances. You must make this decision very early. Don't find yourself abruptly bailing out in mid-operation because the patient is crashing.

How do you choose the operative profile? Consider four key factors: injury pattern, trauma burden, physiology, and system.

- What is the injury pattern?
  For example, in a high-grade liver injury, once you recognize the need

for packing, damage control is your only choice. Similarly, the combination of a major abdominal vascular injury and intestinal perforations usually requires a rapid bail out, because by the time you finish dealing with the injured iliac artery, the patient will be in no condition to undergo bowel resection and anastomosis.

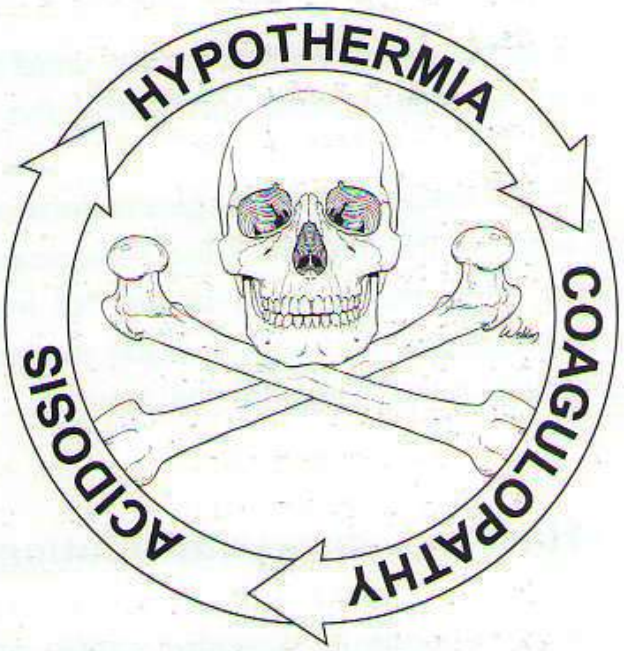
- What is the patient's overall trauma burden?
  Look into the injured belly: how many organs do you need to fix? How much work is involved? What about the chest? Any pressing concerns in the limbs? The patient may need two hours of reconstructive work, but with a head injury and a dilated right pupil, you don't have the time. The overall trauma burden of a patient is a combination of the injuries, their relative urgency, and the amount of work (and time) required to deal with them. Investing precious time in definitive repair of non-life threatening abdominal injuries in the presence of big uncertainties in the head, chest, or neck is a very bad move.
- What is the patient's physiology?
  The numbers you see on the anesthesiologist's monitor are not very helpful because you are not interested in a snapshot of the patient's blood pressure or oxygen saturation. You are interested in the physiological impact of the injury over time. The instantaneous numbers you see on the monitor mean very little. More on this in the next section.
- What system and circumstances are in play?
  Are you an experienced trauma surgeon working in a trauma center or a general surgeon operating in a tent in Africa? How much blood do you have? How good is your anesthesiologist? You must incorporate these considerations into your decision. Damage control is the "great equalizer" of trauma surgery, allowing you to compensate for inexperience and limited resources.

Damage control is the great equalizer of trauma surgery

The decision to bail out and the physiological envelope

If the patient's current blood pressure is 120/70 with good oxygen saturation, the anesthesiologist will often tell you the patient is stable. What if this patient was in shock for an hour before the operation and lost an entire blood volume before you gained control? Are you going to do a

bowel resection and anastomosis? If you answer, "Yes," please say you are joking. This seemingly "stable" patient has, in fact, sustained a terrible physiological blow, and the systemic inflammatory response is going to hit full blast very soon. The bowel and the abdominal wall will swell, oxygenation will drop, and the patient will require massive fluid resuscitation and perhaps even inotropic support. You have to bail out and get the patient to the intensive care unit NOW! Your assessment of the cumulative physiological insult, not the numbers on the monitor screen, should guide your decision.



In the damage control literature there is much discussion of the "lethal triad" of hypothermia, coagulopathy, and acidosis. These three physiological derangements mark the boundaries of the patient's physiological envelope, beyond which there is irreversible shock and death. A core temperature below 32°C during a trauma laparotomy is considered universally fatal. Unfortunately, in real-life trauma surgery the lethal triad does not help you much. If you have a sound strategic grasp of the situation, you will bail out well before the patient's physiological envelope is anywhere near the point of no return. Being forced out of the chest by a core temperature of 33°C, a pH of 6.9, and a desperate anesthesiologist is not a sign of good judgment. You should have been out of that chest long ago.

Don't use the lethal triad as a guide to bailing out

Instead of the lethal triad, rely on a series of subtle perceptual cues to indicate a developing hostile physiology.

Intraoperative Cues of Hostile Physiology

Edema of the bowel mucosa
Midgut distension
Dusky serosal surfaces
Tissues cold to the touch
Non-compliant swollen abdominal wall
Diffuse oozing from surgical incisions

Edema and distension of the small bowel are relatively early warning signs, whereas diffuse oozing from the operative incision is a late one.

Experienced trauma surgeons decide on damage control within minutes of entering the abdomen and sometimes even before making the incision! They often recognize a pattern of injury and physiology that, in their experience, almost always leads to damage control. More on this in the chapter on thoracoabdominal injuries.

How well does your solution fail?

If you choose an operative profile of definitive repair, there is usually more than one repair option. The typical dilemma is between a shorter, simpler repair and a complex and more time-consuming reconstruction.

When choosing between several technical solutions, consider not only how well a particular option works but, more importantly, how well it *fails*. What will happen if the anastomosis leaks? What if the repaired spleen begins to bleed again?

There is a world of difference between a leaking colonic suture line and a failed pancreaticojejunostomy. The former is easily salvaged by proximal diversion; the latter is a much more ominous complication, not easy to manage. Can your patient tolerate a failure? A young healthy patient with

an isolated bowel injury will survive a leak from a gastrointestinal (GI) suture line. A critically injured patient in multi-organ failure will not.

Choose a definitive repair option that fails well

Team leadership

Picture yourself going head-to-head with an inaccessible hole in an iliac vein deep down in the pelvis. Your patient is in profound shock and bleeding audibly. Your team has one circulating nurse. Depending on your next request, the nurse will either go hunting for your personalized needle driver that has the ideal angle for your next 2-3 bites, bring a Fogarty balloon catheter that can free your finger from compressing the bleeder, or hook up an autotransfusion device. Which is more important? One circulator, three essential pieces of equipment needed at the same time - it's your call.

Constantly re-evaluate your priorities and your team, adapt to the situation, and make compromises. It is often said that excellent surgeons "can operate with a knife and fork." Is the special clamp you requested really essential? Can you get by with a less optimal but immediately available clamp? What will you need in five minutes? In ten minutes?

The key to a smooth and well-coordinated operation is to stay ahead of the game. As a rule, the scrub nurse should be at least one step ahead of the operation at any given moment. When you are exposing an injured vessel, the scrub nurse must already have clamps for proximal and distal control. The circulating nurse must be at least two steps ahead, making sure that the Fogarty balloon catheter and the sutures you will need for thrombectomy and repair are ready. You, the surgeon, must be at least three steps ahead, considering your reconstructive options. Just as in chess, the better player you are, the further ahead of the operation you will stay.

Stay well ahead of the operation

Maintain a continuous dialogue with the anesthesiology team across the drape they call "the blood-brain barrier," and provide them with the information they need to stay ahead of the operation. Remember that you are working in one of several potentially injured cavities, and often the only clue that something is amiss in another visceral compartment will be obvious only to the anesthesiologist. Train yourself to listen to the monitor while you are working and to pick up any unusual moves or noises on the other side of the blood-brain barrier. Sometimes the most critical part of the operation is taking place there, outside your field of vision. While you cannot see it, you can train yourself to *feel* it.

Frequent changes in the operative plan are a salient feature of surgery for trauma, and it is your responsibility to make sure that members of the OR team are not left behind when the operative plan suddenly changes. Avoid surprises by sharing your tactical and strategic decisions with them. Consider, for example, the simple act of transporting a damage control patient to the surgical intensive care unit (SICU). If the team is unaware of your intention to bail out well in advance, you will find yourself in the ridiculous situation of having just performed a lightening-speed damage control laparotomy, only to spend an almost equal amount of time waiting for a bed.

Unlike chess, trauma surgery is a dynamic process. In chess, the pieces are just sitting there, waiting for you to make a move. A trauma operation moves forward relentlessly whether you like it or not, confronting you with rapidly changing situations. If you are an effective 3-D surgeon, your handling of the tactical, strategic, and teamwork dimensions translates into a smooth and effective procedure.

THE KEY POINTS

- Sterility is a luxury in severe hemorrhagic shock.
- Always prep for a worst-case scenario.
- Know the key maneuver and pitfall in every operative step.

- Avoid flailing; learn to deal with technical failure.
- Simplify complex tactical situations.
- Damage control is the "great equalizer" of trauma surgery.
- Don't use the "lethal triad" as a guide to bailing out.
- Choose a definitive repair option that fails well.
- Stay well ahead of the operation.

Chapter 2
Stop That Bleeding!

Whenever you encounter massive bleeding, the first thing to remember is: it's not <u>your</u> blood.

