VASCULAR/ ENDOVASCULAR SURGERY TRAINING MANUAL

3rd Edition

STONE
JOHNSON, O'BANION, WEAVER

FORMERLY KNOWN AS THE COMBAT MANUAL

Compliments of W. L. Gore & Associates, Inc.

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Forward

In 1996, when the first edition of this manual was published, scalpels and prolene sutures were the mainstay of our dedicated field. We wore white lab coats and stethoscopes. Duty hours were not recorded or considered a topic, and trainees were required to complete a general surgery residency prior to undergoing a fellowship with additional certification for vascular surgery.

Edited by Christopher Dickson, M.D., a clinical fellow at Eastern Virginia Medical School, the original manual provided "pearls of wisdom" for pre-operative evaluation, and intra-operative and post-operative vascular care.

I carried the original manual in my coat pocket. I found those nuggets of essential pre-operative and post-operative care important to share with rotating medical students or general surgery residents assisting in patient care. Endovascular technology was flourishing. I remember one of my attendings said, "One day, we will be recommending an additional year in open vascular surgery."

In 2013, after co-developing the first fellowship and integrated vascular program in West Virginia with Ali AbuRahma, M.D., we worked with our faculty to update this "Combat Manual." Now, 30 years from its first publication, we've updated the manual again to reflect the evolution of today's vascular training and patient care.

Today, "endovascular first" is so common, more cases are performed by this method than open procedures. Some programs are even considering sending trainees for additional training in open procedures — much like that attending predicted years ago.

Trainees no longer wear white jackets and are often with a cell phone in hand while searching for a stethoscope. Perhaps most impressive, when the original manual was written, less than 5% of vascular surgeons were female. Today, more than 50% of the current class of trainees nationally are women.

This edition provides a diverse editorial and writing staff featuring more women, early career surgeons, surgeons with military experience, and vascular trainees — all from different institutions with fresh views on these familiar topics.

We hope this manual provides necessary updates while maintaining the vision of its original authors.

— Patrick Stone, M.D., FACS

Vascular Surgery Rules of Engagement

1. Imperative to understand points of entry into the vascular surgery team (outpatient procedures/ED/inpatient consultants).
2. Specifics of pre-operative details cannot be overestimated. Updated history and physical, marking of correct surgical site and consent details are final opportunity for questions to be answered prior to an operation.
3. Sabotage in the form of not assuring discharge reconciliation of medication and clear instructions should not occur.
4. Evaluation of patients on rounds prior to daylight should ensure all associated surgery specific areas are assessed. i.e., post lower extremity bypass: no bleeding from incisions and pulses intact.
5. Transitions of care are pitfalls for lost information.
6. Follow the chain of command. If you don't know the answers seek superior help immediately, don't become stranded.
7. Do not battle with other services inappropriately to avoid admissions — we are all on the same side to take care of the patient.
8. Be prepared when it's your opportunity to participate in the OR, know how to tie knots, safely obtain access, etc.
9. Review all images and image reports. This applies to both inpatient and outpatient settings. Final reads can describe harboring issues that must be known, i.e., lung mass, etc.
10. One day you will look across the OR table and realize you are the most experienced surgeon in the room. Don't pass up any opportunity to gain autonomy today.

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HISTORY AND PHYSICAL EXAMINATION

M. Libby Weaver, M.D.

Initial Global Assessment

Frailty, functional status, and ambulatory status are all important considerations in a patient's ability to tolerate an operation. Your examination can begin as the patient enters the office.

Can the patient ambulate independently? Do they use supplemental O^2? Is the patient morbidly obese (calculate Body Mass Index [BMI]) or severely malnourished?

History of Present Illness

Always ask a patient why they have been referred. What is their chief complaint? Sometimes these answers are different.

Characterize and localize the patient's symptoms and determine symptom duration. Are there aggravating or alleviating factors?

To treat or not to treat is always based on the patient's history.

Review of Systems/Past Medical/Surgical History

Cardiac-related morbidity is the number one cause of death following vascular interventions.

All previous surgeries must be known in detail, including non-vascular, so that appropriate pre-op can be performed.

Cardiac: Do they have a history of myocardial infarction (MI), chronic heart failure (CHF), or valvular disease?

Review previous imaging reports, previous coronary interventions including percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) and when they occurred. Are they on anti-platelet therapy or anti-coagulation, and are they at an interval that this can be safely held?

Does patient have a pacemaker or implantable cardioverter-defibrillator (ICD)?

Pulmonary: Do they have a history of smoking, chronic obstructive pulmonary disease (COPD) with or without home oxygen, lung mass, pulmonary embolus, cough, dyspnea with exertion, continuous positive airway pressure (CPAP)?

Renal: Do they have a history of previous central venous catheters or dialysis access, and at what locations?

- Renal insufficiency is a major cause of peri-operative morbidity and mortality.
- Glomerular filtration rate (GFR) is important for medication dosing and ability to administer contrast.
- Dialysis schedules are important for surgical scheduling.

Gastrointestinal (GI): Do they have a history of weight loss, post-prandial abdominal pain/food fear (mesenteric ischemia)? GI bleed with prior aortic surgery (aorto-enteric fistula)?

Infectious disease: Do they have a history of methicillin resistant staph aureus (MRSA), vancomycin resistant enterococcus (VRE), immunosuppression (transplant patient or HIV), increased risk of infection with implant, ongoing remote infection, previous infections with surgery?

Neurologic: Do they have a history of stroke or transient ischemic attack (TIA) history and when? After 6 months from event, the patient's lesion would be characterized as asymptomatic.

Hematologic: Do they have a history of heparin-induced thrombocytopenia (HIT), prolonged bleeding after procedures, or hypercoagulable disorders?

Urology: Do they have a history of hematuria, urethral stricture, urinary retention, or known prostatic hypertrophy? This will likely impact foley insertion.

Musculoskeletal: Any history of orthopedic implants in the extremities? Critical to know if previous ortho implants prior to amputation!

Allergies, Social, and Family History

- ***Allergies:*** Medications and contrast agents (pre-medication regimen listed in appendix).
- ***Alcohol abuse:*** May require clinical institute withdrawal assessment (CIWA) protocol.
- ***Medical power of attorney and code status:*** Who to call in case of emergency, with updates after surgery, and documentation of status.
- ***Religious beliefs that impact medical care:*** Particularly, refusal of blood products, or implant concerns i.e., porcine or bovine.

Medications

All medications must be reviewed in detail. If patients do not know their medications, pharmacies or primary care doctors must be contacted for verification.

Medications are discussed in greater detail in Chapter 2 and throughout this manual.

Physical Examination

A full head-to-toe examination should be performed. However specific attention should be paid to the following areas:

Vitals

Head and neck: Carotid bruit (approximately ⅓ normal, ⅓ disease, ⅓ severe disease—bruit with systolic and diastolic component is a sign of severe disease), signs of previous neck irradiation or scars from prior neck surgeries, tracheostomy?

Cardiac: Murmurs may signify valvular dysfunction and warrant pre-op echocardiogram. Irregular rhythm (atrial fibrillation). Distant heart sounds (pericardial effusion).

Lungs: Crackles, wheezes, or rhonchi may indicate CHF, pneumonia, pulmonary edema, or COPD.

Abdominal: Bruits, pulsatile masses, abdominal scars, distension, or tenderness. Hernias may impact approach in procedure access.

Lower extremity: Look, feel, listen.

Do the limbs look symmetric?

Venous disease: One leg may be more edematous than the other.

Are there varicosities or scars from prior vein harvest?

- ***Arterial:*** Is one limb mottled or does it have pallor compared to the other?

Are there classic stigmata of chronic arterial or venous disease?

- ***Venous:*** Lipodermatosclerois and/or ulcers over gaiter region?
- ***Arterial:*** Hair loss, dependent rubor, or digital ischemia with gangrene?
- Use continuous wave (CW) Doppler if pulses not palpable.
- ***Touch the limb:*** Is it cool in comparison to the other limb? Is there pitting edema?

Pulse examination: Palpate for femoral, popliteal (widened pulse suspect aneurysm), and pedal pulses. Use a continuous wave (CW) Doppler to insonate the signals and describe them as multiphasic, monophasic, or absent. Listen for a venous signal if assessing acute limb ischemia.

Ankle-brachial index (ABI): To perform ABIs, check blood pressure on each arm and at each ankle with a manual cuff while insonating the brachial, dorsalis pedis, and posterior tibial arteries with a doppler. Use the highest pedal pressure of each extremity divided by the highest brachial pressure overall to determine the ABIs.

Diagnostic Tests Prior to Major Operations

Complete blood count: Assess for anemia, thrombocytopenia, or leukocytosis.

Metabolic panel: Evaluate renal function, fluid status, metabolic state, glycemic control.

Coagulation panel: Pro-time (PT), partial thromboplastin time (aPTT), international normalizing ratio (INR). Medications or underlying liver disease or malnutrition.

Electrocardiogram (EKG)

Transthoracic echocardiogram (TEE) in appropriately selected patients.

Pre-Op Check List:

1. NPO after midnight.
   - Consider bowel prep for abdominal surgeries and clear liquids day prior to surgery.
2. Blood type and cross matched when indicated, or type and screen.
3. Patients with renal dysfunction may require pre-hydration prior to contrast administration.
4. All women of childbearing age require a pregnancy test.
5. Pre-medication of patients with contrast allergies (refer to appendix).
6. Administration of cardioprotective medications: Acetylsalicylic acid (ASA-Aspirin), beta blocker, statins prior to open surgery.
7. Appropriately correct any coagulopathies. Refer to the appendix for management of anti-coagulant or anti-platelet medications.
8. Informed consent: The attending is responsible for consenting the patient. However, house staff may be responsible for completing the documentation of this consent process. Informed consent includes:
   - Procedure and laterality: Will the patient be prone?
   - Risks of intervention: Refer to the complication section of each chapter.
   - Alternates: Observation, endovascular, or open surgery, etc.
   - Expected benefits: Refer to individual chapters.
   - Blood product: Religious beliefs may preclude.
   - Covering surgeon: Many institutions require understanding of this policy on consent.
9. Mark the operative location. Wrong site surgery is a "never" event. Always assure correct patient, procedure, and laterality.
10. Assured and updated history and physical examination is documented within 30 days.
11. Apply chlorhexidine wipes the day before and day of surgery.

! *This manual does not include all the information needed to use the drugs listed herein safely and effectively. See full prescribing information and any boxed warnings for these drugs.*

Common Reasons Surgery is Canceled or Delayed

- Failure to place NPO orders.
- Failure to correct coagulation parameters or electrolytes (BMP).
- Failure to discontinue anticoagulants (i.e., 3 days pre-op).
- Failure to arrange hemodialysis, and nephrology team requires it pre-op.
- Failure to obtain cardiac clearance.

Check List for Post-Operative Management

1. Post-op examination and document assessment.
2. Assure proper medications are ordered. ASA beta blocker statins, antibiotics.
3. Make sure antibiotics are stopped within 24 hours of surgery unless active infection and foley removed (National Surgical Quality Improvement Program [NSQIP] guidelines).
4. Check all cultures daily and narrow antibiotics when indicated.
5. Must check pulses and incisions daily for signs and symptoms of complications (i.e., hematoma, infections, etc.).
6. Order and check labs pertinent to specific interventions (i.e., creatinine following contrast-based procedures).
7. Assess for development of surgery specific complications, (i.e., neuro deficit, hematoma following carotid endarterectomy [CEA]).
8. Update family of discharge planning.
9. Confirm plan for antiplatelet and/or anticoagulation regimen ASA/clopidogrel/warfarin.
10. Sign out with on-call staff pending laboratory evaluations/tests—inform on-call house staff if this/then what (transfusion triggers, etc.).

COMMONLY PRESCRIBED MEDICATIONS

M. Libby Weaver, M.D.

Intraoperative Anticoagulants During Vascular Procedures

Unfractionated heparin

From ancient Greek (Hepar: liver). Heparin is naturally occurring in mast cells. Discovered in 1916, heparin is one of the oldest drugs currently still in widespread clinical use.

— **Indication:** Cardiovascular anticoagulation, deep venous thrombosis/PE prophylaxis and treatment.

— **Dosing:**

- Bolus — 60–80 units/kg, depending on diagnosis, in OR 3–5 minutes to become systemic.
- Infusion —18 units/kg/hr.
- Adjusted to keep a PTT of 50–80 seconds.

— **Monitoring dosing in the perioperative period:**

- Activated clotting time — 250 seconds intra op to ensure anticoagulation.
- Sheath removal in many protocols < 180 seconds.

— **Mechanism of action:** Mostly factor Xa.

— **Half-life:** 1 to 1½ hours.

— **Complications:** Major concerns are bleeding and heparin induced thrombocytopenia (HIT).

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Reversal: Protamine sulfate

- **Dosing:** 0.5–1 mg IV for every 100 IU heparin.
- **Mechanism of action:** Cationic peptide that binds to heparin.
- **Complications:** Protamine reaction — Can cause cardiovascular collapse. Treat as an anaphylactic reaction. Administer a test dose and/or administer slowly to prevent reaction.

Low molecular weight heparin (LMWH): i.e., Enoxaparin sodium injection. Factor X inhibitor. No monitoring of the PTT coagulation parameter.

- **Indications:** Cardiovascular anticoagulation, venous thromboembolism (VTE) prophylaxis and treatment.
- **Treatment dose:** 1 mg/kg subq q12 hours or 1 ½ mg/kg subq daily. Prophylaxis is 40 mg subq daily, or 30 mg subq bid daily.
- Must be renal adjusted if creatinine clearance is less than 30. For dialysis patients, enoxaparin sodium injection has not been approved and is not recommended.
- Possibly poses a smaller risk of bleeding than unfractionated heparin.
- Less risk of osteoporosis in long-term use.
- Lower risk of heparin-induced thrombocytopenia.

