Damage Control Vascular Surgery

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Objectives: At the completion of this module fellows will be able to:

1. **Describe surgical exposures for upper extremity, great vessel, visceral, and lower extremity vascular injury.**
2. **Describe methods for hemorrhage control.**
3. **Describe options for both temporary and definitive extremity revascularization.**

Background:

- Rates of morbidity and mortality associated with vascular trauma are significant, particularly with missed injury or delayed diagnosis. Rates of missed vascular injuries range from 5-15%. Associated morbidity can approach 50% and includes stroke, amputation, ischemia, delayed rupture, infection, and claudication.
- Blunt and penetrating mechanisms differ in terms of injury pattern. Penetrating trauma tends to create a full thickness injury to the wall of the vessel with either a surrounding pseudoaneurysm or free extravasation. Blunt injuries can result in full thickness disruption of the vasculature, but more frequently they result in an intimal tear and pseudoaneurysm involving the wall of the vessel. Blunt mechanisms can also lead to either vessel occlusion or distal emboli.
- Low-velocity missiles damage vessels directly in their path, while high velocity missiles dissipate energy at right angles to its trajectory creating a cavitational effect approximately 30-40 times the cross-sectional area of the bullet. Most civilian missiles are low-velocity in nature.
- Major vascular injuries can be associated with a variety of associated injuries that may preclude definitive repair at the initial operation and therefore the surgeon must be well-versed in damage control options.

Diagnosis and Management:

- Extremity wounds with signs of active external hemorrhage, loss of pulse, or an expanding hematoma prompt immediate operative intervention.
- Manual compression, proximal tourniquet, or endovascular balloon inflation can be used for hemostasis and as a bridge to definitive control.
- In the emergency department (ED), first line approach should be digital compression of external hemorrhage.
- In the context of active hemorrhage, CT angiography, duplex ultrasound, and ankle brachial indices (ABI) are not indicated and only increase the time to definitive hemorrhage control.
- Diagnosis of a visceral vascular injury is typically heralded by intraabdominal hemorrhage evident on FAST ultrasound in the ED, however many intra-abdominal vascular injuries may be limited to the retroperitoneum and have a small amount of free blood in the intra-peritoneal cavity.
- Using an operating room table that is fluoroscopy compatible is recommended, in the event that angiography is needed to aid proximal control, diagnosis and/or treatment.
- Massive transfusion protocols are indicated in significant vascular trauma with active hemorrhage.

- For all lower extremity injuries, the entire limb plus the contralateral leg should be prepped; for suspected iliac injuries, the patient should be prepped from nipples to knees.
- For upper extremity injuries, the neck, chest, circumferential extremity, and bilateral groins should be prepped.

<u>Operative Techniques:</u>

Lower extremity injuries:

- Open proximal control can be obtained by groin exposure and direct clamping of the common femoral artery or SFA, particularly when trying to avoid direct dissection into large hematomas at the site of injury.
- Direct dissection at the site of injury should be performed with caution, and undertaken when the operator has experience in gaining proximal control within a hostile wound environment (i.e. active concurrent hemorrhage).
- Close attention should be paid to the potential for compartment syndrome with a low threshold for fasciotomy if the ischemic time has exceeded 4-6 hours, or involves both arterial and venous injury.

Thoracic/Great vessel/Upper extremity injuries:

- Open proximal control of the mid and distal axillary artery can be performed through an infraclavicular incision, after splitting the pectoralis major and transecting the pectoralis minor, with or without extension along the deltopectoral groove.
- Proximal control of the right subclavian or innominate arteries can be performed through a right supraclavicular incision or median sternotomy with "T" extension following the course of the clavicle if needed.
- Proximal control of the left carotid can be accomplished through a median sternotomy. Proximal control of the left subclavian artery can be accomplished through a high left anterolateral thoracotomy. At times disarticulation of the sternoclavicular joint and retraction of the clavicle can provide some additional exposure.
- For carotid injuries, obtaining distal control first to prevent embolization should be considered, particularly in blunt injury without active bleeding.
- Urgent control of the descending thoracic aorta should be done through a left anterolateral thoracotomy. If the injury has occurred at the ligamentum arteriosum, clamping the aorta between the left carotid and left subclavian arteries (as well as the proximal left subclavian artery) allows suitable space for graft anastomosis. Elective exposure is best accomplished through a standard posterolateral thoracotomy.
- Proximal control of the subclavian and carotid arteries can be accomplished by endovascular balloon. The risk of devices in the aortic arch and great vessels should be weighed against the morbidity of the incision that would otherwise occur to achieve proximal control.