~ Raphael Adar, MD, FACS

In 1989, while discussing a paper on liver injuries, Dr. Francis Carter Nance of New Orleans made the following comment:

"I would like to offer Nance's classification of injuries, which has the advantage of not needing to look at the organ injured, but at the resident who is there at the operating table... If he or she looks at the wound and yawns and turns it over to the junior resident, then...it is going to do well. It is going to have a high survival rate. If he looks at the injury and salivates...that means that the resident will have to do some suturing and really help the patient, and the mortality rate will not be high, and he or she will look good during the morbidity-mortality conference. If the resident sweats...that means that he or she will do a lot of sewing, will encounter a complication, and will have to defend himself or herself at the morbidity-mortality conference, and probably receive a lot of heat. And if the resident screams and asks for the attending...you know that the patient will do poorly."

(*Ann Surg* 1990; 211: 673-674)

When you are operating on a bleeding patient, it all comes down to a simple question: can you stop the bleeding before the patient runs out of blood? The key to success is not how you handle a vascular clamp, but, rather, how you handle yourself and your team. Bleeding control is not about mastering some cool moves. It is the ability to rapidly select appropriate hemostatic options and deploy them one after the other in a disciplined, effective fashion. Here's how to do it.

Choosing a hemostatic option

Don't reflexively jump on a bleeding vessel with the first available clamp. Instead, train yourself to think of every bleeding situation as a problem that requires an effective solution. There is always more than one alternative. Your job is to come up with a solution that will work for the specific situation in front of you. Therefore, the first rule of bleeding control is always select the simplest, most expedient hemostatic option.

Begin with the simplest hemostatic option

What are your options? If you have some surgical experience, your list must begin with "do nothing." This is often an excellent choice because relying on intrinsic hemostasis works surprisingly well for certain types of minor hemorrhage, like superficial oozing from solid organs. Your list of options probably goes on to electrocautery and ligation and then gradually escalates through the use of hemostatic sutures, packing, balloon tamponade, and all the way up to a formal vascular repair. You will not insert a hemostatic suture unless simpler means have either failed or are inappropriate. Therefore, the second underlying principle is a graded response.

Bleeding control is a graded response

If the first solution you chose didn't work, gradually escalate your efforts. An experienced surgeon rapidly zooms in on the 2-3 best hemostatic options for a given situation. This principle of a graded response has an important corollary: while you deploy a hemostatic solution, think ahead and prepare an alternative in case your selected technique doesn't work. Why is this important?

The more complex your next hemostatic solution, the more time it takes to prepare. When faced with massive bleeding from an inaccessible site, preparing an alternative becomes crucial. If your chosen solution doesn't work and you are not ready with an immediate alternative, you are up the

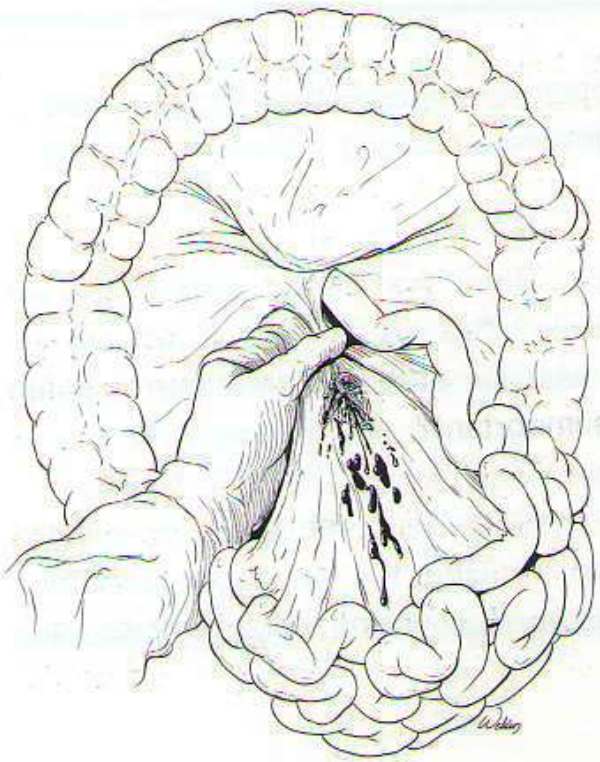
creek in search of a paddle. Having a hemostatic option ready is not an accident. It requires careful planning and intimate familiarity with the equipment or tools you will need and where they can be found.

Be ready with an alternative hemostatic option

Temporary and definitive control

Temporary control is like plugging a hole in a leaky bucket with your finger. Definitive control is fixing the bucket. In massive bleeding, temporary control is always the first step because it allows you to assess the situation and deploy an appropriate definitive hemostatic measure.

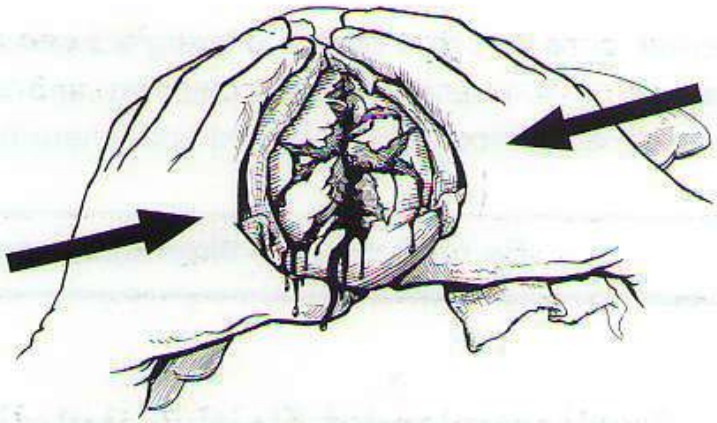
Temporary solutions must be quick, effective, and atraumatic. In certain situations, especially when the bleeder is either inaccessible or difficult to control, your temporary control maneuver (such as packing or balloon tamponade) may turn out to be the definitive measure because there is no better option. If you temporarily packed a badly injured liver and it stopped bleeding, don't remove the packs. You have achieved effective hemostasis - good enough. Move on.



Obtaining temporary control

Manual or digital pressure is an excellent first choice. Control bleeding from a cardiac laceration with your finger. Pinch a mesenteric bleeder between thumb and forefinger. Compress a bleeding internal jugular vein with your finger. Insert a finger into a hosing groin wound.

Have your assistant compress an injured liver between the palms of both hands. Using your hands is quick, instinctive, completely atraumatic, and very effective.



A classic error of the novice is to grab a clamp and try to blindly apply it in a pool of blood. This never works. Vascular clamps are effective when the target vessel has been dissected out and isolated, not when it has retracted into the tissue or is barely visible. Blind clamping is a sign of panic. You will not only fail to achieve control, but also will end up with an iatrogenic injury. Wild clamping of the descending thoracic aorta can easily result in an avulsed intercostal artery. A clamp applied hastily to the supraceliac aorta may perforate the esophagus. Blind clamping of a limb artery in a pool of blood will crush the adjacent nerve or injure the neighboring vein. Unless you are unusually talented, you cannot perforate the esophagus or crush the median nerve with your finger.

The finger is mightier than the clamp

Temporary packing is a good option for diffusely bleeding surfaces or cavities. It also frees your hands. However, packing will not control major arterial hemorrhage.

Pedicle control is another option. Does the injured organ have an immediately accessible vascular pedicle? The spleen, kidney and lung do, as does the bowel. One of the two vascular pedicles of the liver is easily accessible and can be rapidly pinched between thumb and forefinger or clamped with a non-crushing clamp, the famous Pringle maneuver. Similarly, if you mobilize the spleen or kidney you can rapidly control the pedicle with your fingers or a clamp. Twisting the lung upon itself is a simple and effective technique for hemorrhage control, as you will discover later (Chapter 11).

Temporary control buys you time. You can relax for just a moment, get the circulation back into your compressing hand, survey the situation and decide how to proceed.

Determine if the bleeding organ has a vascular pedicle

Small problem or BIG TROUBLE?

Now that you have gained temporary control and blood is no longer pouring all over your operative field, you have reached the key tactical decision in hemorrhage control: the distinction between a small problem and BIG TROUBLE.

A small problem is bleeding you can control using a direct hemostatic maneuver like clamping, suturing, or resecting the injured organ. Hemorrhage from an injured spleen is a small problem, as is a peripheral lung laceration or a low-grade liver injury. The great majority of bleeding situations you encounter during a trauma operation belong in this category.

BIG TROUBLE is an entirely different kettle of fish - a complex or inaccessible injury that poses a clear and immediate danger to your patient's life. A high-grade liver injury is the prototype of BIG TROUBLE. Bleeding from an iliac vein or a posterior intercostal artery deep in the lower chest are other examples.