The anticoagulant effects of heparin are typically reversible with protamine sulfate, while the effect on LMWH is limited.

Warfarin Sodium

It is a synthetic derivative of coumarin, a chemical found naturally in many plants — it decreases blood coagulation by interfering with vitamin K metabolism.

- **Indication:** Atrial fibrillation, DVT/PE, high-risk vascular reconstructions.
- **Mechanism of action:** Inhibits the synthesis of vitamin
- **K-dependent clotting factors:** II, VII, IX, and X, and proteins C and S.
- **Complications:** Bleeding, rash (warfarin-induced skin necrosis), osteoporosis.
- **Reversal:** Fresh frozen plasma (FFP)

Patient education imperative

- Discuss the influence of dietary vitamin K on INR.
- Discuss potential drug interactions (prescription, over-the-counter, herbal).
- Discuss the need to avoid or limit alcohol consumption.
- Women of childbearing age should be counseled on the teratogenic effects.
- Specify when to take warfarin and what to do if a dose is missed.
- Must notify patient's PCP that the patient is taking warfarin and make sure that appropriate follow-up is arranged for dose titration and INR testing.
- Warfarin should be started at a dose of 5 mg per day. Randomized trials have shown that patients are more likely to have a therapeutic INR three to five days after starting warfarin with a 5 mg dose than with a 10 mg dose.

Recommend a lower starting dose in:

- Elderly patients.
- Those with low body weight or low albumin levels.
- Patients with congestive heart failure or liver disease.
- Patients taking certain medications (e.g., amiodarone, trimethoprim-sulfamethoxazole, or metronidazole).

An initial increase in the INR (the anticoagulant effect) is primarily a response to decreased levels of circulating factor VII, which is the factor with the shortest half-life—approximately six hours. Factor IX also has a relatively short half-life.

However, the antithrombotic effect (the body's ability to prevent further thrombus formation) may not be achieved for up to five days. This effect depends on the clearance of circulating prothrombin, which has an elimination half-life of about 60 hours.

Patients with Protein C and S deficiency should be bridged to therapeutic INR levels with concomitant systemic anti-coagulation.

Direct Thrombin Inhibitors

Intravenous

Lepirudin: Hirudin derivative, indicated for heparin-induced thrombocytopenia with thrombosis. Renal excretion.

Argatroban: Indicated for heparin-induced thrombocytopenia with thrombosis. Metabolized by the liver.

Bivalirudin: Hirudin derivative. Indicated for unstable angina or angioplasty.

- Commonly used in complex interventions for consistent anticoagulation rather than the peaks and troughs that are seen with heparin bolus.

Oral

Rivaroxaban

- **Indication:** Alternate of warfarin for atrial fibrillation.
- Half dose indicated to decrease major adverse cardiac events (MACE) in patients with peripheral arterial disease per the COMPASS trial, and to decrease major adverse limb events (Male) in patients who have undergone lower extremity revascularization per the VOYAGEUR trial.
- **Dosing:** 5 mg bid; 2.5 mg bid for 'COMPASS/VOYAGEUR' dosing.
- **Mechanism of action:** Factor Xa inhibitor.
- **Half-life:** 11–13 hours.
- **Reversal:** Andexanet alfa or 4-factor prothrombin complex concentrate (PCC).

Apixaban

- **Indication:** Alternate of warfarin for atrial fibrillation.
- **Dosing:** 10 mg bid x 7days followed by 5 mg bid.
- **Mechanism of action:** Factor Xa antagonist.
- **Half-life:** 12 hours.
- **Reversal:** Andexanet alfa or 4-factor prothrombin complex concentrate (PCC).

Dabigatran etexilate mesylate

- **Indication:** Alternate of warfarin for atrial fibrillation.
- **Dosing:** 150 mg bid: renal dosing.
- **Mechanism of action:** Direct thrombin inhibitor.
- **Half-life:** 12–17 hours.
- **Reversing:** Idarucizumab is the primary reversal agent. When this is not available, activated charcoal to prevent absorption of residual drug in the stomach, consideration of one to two sessions of hemodialysis to remove Dabigatran etexilate mesylate from circulation; recombinant factor VIIa coagulation factor VIIa (recombinant) intravenously; FFP does not appear effective.

Antiplatelets

ASA

- **Indications:** For primary and secondary prevention of cardiovascular events in patients with clinical evidence of vascular disease. Daily ASA is no longer recommended for prevention of stroke or cardiac events in patients aged 60 and older without a history of vascular disease.
- **Dosing:** 81 mg–325 mg daily.
- **Mechanism of action:** Aspirin causes irreversible inhibition of cyclooxygenase-1 (COX-1), resulting in decreased synthesis of thromboxane A2.
- The peak effect of Aspirin on platelets occurs quickly (within one hour). Platelets are non-functional for the rest of their life span (7–10 days).
- Therefore, if no antiplatelet effect is desired, aspirin therapy should be discontinued 7–10 days prior to surgery.

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Clopidogrel bisulfate

- **Indication:** Acute coronary syndrome, recent MI, stroke, or PAD. Clopidogrel bisulfate has been shown to reduce the rate of a combined endpoint of new ischemic stroke (fatal or not), new MI (fatal or not), and other vascular death. Also required for carotid stent placement (see cerebrovascular chapter for dosing and duration recommendations). Dual antiplatelet therapy (DAPT) for a minimum of 90 days.
- **Dosing:** Loading dose 300 mg–600 mg. Maintenance dose thereafter is 75 mg daily.
- **Mechanism of action:** Irreversibly inhibits platelet activation through blockade of adenosine diphosphate (ADP) receptors found on platelets.
- Concomitant PPI administration can reduce effect of drug. Patients who are poor metabolizers with CYP2C19 have higher coronary complications than normal metabolizers.
- If clopidogrel bisulfate use is imperative peri-operatively due to recent percutaneous coronary intervention (PCI), can use intravenous cangrelor for shorter half-life.

Ticagrelor

- **Indication:** Alternative treatment for clopidogrel bisulfate non-responders. Based on verify now results.
- **Mechanism of action:** Reversibly binds ADP P2Y12 receptor.
- **Half-life:** 7 hours.
- **Dosing:** 90 mg, bid.
- **Loading:** 180 mg for carotid stenting.

Aspirin/extended-release dipyridamole

- **Indication:** Secondary prevention of stroke (20% less likely to have secondary stroke than 50 mg bid ASA only).
- **Mechanism of action:** Thromboxane synthase inhibitor. Dipyridamole inhibits PDE in tissues and inhibits the uptake of adenosine into platelets and augments the increase in cGMP.
- **Half-life:** 10 hours.
- **Dosing:** (25 mg ASA/200 mg dipyridamole) bid.
- **Side effects:** Headache and GI complaints.

Claudication Agents:

Cilostazol

— **Indication:** Medical management of claudication (studies report increase in walking distance from 25–100% of baseline).

— **Dosing:** 50 or 100 mg bid.

— **Mechanism of action:** Phosphodiesterase inhibitor, mild antiplatelet- reversible inhibition. Typically given as 3-month trial if no improvement then no benefit for keeping on regimen.

— **Complication:** Contraindicated in CHF patients. Most common reason for drug cessation is gastrointestinal symptoms. The most effective medication to increase walking distances in patients with peripheral vascular disease.

Commonly Prescribed Antibiotics

Cefazolin—First generation cephalosporin-bactericidal

— **Indication:** Pre-operative prior to open vascular surgery.

— **Dosing:** Wt. based typically 1–2 grams given q 6–8 hours for up to 24 hours after operation. < 60 min prior to incision, in OR every 3–4 hours.

Vancomycin—Bactericidal

— **Indication:**

- Surgical prophylaxis in patients with PCN allergy.
- Treatment of suspected or documented MRSA infection. Consider addition of gentamicin 4 mg/kg secondary to lack of gram neg. coverage with vanc. if needed.

— **Dosing:** Periop: Wt. based; second dose given if operation exceeds 6 hours.

— **Treatment dosing:** Wt. based with troughs checked after third dose.

— *Serial BMP's-renal dysfunction not uncommon.

Piperacillin/tazobactam—Extended spectrum PCN (bactericidal)

— **Indication:** Treatment of suspected or confirmed polymicrobial gram positive/negative infections.

— **Dosing:** Wt. based/renal clearance. Normal renal function: 3.375 g IV q 6 hours.

— *Pseudomonas coverage, and anaerobe coverage. Once microbes specified then narrow coverage.

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Diabetic Medications

Metformin hydrochloride

An oral medication in a class of drugs called biguanide. Does not cause hypoglycemia. Must be stopped 24 hours before any IV contrast and should be stopped prior to surgery secondary to risk for lactic acidosis. Can be reinitiated 48-hours post-operative if no acute kidney injury.

Sulfonylureas

Increases insulin production. Should be stopped 48 to 72 hours prior to surgery secondary to risk for hypoglycemia. Post-operatively these medications can cause hypoglycemia if initiated with poor caloric intake by patient. Should always be held in NPO patient.

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NONINVASIVE IMAGING

M. Libby Weaver, M.D.
Amanda Fobare, M.D.

Basic Concepts

As vascular surgeons, we love numbers and statistics. If you can only remember two numbers related to Doppler criteria, they would include the velocities **< 50 cm/sec** (associated with low flow from either severe proximal stenosis or occlusion) and **> 300 cm/sec** (elevated velocities detected within or adjacent to a stenosis).

Basics

Doppler equation: $\text{Frequency} = \frac{2F_t V \text{Cos}\Theta}{C}$

Frequency shift = 2 x frequency transmitted x velocity x cosign of beam angle/Speed of sound in tissue (1540 meters/sec).

Velocity criteria for vascular beds developed at 60-degree angle.

Frequency of probe: Inversely related to depth of beam penetration.

Continuous wave Doppler: Detects all velocities across vessel.

Pulse wave Doppler: Detects only sampled velocities.

Duplex:

- — ***B-Mode:*** Used to image soft tissue structures.
- — ***Pulse Doppler:*** Sample velocities at visualized location.

Carotid Artery

Routine components of vascular imaging include grayscale and Doppler U.S. interpretation of the internal carotid artery (ICA)[1]:

- ***Plaque characteristics:*** Heterogenous plaques are more likely to be symptomatic.
- ***Differentiate external carotid artery (ECA) vs. ICA:*** ECA with branches and high resistance with minimal diastolic flow, whereas the ICA has low resistance (gentler upstroke with continuous antegrade flow during diastole).
- Some recommend a temporal artery tap.

Duplex Velocity Criteria for Native Carotid Artery[2]

PSV = Peak systolic velocity (cm/sec)

EDV = End diastolic velocity (cm/sec)

Primary Parameters		Additional Parameters		
ICA PSV	B-mode Stenosis Severity	ICA/CCA PSV ratio	ICA EDV	Stenosis Severity
< 180	none	< 2	< 40	normal
> 180	< 50%	< 2	< 40	< 50%
180–230	> 50%	2–4	40–100	"50–69"
> 230	> 50%	> 4	> 100	"> 70"

October 2021, updated: SRU consensus criteria by Intersocietal Accreditation Commission

- The common carotid artery (CCA) typically has a combined waveform of the internal and external carotid artery. When the ICA is occluded, a more peripheral appearing waveform is seen in the CCA with little diastolic flow termed-externalization of CCA waveform. Also, the absence of color flow or Doppler signal in ICA are common findings.
- Low velocities in CCA < 50 cm/sec suggest ostial carotid stenosis or intrinsic cardiac disease.
- Current criteria is for de novo stenosis, there is no consensus for post carotid endarterectomy (CEA) with patch or stenting.

* Contralateral critical stenosis or occlusion generally falsely elevates PSV of the ipsilateral artery by 10–15%. Up to 25% of patients will be

reclassified following CEA of the contralateral artery, therefore repeat imaging should be considered prior to contralateral endarterectomy. In-stent PSVs can also be elevated without significant stenosis.

Subclavian artery:

PSV > 240 cm/s are indicative of significant subclavian artery stenosis.[3]

Asymmetry in brachial blood pressures > 20 mmHg with reversal of blood flow in the vertebral arteries also demonstrate anatomic subclavian steal.

Peripheral

An ankle brachial index (ABI) should be performed as an initial screening exam for peripheral arterial occlusive disease and as the American Heart Association (AHA) recommends examination following lower extremity revascularization procedures.

This is performed by using a hand-held continuous wave Doppler probe and a manual sphygmomanometer. When the pulse is identified with Doppler at the ankle (dorsalis pedis or posterior tibial), inflate the cuff at the level of the calf until the arterial Doppler signal disappears. When the signal returns after slowly deflating the cuff, this number represents the examined tibial vessel's pressure. The procedure is repeated on the other tibial vessel as well as the other limb. The highest tibial pressure of each extremity is used against the highest of the brachial blood pressures to calculate the ABI (highest tibial pressure/highest brachial pressure = ABI).

ABI

Best predictor of long-term limb loss and survival in patients with peripheral artery disease (PAD).

- ≥ 1.3 signifies heavily calcified, noncompressible tibial arteries
- **1.0 to < 1.3 normal**
- < 0.9 to 0.7 mild PAD
- < 0.7 to 0.4 moderate PAD
- < 0.4 severe PAD

If the patient is diabetic and the arteries are non-compressible, (i.e., pressure > 250 mmHg) then toe pressures are recommended as a baseline examination.

Toe Brachial Index (TBI)

Normal TBI > 0.75.

- Toe pressures > 65 mmHg in diabetic patient should permit healing of a digit amputation.
- Toe pressures < 45 mmHg unlikely to heal in either a diabetic or nondiabetic patient.