Ligation of arteries and veins:

- Life-threatening hemorrhage is an indication for ligation of vessels. Revascularization depends on overall physiology, local factors, disease, and extent of injury

- The following arteries can usually be ligated: external carotid, proximal subclavian, celiac, proximal splenic, gastroduodenal, and hypogastric.
- The following veins can usually be ligated: infrarenal IVC, hypogastric, splenic, femoral, tibials, L innominate, IJ, subclavian, facial. Popliteal vein ligation may increase the risk of amputation.

Damage Control techniques for Abdominal Vascular Injury:

- Control of the aorta at the diaphragmatic hiatus can be achieved by retracting the left lobe of the liver to the right, taking down the diaphragmatic crus, and mobilizing the esophagus. The retroperitoneum must be opened in order to fully control the aorta. This exposure is difficult and time consuming. Digital occlusion or application of an aortic compressor without dissection may facilitate quicker temporary aortic control.
- Proximal control of the celiac, superior mesenteric, and right renal arteries, as well as the inferior vena cava, right renal and proximal left renal veins is accomplished via a right medial visceral rotation, mobilization of the hepatic flexure, and Kocher maneuver.
- SMA and celiac exposure can be accomplished through a left medial visceral rotation. Celiac artery injuries can be ligated. SMA injuries require immediate revascularization proximal to the jejunal branches. Options for conduit are challenging in the face of possible pancreatic injury with leak or bowel injury with contamination. Options for reconstruction include iliac-, renal-, supraceliac-, or suprarenal aorta- to the SMA. Although vein is preferred in any setting with contamination, ringed PTFE provides better stability of the bypass and can be covered with omentum. Retrograde stenting is a viable option for the proximal SMA, and can be performed by placing a sheath retrograde in the distal SMA and deployment of a stent-graft proximal to the jejunal branches.
- Control of the left renal artery and mid to distal left renal vein is accomplished by left medial visceral rotation, or entering the retroperitoneum at the base of the mesocolon and mobilizing the Ligament of Treitz. The remainder of the distal aorta can also be exposed through a direct midline approach.
- Retrohepatic inferior vena cava injuries are rarely explored unless massive hemorrhage is noted from this area that is refractory to packing and the Pringle maneuver. The falciform, right and left triangular ligaments are taken down, with medial rotation of the right lobe to expose the hepatic veins and inferior vena cava. These injuries are highly morbid.
- Ligation of the inferior vena cava below the renal veins is reasonable if shunting and/or repair are not feasible. Compression wraps should be applied to the extremities and they should be elevated to minimize complications from the ensuing venous hypertension. Hourly pulse checks and monitoring for compartment syndrome must be diligent in the postoperative period. This is particularly true for ligation of the external iliac vein.

Resuscitative endovascular balloon occlusion of the aorta (REBOA):

- Through a percutaneous or open groin approach, compliant balloon catheters can be inserted through the common femoral artery, advanced, and inflated proximal to the site of injury.
- This procedure can be performed in the resuscitation area with or without the aid of portable radiography.

- For severe hemorrhage below the diaphragm, the balloon can be inflated at the level of the diaphragm, or Zone 1 (between the left subclavian and celiac arteries).
- For severe pelvic hemorrhage, the balloon can be inflated just above the aortic bifurcation, or Zone 3 (between the lowest renal and the aortic bifurcation).
- Zone 2 is between the celiac and lowest renal artery and aortic occlusion should be avoided in this area
- Major pulmonary, hilar, or cardiac sources of hemorrhage should not be controlled utilizing balloon occlusion.
- Maximum balloon occlusion times are not known at this time. Once the balloon is inflated it is advisable to transport the patient expeditiously to the location that permits definitive hemorrhage control (including interventional radiology or operating room), followed by deflation and removal of the devices as rapidly as possible.