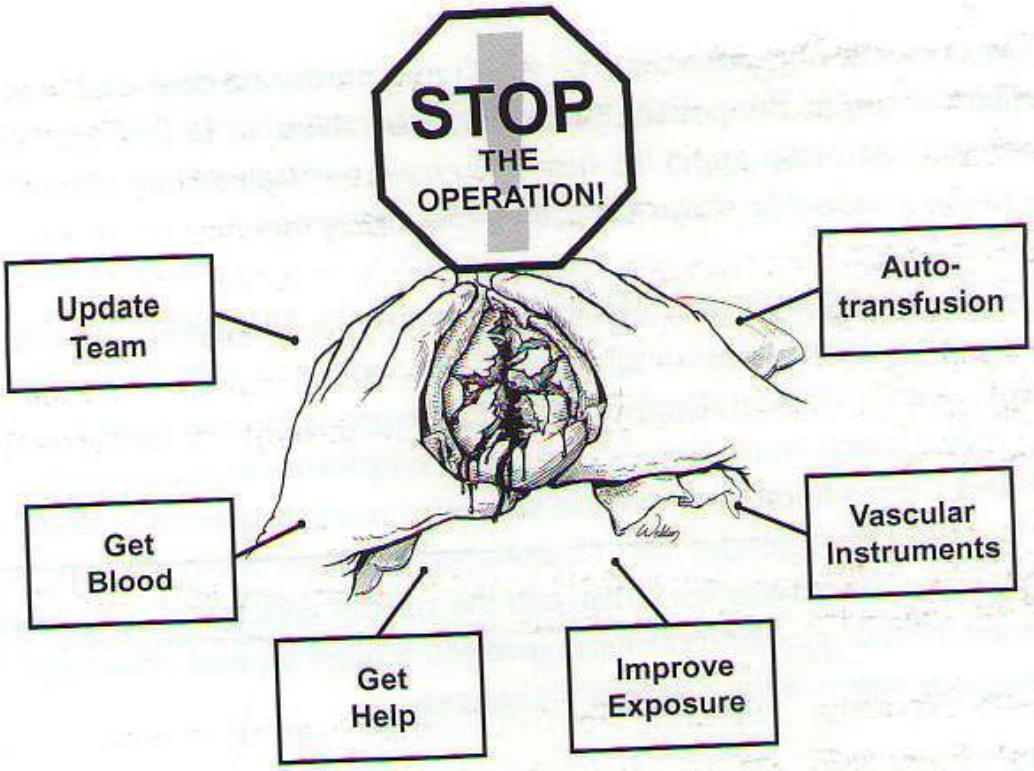
The distinction between a small problem and BIG TROUBLE hinges on a combination of the bleeding rate and the accessibility of the bleeder. Several torn peripheral mesenteric vessels can bleed more than a contained hematoma in the base of the mesentery. Yet peripheral mesenteric bleeders are a small problem because they are accessible and easy to deal with. Bleeding from the root of the mesentery is BIG TROUBLE because it implies the need for vascular repair of an inaccessible superior mesenteric vessel.

The upper abdominal aorta is difficult to access and control; therefore, a midline supramesocolic hematoma is always BIG TROUBLE, regardless of how much it has bled. Free hemorrhage from the retrohepatic veins is BIG TROUBLE, not only because it is fast and furious, but also because you cannot get to it. Accessibility depends on the patient's position and on your incision. For example, an injury to the posterior thoracic wall may be inaccessible from an anterolateral thoracotomy incision, but easy to reach through a posterolateral thoracotomy.

Learn to distinguish between a small problem and BIG TROUBLE

Small problems and BIG TROUBLE require different mindsets and different operative approaches. You can tackle a small problem directly by immediately deploying appropriate hemostatic solutions until the bleeding stops. One of those solutions is likely to work, and the blood loss will be limited.

If you jump in and go head-to-head with BIG TROUBLE, you lose. The patient is profoundly hypotensive from massive blood loss. The OR team has no idea how bad the situation is or how you plan to deal with it. Exposure is bad. The 10-12 units of blood the patient will need are still in the blood bank. The vascular instruments you will need are stored outside the OR. In other words, the odds are overwhelmingly stacked against you and your patient even before you begin. A frontal attack (as you did for a small problem), will be like a bungee jump without a cord. Unless you do something to even the odds, you're finished before you start. So, what to do? The answer may surprise you.



Once you have gained temporary control - STOP! Resist the temptation to immediately proceed to definitive control. Instead, organize and optimize your attack:

- Tell the anesthesiology team you are preparing for massive blood loss, urge them to catch up with volume replacement, and obtain at least 8-10 units of blood and a rapid infuser.
- Get an autotransfusion device primed and working.
- Have the OR team open and prepare vascular and thoracotomy instrument trays. Have the scrub nurse mount several polypropylene sutures (typically 3:0 - 5:0) on appropriate needle drivers.
- Determine your next 2-3 hemostatic options if you can. Will you need additional equipment like a Foley or Fogarty catheter? Will you need to improvise a balloon tamponade?
- Assess the capabilities of your OR team. Can they handle the roller-coaster ride ahead? Should you get additional help?
- Improve exposure by extending your incision, by inserting a self-retaining retractor, or by rearranging your assistants.

While all these preparations are moving forward, don't fiddle with your temporary control. Leave the packs alone, maintain manual pressure, and don't move any clamps.

Don't fiddle - be a rock

Stand calmly and patiently with your hand on the bleeder and wait until the team is ready, the patient has been resuscitated, and the appropriate instruments and help are in the field. You have carefully set up your attack; now wage your battle under favorable circumstances.

When dealing with BIG TROUBLE, resist the temptation to keep on moving. The drama of exsanguinating hemorrhage is such that the team expects you to "do something." Stopping the operation in mid-air is the last thing they expect. Nevertheless, insist on completing all preparations even if it takes a considerable amount of time. We have occasionally stood with our hand on the bleeder for 15 minutes or more while the OR team completed preparations for battle and the patient was being resuscitated. Patience, preparation and planning give you a huge tactical advantage and dramatically improve your patient's chances.

We cannot overemphasize how critical it is to distinguish between a small problem and BIG TROUBLE. This may well be the most important decision of the entire operation. It is often a subjective decision that depends on your experience and confidence. A situation that a surgeon with limited trauma experience considers BIG TROUBLE may turn out to be a small problem for an experienced colleague. Nevertheless, if your impression is that the situation merits an organized attack, you will never go wrong by approaching it as BIG TROUBLE.

Always err on the side of caution

Selected hemostatic techniques

Packing 101

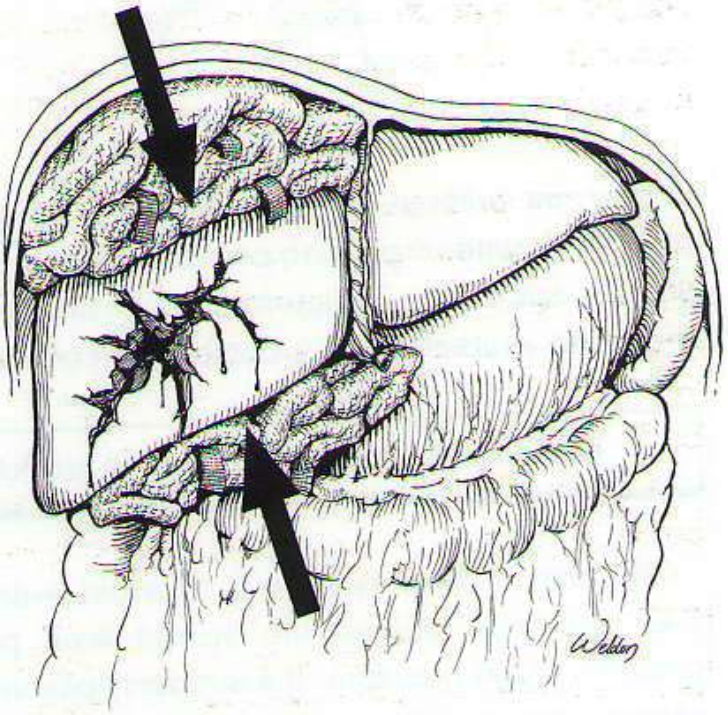
Packing is one of the most underrated and badly taught techniques in trauma surgery. It is also one of your best weapons for dealing with BIG TROUBLE. Surgeons tend to think of packing as such an intuitive skill that they rarely bother to teach it properly. After all, you don't have to be a surgical genius to stuff some pieces of cloth around a bleeding liver - wrong!

The first rule of packing is to do it early. Since packing relies on clot formation, it can only be effective if done when the patient can still form good clots. Packing as a last resort, when the patient is coagulopathic and oozing from everywhere, is futile.

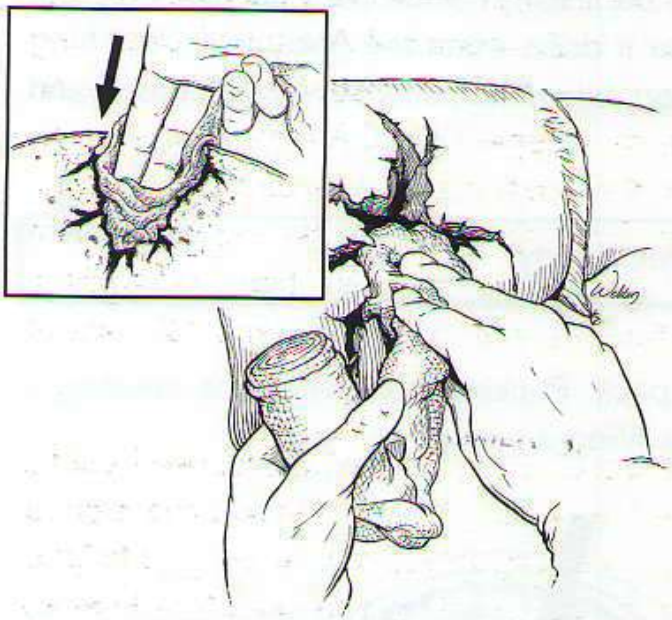
Pack early!