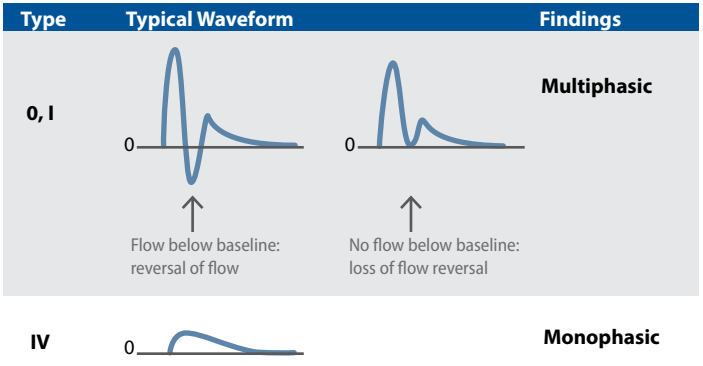
Segmental Pressures

Classic examination includes four cuffs: high thigh, low thigh, calf, and ankle to determine the level of stenosis. A 20 mm drop in blood pressure between two cuffs is considered significant. The high thigh should be at least the same as the brachial pressure, if less than brachial blood pressure, then consider inflow disease.

Peripheral Arterial Duplex

Analysis of lower extremity Doppler arterial waveform patterns

The Doppler arterial waveforms obtained from the lower extremity may be classified into categories as an aid in interpretation. Waveform morphology, standalone PSV, and the ratio of PSV from one point to an adjacent point in a given artery (VR = velocity ratio) may all signify the presence of disease.



- ***Normal:*** Multiphasic waveform.
- ***Mild disease:*** Lose reversal of flow first, resulting in a multiphasic waveform pattern.
- ***Severe disease:*** Monophasic waveform appreciated.
- > 200 cm/sec = 50%–75% stenosis and 'step up' in velocity with VR 2.0–3.4 in adjacent segment.
- > 300 cm/sec = > 75% stenosis and VR > 3.5.

Abdominal Aortic Aneurysm (AAA)

- Screening ultrasonography should be obtained in men or women aged 65–75 with a history of tobacco use per Society of Vascular Surgery guidelines.[4]
- Recommended follow-up examination for AAA: 3.5–4.4 cm, annually.
- 4.5–4.9 (women) or 5.4 (men) cm, every 6 months consider CT for confirmation of ultrasound diameter.
- ≥ 5.0 (women) or 5.5 (men) cm, CT scan and consider repair.

Renal

> 60% stenosis: PSV >180 cm/sec **and** Renal-Aortic Ratio (RAR) > 3.5.

Other significant components on exam:

- > 1 cm difference in kidney length either of the same kidney on serial exams or in comparison to contralateral kidney.
- ***Renal resistive index (RI):*** > 0.7 indicative of parenchymal disease.
- ***Normal kidney length:*** 9–12 cm.

Mesenteric

Visceral imaging is obviously difficult to perform and visualize in obese patients and inaccurate in patients who have not fasted.[5]

- ***Celiac:*** PSV > 200 cm/sec = > 70% stenosis EDV > 55 cm/sec > 50% stenosis
- ***Retrograde hepatic artery flow:***
  — Specificity of nearly 100% for celiac artery stenosis/occlusion
- ***SMA:***
  — PSV > 275 cm/sec = > 70% stenosis
  — EDV > 45 cm/sec — > 50% Stenosis
- ***IMA:*** No accepted criteria.

Venous

Reflux: > 0.5 sec is consistent with significant reflux in superficial and calf veins. (> 1.0 sec in femoral and popliteal veins, > 0.5 sec and > 3.5 mm in perforators). Retrograde flow while standing with valsalva maneuver. Also assess for deep venous reflux and thrombosis.

Assessment of diameter of greater and lesser saphenous vein is helpful.

Identify dual saphenous and poly-branched systems prior to intervention.

Deep Vein Thrombosis (DVT)

Acute: Non-compressible dilated vein, limited or no color flow, faintly echogenic, homogenous in nature, no collaterals.

Chronic: Often has collaterals and is not dilated, has partial degree of occlusion, heterogenous.

AV access mapping

Bilateral upper extremity BP: If > 20 mmHg difference, use extremity with better BP.

Diameters of radial and brachial artery: If < 2 mm, not suitable.

Vein diameter ≥ 2.5 mm from planned access site. For example, if cephalic vein is 2.5 mm at wrist but at 1 mm mid-forearm, then inadequate.

On-table vein mapping post-regional block improves access option 30% of the time.

Saphenous vein mapping prior to infrainguinal reconstructions

Examination should include diameter from ankle to groin: > 3 mm ideal for segment to be used for bypass.

* If previously harvested for CABG then consider upper extremity mapping.

Post-Intervention Imaging

Carotid: SVS guidelines recommend surveillance with duplex ultrasound at ≤ 3 months and annually thereafter until disease is stable, at which point surveillance intervals may be increased. Patients at high-risk for restenosis should undergo duplex imaging every six months until disease is stable and annually thereafter.

AAA

Following open repair: Ultrasound after five years to assess for development of anastomotic aneurysm. Occurs in < 5%.

After endovascular abdominal aneurysm repair (EVAR): 1/6/12 months—with CT angiography (CTA). If endoleak identified, then intervals may be shortened.

For patients with elevated creatinine, consider duplex and non-contrasted CT to follow sac size. In patients at one year and no leak, consider ultrasound-based imaging and follow-up every 6–12 months.

PAD Procedures

Autologous bypass duplex at 1/6/12 months, but more frequently with abnormal findings (i.e., velocities over 200 cm/sec in the conduit).

When velocities exceed 300 cm/sec or ABI drops 0.15, contrast-based imaging recommended to assess for critical vein graft stenosis.

After prosthetic bypass or endovascular intervention: ABIs +/- duplex at 1/6/12 month.

Source SVS Practice guidelines: 2018 recommendations for follow up after vascular surgery arterial procedures.

Following ablation of GSV

Venous duplex imaging to assess for successful vein closure and assessment for post-operative DVT—duplex examination within seven days of procedure. Endothermal heat-induced thrombosis (EHIT) with thrombus extending from the sapheno-femoral junction (SFJ) into the common femoral vein can occur in up to 3% of patients, mostly in patients with large saphenous veins and history of DVT. Treatment is dependent upon degree of thrombus identified.

Following mesenteric and renal interventions

Duplex examination of the treated vessel should be at 1/6/12 months.

“My senior fellow would say we should get credit for cases that we obtain access, regardless of how much of the rest of the procedure the attending performs since, ‘they can’t do the procedure unless we get access.’”

— Paul Armstrong, D.O.

ENDOVASCULAR BASICS

M. Libby Weaver, M.D.
Amanda Fobare, M.D.

Arterial Access

Most common: Retrograde femoral artery

- Other options include antegrade femoral artery access, retrograde pedal access.
- Upper extremity access via axillary, brachial, or radial arteries.
- The brachial artery is smaller than the femoral artery, and brachial sheath has less tolerance for hematoma and is more likely to result in nerve-related complications when accessed percutaneously. Some surgeons routinely perform open access so repair can be directly.

Techniques to obtain access of the femoral artery

- Ultrasound guidance — 5–10 MHz Linear transducer, transverse, and longitudinal views for access. Identify the bifurcation of the profunda femoris and superficial femoral arteries, and identify the distal external iliac artery.
- Fluoroscopic-guided puncture over mid-femoral head with or without Doppler assistance.[1]

Key study: The FAUST trial[2] >1,000 patients randomized to fluoroscopic vs. ultrasound guided access.

— No difference in common femoral artery cannulation rates with > 80% success in both groups, except in the subgroup where bifurcation was over the femoral head. More importantly, there were less first-pass attempts and reduced venipuncture and vascular complications in the ultrasound group.

- A modified Seldinger technique is used to obtain access which consists of puncturing the artery, advancement of a guidewire into the aorta during access, and removing the needle and subsequent insertion of sheath. The introducer is then removed, and a catheter is advanced over the wire to the desired location.

Wire Basics

Wires come in a variety of lengths, diameters, degree of support, coating, and shape of tip. Wires with a high degree of support are needed in tortuous vessels or if passing a large device such as a stent-graft. Hydrophilic-coated wires are useful in navigating tortuous anatomy or complex lesions but do have a risk of perforation in visceral vessels. No two wires are the same and care should be taken in choosing each wire for each specific situation. A list of different wire characteristics is shown on the following page:

Wires crossed in distal abdominal aorta

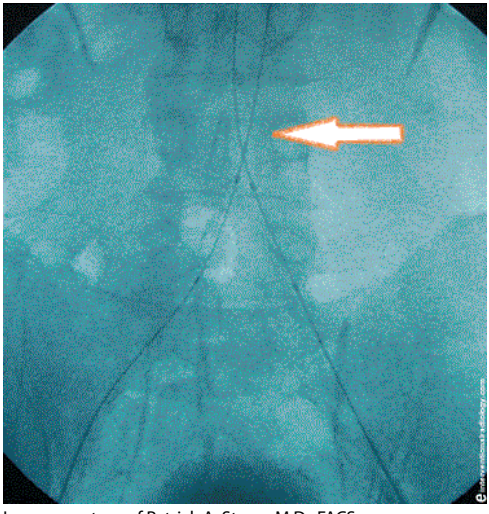


Image courtesy of Patrick A. Stone, M.D., FACS.
Used with permission.

- ***Diameter:*** .014", .018", .035"
  — Monorail/rapid exchange requires .014" (usually used in renal, mesenteric, carotid, some tibial interventions).
- ***Length:*** Separated in regular or exchange length (≥ 260 cm)
  — Always consider if an exchange length wire is needed before crossing a difficult lesion.
- ***Coating:*** Silicone, hydrophilic, non-coated. Hydrophilic coating decreases the coefficient of friction making it easier to advance the wire through tortuous vessels.
- ***Support:*** Different degrees of support from little support (e.g., J-wire) to extreme support (e.g., COOK® LUNDERQUIST® Extra Stiff Wire Guide).
- ***Wire design:*** Different wires have different transitions at the tip of the wire. This can range from a very short transition (e.g., TERUMO® GLIDEWIRE® Hydrophilic Coated Guidewire with a nickel titanium core) to a very long transition (e.g., ABBOTT® BALANCE MIDDLEWEIGHT Guide Wire).

Frequently Used Wires

- COOK® Bentson Wire Guide: Design of outer coil wrapped around core, floppy distal tip, inexpensive. Often used as initial access wire. Caveat: may not have enough support for sheath advancement in obese patients or if scar tissue present from previous surgery.
- ABBOTT® HI-TORQUE® SUPRA CORE® Guide Wire: 17 cm tapered core, moderate support, and stainless-steel shaft. Has "soft tip" with the transition of the distal segment of the wire providing good "feedback" during wire advancement.
- BOSTON SCIENTIFIC® AMPLATZ SUPER STIFF Guidewire: Good support, useful for advancing large devices, or in tortuous anatomy.
- COOK® LUNDERQUIST® Extra Stiff Wire Guide: Exceptionally supportive: Typically used for Endo AAA/TAA.
- TERUMO® GLIDEWIRE® Hydrophilic Coated Guidewire: Super-elastic core gives 1:1 torque ratio. Hydrophilic coating useful to navigate through stenosis and tortuosity as well as through CTOs. However, there is a risk of perforation of small branch arteries, especially when used in visceral vessels.
- J-wire: Inexpensive and provides minimal support. The wire with "J" shape to avoid cannulation of side branches during vessel access.

One of the most common wires used for access, secondary to being inexpensive and included with most 10 cm sheaths.

Catheter Definitions and Basics

- French (Fr) = 0.33 mm.
- OD = Outer diameter of catheter.
- ID = Inner diameter of catheter.
- French size ÷ 3 = Approximate catheter diameter in mm.
- Sheath's diameter is defined by the ID.
- Catheters/guide catheters are defined by their OD.
  - **Note:** A 5 Fr catheter can pass through a 5 Fr sheath.

Frequently Used Catheters

- ***Flush catheters:*** Pigtail, tennis racket, universal flush
- ***Selective catheters:*** Passive, intermediate, active
  - ***Passive:*** (e.g., Berenstein, multipurpose, vertebral, etc.).
  - ***Active:*** (e.g., Simmons Catheter) Active catheters must be formed and this is usually done in the aortic arch using the left subclavian artery. These catheters need to be used carefully and formed correctly. Given the "energy" stored in the tip of the catheter it can "dig" into plaque more easily than passive and cause atheroembolism (i.e., stroke). Only use when necessary!
- ***Guide catheters:*** Used primarily for renal and mesenteric interventions, however, can be used for carotid stenting as well as intervention for infrapopliteal disease. The IMA guide is also used often and on difficult renal cannulations (severe caudal angulation or a tortuous renal artery) an 8 Fr COOK® Renal Access Cobra Catheter or steerable sheaths are good options. Many of these pre-shaped catheters can be replaced with a steerable sheath.
- ***Micro catheters:*** Can be used for super selective imaging and for embolization procedures.

Sheaths

- Sheaths can be guiding sheaths, introducer sheaths, or steerable sheaths. Guiding sheaths are usually braided for extra support and can be used for carotid intervention or contralateral access for lower extremity arterial intervention.

- A short introducer sheath (10 cm) is used for basic access for diagnostic angiography or for renal or visceral intervention (guide is advanced through sheath). Remember that patients with elevated body mass index may need a longer sheath to maintain access. There are short introducer sheaths (6 cm) available that are ideal for AV graft declots or for fistulograms.
- Steerable sheaths allow for angulation of the sheath tip such that it can be utilized to provide stability during selection of inferior projected vessels when approaching from a groin access site. i.e., SMA or hypogastric artery.
- **Remember that once sheath size is ≥ 8 Fr for femoral artery access, complication risk increases.** In the brachial artery great caution should be used if the sheath size is greater than 6 Fr. Some providers recommend routine surgical exposure of brachial artery for this access site.
- Just because two different sheaths have the same ID does not mean they have the same OD. Sheaths are measured by ID and the OD differs depending on the type of sheath used. 'Slender' sheaths are now available, which allow for larger sheath access of small vessels such as the radial and pedal arteries. Most use an 0.018" wire for the introducer.