Intraoperative Considerations:

- Proximal and distal vascular control is the mainstay of damage control vascular surgery.
- Proximal control can be accomplished via direct exposure and clamping, retrograde insertion of a compliant balloon through the open wound, or distant percutaneous access and endovascular balloon inflation.
- Aortoiliac and great vessel control can be achieved with a 10-32mm compliant balloon. Cerebrovascular control can be performed with smaller compliant balloons such as 2-4mm Fogartys. Femoropopliteal vessels can accommodate 3-4mm Fogarty balloons, and the distal tibial vessels can be occluded with 2mm. Care must be taken to constantly appreciate feedback from the inflated balloon, and not to overinflate, as this can cause irreversible intimal disruption.
- Once hemostasis is achieved, temporary shunting should be performed in cases of severe physiologic devastation, or prior to long bone fracture manipulation. A shunt should be placed that allows for up to 15 centimeters of disruption. Pruitt-Inahara shunts are quite malleable and provide a side port to allow for injection of contrast, heparin, or for blood sampling. Other commercially available options include the Javid, Argyle, and Sundt shunts. If shunts are not available, any circular plastic tubing with a comparable-sized lumen can be utilized including IV tubing. Smaller caliber chest tubes can be used in larger vessels including the aorta and vena cava.
- Blind clamping of injuries can result in incomplete hemostasis, vessel disruption/dissection, further vessel disruption, and nerve and/or venous injury.
- Concomitant venous injury is common and should be repaired or ligated if encountered on exploration to avoid further hemorrhage and possible fistula or pseudoaneurysm formation.
- If available and timely, an endovascular approach to injury repair can be considered. Embolization is permanent; however, stent-grafting is an acceptable alternative for temporary and possibly definitive hemorrhage control.
- If primary repair is not possible, autologous conduits such as reversed greater saphenous vein (RGSV) or cephalic are preferred. PTFE grafts are an acceptable alternative for vessels greater than 6mm. Biologic options such as Cryovein™ or Artegraft™ may be preferred in settings with severe contamination but no data is available to support use in

trauma patients. Particularly in the SFA, mobilization of the proximal and distal vessel may allow for primary repair.
- Completion angiograms are highly recommended and can be done with a flat plate x-ray and timed contrast injection, or with the patient on a table suitable for portable or fixed C-arm fluoroscopy.
- Consider fasciotomy in patients with prolonged (>6 hour) ischemia time or in those patients with combined arterial and venous injuries.

Postoperative Management:
- Complete neurovascular examinations should occur hourly in the acute setting.
- Resuscitate as needed.
- There is no evidence-based recommendation for anti-coagulation after revascularization; however most repairs, particularly in large vessels do not require heparinization.
- Use of anti-platelet agents can be considered as an alternative to heparin.

Outcomes:
- PTFE grafts 6mm or greater have satisfactory patency and are reasonably resistant to infection
- Temporary intravascular shunts should be removed as soon as the patient can tolerate reconstruction. Infection of grafts placed after indwelling shunts have been reported.

Pearls from the experts: Drs. Steven R. Shackford and Michael Sise
- The decision to perform vascular damage control versus definitive repair is based on the following priorities:
  1) The overall status of the patient – presence of systemic acidosis, hypothermia, coagulopathy, and overall stability.
  2) The priorities in management of other injuries – TBI, torso injuries, orthopedic injuries, etc.
  3) The complexity and time required for definitive vascular repair and the appropriateness relative to the overall management of the patients injuries.

- Once the decision is made to perform damage control, the following priorities are essential to success;
  1) Control of hemorrhage.
  2) Restoration of sufficient arterial flow to maintain limb viability with an intravascular shunt.
  3) Prevention of compartment syndrome with fasciotomy when appropriate.
  4) Preservation of adjacent uninjured vessels which will be the basis for adequate definitive repair.
  5) Sufficient temporary closure to avoid dessication of vascular structures or dislodging the shunt.

- Life threatening torso vascular injuries are often diagnosed at the time of either emergency thoracotomy or laparotomy for hemorrhage control. Measures to control hemorrhage are often performed in conjunction with visualizing the injured vessel in these life-threatening injuries.

- Life threatening external hemorrhage from extremity wounds similarly requires immediate control measures and direct visualization in the operating room. For example, tourniquet application or direct pressure precludes CT imaging of the site of injury.

- Damage control of vascular injuries includes the planning, timing, and completion of definitive repair. The initial damage control measures are only the first step and should initiate an aggressive timeline for return to the operating room for completion of an appropriate repair. This timeline is distinctly shorter than that used in damage control of abdominal visceral injuries. Arterial shunt thrombosis with distal ischemia, the development of muscle compartment syndrome, and distal thrombosis beyond ligated arteries or proximal to ligated major veins are significant risks in vascular damage control and can often be avoided by early reoperation.