There are two main ways to pack. Packing *from without* is creating a sandwich. Packing *from within* is filling a cavity.

Pack from without by placing laparotomy pads outside the injured organ to reapproximate disrupted tissue planes. To achieve effective hemostasis you must create two opposing pressure vectors that compress the injured tissue between them; otherwise, your packing will not work. Effective packing is a sandwich, not a wrap.



This technique is most often used in the injured liver. A good sandwich around the liver consists of two layers of laparotomy pads (above and below or anterior and posterior), approximating the disrupted tissue planes between them. These layers are supported, in turn, by the abdominal wall, the diaphragm, or by adjacent abdominal organs such as the stomach or large bowel. You cannot create a good sandwich by hanging two pieces of bread in mid-air. Your sandwich must make mechanical sense.



Packing from within is stuffing a crevice or an actively bleeding cavity with absorptive gauze. The filling, consisting of an unfolded gauze roll, is pushing outward against the walls of the injured parenchyma.

Your packing technique must be tailored to the shape of the injury. If dealing with a large bleeding surface or multiple injuries to a solid organ, pack from without. When packing a bleeding crevice, like the deep perineal wound of an open pelvic fracture, pack from within. In severe liver injuries, such as a stellate fracture of the dome of the right lobe, you will often find yourself using a combination of both techniques.

Packing from without or within works in opposite direction

The third rule of packing is to avoid overpacking. While constructing your sandwich around the injured liver, pay special attention to the patient's blood pressure. If it suddenly plummets and the anesthesiologist shows signs of distress, your packs may be compressing the inferior vena cava (IVC) and diminishing venous return to the heart. Carefully remove a few packs and reassess.

Too much packing is bad

The fourth (and last) rule of effective packing is to be paranoid. There is always the danger that your packs will not work, but it usually takes time to find out. Laparotomy pads have an amazing absorptive capacity, and the patient may well continue to bleed underneath them. If the patient's physiology allows, spend at least a few minutes doing something else, and

then return to the packed area and re-examine it with very suspicious eyes. Is blood beginning to reaccumulate in the corners? Are the packs being slowly soaked? If you are not sure, peel off the most superficial layer of the sandwich and take a good look at the deeper layers. Are they turning pink and moist? If so, you have to take the sandwich apart because you do not have effective hemostasis. Never rely on the patient's clotting mechanism to compensate for ineffective packing. The best time to achieve hemostasis is before you leave the OR, not two hours (and 12 units of blood) later.

What if your packing doesn't work? First, remove the soaked packs one by one and inspect the injured area once more. Did you have a good sandwich solidly supported by surrounding structures, or did you build a "floating sandwich" in mid-air with no support? Do you need to add more packs? Should you add packing from within or from without? Is there an arterial bleeder in the injured area? If there is, you must deal with it directly using another hemostatic technique. Can you do something else to help stop the bleeding? Add a topical hemostatic agent? A blind hemostatic suture? Repack and wait again until you are sure that you have effective bleeding control.

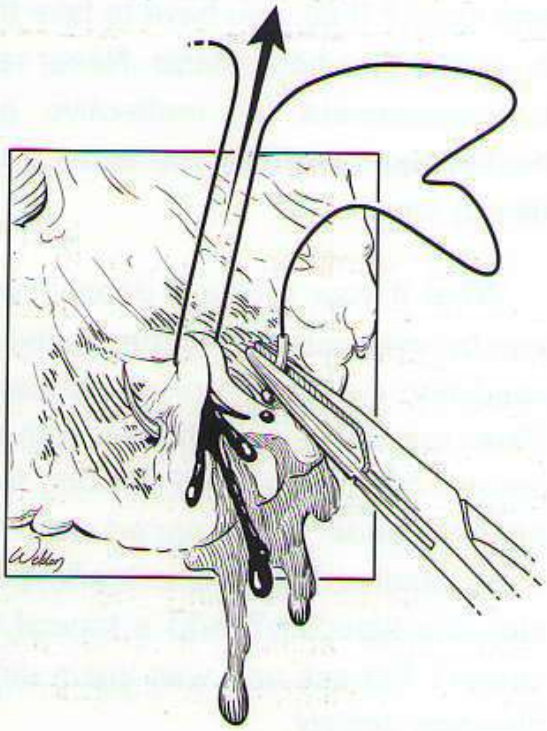
Be paranoid about your packs

Inserting a blind hemostatic (figure of 8) suture

Use a blind hemostatic suture to control a bleeder that is either invisible or has retracted into the tissue. You cannot see the bleeder nor can you clamp and ligate it, but you can imagine where it is. After using blind hemostatic sutures so many times in elective and emergency surgery, you may feel confident that you know how to do it well. Chances are, you don't; here are some useful pointers:

- Make sure the anatomical situation is appropriate for a blind hemostatic suture. If the bleeding is close to an unexposed major vessel, always assume that the major vessel is the bleeder and expose it.

- Use a monofilament suture that will slide through the tissue rather than saw through it. Strange as it may seem, the key to success is not the suture, but the *size of the needle*. Choose the biggest needle that is appropriate for the situation.
- Place your first bite as close as possible to the site of bleeding. The purpose of this bite is not to achieve hemostasis, but to gain a good purchase on the tissue so you can lift it up by gently pulling on the suture with your non-dominant hand. Now you can see on which side of your first bite the bleeder is spurting. Your next bite will be for hemostasis, and since it is well-targeted, it will do useful work.



- If anyone ever bothered to teach you about blind hemostatic sutures, you probably know that your aim is to end up with a figure of 8 configuration that runs under the vessel proximally and distally to the bleeding site. This is nice in theory, but in practice you can never be sure in which direction the bleeding vessels lies. That's why they call it a blind stitch. Don't be disappointed if you end up needing more bites. It is okay to insert 3-4 bites instead of two, as long as the bites are close together and they work. We call this 4-bite suture a "figure of 16."
- Often, pulling on your blind suture will stop the bleeding. You must then decide if you wish to use it merely as a temporary hemostatic maneuver or tie it as a permanent solution. If you decide to tie it, remember to leave the ends long because you may wish to remove it later.

While inserting a blind stitch, plan your next hemostatic alternative. Experience has taught us that if you have not obtained hemostasis with

four bites, you are not likely to achieve it with this stitch. Don't flail. Try something else.

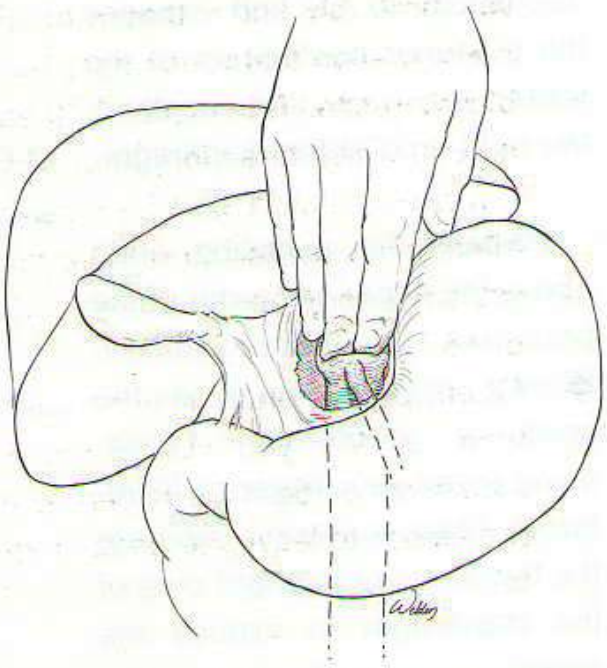
The first bite of a hemostatic stitch gains purchase on the tissue

Aortic clamping

Aortic clamping is one of the traditional heroic maneuvers in trauma surgery. Use it either as an adjunct to resuscitation in a crashing patient or for global proximal control in major abdominal vascular trauma. You are unlikely to learn how to properly control the supraceliac abdominal aorta if you attempt it for the first time in a belly full of blood. Learn and practice the technique under elective circumstances.

Use aortic clamping judiciously, not reflexively. When used as a resuscitative adjunct, it temporarily corrects the numbers on the blood pressure monitor, but at the price of global visceral ischemia.