Endovascular Therapy

Forefathers of endovascular therapy

- Werner Forssmann — Performed the first heart catheterization in 1929.
- Charles Dotter — Performed first angioplasty in 1964.
- Andreas Gruentzig — Performed first coronary angioplasty in 1977.
- Julio Palmaz — Invented the balloon-expandable stent.

Balloon Angioplasty

Definitions

- ***Rated burst pressure*** — The pressure at which 99.9% of balloons will not rupture with 95% confidence.
- ***Nominal pressure*** — The pressure at which the balloon reaches its labeled diameter.

Characteristics of balloon catheters

- ***Compliance*** — Defined as the unit of volume change per unit of pressure change.
  - — **Compliant** — Used as an aortic occlusion balloon or to "mold" stent-graft.
  - — **Semi-compliant** — Balloon catheter used for most interventions.
  - — **Non-compliant** — No appreciable change in diameter once nominal pressure reached even with high pressures.
- ***Delivery system***
  - — **"Over-the-wire" system** — Designed so that the wire enters the tip of the catheter and exits the end of the catheter.
    - **Advantage** — Excellent pushability.
    - **Disadvantage** — More potential for movement of wire during removal of the balloon (must "walk off" the entire balloon).
- ***Monorail (rapid exchange)*** — Designed so that the wire enters the tip of the balloon catheter but exits in the proximal segment out of a side port. The remainder of the catheter after the side port has only one lumen that allows delivery of contrast to the balloon.
  - — **Advantages** — Quicker exchanges, less potential for loss of wire during exchanges since only the distal segment needs "walked off."
  - — **Disadvantage** — Less pushability than "over-the-wire."

Stents

- Designed to treat failures of angioplasty: Flow limiting dissections, significant recoil resulting in residual stenosis > 30%. However, with maturation of technology, they are now used for primary stenting in several vascular beds and perforations with angioplasty.

There are two classifications of stents:

- ***Balloon-expandable*** — Stent is mounted on the balloon and expanded with initial dilation of balloon. In the past it was typically stainless steel, however new designs are utilizing cobalt chromium. High radial force and accurate placement that is ideal for calcified ostial lesions.
  - — Used commonly off-label for in-stent restenosis of iliac, renal, and mesenteric arteries. Can also be used for treatment of perforation of arteries or with fenestrated stent-grafts.

- ***Self-expanding*** — Composed of nitinol (except the BOSTON SCIENTIFIC® WALLSTENT® Endoprosthesis which is composed of elgiloy). Ideal for tortuous vessels or areas where there is inherent motion of the artery. Key properties of nitinol are both superelasticity and shape memory. Less accurate deployment than balloon-expandable and less radial force, however, must be used in areas of motion since balloon-expandable stents will have permanent deformation once a critical external force is exceeded.

Key points to understand

- Sizing of balloon-expandable and self-expanding stents are different:
  - — Balloon-expandable stent sized 1:1 to vessel.
  - — Self-expanding stent is slightly oversized (~10–15%).
- Both can have open or closed cell design:
  - — Open cell design is more flexible.
  - — Closed cell design is less flexible but generally less risk of plaque protrusion.

Covered stents

- Both balloon-expandable and self-expanding stents can be covered.
- There are several covered self-expanding stents but the most commonly used are:
  - — GORE® VIABAHN® Endoprosthesis with Heparin Bioactive Surface*,†: Diameter: 5–13 mm, Length: 25–250 mm, Catheter length: 75/120 cm, Device profile: 6–10 Fr. ePTFE covered stent-graft that is FDA approved to treat lesions in the SFA and iliac arteries, in-stent restenotic lesions in the SFA, and stenosis or thrombotic occlusions at the venous anastomosis of synthetic arteriovenous (AV) access grafts.
  - — BD FLUENCY® Plus® Endovascular Stent Graft: Diameter: 6–13.5 mm, Length: 40–120 mm, Delivery system length: 80/117 cm, Device profile: 8-10 Fr. ePTFE covered self-expanding stent that FDA approved to treat venous outflow stenosis in AV grafts and AV fistulas.
  - — BD COVERA® Vascular Covered Stent Graft: Diameter: 6–10 mm, Length: 30–100 mm, Delivery system working length: 80/120 cm, Device profile: 8, 9 Fr. ePTFE covered self-expanding stent that is FDA approved for treatment of stenoses in the venous outflow of an AV fistula and at the venous anastomosis of ePTFE or other synthetic AV grafts.

* As used by Gore, Heparin Bioactive Surface refers to Gore's proprietary CBAS® Heparin Surface.
† Also referred to as the GORE® VIABAHN® Endoprosthesis with PROPATEN Bioactive Surface in some regions.

- There are several PTFE-covered balloon-expandable stents, the most commonly used are:
  - — ATRIUM® iCAST® Covered Stent System: Diameter: 5–10 mm, Length: 16, 22, 38, 59 mm, Catheter length: 80/120 cm, Device profile: 6, 7 Fr. The iCAST Covered Stent System is indicated for improving luminal diameter in patients with symptomatic atherosclerotic disease of the native common and/or external iliac arteries up to 110 mm in length, with a reference vessel diameter of 5 to 10 mm.
  - — GORE® VIABAHN® VBX Balloon Expandable Endoprosthesis (VBX Stent Graft): Diameter: 5–11 mm, Length: 15, 19, 29, 39, 59, 79 mm, Catheter length: 80/135 cm, Device profile: 6, 7, 8 Fr. The VBX Stent Graft is indicated for treatment of iliac artery stenosis in the U.S. It is also indicated for use with thoracoabdominal and pararenal branched devices indicated with the VBX Stent Graft as a branch component.

Drug-eluting balloon expandable stents

- Balloon-expandable coronary stents — Used off-label for the treatment of restenosis of renal artery stents and in the treatment of infrapopliteal disease.

Bare metal stents: There are bare metal balloon-expandable and self-expanding stents.

- There are several self-expanding bare metal stents, the most commonly used are:
  - — ABBOTT® ABSOLUTE PRO® Biliary Self-expanding Stent: Diameter: 6–10 mm, Length: 20–100 mm, Delivery system length: 80/135 cm, Device profile: 6 Fr. FDA approved for use in the iliac arteries.
  - — ABBOTT® SUPERA® Peripheral Stent: Diameter: 4.5–7.5 mm, Length: 20–150 mm, Delivery system length: 120 cm, Wire compatibility: 0.018", Device profile: 6 Fr. FDA approved for use in the SFA and proximal popliteal.
  - — COOK® ZILVER 635® Vascular Stent: Diameter: 6–10 mm, Length: 20–80 mm, Delivery system length: 80/125 cm, Device profile: 6 Fr. FDA approved for use in the iliac arteries, though many use these stents for the SFA (off label).
- There are several balloon expandable bare metal stents, the most commonly used are:
  - — ABBOTT® HERCULINK ELITE® Renal Stent: Diameter: 4–7 mm, Length: 12, 15, 18 mm, Delivery system length: 80/135 cm, Device profile: 5 Fr. FDA approved for use in the renal arteries.

Atherectomy

Rather than displace plaque with angioplasty or stents, atherectomy removes the plaque from the artery.

Intravascular Lithotripsy

This technology allows for inflation of a balloon to oppose the endoluminal wall of heavily calcified arteries with delivery of ultrasonographic energy to separate medial calcification of the vessel.

- SHOCKWAVE IVL Catheter:
  - — ***Diameter:*** 2.5 mm to 12 mm
  - — ***Length:*** 12 mm

Intravascular Ultrasound (IVUS)

- 8 Fr — Used when imaging the thoracic and abdominal aortic cases. Also, Iliac vein proximal veins.
- 5/6 Fr — The 0.014" and 0.018" IVUS catheters have improved resolution over the 8 Fr system but have a smaller field of view (0.014"— 20 mm, 0.018"— 24 mm).
- ***Important tip:*** With venous disease such as May-Thurner syndrome, IVUS is essential to determine size of stent needed, as well as to visualize the external compression.

Pearls on IVUS

- Use in AAA cases when limited contrast is desired.
- Can be used as the sole imaging modality for IVC filter placement.
- Imperative in endovascular treatment of dissection.
- Used in conjunction with reentry devices to find true lumen: PHILIPS PIONEER PLUS IVUS-guided Re-entry Catheter.
- In cases of infrainguinal vein bypass, it can help evaluate the presence of a retained valve.
- May be used for infrainguinal PAD to better assess luminal diameter either before or after intervention.

Description of Individual Endovascular Procedures

- ***Safely obtaining access*** — Refer to previous section:
  - — You can't move to any other part of the procedure without completing this step safely.
- ***IVC filter placement:*** The placement of an IVC filter is one of the most basic procedures performed by vascular surgeons. We choose the femoral vein for access with ultrasound interrogation in the majority of cases and then advance a sheath after serial dilations into the proximal ipsilateral iliac vein for venography. Assessment for IVC diameter, presence of thrombus and level of renal veins is routinely performed. The filter is then advanced in its sheath to just below the renal veins and the sheath is withdrawn with release of the IVC filter.
- ***Abdominal flush angiography and lower extremity runoff:*** After access is obtained, the pigtail is advanced into the abdominal aorta. The wire is withdrawn, and the shape of the catheter is allowed to be formed. The pigtail should always be spun to make sure that the tip is not in a side branch before power injection is performed. If no aortic pathology is expected and a lower extremity runoff is planned, the pigtail should be placed 2–3 cm above the level of the aortic bifurcation so that contrast is not "lost" to the renal arteries. The flow rate is generally 7–8 ml/sec for a total of 10–12 sec depending on the size of the aorta and speed of the table performing steps.
- ***Contralateral lower extremity angiography:*** Several different catheters can be used to go up and over the aortic bifurcation (ANGIODYNAMICS ACCU-VU OMNI FLUSH Sizing Catheter, IM, RIM, etc.). The most common catheter used in our practice is the ANGIODYNAMICS ACCU-VU OMNI FLUSH Sizing Catheter. Technique involves allowing the catheter to form in the distal aorta, then advancing the wire 1–2 cm from the tip and pulling the catheter down with the wire entering the contralateral iliac. The catheter is then "engaged" on the bifurcation and the wire is advanced to the contralateral common femoral artery (CFA). The catheter is then advanced down to the distal external iliac artery (EIA) or CFA over the wire. If the patient has a challenging aortic bifurcation secondary to it being high/steep or iliac tortuosity, then the ANGIODYNAMICS ACCU-VU OMNI FLUSH Sizing Catheter can be removed leaving the hydrophilic wire in the contralateral lower extremity (at times wire may need to be advanced deep into the SFA or carefully into the profunda femoris) and a TERUMO® GLIDECATH® Catheter can then be advanced over the bifurcation to the CFA.

- ***Treatment of stenotic arteriovenous fistula:*** Access with a micropuncture kit with access a few centimeters distal to arterial anastomosis with the micropuncture introducer left in place. We prefer the micropuncture 4 Fr introducer for the initial imaging since 10–20% will not require treatment but are solely diagnostic. Check initial pressure and then a compressed outflow pressure. If intervention is needed, then a sheath will need to be placed and once intervention is complete, pressures should be rechecked to determine if intervention had a successful hemodynamic impact.
- ***Treatment of iliac artery stenosis by retrograde access:*** This requires crossing a lesion with a steerable wire, then exchanging it for a working wire (high support wire). When placing balloon-expandable stents, the lesion should be crossed with a long introducer sheath so that the stent does not become dislodged from the balloon during advancement. The sheath is withdrawn after the stent is positioned in the desired location. This allows for no predilation and the lesion can be primarily stented. If there is concern for plaque shift at the ostium then at times "kissing iliac stents" can be placed raising the bifurcation 1–3 mm.
  - ***Important:***
    - The bifurcation should not be raised unless necessary and if raising the bifurcation is necessary, then no more than 1–3 mm.
    - Always perform completion angiogram of the infrapopliteal vessels after treatment of an iliac occlusion secondary to the risk of distal ipsilateral embolization (up to 5%).
- ***Treatment of iliac or infrainguinal arterial stenosis by a contralateral approach:*** Guiding sheath is advanced over the aortic bifurcation to the CFA. Traditionally, most interventions on the SFA were performed with a .035" system, however, some new stent platforms are deployed over a .018" system.
- When performing infrapopliteal interventions, it is important, when possible, to have a guide catheter or guide sheath positioned with the tip in the popliteal segment for extra support. Most infrapopliteal interventions are performed with a .014" or .018" system.

- ***Treatment of thrombosed arteriovenous graft — Percutaneous technique:*** Review prior operative reports to assess which limb is the venous and which is the arterial limb of the graft, if the graft has required balloon angioplasty, or if the graft or central veins have been stented. If this is not available, always perform a diagnostic angiogram to confirm if the catheter is in the artery or vein. Access needs to be obtained in both limbs, and generally a 6 Fr sheath is needed to treat the arterial anastomosis and a 7 Fr sheath for the venous outflow. The sheaths are pointed toward each other with the wires overlapped in between. Once access is obtained, then rheolytic thrombectomy is performed followed by removal of the arterial plug at the arterial anastomosis with an EDWARDS FOGARTY® Catheter. An over-the-wire EDWARDS FOGARTY® Catheter can be used. Angiogram is then performed of the graft, venous outflow, and arterial anastomosis. At this point angioplasty, and if needed for recoil, stenting, can be performed.
  - ***Important:***
    - Angiogram of the arterial anastomosis should be performed by placing a catheter proximal to the anastomosis in the feeding artery with visualization of the distal artery branches as well as the arterial anastomosis. Never compress the venous outflow and perform retrograde angiogram secondary to the risk of residual thrombus embolizing to the arterial outflow.
- ***Renal interventions:*** These interventions are more advanced, and the skill set needed is more demanding. Most stents are placed in the ostium given that atherosclerosis of both the renal and visceral arteries is aorto-ostial in most patients. Precise placement is essential, and the stent should extend no more than 3 mm into the aorta secondary to the difficulty in accessing the stent for subsequent procedures. There is inherent risk of a future interventionalist deforming the stent when passing sheaths or catheters above this level.