- "Pre-emptive" lower extremity fasciotomy should be performed in patients with anticipated need for interposition grafting if the ischemia time has exceeded four hours. This is done for three reasons: 1) ischemia "time" is always an estimate because the time of injury (at which ischemia is initiated) is generally unknown; 2) there is now reasonable laboratory evidence (porcine model) that histologic change in muscle and nerve occurs in 3 hours, and 3) the time to reperfusion is often underestimated. The fasciotomy is done after proximal and distal exposure and control of hemorrhage is attained. The artery should be shunted prior to fasciotomy. If the patient has stabilized and will tolerate more than simple damage control, definitive revascularization may be performed.
    - <u>Technical adjuncts</u>:
        1) Mark landmarks and incision lines – note head of fibula and mark 2 finger breadths below for exclusion zone for peroneal nerve safety.
        2) Lateral skin incision – full length to create a dermotomy.
        3) Anterior compartment release –generous longitudinal incision at 45º to A-P axis but stay below peroneal nerve exclusion zone proximally.
        4) Incise anterior compartment fascia proximally and distally, avoiding peroneal nerve exclusion zone proximally.
        5) Probe under fascia to the tibia to assure in the anterior compartment.
        6) Release lateral compartment fascia in similar fashion probing under fascia to confirm in proper space posterior to the inter-muscular septum.
        7) Posterior compartment release –generous longitudinal medial incision 2cm behind tibia and avoid the saphenous vein.
        8) Superficial posterior fascia release under direct vision .
        9) Deep posterior release under direct vision to locate and avoid posterior tibia artery – do all of this under direct vision by retracting the gastrocnemius and soleus muscles in the distal calf.

10) Hemostasis on skin, check muscle contraction with electrocautery in all compartments.
11) Place loose moist sponge or Kerlex in wounds – wrap leg loosely.
12) Recheck perfusion at DP, PT sites at ankle and foot.
13) Reassess wounds for hemorrhage and dressing tension regularly and frequently over next 24 hours – avoid secondary compression from dressings.

- Be liberal with calf fasciotomy in lower extremity vascular damage control. The failure to perform four-compartment calf fasciotomy is the most common contributing factor in preventable lower extremity limb loss after vascular injury.

- It is important to emphasize the importance of taking down the pectoralis minor tendon for adequate exposure of the axillary artery. To do this, it is best to gently grasp the muscle after you have finger dissected anteriorly and posteriorly, and then pull down so that the tendinous portion is apparent at its insertion on the coracoid process. Use the Bovie to divide it as close to the coracoid as possible. It will then retract by itself out of the way or can be retracted easily.

- The left subclavian artery does not "rise" as high into the supraclavicular fossa as the right subclavian does; hence, the need for the procedures indicated. If one is not prepared to do a sternotomy or thoracotomy, it is important to remember that the clavicle can be totally removed without any disability. Thus, if time permits, one can incise the skin and subcutaneous tissue over the clavicle, do a subperiosteal mobilization, and divide the clavicle. Once this is done the posterior periosteum and the subclavius muscle must be divided to expose the subclavian artery and vein.

- If aortic inflow occlusion is needed, and the suprarenal aorta does not need to be exposed, the aortic compressor is an excellent tool due to the speed with which the aorta can be occluded. In addition, it can be held in place by a person with little operative experience and it can easily be "released" temporarily to give the viscera "a drink".

- In the relatively stable patient with a juxtahepatic caval injury, veno-veno bypass can be utilized. After packing the liver and exposing the suprarenal and suprahepatic inferior vena cava, cutdowns are performed on the right axillary vein and the right femoral vein at the sapheno-femoral junction. A 20 Fr catheter is inserted into the femoral vein through the saphenous vein junction, and an 18 Fr catheter is inserted into the right axillary vein. Both catheters are connected to a Biomedicus pump such that the blood is taken from the femoral vein and returned through the axillary vein. Then a clamp is placed across the portal triad, the suprarenal vena cava, and the suprahepatic cava just below the diaphragm. This will give adequate vascular isolation of the liver.

- For shunting medium sized arteries and veins (i.e., popliteal), intravenous extension tubing may be preferred. Cut off the "male" and "female" ends and bevel the ends to be inserted. For larger vessels a pediatric chest tube may be used.