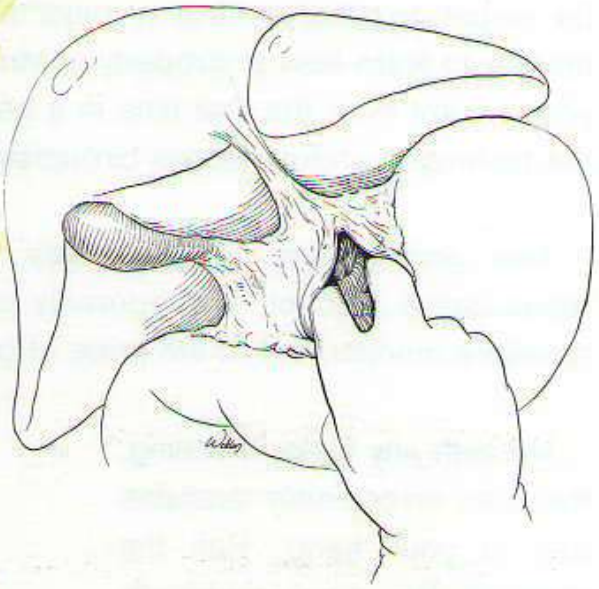
As with any major bleeding, the best immediately available tool is your hand. Pull the stomach downward and bluntly enter the lesser omentum in its avascular portion. Feel the aorta pulsating immediately below and to the right of the esophagus, and compress it against the spine. If you are occluding the aorta as a resuscitative maneuver, manual compression is often good enough. If you need formal aortic control, proceed with transabdominal supraceliac aortic clamping.



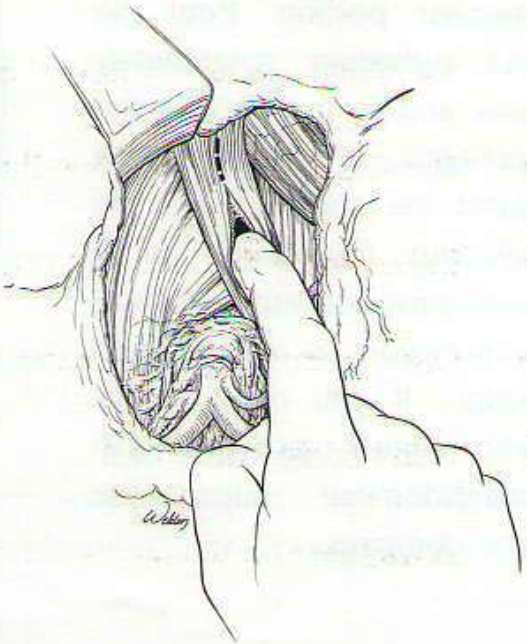
The key anatomical consideration in supraceliac clamping is that you are clamping the lowermost *thoracic* aorta, but doing it through the abdomen. As it emerges between the diaphragmatic crura, the aorta is enfolded by dense neural and fibrous tissue. In this particular aortic segment, it is difficult to obtain a good purchase with a clamp without dissecting around the aorta. Your best bet, therefore, is to go higher up, into the lower chest.

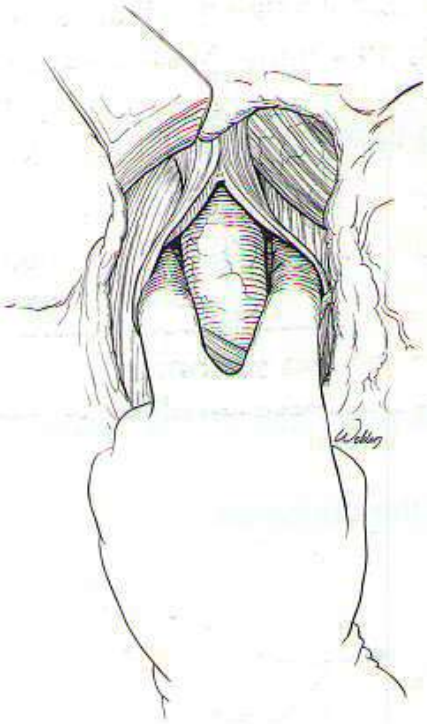
Clamp the lower thoracic aorta through the abdomen

If you have time, mobilize the left lateral lobe of the liver by incising the left triangular ligament. This improves your work space but is not essential to get to the aorta. Bluntly open the lesser omentum immediately to the right of the lesser curve of the stomach, and insert a Deaver retractor into the hole. Retraction of the stomach and duodenum to the left exposes the posterior peritoneum of the lesser sac and, underneath it, the right crus of the diaphragm.



Palpate the pulsating aorta above the superior border of the pancreas to orient yourself. Bluntly make a hole in the posterior peritoneum; then, using either your finger or blunt-tipped Mayo scissors, separate the two limbs of the right crus of the diaphragm to expose the anterior wall of the lowermost thoracic aorta.





Using the fingers of your left hand, create just enough space on both sides of the aorta to accommodate a clamp. That is all the dissection you need. Take an aortic clamp and guide it to the correct position using the fingers of your left hand as a guide. Clamp, and check the distal aorta for pulsation.

The aortic clamp tends to fall forward into the wound. Encircle it with an umbilical tape and secure the tape to the drape over the patient's lower chest to immobilize the clamp. You are done.

THE KEY POINTS

- Begin with the simplest hemostatic option.
- Bleeding control is a graded response.
- Be ready with an alternative hemostatic option.
- The finger is mightier than the clamp.
- Determine if the bleeding organ has a vascular pedicle.
- Learn to distinguish between a small problem and BIG TROUBLE.
- Don't fiddle - be a rock.
- Always err on the side of caution.

- Pack early!
- Packing from without or within works in opposite direction.
- Too much packing is bad.
- Be paranoid about your packs.
- The first bite of a hemostatic stitch gains purchase on the tissue.
- Clamp the lower thoracic aorta through the abdomen.

Chapter 3
Your Vascular Toolkit

Human beings, who are almost unique in having the ability to learn from the experience of others, are also remarkable for their apparent disinclination to do so

~ Douglas Adams

Imagine yourself preparing to repair a gunshot injury to the femoral artery. The 29-year-old patient has an arteriovenous fistula just below the right groin. You feel a strong thrill and hear a bruit, definitely what our residents call "a great case."

You have a small problem: no angiogram of the injured area. Come to think of it, you have neither heparin nor monofilament suture. You don't even have a proper vascular clamp. Your great case is rapidly becoming a nightmare. How would you feel if the only vascular tools you had were some fine cotton sutures on straight needles and a pair of crude non-crushing clamps? Can you imagine grabbing a scalpel and just going for the injured vessel? This is exactly what J.B. Murphy, an amazing Chicago surgeon, did in 1897. He fixed a femoral arteriovenous fistula armed only with a detailed knowledge of the anatomy, years of practicing vascular repairs in the laboratory, and sheer guts. The operation took 2.5 hours and went smoothly with no complications.

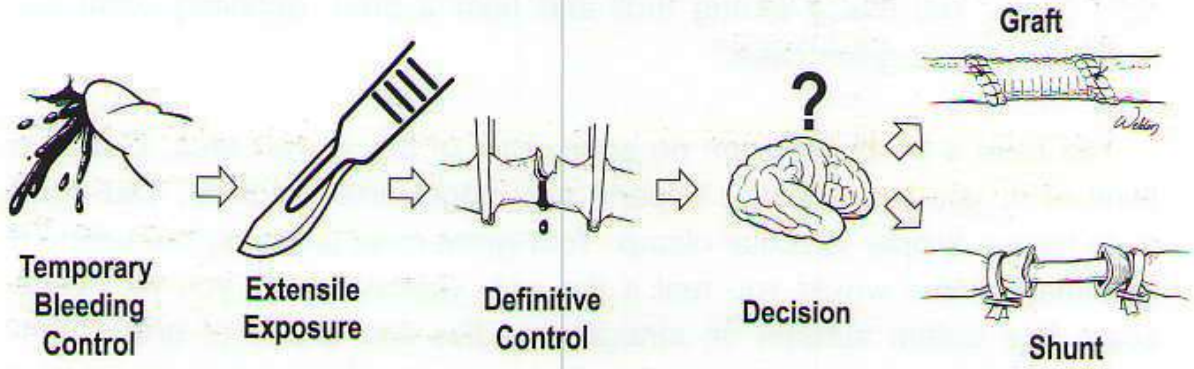
More than a hundred years later, you have a dazzling array of vascular instruments at your disposal when facing major vascular trauma. But you cannot zoom in on a lacerated popliteal artery and forget that it belongs to a critically injured patient who also has a fractured pelvis, a contused lung, and possibly an intracranial hemorrhage.

This chapter will first acquaint you with useful general principles to guide you when coming face-to-face with a vascular injury. We assume you are familiar with basic vascular techniques and will show you how to adapt them to the trauma situation. Second, we will present a useful toolkit

of technical options for damage control and definitive repair of vascular injuries. Remember, a good outcome in vascular trauma depends more on clear thinking and keeping priorities straight than on cool gadgets and elegant moves. Keep your vascular toolkit in mind as you learn to deal with specific vascular injuries in subsequent chapters.

Sequence and priorities

Much like any other trauma operation, avoid making "exciting discoveries" when dealing with major vascular injuries by following a well-defined sequence of steps.