Renal artery stenting no-touch technique

There are two techniques which should be used for renal artery stenting:

- ***No-touch technique:*** This was championed by Mark C. Bates, M.D. We have a strong belief that there is a high potential for occult atheroembolism by guide catheter manipulation if performed without this technique — with the potential for worsening chronic kidney disease.

- The technique is usually performed with a 6 Fr system and using the guide of choice for the interventionalist (At our institution, this is usually a Bates 1 or 2 guide.)
- The guide is advanced over a moderate support wire using a wire with a good transition at the distal segment (i.e., ABBOTT® HI-TORQUE SUPRA CORE® Guidewire. Next a .014" wire (i.e., ABBOTT® HI-TORQUE SPARTACORE® Guidewire with both a short transition at the distal segment and high degree of support is advanced to the distal segment of the guide catheter
- Next the .035" wire is withdrawn to let the guide catheter take shape, however at least 3 cm of wire should still be left extending into the aorta to keep guide tip from scraping the wall of the aorta and potentially causing atheroembolism.
- Next the .014" wire is advanced into the renal artery, and the .035" wire is removed. At this point the guide should fall into place at the ostium and PTA/stenting can be performed.

— ***Telescoping technique:*** This technique can be used to treat de novo renal artery stenosis but is especially useful for renal artery in-stent stenosis since it will prevent the wire from advancing through a stent strut in the aorta. Again, most of the time this can be performed with a 6 Fr system. A diagnostic catheter (JR4, IM, etc.) is advanced through the guide of choice and secured with the tuohy borst. The renal artery is selected and the .014" wire is advanced into the renal artery. The guide is then advanced over the diagnostic catheter to the ostium of the renal artery. The diagnostic catheter is then "walked off" the wire while leaving the guide in place. At this point the operator can proceed with PTA/stenting.

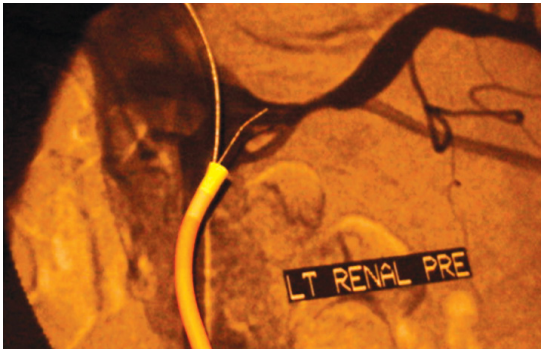


Image courtesy of Patrick A. Stone, M.D., FACS. Used with permission.

- **Tip:** In highly tortuous renal arteries, a steerable guiding sheath can be used for added support. Also, interventionists prefer upper extremity access for renal or visceral interventions which can be helpful for renal arteries with a high degree of inferior angulation.
- **Tip:** A wire with a curved tip such as a COOK® Rosen Wire Guides *may be used to decrease the risk of wire perforation of renal vessels.*

- ***Visceral interventions:*** Performed just like renal artery interventions except that, secondary to tortuosity, and especially with the inferior angulation of the SMA, usually an 8 Fr system is needed for added support. Again, if needed, a brachial approach can be used.
- ***Brachiocephalic interventions:*** Ostial great vessel interventions are not common but occasionally do need to be performed. If stenting is needed, then a balloon-expandable stent is preferred. Subclavian stenting can usually be performed with a 90 cm sheath via a .035" system from a CFA approach. At times a brachial artery approach is needed, especially with subclavian artery occlusions. Both innominate and ostial carotid intervention can be difficult and often should be performed with the use of an embolic protection device. Techniques include the use of a guide catheter or guiding sheath from a CFA approach. For type 3 arches and at the time of concomitant carotid surgery, consider retrograde stenting. Again, these are technically demanding interventions from a femoral approach with potential for misplacement of stents extending too far into the thoracic aorta and should only have hands-on involvement by residents with significant experience in the endovascular suite.

RADIATION SAFETY

M. Libby Weaver, M.D.
Amanda Fobare, M.D.

Background

The average environmental exposure of radiation in the U.S. has risen to 6.2 millisieverts (mSr) each year.[1] Since the prior iteration of this manual, occupational risks of radiation to physicians have changed in both positive and negative ways. Improved technologies limit radiation exposure, and education on radiation safety has improved, however, the complexity of endovascular procedures continues to evolve, and an increasing number of endovascular procedures are performed year over year. Patient, staff, and physician exposure to radiation is of increasing concern in the era of complex fluoroscopic guided intervention, high-resolution 3D CT imaging, and new PET and nuclear imaging algorithms. Radiation safety responsibility is shared by the endovascular laboratory personnel and radiation monitoring specialists, but the primary owner of radiation risk management is the physician operator.

Radiation exposure for peripheral and aortic vascular disease procedures is increased exponentially with new developments in the field and the goal of this chapter is to address the basics of radiation safety and steps to reduce the radiation exposure for the patient and interventional team. For more detailed explanations and guidelines, the European Society for Vascular Surgery recently released Clinical Practice Guidelines for radiation safety that are recommended as an additional reference.[2]

Principles of Radiation

X-rays are generated from a rotating anode that is being bombarded by a stream of electrons being driven from the cathode under a high potential difference (between 50 to 150 kilovolts.) X-rays are like any other kind of electromagnetic energy but are packaged in parcels called photons at a specific wavelength. The X-rays leave the X-ray tube (generator) and are directed toward the image intensifier (II) where they are collected and transmitted to the digital analyzer to be seen as images. The highest dose of radiation occurs between the generator and image intensifier; thus the patient receives much of the dose, but scatter occurs and impacts all those around the procedure.

Thus, the operator must have a detailed understanding of X-ray physics before stepping on the fluoroscopy pedal to protect not only the patient but also his or her team.

The ALARA (As Low as Reasonably Achievable) guidelines stress the need to develop a strategy to keep patient and staff radiation exposure as low as possible. Skin exposure of the patient is the greatest. Radiation exposure is the greatest to the operator if he or she stands close to the X-ray generator. The radiation dose is exponentially reduced as the operator steps away from the generator. The X-ray beam is attenuated by the inverse square law ($1/d^2$) from the X-ray tube. To better understand this law, note that if one steps 25 feet from the table, they will receive $< 1/25$ the dose of one standing at one foot. The two views that have the highest radiation exposure to the physician are left anterior oblique with cranial angulations and left lateral view. The procedures with the highest radiation exposure are usually stent grafting and critical limb ischemia. Radiation effects can be estimated based on a single exposure but the effect is cumulative so serial procedures must be considered as additive.

Steps to Reduce Radiation Exposure

1. It is the operator's responsibility to scan the room and make certain all staff has the appropriate radiation protection **before** stepping on the fluoroscopy pedal. Front-line physicians, nurses, and technicians within four feet of the image intensifier for prolonged periods of time should have .50 lead equivalence and preferred wrap around two-piece lead with a thyroid collar and lead glasses. Those distant from the image intensifier (II) could use lower lead equivalence.

In addition, one-piece aprons should be discouraged for anyone who may be circulating close to the image intensifier (II).

2. Most contemporary generators have a spacer to avoid placing the source too close to the patient. However, note that the closer the generator is to the patient's skin, then the higher skin dose they will receive, and this is the zone most at risk for skin radiation injury.
3. Whenever possible use radiation shield pads, a radiation shield door, lead skirt in front of the X-ray tube generator, and a ceiling suspended lead glass shield to reduce patient/table scatter and team exposure.
4. Use fluoroscopy more than Cine, as Cine utilizes 10 to 20 times more radiation than fluoroscopy.
5. Use pulse dose fluoroscopy instead of continuous fluoroscopy when possible.
6. Use collimation to reduce radiation scatter.
7. Radiation is only produced when the beam is on, so irradiate only when it is necessary to observe motion. Last-image-hold and instant replay are important tools to reduce dose.
8. Keep the X-ray source (X-ray tube) as far away from the team as possible consistent with optimal imaging.
9. Keep the distance between the patient and the X-ray generator close and keep the image intensifier as close to the patient as possible. However, understand that the patient will receive higher doses with the X-ray generator close and that operator and patient safety does need to be balanced.
10. Use the least amount of magnification consistent with seeing the target vessel adequately.
11. Try not to extend the fluoroscopy time beyond 60 minutes. After one hour of fluoroscopy, exposure hazards of radiation such as skin ulceration/necrosis increase. Most centers require notification of the radiation safety officer when fluoroscopy time exceeds 60 minutes. Note that skin ulceration may not show up for weeks or months, and you must educate the patient about what to look for and ensure follow-up. You should also explain to the patient and document which area is at highest risk for dermal injury based on the skin closest to the generator.

12. Use the inverse square law to your advantage and whenever possible move away from the X-ray source before activating the generator.
13. Wear a radiation badge as it is for your own benefit. The readings should correlate with your workload. Place the badge over-lead and monitor on midline at neck level as well as under-lead and monitor on midline at waist level.
14. Some procedures, such as de-clotting of AV grafts and AV fistula, can result in exposure of hands to radiation and could result in radiation burn to the operator if the operator's hands are placed repeatedly in the beam.

Please note: These are standard recommended guidelines. Your facility or institution may have their own radiation safety protocols in place. Please consult your own safety officers or institution's guidelines for more information.

Effects of Radiation

Two main effects are stochastic and non-stochastic/deterministic.

- ***Stochastic effects:*** Here probability is proportional to dose. Severity is independent of dose and assumes zero thresholds. The risks are radiogenic cancer and genetic damage.
- ***Deterministic effects:*** Certainty of effect and severity is a function of dose. It does have a substantial threshold. High dose risks are: hair loss, skin damage, cataracts, and congenital abnormalities.

Acute risk is primarily limited to the skin exposure, but this can be devastating. One minute of fluoroscopy is equal to 250 CXRs and larger patients result in greater exposure to both patient and operator. Depending on patient weight, technique (collimation, magnification, image angle, distance from generator) and efficiency of equipment (improved with contemporary digital systems), early dermal injury like erythema and temporary epilation can be expected to begin from 45–150 minutes of fluoroscopy exposure and skin necrosis after 2 hours.

Radiation exposure in the pregnant surgeon

Women comprise a small, but increasing, percentage of the practicing vascular surgery workforce. With women now representing up to ⅓ of vascular surgery trainees, it is important to establish safety standards for pregnant women surgeons:

- ***Confidential reporting and consultation:*** Establish a confidential reporting system for your trainees and surgeons during job orientation, as surgeons may wish to keep their pregnancy status private, particularly in the first trimester when radiation effects may be of highest concern. Ensuring a confidential system is in place will allow for surgeons to implement pregnancy-related radiation safety measures early and often.
- ***Dosimetry monitoring[3]:*** The maximum occupational exposure during pregnancy is 5 mSV total and 0.5 mSV monthly. Dosimeters should be worn both over and under lead at the waist level. The 'under lead' dosimeter acts as the fetal dosimeter. Levels should be monitored monthly.
- ***Safety[3]:*** The average maternal exposure of working interventional radiologists is 0.3 mSv per pregnancy. Studies also show a range of 0.2–7.3 mSV of total maternal exposure for vascular surgeons, with fetal levels of exposure averaging 0 mSV in this cohort of full-time practicing vascular surgeons, and a maximum fetal exposure of 0.07 mSV in an entire pregnancy. Studies have shown that single-lead aprons provide adequate fetal protection during pregnancy, and that double-lead aprons are not necessary.

In Conclusion

Remember to follow these few steps to reduce radiation:

- ***Time:*** Short exposure to radiation.
- ***Distance (inverse square law):*** Stay far away from X-ray generator.
- ***Shielding:*** Shields, apron lead, thyroid shield, and lead eyeglasses.
- ***Contamination control:*** Collimation and keep the source to image distance minimum.
- ***Pregnancy:*** Provide confidential reporting systems and monthly monitoring of both over- and under-lead dosimeters for pregnant surgeons.

“I never saw an access-related amputation until the advent of closure devices.”

— Mark Bates, M.D.

ENDOVASCULAR COMPLICATIONS

M. Libby Weaver, M.D.
Amanda Fobare, M.D.

Access Complications

Access complications are the most common complication of any endovascular procedure. The American Heart Association divided the risk of complications into three patient groups for cardiovascular procedures.[1]

1. ***Low-risk procedures (< 1% complication rate):*** These include diagnostic angiograms generally using 4 or 5 Fr sheaths, shorter length procedures, and procedures that use little concomitant anticoagulation. Low-risk patient characteristics include male sex, younger age, normal renal function, and increased body size.
2. ***Moderate-risk procedures (1 to 3% complication rate):*** These include routine percutaneous intervention and include procedures that have sheath sizes of 6 or 7 Fr, increased procedure time compared to a diagnostic procedure, and involve the use of adjunctive anticoagulants and antithrombotic regimens. Moderate-risk patient characteristics include older patients, female sex, adrenal dysfunction.
3. ***High-risk procedures (> 3% complication rate):*** These include, but are not limited to, patients with peripheral artery disease, advanced age, female sex, liver disease, coagulopathy, immunosuppression, previous valve replacement, and renal dysfunction. Procedures that require a sheath size ≥ 8 Fr are also at high risk for access site complications.