- In addition to ligation and repair of veins, one always has the option of shunting larger and more critical veins (i.e., femoral). If you elect to shunt a vein, make sure that the end of shunt placed distally does not end up in a valve cusp. You can check this by placing the distal end first and then gently flushing the distal end.

- Don't use a long shunt and don't loop it between ends of the vessels. The needlessly longer the shunt is the more likely it will thrombose or by dislodged. Keep it short and tie it in well. Remember that you have started a process that will ultimately lead to shunt thrombosis and distal ischemia – shunt perfusion time is limited. Get back to the operating room for definitive repair as soon as the patient is stable. This is not analogous to an open abdomen where there is longer discretionary time to go back to the operating room.

- <u>Step by step checklist for the operative approach in vascular damage control:</u>
  1) Widely prep and drape to allow access to vessels proximal and distal to the injury – fully prep injured extremities and adjacent areas of the chest in proximal upper extremity injury or the abdomen in proximal lower extremity injury.
  2) Prepare appropriate sized Fogarty catheters with stop cocks to obtain proximal and or distal control in difficult to access areas.
  3) When possible in the extremities, place a proximal sterile pneumatic tourniquet and tightly wrap the extremity to reduce blood volume then inflate and record ischemia time.
  4) Make a generous incision that includes adjacent proximal and distal uninjured areas.
  5) Expose the proximal vessels and obtain control with non-traumatic clamps or vessel loops.
  6) Carry dissection across the area of injury to identify distal vessels and place clamps or vessel loops or intra-vascular Fogarty balloon catheters if needed.
  7) Deflate the tourniquet if used and assess the adequacy of vascular control – re-inflate and take further steps if needed.
  8) Adequately expose a sufficient length of the injured vessels.
  9) Perform local Fogarty catheter thrombectomy and instillation of heparinized saline solution (10 unit of heparin per ml saline – 5,000 units heparin in 500 cc saline).
  10) Debridement of damage vessel wall back to healthy intima.
  11) Place an intravascular shunt of sufficient width and length to restore perfusion.
  12) Secure the shunts with ties as close to the margin of damage vs. healthy tissue to avoid more vessel damage and to secure the shunt from becoming dislodged with a 2-0 silk tie around the center of the shunt with each end then tied to the ties securing the ends of the vessel.
  13) Assess distal flow with pulse or Doppler signal assessment.
  14) Rapidly address venous injury–if simple arterial suture repair not possible, rapidly ligate.
  15) Cover the injured vessels with viable local tissue loosely approximated.
  16) Decide ASAP regarding the need for calf or forearm fasciotomy based upon compartment pressure measurements, the extent of soft tissue injury, and duration of ischemia – always add fasciotomy when major veins ligated.

17) Apply appropriate dressings that allow serial distal vascular checks and avoid secondary compression of the extremity compromising perfusion.
18) Plan for rapid return to the operating room as soon as possible for definitive repair as soon as the patient hemodynamically stable, normothermic, and not coagulopathic.
19) Consult an experienced vascular surgeon to assist in the definitive repair if needed.

- Call an experienced colleague for help early and often in managing major vascular injuries – it is not a sign of weakness, rather it is an indicator of wisdom. Vascular injuries are difficult management problems even for the most experienced vascular or trauma surgeon.

- In the torso, damage control is difficult at best. There is, however, a very promising approach that combines open and endovascular techniques. A hybrid operating room capability can be created in any OR with a fluoroscopy capable OR table, a digital subtraction angiography capable C-arm and the appropriate catheters and equipment in rolling carts. An interventional radiologist or surgeon with catheter skills can place proximal occluding balloons across an area of injury in torso vessels that are being controlled by direct pressure by a colleague in the operating room. Areas that are difficult to access may be controlled and definitively treated with covered stents; this incorporates both damage control and final repair. However, this capability requires prior planning and preparation. Many trauma centers create these "hybrid ORs of opportunity" for their elective endovascular aortic aneurysm repairs. By planning ahead with colleagues with catheter skills, having equipment ready to roll, and placing all major trauma patients on an orthopedic table that is fluoroscopy capable, you have created a hybrid vascular operating room for your trauma patient.

- Prepare a checklist for your procedures, particularly those that you perform infrequently. The step by step list above can be quickly adapted into a brief checklist for damage control.

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