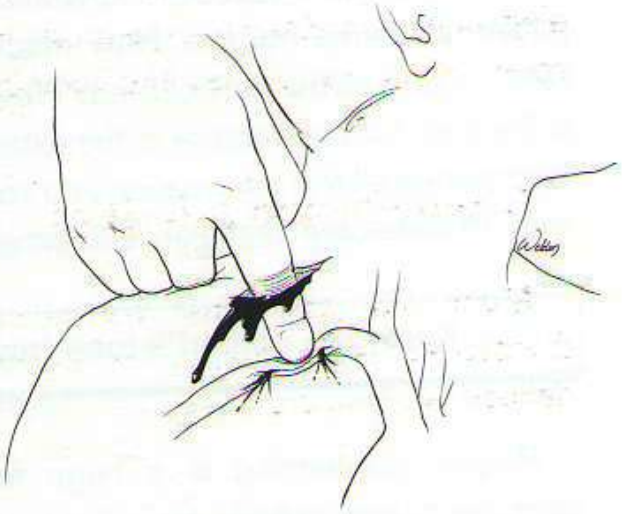


Bleeding and ischemia, the two manifestations of vascular trauma, represent different priorities. A bleeding carotid artery is an immediate threat to the patient's life, and you must control it NOW! Not so with an ischemic leg from a superficial femoral artery injury, where you have a window of several hours to save the leg. This is why bleeding is part of the ABC of the primary survey of the injured patient, while ischemia isn't.

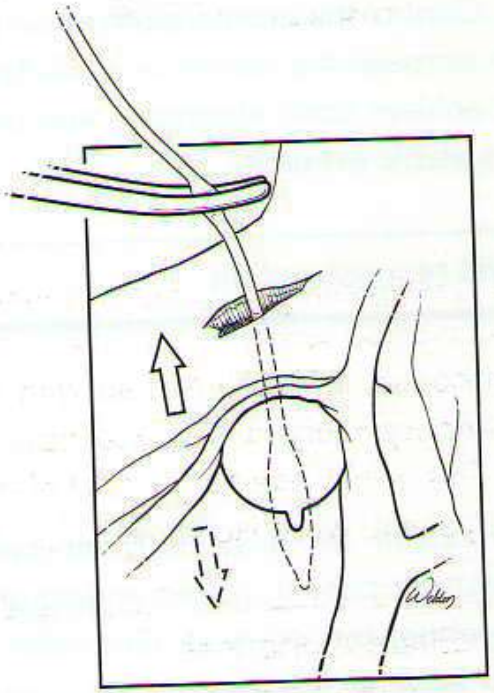
Bleeding and ischemia are different priorities

Control external bleeding

Obtain initial control of external hemorrhage by simple digital or manual pressure. If possible, rapidly transfer responsibility for compressing the bleeding vessel to an assistant, and prep the hand as part of the operative field. Your assistant can then continue to apply pressure while you make an incision proximal to (or around) the compressing hand to expose the injured vessel.



Use a balloon catheter when the bleeding source is deep and the wound is narrow (e.g. bullet wound), especially in transition zones between the trunk and the limbs, such as the groin, supraclavicular fossa, axilla, or neck. In these locations, manual compression is less effective. Insert a Foley catheter into the bleeding tract, inflate the balloon until bleeding stops, and then clamp the main port of the Foley. If the wound is wide and the balloon pops out, approximate the wound edges around it with a stitch to help hold it in place.



Balloon tamponade controls external bleeding in transition zones

Before you begin

Do not begin a vascular exploration without complete knowledge of the patient's trauma burden. How much time has passed since the injury? How much has the patient bled? How urgent is the brain contusion? What is the plan for the fracture in the extremity you are operating on? You must incorporate all this information into your decision-making or you will end up with an awesome vascular reconstruction - in a dead patient.

Know the patient's total trauma burden and physiology

Proper sequencing is a huge factor in peripheral vascular trauma because injuries to limbs typically also involve bones, nerves and soft tissue. As a general rule, bone alignment comes before vascular repair. Fixing fractures involves such fun activities as hammering, rimming and chiseling, moving bones, and other tricks that a 5:0 suture line does not tolerate very well. So, if the limb is not grossly ischemic and the planned orthopedic procedure is short (e.g. external fixation), let the orthopedic surgeon do it before the vascular exploration. If the limb is grossly ischemic or if the injury is actively bleeding, you have to go first. Control the injured artery, insert a temporary shunt, and do a fasciotomy to increase the tolerance of the limb to ischemia. Let the orthopedic surgeon achieve bone alignment, and only then do the definitive vascular repair on a stable extremity.

Align bone before arterial reconstruction

Angiography

Preoperative angiography is not an option for a hemodynamically unstable or actively bleeding patient. In a stable patient, get an angiogram if you can, especially if you aren't sure where the injury is. Consider a patient with multiple gunshot wounds or several fractures in the same extremity. How will you know where the injury is without a road map? With a single penetrating injury, things are simpler because you can find the injury with a limited exploration, so you can skip the angiogram.

Depending on your experience and the local circumstances, you have three options for obtaining an angiogram:

1. A single-shot angiogram performed in the ER - rapidly becoming a lost art.
2. A formal study performed in the angiography suite or OR - endovascular intervention could preclude the need for open repair.
3. Intraoperative angiography by cannulation of the exposed artery - best results are obtained by clamping the inflow before injecting the dye.

Get an angiogram if the patient is stable

Pre-emptive fasciotomy

Consider doing a fasciotomy *before* beginning the vascular repair, not when compartment syndrome is clinically obvious. When operating on an ischemic extremity, you often know that the formal repair is going to take time. Your safest course of action is to do a pre-emptive fasciotomy.

A popliteal artery repair is a good example. Regardless of your experience, popliteal reconstructions always end up taking longer than you expected. The unforgiving nature of these injuries and the paucity of collaterals around the knee virtually guarantee you will not finish this operation without a fasciotomy. Be smart. Do it before the vascular reconstruction.

We do a four-compartment fasciotomy using a double incision technique. Place your lateral incision approximately two fingerbreadths lateral to the edge of the tibia. Open the fascia all the way down to the ankle; then, identify and incise the intermuscular septum separating the anterior and lateral compartments. Avoid damage to the lateral peroneal nerve that lies in close proximity to the head of the fibula. Then, make a medial incision approximately a fingerbreadth behind the medial edge of

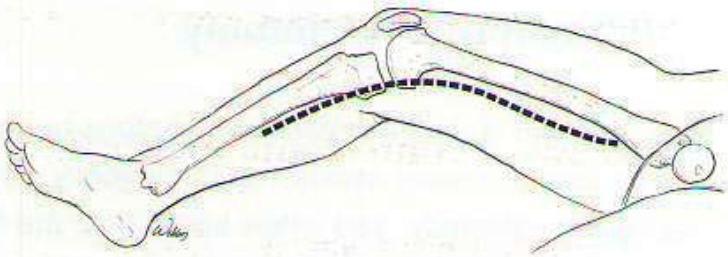
PTZMAN.
Chapter 34

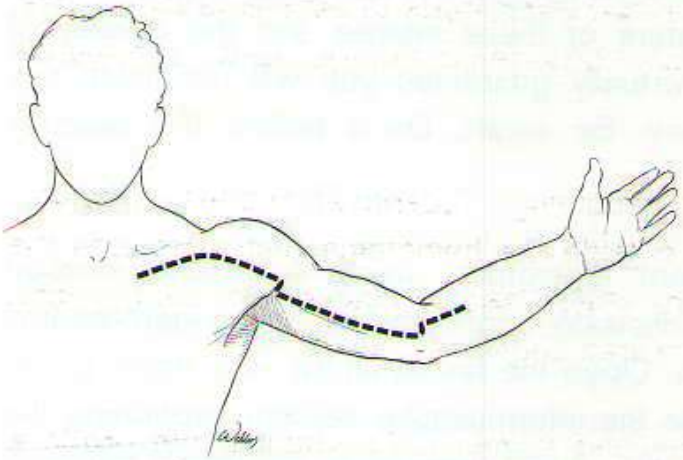
the tibial shaft. Injury to the greater saphenous vein is not part of this incision, so be careful. Using the cautery, detach the soleus muscle from the medial aspect of the tibia to decompress the deep posterior compartment.

Do pre-emptive fasciotomy before popliteal artery repair

Extensile exposure and key landmarks

The fundamental principle of vascular exploration is extensile exposure, which means that you must be able to extend your incision proximally or distally along the same axis as the original incision. The obvious examples are lower extremity incisions along the medial aspect of the leg. Using these incisions, exposure of the superficial femoral, popliteal, and tibial vessels can easily be extended into each other.





In the upper extremity, subclavian, axillary and brachial exposures are similarly extensile. Avoid non-extensile exposures, such as the posterior approach to the popliteal vessels or the transaxillary approach to the axillary artery, because they limit your access and restrict your options.

When dissecting an injured vessel, it is easy to get lost. The broken bones, bleeding muscle, and torn vessels are a minefield, even for an experienced vascular surgeon. Safe dissection in hostile territory hinges on the use of key anatomical landmarks to help you orient yourself and identify your target. In the lower extremity, key landmarks are the bones (femur and tibia), because the neurovascular bundle is located immediately behind it. Find the posterior aspect of the femur or tibia, and you have found the femoral or posterior tibial artery, respectively. The pectoralis minor is your key landmark when looking for the axillary vessels, as is the median nerve when exposing the brachial artery. You will find many examples of the use of key anatomical landmarks throughout this book because it is an extremely useful concept when you're in trouble in unfamiliar territory.