List of Access Complications

- ***Groin hematoma (occurs in 1–3% of patients, reported much higher in some series):*** Can be caused by puncture of the artery above or below the femoral head, which is used for support during manual compression. Also, a sheath should never be pulled if the SBP is > 170 mmHg or if the activated clotting time (ACT) is too high (> 180 seconds). Rarely is surgery indicated except for:
  - — Progressive enlargement of hematoma
  - — Skin compromise
  - — Evidence of femoral nerve compression
  - — Severe pain

Remember that up to 20% of patients will develop wound infection after surgery for hematoma, and seroma formation is common.

- ***Pseudoaneurysm (≤ 1% of cases, though reported much higher in some series):*** If the pseudoaneurysm is < 3 cm then repeat duplex is needed in one to two weeks to assess for spontaneous thrombosis (89% of patients with pseudoaneurysm < 3 cm will resolve in 21 days[2]). Treatment should be performed if size ≥ 2 cm or if there is failure of conservative therapy with observation with either growth of the aneurysm sac or failure to thrombose. Treatment includes:
  - — **Surgery** — Gold standard, though now only used for emergent purposes or when more conservative methods fail (i.e., Thrombin injection).
  - — **Mechanical compression** — Usually ultrasound-guided compression or by Femostop. This treatment has fallen out of favor secondary to patient discomfort with the technique.
  - — **Thrombin injection** — This is now the most widely used method for treatment. Needle is advanced under ultrasound guidance and thrombin is injected to thrombose the aneurysm sac. Care must be taken to not inject into the artery proper and very slow injection is needed to prevent reflux of thrombin into the native artery. Typically, 0.1-0.3 ml is needed for successful closure.
- ***Retroperitoneal hematoma (occurs in approximately 0.5% of cases):*** This is the most dreaded access complication secondary to having a delayed diagnosis and the potential of high morbidity/mortality. Usually this occurs secondary to a high puncture. If the sheath (arterial puncture) is located above the origin of the inferior epigastric or deep circumflex iliac artery (consistent with puncture of the external iliac artery), then pulling the sheath will likely lead to

a retroperitoneal hematoma. However, it should be noted that even if the sheath is located below the origin of the inferior epigastric artery, but superior to the inferior border of the inferior epigastric artery (the borderline area), there still may be increased risk of retroperitoneal hemorrhage[3]. It has been our practice to use a closure device rather than performing manual compression for hemostasis when the sheath is removed, and the access site is high. We can consider a suture mediated closure device that allows the sheath to be reinserted if the device fails (i.e., ABBOTT® PERCLOSE® PROSTYLE Suture-Mediated Closure and Repair [SMCR] System).

Contralateral access for balloon-protected closure device deployment or placement of a covered stent can also be used. If a vascular closure device is used for hemostasis when the sheath was clearly placed in the external iliac artery, then confirmatory angiography should always be performed to make sure hemostasis has been achieved.

Key Points:

1. If good access techniques are used, and a femoral angiogram is routinely performed to evaluate for high puncture, the rate of retroperitoneal hematoma can be drastically decreased. Twenty degrees ipsilateral oblique imaging is recommended to best image the femoral bifurcation.

Femoral angiogram

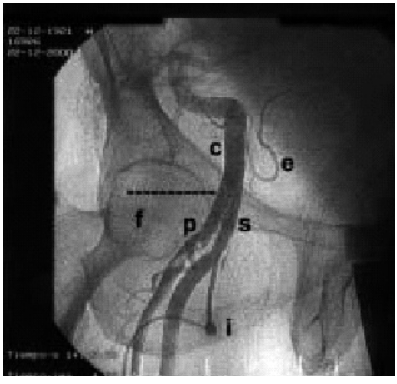


Image courtesy of Patrick A. Stone, M.D., FACS. Used with permission.

C – External iliac artery
f – Femoral head
P – Profunda femoris artery
S – Superficial femoral artery
e – Inferior epigastric artery
i – Sheath

Femoral angiogram demonstrating sheath placed below the level of the femoral head in the superficial femoral artery. Note there is a high CFA bifurcation.

2. Have a low index of suspicion for retroperitoneal hematoma. Any patient who is status post CFA access with increasing back or flank pain, decreasing hematocrit, or decreased BP should have stat with and without contrasted Computed Tomography including late phase.
3. Depending on how stable a patient is at the time, treatment can be conservative in stable patients, but unstable patients can be treated with transcatheter embolization or covered stent or open repair.
   - ***Arteriovenous fistula (occurs in < 1% of patients):*** Most common cause is inadvertent puncture of the profunda femoris artery and vein. Low stick is most common. Most patients will have spontaneous resolution (80% resolve by one month) but even when persistent, treatment is rarely needed.[4] Indications for treatment include arterial insufficiency or venous hypertension, and potentially heart failure.
   - ***Acute thrombosis of the access artery:*** This can be secondary to dissection caused by access, occlusive sheath in a small or diseased artery, or secondary to a complication from a vascular closure device (most common).
   - ***Dissection:*** Usually secondary to disruption of large posterior plaque when advancing the wire during initial access. Can be recognized by not being able to aspirate blood from the sheath after it has been placed. A transducer is very helpful to evaluate if the sheath is in the true lumen, and there should be an arterial waveform present. Never flush forward with saline or contrast if blood cannot be aspirated. If the sheath is subintimal this can enlarge the dissection plane.
     - Wires with a good transition at the distal segment will give the operator feedback and help decrease the risk of advancing the wire subintimally.

Safely Obtaining Access

1. Access can be obtained utilizing fluoroscopy-guided or ultrasound-guided techniques.
   - Fluoroscopy-guided access should include routine use of a micropuncture needle with confirmation of the level of the femoral head before and after needle placement. This allows for a smaller arteriotomy if the initial access is too high or low. Although this is slower, and has a lower success rate than ultrasound-guided techniques, the complication rates are similar.[3]

— Ultrasound-guided access allows for assessment of the anterior vessel wall for calcifications and ensures placement directly in the common femoral artery. This technique was shown in a prospective, randomized trial to be faster and have a higher rate of success than fluoroscopy-guided techniques.[3]

Other Endovascular Complications

- ***Perforations or rupture of artery:***
  — ***Wire perforations:*** This is usually secondary to use of a hydrophilic wire in a visceral artery, though it can happen in any arterial territory (internal iliac, profunda femoris, infrapopliteal vessels, etc.). Hydrophilic wires should be avoided during mesenteric and renal artery intervention except in very rare cases secondary to this potential risk. If perforation does occur, then this can be treated with superselective embolization.
- ***Vessel rupture:***
  — There are many causes including:
    - Oversize of a balloon-expandable stent or balloon.
    - Can occur with 1:1 sizing if the vessel is highly calcified.
    - Advancing large bore device such as thoracic stent graft through either a small, tortuous, or highly calcified vessel.
    - Balloon developing a pinhole rupture during angioplasty.
  — This can be treated with the placement of a covered stent in most cases, but at times open surgery is needed. Always quickly reinflate the balloon to obtain hemostasis while the appropriate devices are gathered for repair.
- ***Atheroembolism:*** Potentially one of the most devastating complications that can occur during an endovascular procedure. Can range from sub-clinical to fatal. Can be greatly avoided with careful catheter manipulation and constant monitoring of the pressure at the tip of the catheter with a pressure transducer. A hostile aorta can quickly be diagnosed if the pressure dampens at the tip of the catheter during attempted selective angiography. When performing transfemoral carotid stenting, strokes can be related to atheroembolism during ostial cannulation to gain access to the carotid artery before the lesion is ever crossed!
  — Signs of atheroembolism include livedo reticularis, blue toe syndrome, and renal failure.

Pearls to Avoid Complications

1. To prevent clot from forming at the tip of the catheter, always keep a column of heparinized saline in the catheter by using a flow switch or manifold to prevent back bleeding.
2. Never let a flush catheter (i.e., pigtail) sit in the aorta and then flush it. When you aspirate you may have blood return secondary to the side holes, but there can be clot located at the tip distal to the side holes that dislodges with forward flushing. In relation to this, always pull the pigtail to the descending aorta after performing an aortic arch angiogram before exchanging for a different catheter to prevent potential stroke with advancement of the guidewire through the pigtail.
3. Hemodynamic assessment at the tip of the catheter should always be performed prior to any forward injection of contrast or saline to avoid inadvertent injection of clot from the catheter tip, atheroembolism, barotrauma to the vessel wall, and aggressive injection into a hemodynamically significant complex stenosis.
4. Spin the pigtail in the distal aorta to make sure the tip is not in a lumbar artery prior to power injecting.
5. Never advance a sheath without an introducer or diagnostic catheter without a wire.
6. Be very careful to let guide catheters back bleed before injection after advancing through the aorta secondary to the risk of injection of atheroembolic material. Guide catheters can "snowplow" plaque when advanced through hostile arteries secondary to lack of an introducer and a larger ID than diagnostic catheters.
7. Ultrasound-guided puncture to assure you are not puncturing above the inguinal ligament. Always perform a routine femoral angiogram at the conclusion of the procedure to document location of sheath placement.
8. If the wire does not pass easily in the common femoral artery, then DO NOT FORCE IT.

9. It is very important to "form" catheters correctly to prevent distal embolization with "aggressive maneuvering" (i.e., SIMMONS SIDEWINDER Catheter is an active catheter and must be formed with care, arch manipulation can result in neurologic events).
10. Always keep the patient's renal function status in the "back of your mind" to limit contrast in patients at risk and avoid contrast-induced nephropathy. With modern fluoroscopic equipment, rarely is full strength contrast needed during subtraction angiography. Consider CO_2 angiography to minimize contrast use and intravascular ultrasound to reduce contrast load.
11. If you rupture an artery with an oversized balloon, do not tamponade the artery with a smaller balloon because you will not achieve hemostasis!

Never pull a wire briskly back from the subclavian artery or aortic bifurcation secondary to risk of "cutting" the bifurcation. We have termed this a "cheese cutter effect."

CLOSURE DEVICES AND THEIR COMPLICATIONS

M. Libby Weaver, M.D.
Amanda Fobare, M.D.

Background

The importance of meticulous access technique and proper access management can't be overstated since access complications are the most common adverse event in most endovascular studies and procedures. This is particularly critical in the radiology suite or office-based laboratory setting, as these settings limit the ability to perform open exploration of the access artery when complications occur. The historic method of achieving hemostasis has been manual compression. Manual compression should begin when the ACT is < 160 seconds and should be for 5 minutes per French size. Vascular closure devices (VCDs) have been used since the mid '90s to provide patient comfort, early ambulation, and early hospital discharge after a diagnostic or interventional cardiovascular procedure. Despite the numerous devices available and changing landscape of devices available and ease of use of VCDs, the complications continue to be the Achilles' heel. The main complications of the VCDs are device failure, bleeding, hematoma, infection, femoral artery dissection, inadvertent intra-arterial deployment of procoagulant material, limb loss, and need for surgical rescue in a minority of cases.

Commercially Available VCDs Can Be Categorized As:

1. ***Compression devices:*** e.g., ABBOTT® FEMOSTOP Compression System and MERIT MEDICAL SAFEGUARD® Pressure Assisted Device.
2. ***Topical hemostasis agents:*** e.g., TELEFLEX® D-STAT® Flowable Hemostat, SYVEK® SYVEKEXCEL® Hemostasis System, and MERIT MEDICAL SCION CLO-SUR PLUS P.A.D.® Antimicrobial Barrier.

3. ***Invasive:*** (A) suture-based, e.g., ABBOTT® PERCLOSE® PROGLIDE® Suture and ABBOTT® PROSTAR® Percutaneous Vascular Surgical System; (B) invasive, medicated collagen plug, e.g., CORDIS MYNX CONTROL® Vascular Closure Device, up to7 Fr; TERUMO ANGIO-SEAL® Vascular Closure Device, up to 8 Fr; TELEFLEX® MANTA® Vascular Closure Device, up to 25 Fr; and (C) clip-based, e.g., ABBOTT® STARCLOSE® Vascular Closure System and ANGIOLINK EVS® Vascular Closure System.
4. ***Invasive without a foreign body:*** Some categorize also as active closure devices: Collagen plugs, sutures, clips, etc. and passive devices help by mechanical compression or by increasing thrombosis, i.e., sealant or gel-based.

Large Bore Closure Devices

In cases where large sheaths are to be introduced, several percutaneous options are available.

- The Perclose Technique whereby 2 perclose devices are placed PRIOR to placing a sheath > 8 Fr has been widely studied and reported. Placement of the 2 devices slightly oblique to a central over-the-wire deployment is an option for arterial sheaths up to 21 Fr and for up to 24 Fr when used for venous closure.
- Collagen-based closure devices like the CORDIS MYNX CONTROL® Device, can be deployed for sheaths from 10–20 Fr. The anchor is bioabsorbable. Potentially beneficial in cases where large sheath > 10 Fr placed urgently, and arterial defect will be too large to place devices listed above at the time of sheath removal.

Key Steps to a Successful Use of Vascular Closure Device

1. Femoral angiography in an ipsilateral oblique projection 20–30 degrees should be done before placement of any VCD. The angiogram should confirm the arterial puncture/sheath interface is in the common femoral artery (CFA) and preferably is consistent with an anterior wall puncture. The angiogram should also confirm the CFA is within the size threshold (5 mm for most devices) for the selected device (most critical in systems that have a footpad for anchoring the system against the anterior wall). Finally, the CFA must be free of significant disease < 50% stenosis, and for some

closure systems that are clip or suture based there should also not be severe calcification. (This can be appreciated during ultrasound guided puncture.)

2. Learn the proper technique for use of each device.
3. Adhere to *Instructions for Use* (IFU) and understand that off-label use may result in complications. Reading the IFU is critical before using any device for the first time.
4. Preferably use the device that you are familiar and comfortable with in a consistent fashion.

Potential Complications with Closure Devices

1. ***Hematoma:*** Additional manual compression should be performed if a hematoma develops. Generally, 3–5 minutes per final French size. Late hematoma both large and small can result in significant pain, discomfort, ecchymosis, possible nidus for infection and rarely require surgical evacuation. Generally, in cases of impending skin necrosis or if the patient has severe pain and continued enlargement.
2. ***Surface hemorrhage:*** Small oozing from the arterial puncture site is common and can often be effectively treated with manual pressure. Persistent bleeding will require additional manual compression, superficial suturing of defect or adjuvant compression device such as C clamp or femostop.
3. ***Retroperitoneal bleed (RP):*** A serious complication that can be fatal. RP bleed can occur when VCDs are deployed in cases outside the IFU. These scenarios are usually related to a high femoral artery puncture or external iliac artery puncture, concomitant puncture of inferior epigastric artery or deep circumflex iliac artery, multiple punctures for access, and device failure. Management of RP bleeding is discussed in further detail in the *Endovascular Complications* chapter.
4. ***Infection:*** Clean the puncture site with Chlorhexidine or alcohol pad. New gloves and selective antibiotic use may reduce infections although these techniques have not been systematically studied. Localized and deep infections have been reported in rare cases.
5. ***Device failure:*** Strict adherence to indications and IFU for each device can reduce the device failure rate.

6. ***Embolization:*** This can lead to acute limb ischemia, limb loss, and death. Usually secondary to inadvertent deployment of the device intra-arterially. This can be avoided by not using VCDs in small diameter arteries < 5 mm or arteries that are diseased (anchor can "catch" plaque resulting in intra-arterial deployment of device) > 50% stenosis. Emergent angiogram, use of a snare, or adjuvant covered stent can correct the maldeployment but surgical rescue often needed.
7. ***Vessel thrombosis:*** Can occur if the back wall of the artery is "captured" by the device or if foreign material is introduced into the artery (i.e., collagen). This too can usually be circumvented by avoiding use of VCDs in small diameter arteries and arteries that are diseased. Angiogram and use of balloon angioplasty and lytic therapy can be considered but stenting of the CFA has long-term negative consequences and should be avoided unless the patient is a nonsurgical candidate. Surgery is the mainstay of therapy in most cases.

Tips and Tricks to Avoid VCD Complications

1. Perform femoral access angiogram prior to deployment of device.
2. Check activated clotting time manual pressure optimal when less than 160 seconds as back up.
3. Remember manual compression is the standard of care that VCDs are measured against.
4. Adhere to IFU for each device.
5. Learn each deployment step well and master the device that you want to use.
6. Anticipate failure mechanisms for the specific device used and have a management strategy.
7. Have covered stents available and know techniques for coil embolization.
8. Early studies on the use of VCDs outside the femoral artery suggest safe and effective use is possible in both the axillary and brachial arteries.[1,2] However, these uses remain off-label and use should only be considered in unique circumstances with careful consideration of risk-benefits.

ANEURYSM DISEASE

Clara Gomez-Sanchez, M.D.

Background

Definition of aneurysm: Dilation of vessel > 1.5 × the diameter of normal adjacent vessel.

- ***Ectasia:*** Enlargement but less than 1.5 × the normal diameter of the vessel.
- ***Aneurysmosis:*** Patients with multiple discrete aneurysms.

Etiology — multifactoral: **DEGENERATIVE**, genetic component, smoking, infectious, and other theories.

Classifications

True aneurysm: All layers of vessel involved.

Pseudoaneurysm: Contained rupture.

As a rule:

- Intracavitary aneurysms have the propensity to rupture.
- Peripheral aneurysms more often present with thrombo-embolic complications.

Pearls

Visceral aneurysms: Splenic > hepatic > celiac > SMA.

- ***Repair when asymptomatic:*** Splenic > 3 cm unless childbearing age.
- Hepatic and Celiac > 2 cm.
- SMA — Any size.
- All visceral aneurysms should consider endovascular as first approach if appropriate (whereas renal first approach is surgical.)

Subclavian aneurysms: Up to 50% have aortoiliac or peripheral aneurysms.

Ulnar artery aneurysms: Mostly male, < 50 years old, present with digital ischemia (4th and 5th digits), thrombolysis beneficial, vein interposition best treatment.

ABDOMINAL AORTIC ANEURYSMS (AAA)

Background

First successful open AAA repair in 1951 by Dr. Dubost in Paris using homograft via extraperitoneal approach.

Dr. Cooley developed a double velour DACRON® Material graft in 1978.

Incidence[1]

- 3% of males older than 65 years old.
- 5% of patients with coronary artery disease (CAD).
- 10% of patients with peripheral artery disease (PAD).
- 50% of patients with popliteal aneurysm.

Risk factors

- Men (3:1), smoking (8:1), hereditary, infectious
- Average age: 70

Miscellaneous facts

- Average growth 10%/year (2–3 mm/year).
- > 50% will require repair within three years for those with diameters 5.0–5.4 in both UK and The Aneurysm Detection and Management (ADAM) study.[2]
- 95% of aneurysms are below renal arteries.
- Normal aorta diameter: infra-renal aorta 16–22 mm.
  — Approximately 2 mm larger in men.

Physical Examination

Pulsatile abdominal mass (typically non-palpable until near 5 cm).
Examine for other aneurysms — popliteal most common.

Screening

January 1, 2007 Screening Abdominal Aortic Aneurysms Very Efficiently (SAAAVE) ACT

One time ultrasound screening for males ages 65–75 who have smoked 100 lifetime cigarettes, or males or females with family history.

The Society of Vascular Surgery (SVS) recommends screening with ultrasound for all people > 65 years who have smoked (male and female).

Diagnosis

1. ***Plain abdominal X-ray*** — 70% of cases have enough calcium present that AAA seen on abdominal X-ray.
2. ***Ultrasound*** — Modality of choice for surveillance, accurate within 3 mm of operative findings.
3. ***Computed tomography (CT)*** — Primary imaging modality to plan intervention.
4. ***Magnetic Resonance Imaging (MRI)*** — Seldom used as primary imaging modality, but accurate if imaging for other pathology, i.e., back pain and find AAA.

Estimated annual risk of rupture[3]

AAA in Diameter	Annual Risk of Rupture
Less than 4.0 cm in diameter	0%
4.0 cm to 4.9 cm in diameter	0.5% to 5%
5.0 cm to 5.9 cm in diameter	3% to 15%
6.0 cm to 6.9 cm in diameter	10% to 20%
7.0 cm to 7.9 cm in diameter	20% to 40%
8.0 cm in diameter or greater	30% to 50%

Laboratory Tests/Evaluations

- CBC, BMP, PT, PTT, chest X-ray, EKG.
- Formal cardiac evaluation in patients considered for open repair.
- Type and crossmatch.

Intervention

- ***Symptomatic any size:*** Abdominal/back pain, rupture, atheroemboli, and rarely heart failure from aortacaval fistula.
- ***Asymptomatic:*** Abdominal aneurysms at 5.5 cm in males, 5 cm in females.
- Rapid growth, 0.5 cm in six months or 1 cm in one year with same imaging modality.

Once an intervention is considered, a CT with contrast (computed tomographic angiography with 3-D Recon) should be performed to evaluate endovascular candidacy.

- ***Late survival:*** Mean survival seven years compared to 15 years for general U.S. population.

Critical Points in Evaluating CT

Anatomic features to note on review of CT: Figure chart for measurements

- ***Location of left renal vein in respect to aorta:*** Anterior, posterior, collar vein.
- ***Neck:*** Amount of mural thrombus, length from lowest renal artery to aneurysm, and diameter of neck.
  — Reverse conical neck — highest predictor of early and late Type I endoleak from endovascular aortic repair (EVAR).
- ***Length:*** From lowest renal to aortic bifurcation and to internal iliac arteries.
- ***Patency of visceral and renal arteries and hypogastric arteries:*** May need to consider concomitant repair.
- ***Diameter of aorta bifurcation:*** < 18 mm — concern for graft compression.
- ***Number of lumbar vessels and evaluation of inferior mesenteric artery (IMA):*** Patent IMA associated with increased Type 2 leaks.
- ***Diameter:*** Measuring 10–15 mm proximal to the internal iliac artery origin(which will be the location of the (distal seal zone).
- ***Most common reason for off-label use for EVAR:*** Short neck length.
  — In patients who are high risk for open repair then consider: Fenestrated repair or referral to a center with investigational device exemption (IDE) for other custom devices (e.g., physician-modified endograft).

OPEN REPAIR

Open Pearls

Pre-op preparation

- Bowel prep: One bottle of magnesium citrate.
- Chlorhexidine gluconate solution 4.0% w/v shower preop.
- Nothing by mouth (NPO) after midnight.
- Type and crossmatch.
- Informed consent on chart.

Key portions of informed consent

The following elements are relevant for inclusion in informed consent documents for patients undergoing open aneurysm repair, but these alone may not create informed consent. Each patient presents individualized risks. Consult your institution's instructions, guidelines, and templates, if applicable, for obtaining informed consent.

1. ***Indications for procedure:*** i.e., size, symptom status and risk with observation.
2. ***Alternatives:*** Open has higher early morbidity and mortality compared to EVAR but risks are equivalent after two years and long-term outcomes may be better with open (so should be considered first in younger/healthier patients).
3. ***Major risks:*** Estimated risk of perioperative mortality < 3%[4]; other common risks: Renal failure, embolization requiring lower extremity revascularization, ileus, hernia, infection, etc. This estimate is different than clinical trials with patients typically undergoing open repair prior to the EVAR era. Refer to Chapter 6, Endovascular Complications.
4. If thoracic aneurysm repair planned, must discuss risk of paraplegia.
5. ***For EVAR:*** continued surveillance, contrast issues, risk of endoleaks and their management.

! *This manual does not include all the information needed to use the drugs listed herein safely and effectively. See full prescribing information and any boxed warnings for these drugs.*

General principles of open repair

- Suprarenal crossclamping is associated with exponential incidence of post-operative complications when > 35 min.
- Repair iliacs at time of open repair if iliac diameter is > 2.0 cm.
- Reimplant IMA if poor back bleeding, stump pressure < 40 mmHg, severe hypogastric disease, previous colon resection secondary to poor collateralization, or if colon appears ischemic at end of operation. If robust backbleeding or already occluded, safe to ligate.
- Alert anesthesia prior to unclamping. Unclamping can result in severe hypotension.

Transperitoneal (midline) Incision

- Allows ability to explore the abdomen.
- More difficult to expose visceral aorta (medial visceral rotation).
- May encounter previous abdominal adhesions.
- Familiar to most surgeons.

Technique

- Either midline incision or transverse incision can be used.
- Mobilization of ligament of Treitz to retract all small bowel to right side, posterior peritoneum opened from ligament of Treitz to aortic bifurcation.
- Square of veins surrounding AAA from transperitoneal approach: left renal, inferior vena cava inferior mesenteric vein, left common iliac vein.
- Minimize dissection of left common iliac artery region
  - Parasympathetic nerves responsible for male erectile function. If graft is to extend past proximal common iliac arteries, must identify and protect ureters.
  - Typically cross the iliac artery at common/ internal/external iliac confluence.
- Circumferential dissection around the iliac arteries poses a risk to iliac vein injury.
- Can ligate left renal vein but it should be ligated near IVC. Additional drainage via gonadal, phrenic, adrenal veins, and lumbar vein.

Retroperitoneal Approach

- Potentially less pain and decreased ileus and lower respiratory complications.
- Ideal for patients with previous abdominal surgery.
- Easier access to visceral and supraceliac aorta.
- Difficulty with exposure of right iliac artery.
- Risk of pesudo hernia secondary to protrusion of abdominal wall laterally.

Technique

- Place patient on bean bag, kidney rests between iliac crest and costal margin, right side down with left arm on ether screen or arm rest.
- Once bean bag inflated, adjust the pelvis closer to flat.

Incision

- 10th intercostal space — juxtarenal aneurysms.
- 8th intercostal space — visceral involvement with need for supraceliac clamp.

Dissection

- Peritoneum thickest laterally— transect obliques and then sweep peritoneum medially.
- Lumbar vein — landmark for left renal artery.
- The Achilles' heel of this approach is exposure of the right iliac artery.
  — This limitation can be overcome by extending the incision across the midline or a counter incision in the right lower quadrant.
- Consider balloon occlusion of the iliac artery from within the vessel if needed.
- If the diaphragm needs to be divided for more proximal control, consider using a stapler device radially to allow for easier approximation at the conclusion of the procedure.
  — Transect 2 cm away from chest wall to allow for diaphragmatic closure.

Post-operative Complications

- ***Hypertension — keep systolics < 140 mmHg:*** Increased bleeding risk.
- ***Death:*** 3–5% from national estimates.
- ***Myocardial Infarction (MI) up to 15%:*** If suspicious, check Troponin, EKG.

- ***Hypotension:*** Intraoperative/post-operative hemorrhage secondary to venous injury or lumbar veins.
- ***Ischemic colitis:*** 2% of elective cases.
  - — Presentation: Bloody or any diarrhea, acidosis, requiring persistent fluid administration without anemia, usually within 48 hours of surgery.
  - — Mortality between 50–90% if colonic gangrene occurs.
  - — STAT GI consult for flexible sigmoidoscopy if suspicious, consider consultation for service that performs endoscopy.
- ***Renal failure:*** Hypotension, atheromatous embolization.
- ***Limb ischemia:*** Usually secondary to embolization.
  - — Prevention: Clamp iliac arteries first, then aorta.
- ***Abdominal compartment syndrome:*** Common in ruptures or massive fluid resuscitation — must rule out hemorrhage, check bladder pressures.
- ***Paraplegia:*** Rare < 0.5% with abdominal repair. With thoracic repair, risk ranges from 5–15% depending on extent of aneurysm treated and clamp is treated.