Know the key anatomical landmarks

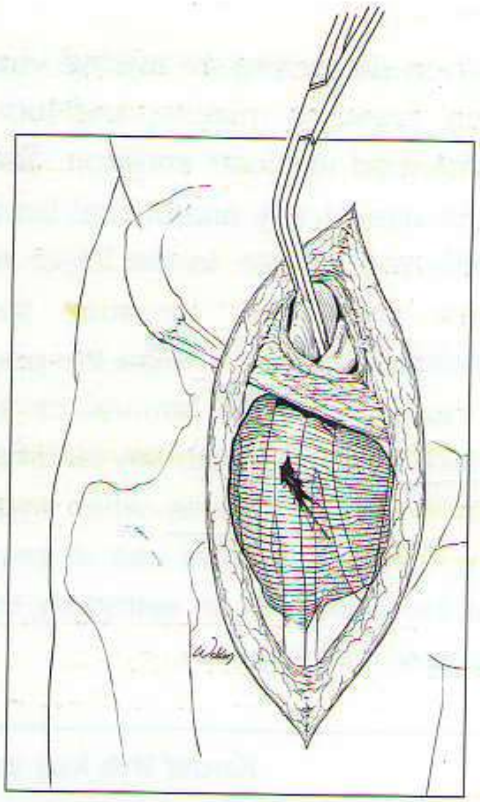
Proximal control and anatomical barriers

What is definitive vascular control? It is the accurate placement of vascular clamps (or other atraumatic means of occlusion) across the inflow and outflow tracts of an injured vessel. Proximal control is key. Entering a hematoma without first obtaining proximal control away from the site of injury is a stupid mistake that often leads to excessive blood loss, disorganized fumbling, panic, iatrogenic injury, and sometimes exsanguination.

Prevent your dissection from becoming a "search and destroy mission," by obtaining proximal control outside the hematoma that surrounds the injury. Begin in virgin territory where tissue planes are normal, and gradually advance toward the injured segment.

Experienced surgeons go beyond *anatomical barriers* to get proximal control. Yes, you guessed it - another key concept. Many anatomical structures serve as barriers to the expansion of hematoma. Consider the

inguinal ligament in penetrating injuries to the groin. Below the ligament you will find only blood, sweat, and tears. Above it, you are in virgin territory where you can easily isolate and control the external iliac artery. The pericardium is, similarly, a barrier to the expansion of a mediastinal hematoma, and the diaphragm blocks the extension of a midline retroperitoneal hematoma. Go to the other side of anatomical barriers to find easy proximal control.



A useful option for proximal control in the limbs, often forgotten in the heat of battle, is a pneumatic tourniquet on the upper arm or proximal thigh. Using it saves blood and simplifies the dissection. Once you have isolated and clamped the injured vessels, deflate the tourniquet.

Get proximal control outside the hematoma

Distal control

How important is distal control? It depends. Usually proximal control alone does not dry up the operative field because back bleeding from the distal vessel continues to give you grief. The patient will not exsanguinate, but you will not be able to do a vascular reconstruction in peace.

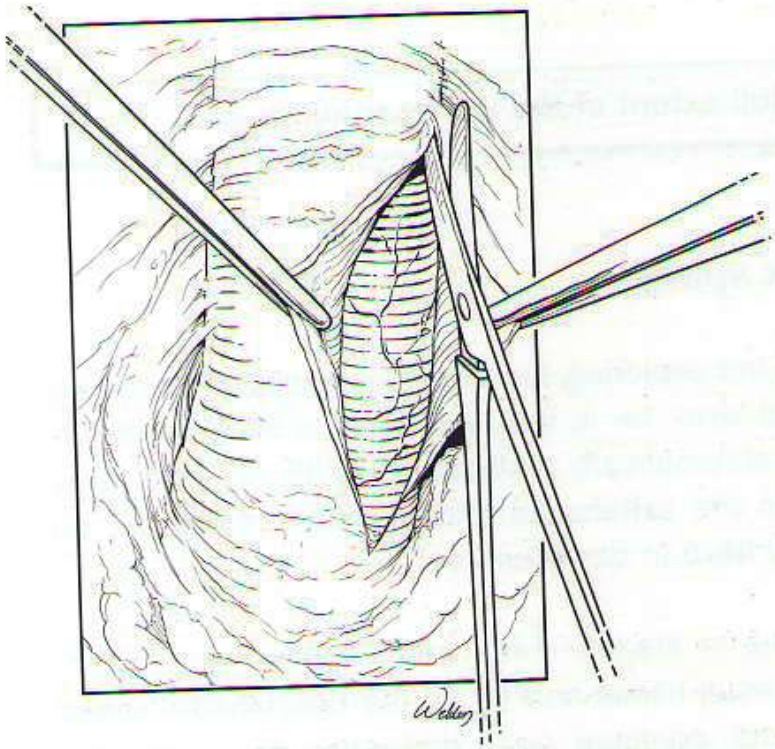
For the aorta and its proximal branches (e.g. subclavian and common iliac arteries), proximal clamping serves only to convert fierce audible bleeding into weaker bleeding, but you still cannot see the injury well, and the patient is losing blood at an alarming rate. You must obtain distal control. Do this outside the hematoma if you can. If not, expose the injury

under proximal control, and gain distal control from within the hematoma. Typical locations where distal control is difficult are the distal internal carotid artery, subclavian artery and the large veins of the pelvis.

For distal control from within the hematoma, choose the technique that makes the most tactical sense. Can you rapidly dissect the distal vessel and clamp it? Apply a side-biting clamp? Insert an intraluminal balloon catheter (typically a Fogarty catheter connected to a 3-way stopcock) into the outflow tract? This last technique, frequently used in elective vascular surgery, allows you to gain distal control without having to dissect out the distal vessel.

Use an intraluminal balloon for problematic distal control

Exploring the injured vessel



Your safe dissection plane along an artery is the periadventitial plane directly on the arterial wall. It will carry you safely from uninjured territory to the injured segment without lacerating the vessel or ripping off branches. You know you are in this safe plane when you see the pearly-white arterial wall with the vasa-vasorum on it.

As you enter the hematoma, define the injury by rapidly answering three questions:

- Which vessels are involved? Artery, vein, or both?
- How bad is it? Laceration or complete transection?
- Where are you? Are there major branches, joints, or other structures nearby?

You cannot assess an arterial injury by external inspection. This is especially true in blunt trauma, where the artery may appear intact on the outside yet hide a disrupted intima on the inside. You must open the artery and define the extent of intimal damage. With few exceptions, your arteriotomy will be longitudinal. Make sure you see the full length of the intimal damage.

Once you have defined the injury, carefully debride the injured wall back to healthy tissue. Don't compromise on intima that looks "almost normal" or is "slightly bruised," because you are buying yourself and your patient early postoperative thrombosis. There are no grey areas here - the intima is either healthy or it's not.

Define the full extent of the vascular injury

Developing a work space

Remember that you are not exploring the injured vessel just to have a look at it. You are going to work on it, and you need a work space. A laparotomy or thoracotomy automatically provides you with an open cavity that is your work space. In the extremities and the neck, there are no ready-made cavities, so you have to carve one out.

Develop your work space in stages. First, make the incision. Then, deepen it into the subcutaneous tissue and incise the deep fascia. Insert a self-retaining retractor and continue your dissection to isolate the neurovascular bundle using the key landmarks. As you make progress, continuously reassess your emerging work space. Is the incision long enough? Should you relocate the self-retaining retractor to a deeper

plane? Should the corner of the wound be manually retracted? Do you have enough space on both sides of the artery to sew conveniently? Can you bring the vessel more toward you (make it more superficial) by mobilizing it? The more you invest in optimizing your work space, the more time you will save during the reconstruction. When called to assist in a vascular trauma case, our first move is to extend the incision and optimize the work space.

Gradually develop and optimize your work space

The key strategic decision

Now it's time for your strategic decision, the choice between vascular damage control and definitive repair - a simple enough concept, but often a tough decision.

First, consider the type of repair required. Formal vascular repairs come in two flavors: simple and complex. A simple repair is a single, short suture line that can be completed quickly, even under adverse circumstances. If such a lateral repair will work - just do it.

A *complex repair* is a vascular anastomosis (or more than one). An end-to-end anastomosis, a patch angioplasty and an interposition graft are complex repairs. They take time to set up and perform but do you have the time? First, consider the patient's physiology. There is no point in doing an interposition graft in a coagulopathic patient who will just bleed on and on from the suture lines. This patient needs to be in the intensive care unit, rewarmed and resuscitated, not on the operating table losing more blood and becoming progressively hypothermic. You must bail out.

Second, consider additional factors. Is the patient unstable or actively bleeding in another cavity? If the answer is yes, damage control is your only option. Do you have the experience required? Can you get adequate help? Are the necessary vascular instruments at hand? If the answer to any of these questions is no, again choose damage control.

Decide between complex vascular repair and damage control

Vascular damage control techniques

The two major damage control techniques for vascular trauma are ligation and shunt insertion.

Ligation

Ligation of an injured vessel is often a no brainer. The external carotid artery, celiac axis, and internal iliac artery are obvious examples of arteries that can be ligated with impunity. Other arteries, such as the subclavian or brachial, can be ligated with a low risk of limb-threatening ischemia. If you are forced to bail out but plan to repair the vessel later, don't ligate it - use a temporary shunt instead.

Most large veins can be ligated with impunity or with acceptable consequences (such as leg edema). In the past, repair of the popliteal vein was viewed as crucial for a good outcome with popliteal artery reconstruction, but this sacred cow was slaughtered long ago. There are even reports of successful ligation of the portal vein, although this is probably one of the very few visceral veins that you should repair if you can. Remember, ligating a vessel is not an admission of defeat; it can be a sign of good judgment.

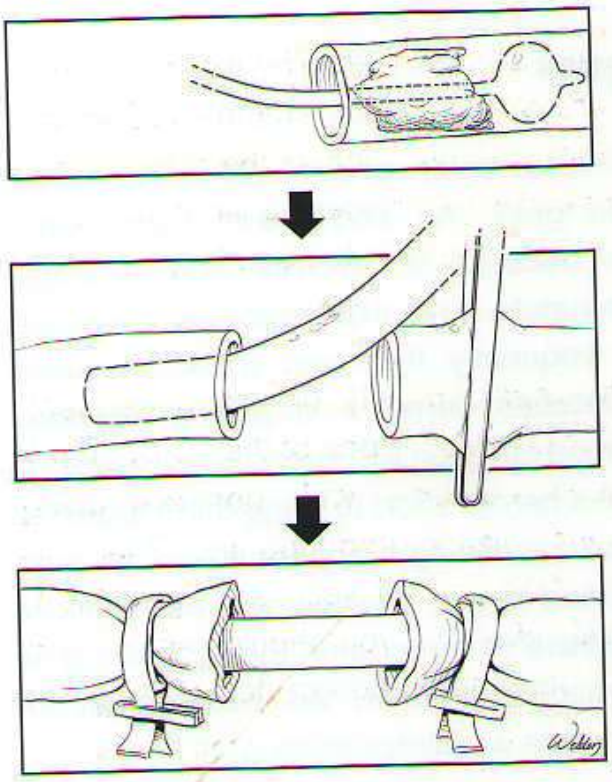
Ligation is not an admission of defeat

Temporary shunts

If you have little vascular experience or are operating in austere circumstances, a temporary shunt may be your best option. Insert a shunt when the patient's physiology is prohibitive, when orthopedic alignment of the bones precedes the arterial repair, or when you lack the resources to do a complex reconstruction.

Shunt material is not an issue; use whatever is immediately available. We have successfully used pieces of nasogastric tubes, suction catheters,

carotid shunts, and silastic T-tubes. We prefer to use an Argyle shunt (pediatric chest tube) because we use it regularly in carotid surgery, and it is easy to handle. However, in one of the most spectacular cases of successful shunting that we have seen, a military surgeon in the field used a segment of nasogastric tube to shunt a transected femoral artery in the groin.



Insert the shunt using a well-defined sequence of steps. Begin by clearing the inflow and outflow tracts of the injured artery with a Fogarty catheter, if available. If not, gently squeeze the proximal and distal ends of the transected artery to express clot, and release the clamps momentarily to flush out both inflow and outflow. Choose a shunt of the largest diameter that will fit comfortably in the vessel, trimming it to the desired length. Gently insert it into the distal, then proximal artery (since backflow is easier to control than foreflow). Now, fix the shunt in place. The simplest technique is to secure the shunt to the artery proximally and distally with heavy silk ties. However, this is traumatic to the arterial wall and will later require additional debridement of the artery beyond the ligature line when you remove the shunt. Our preference is to pass a vessel loop twice around the shunted artery and gently cinch it with a large metal clip or a Rummel tourniquet. Now, assess the distal perfusion by listening for a Doppler signal over the outflow artery. You're done.

Shunt failure shortly after insertion is due to one of the following:

- Inadequate inflow (proximal injury or residual thrombus).
- Compromised outflow (residual clot or migration of the shunt into a distal arterial branch).

- Obstructed shunt (angulation due to excessive length or ligatures that are too tight).
- Shunt dislodgement (presents as a rapidly expanding hematoma).

Clear the inflow and outflow tracts before shunt insertion

Definitive repair techniques

You have three options for definitive repair: end-to-end anastomosis, patch angioplasty, or interposition graft. An end-to-end anastomosis sounds like an excellent choice because it involves only a single straightforward suture line. Unfortunately, with experience you will find yourself using this solution less frequently than you think. In young patients, the ends of transected arteries retract a surprising distance, creating a large gap. The inexperienced surgeon will spend time mobilizing both ends of the transected artery in a heroic effort to bring them together. This entails additional dissection and sacrificing branches along the way. Despite these efforts, the resulting end-to-end anastomosis will often be under considerable tension and will have to be redone, this time using an interposition graft. Therefore, in vascular trauma, the best option for complete transection of an artery is often an interposition graft.

Transected artery = interposition graft

Patch angioplasty is an option to keep in mind, especially if at least half the circumference of the artery is still intact or if the vessel is small. We rarely repair a laceration in a brachial or popliteal artery without a small vein patch, because even a transversely oriented lateral repair will narrow the lumen of these small vessels.

Before you begin the repair, pass a Fogarty catheter proximally and distally, and then flush the vessel with heparinized saline. The Fogarty catheter will not only evacuate clot, but also will dilate a spastic vessel, facilitating your repair.

Systemic heparin has a bad reputation in vascular trauma, raising fears of causing bleeding in the adjacent traumatized soft tissue or in remote injuries. However, when dealing with an isolated arterial injury, especially if your repair is going to take time, give systemic heparin to protect the distal microcirculation. Popliteal artery repairs are a good example where systemic heparin makes a difference.

Do you have to repair injured veins? It is a luxury, not a must. If a vein injury requires a complex repair, it may not be worth the trouble. These repairs are technically more demanding than arterial reconstructions, often with inferior long-term patency, and may be unnecessary. If the patient has other injuries that require attention, sustained a significant physiological insult, or has been in the OR for many hours, ligate the injured vein without hesitation.

If you decide to indulge in a combined arterial and venous repair, the venous reconstruction should come first because a thrombosed vein cannot be effectively cleared. Remember to interpose viable soft tissue between the venous and arterial repairs to prevent a fistula.

Vein repair is a luxury - not a must

Working with grafts

Choice of graft material is a major controversy in vascular trauma. No one would consider a synthetic graft below the knee or distal to the shoulder because the vessels are too small; 4mm synthetic grafts simply don't work. This focuses the controversy on the femoral artery. The proponents of vein grafts emphasize how well they work, although there is no good evidence that they do better than synthetic grafts in young patients with intact outflow tracts. The proponents of synthetic grafts emphasize how well they *fail*, since, in the presence of infection and exposure, a vein graft dessicates and dissolves, resulting in sudden hemorrhage. A synthetic graft fails gradually by forming a pseudoaneurysm. Another advantage of the synthetic graft is expediency. Our personal preference is synthetic graft for femoral artery

reconstruction. The truth is that it does not matter which material you use, as long as you do it well.

Graft protection is a cardinal principle in vascular trauma. When planning your reconstruction, remember that an interposition graft in a traumatized and contaminated field invites disaster. You have to route the graft through a clean field or cover it with well-vascularized soft tissue. Graft protection considerations may dictate the operative sequence: bowel repair and peritoneal toilet before an abdominal vascular reconstruction; soft tissue debridement before an interposition graft in an injured extremity. Occasionally, you may have to improvise an unconventional extra-anatomic route for the graft to avoid either a heavily contaminated environment or a large soft tissue defect.

Vascular trauma is essentially the art of dealing with young arteries that are soft, pliable, and easily undergo vasoconstriction. Remember these inherent qualities when sewing in a graft. The technical principle of driving the needle always from inside the artery out, so religiously taught in elective vascular surgery, is irrelevant in vascular trauma. You won't raise an intimal flap in a healthy artery, even if you go from outside in. So, work in whatever direction is most convenient, but always have tremendous respect for the arterial wall, because it will not forgive bad passage of the needle or jerking the suture sideways. The trajectory of the needle must always be perpendicular to the arterial wall.

Do not injure the artery with your vascular instruments. Pass a Fogarty catheter only a few centimeters above and below the injury, and do not over-inflate, or you will denude the healthy intima. Close the jaws of a vascular clamp gently ("only two clicks") so as not to crush the artery.

A major pitfall with young arteries is size mismatch. It is easy to insert too small a graft into a vasoconstricted artery, only to later realize you have created a bottleneck that invites early failure. This is particularly common in the aorta and iliac arteries of young adults. Because the vasoconstricted aorta will dilate later, make a conscious decision to select a slightly larger graft than what you deem necessary at the moment.

Vascular trauma is the art of dealing with healthy arteries

THE KEY POINTS

- Bleeding and ischemia are different priorities.
- Balloon tamponade controls external bleeding in transition zones.
- Know the patient's total trauma burden and physiology.
- Align bone before arterial reconstruction.
- Get an angiogram if the patient is stable.
- Do pre-emptive fasciotomy before popliteal artery repair.
- Know the key anatomical landmarks.
- Get proximal control outside the hematoma.
- Use an intraluminal balloon for problematic distal control.
- Define the full extent of the vascular injury.
- Gradually develop and optimize your work space.
- Decide between complex vascular repair and damage control.
- Ligation is not an admission of defeat.
- Clear the inflow and outflow tracts before shunt insertion.
- Transected artery = interposition graft.
- Vein repair is a luxury - not a must.
- Vascular trauma is the art of dealing with healthy arteries.