EVAR

Background

1990 First successful endovascular aneurysm exclusion performed by Juan Parodi in Argentina.

1999 FDA approval of first stent-graft in U.S.: MEDTRONIC ANEURX® Stent Graft System and GUIDANT® ANCURE® Aortoiliac System.

Courtesy of Leigh Ann O'Banion. M.D. Used with permission.

Aortic angulation: < 60 degrees; GORE® EXCLUDER® Conformable AAA Device ≤ 90 degrees. The GORE® ACTIVE CONTROL System to help the graft deployment with angulated necks.

Non-fenestrated Devices

The FDA-approved devices have *Indications for Use* which include anatomic suitability based on approval. These indications are based on neck and distal seal length, neck and distal seal diameter, and angulation of the aneurysm.

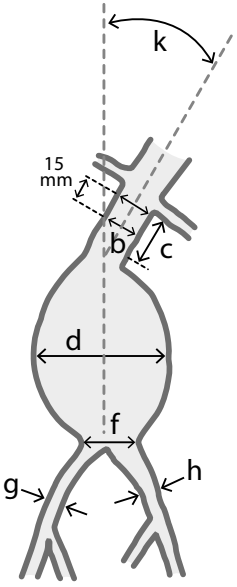
Approved devices for infrarenal AAA: GORE® EXCLUDER® AAA Endoprosthesis / GORE® EXCLUDER® Conformable AAA Endoprosthesis, MEDTRONIC ENDURANT® Stent Grafts, MEDTRONIC ENDURANT II® AAA Stent Graft System, TERUMO TREO® Abdominal Stent Graft System and ENDOLOGIX OVATION ALTO® Abdominal Stent Graft System, ENDOLOGIX AFX2 AAA Endovascular System, and COOK ZENITH® FLEX® AAA Endovascular Graft.

- ***≥ 10–15 mm neck length:*** Check specific IFUs for indication. Approved in as short as 7 mm with some devices.
- ***Neck diameter ≤ 32 mm:*** Check specific IFU for guide to performing measurements for each device.
- ***Infrarenal aortic neck angulation:*** ≤ 60-90 degrees. Check specific IFU for indication.
- ***Distance from renals to aortic bifurcation:*** Varies with device
- ***Aortic bifurcation diameter:*** Recommendations vary by device.
- ***Access vessels:*** Must be able to accommodate the delivery sheath of device. This may require a conduit, pre-dilation, intravascular lithotripsy, or endografting in small iliac cases.

Fenestrated EVAR

The COOK® ZENITH® Fenestrated Device is the only commercially available device. Custom graft designed for short infrarenal neck of ≥ 4 mm. Option for two sealing fenestrations + one large fenestration or one large scallop. Requires 4–6 weeks for manufacturing so only used in elective cases.

EVAR Sizing (W. L. Gore & Associates, Inc.)



Consult Instructions for Use
eifu.goremedical.com

	Anatomical Location	Measurement (mm)
a	Aortic Diameter at Proximal Implantation Site	16–32
b	Aortic Diameter — 15 mm Inferior to Proximal Implantation Site	16–32
c	Aortic Neck Length	≥ 7–15
d	Maximum Outer Aneurysm Diameter	No Requirements Baseline
e	Length from Lowest Renal to Native Bifurcation of the Aorta	> 70 for 23, 26, 28.5 mm EXCLUDER Devices, > 80 for 31 mm device, 90 for 35 mm EXCLUDER Device > 85 for 20, 23, 26, 28.5 mm EXCLUDER Conformable Devices, 95 for 32 and 36 mm EXCLUDER Conformable Devices
f	Recommended Minimum Diameter of Distal Aorta	≥ 18
g	Right Common Iliac Diameter	8–25
h	Left Common Iliac Diameter	8–25
i	Right Iliac Length for Sealing	≥ 10
j	Left Iliac Length for Sealing	≥ 10
k	Proximal Aortic Neck Angle	≤ 60 degrees for EXCLUDER Devices ≤ 90 degrees for EXCLUDER Conformable Devices

- Measure inner-wall to inner-wall for Gore (outer for other companies). Plan for 10–20% oversizing for Gore devices.
- **Do Not** measure calcium.
- Should be within 10% of infarenal neck measurement to avoid reverse taper.
- Measure thrombus **≤ 2 mm** thickness and/or **≤ 25%** circumference.
- Measure short axis for all measurements, **except Measurement D** is long axis.
- **Measurement F** is short axis and long axis, **not measuring thrombus.**

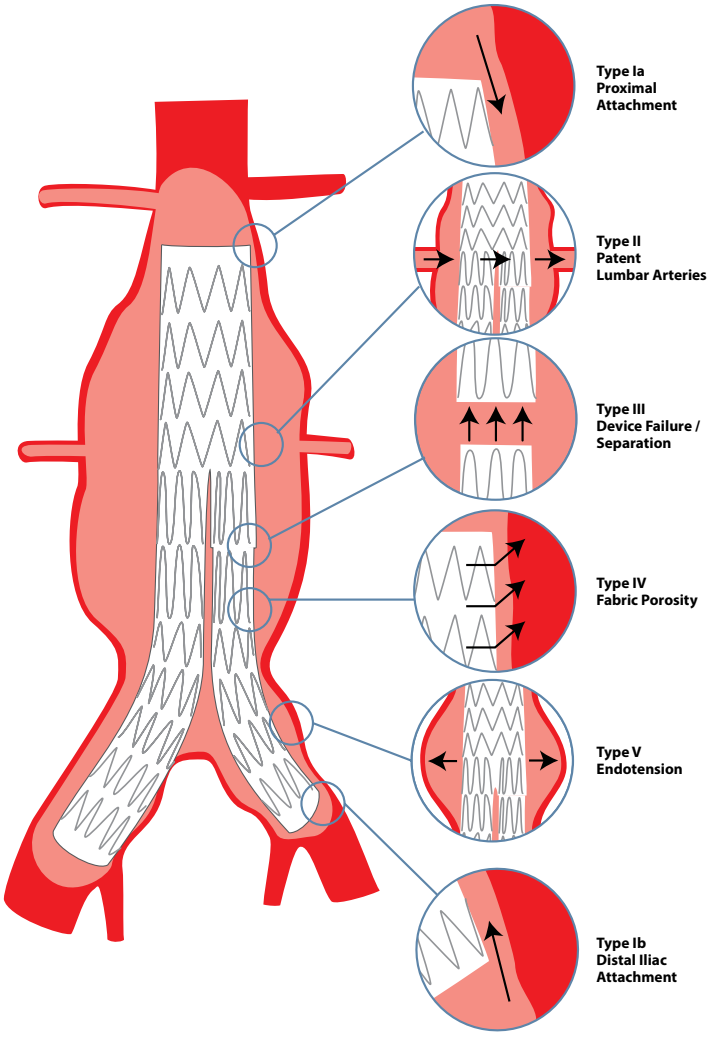
Basic Concepts of EVAR

- Cover from renals to hypogastric arteries.
- Most common complication involves access vessels.
- Treating patients off IFU is the most common cause of graft dysfunction.
- ***Reverse conical neck:*** Poses a significant risk factor for late endoleak.
- ***Distal extensions and cuffs:*** Are often useful to preserve hypogastric blood flow. If no distal seal zone in common iliac artery (CIA) options are: coil embolize hypogastric and extend to external iliac artery (EIA), internal iliac artery to EIA bypass and extend to EIA, or GORE® EXCLUDER® Iliac Branch Endoprosthesis (IBE).

Standard EVAR Procedure

- Ipsilateral side of main body placement.
- Contralateral side designated by side where contralateral limb will be inserted.
- Percutaneous access with pre-closure technique (ABBOTT® PERCLOSE PROGLIDE® Suture-Mediated Closure System x 2 placed prior to upsizing sheath and tied down at end of case) is commonly used vs. cutdown. Exposure of CFA can be performed if groin is scarred or femoral access significantly diseased/calcified, or surgeon is not sufficiently comfortable with closure devices.
- Skin incision should be performed via small transverse incisions over common femoral artery **unless previous vertical incision is present.**
- ***Percutaneous access:*** Two ABBOTT® PERCLOSE® PROGLIDE Suture-Mediated Closure System oriented 45 degrees off vertical axis placed bilaterally (10- or 2-o'clock position)
- From the contralateral side — pigtail catheter inserted and positioned around L1. Aortogram in magnified view to identify lowest renal artery ostium. The appropriate angle of the image intensifier can be obtained by the preoperative CT scan and is generally in the range of 15–30 degrees left anterior oblique (LAO) and 20–30 degrees cranial to caudal. After deploying the main device inferior to the lowest renal artery, the contralateral gate is selected usually with an angled hydrophilic catheter and angled hydrophilic wire.

Follow-Up Imaging and Types of Endoleaks



- Assurance that gate cannulation is achieved and that the wire is not behind the graft is imperative. Spin the pigtail catheter within the main body. Intravascular ultrasound (IVUS) can also be used or a contralateral catheter to hook the flow divider.
  - If gate cannulation is unsuccessful via retrograde cannulation of the contralateral gate, then attempts by up-and-over from the main body side or brachial artery with snare technique should be pursued. If gate cannulation is deemed not possible (i.e., jailed out), then convert to aorto-uni-iliac (AUI). Subsequently the contralateral common iliac artery should be occluded and a surgical (8 mm ringed prosthetic) femoral-femoral bypass created.
- Iliac limbs should be deployed to within 1 cm of the hypogastric artery.

Imaging Follow Up

At 1, 6, 12 months, CT angiograms should be performed to assess for endoleak and sac regression. If Type II is detected at one month, a three-month imaging study is advised. If Type I or III is detected, repair should be performed. Annual imaging recommended after one year if no complications and may use ultrasound if there is no endoleak.

Endoleak: 10–15% of patients will have an endoleak.

- Type I, III, IV, and V all require repair.
- Type II — lumbar, accessory renal, or inferior mesenteric artery (IMA) related — can be observed as long as sac size is stable, i.e., < 5 mm growth from baseline. Most common detected.

Endoleak Types

- If a Type II endoleak is present, and the aneurysm sac grows by ≥ 5 mm, then intervention is indicated. Options include transarterial embolization (lumbars via hypogastric, inferior mesenteric artery (IMA) via the superior mesenteric artery (SMA), translumbar embolization of lumbar arteries, and transcaval puncture of aortic sac. If endovascular measures fail, then consider operative repair with sac decompression and ligation of culprit vessels (i.e., lumbar or IMA) vs. graft explantation.

See previous page for diagram of endoleak types.

RUPTURE AAA

Background

- ***50% rule:*** 50% make it to hospital alive. Of those alive on arrival, there is ~50% in-hospital mortality. There is an overall 75% mortality — inclusive of in and out of the hospital.
- 15,000 patients die annually of rupture.
- 13th leading cause of death in United States.
- ***Predictors of mortality in ED:*** Advanced age, chronic kidney disease (CKD), altered level of consciousness on arrival, presence of shock on arrival (hypotension), cardiac arrest.

History and Physical Examination

- ***Classic triad of:*** Abdominal pain, pulsatile abdominal mass and hypotension.
- Most common misdiagnosis — renal colic.
- ***Pre-operative predictors of mortality for ruptured aortic aneurysm:*** Age > 76, Creatine > 2.0, ph < 7.2, and any episode of b.p < 70 mmHg. Mortality approaches 100% if three or more are present.

Diagnosis/Imaging

- ***Ultrasound:*** Focused assessment with sonography for trauma (FAST) is available in most emergency departments.
- ***CT:*** In hemodynamically stable patients this will provide the essential information for determining mode of therapy. If able to get this, prepare to go to the operating room even if patient is marginally stable. Do not delay surgery if OR is ready to go.
- ***Laboratory evaluation:*** Basic metabolic panel, complete blood count, and type and crossmatch packed red blood cells, blood gas, lactic acid, urinalysis — hematuria in up to one-third of patients.

Treatment

Permissive hypotension: Massive fluid resuscitation will actually result in more bleeding and worse outcome. Aim for systolic > 80 mmHg and immediately treat hypertension with esmolol drip to maintain systolic no higher than 120 mmHg.

Intervention:

- — ***Open:*** Should be reserved for non-endovascular candidates or those too unstable for pre-op imaging. If hybrid suite available, may still consider placing occlusion balloon prior to induction of anesthesia.
- — ***Endovascular:*** If hypotensive, rapidly place balloon to occlude thoracic aorta and allow anesthesia to catch up with resuscitation. This can be done with patient awake. If difficulties cannulating the contralateral gate, then be prepared to convert to aortouniiliac (AUI) repair with contralateral iliac occlusion and femoral-femoral bypass. Some centers advocate initial AUI placement.

While waiting for anesthesia team or angio suite staff, place foley catheter, large ore venous access in jugular and radial arterial line if possible to expedite the case once in the OR.

Improvement in morbidity and mortality when comparing endovascular vs. open repair but outcomes in ruptured patients treated with off-label EVAR are not equivalent to on-label In-situ laser fenestration may be an option for patients who are not candidates for open surgery, but this is off-label and should only be performed by experienced centers.

Open Repair Pearls

- ***Prep neck to knees:*** Retroperitoneal vs. transabdominal.
- ***Be draped and ready to make incision during induction:*** Often patient decompensate at that time because of loss of preload.
- ***Supraceliac control:*** Take down triangular ligament to retract left lobe of liver, incise lesser sac at pars flaccidum. Esophagus is mobilized to left (helpful to have an NG tube in place), the right crus of diaphragm is divided and large aortic clamp placed with tip at the spine. Rapid exposure of infrarenal aorta to re-clamp below renals is imperative to lessen ischemic injury.
- Often a tube graft can be performed instead of bifurcated graft (faster). Also, sometimes secondary to retroperitoneal hematoma, visualization of the iliac arteries is limited, and intravascular balloon control is a safer maneuver.
- Concern for development of abdominal compartment syndrome and ischemic colitis post-op.
- Some surgeons feel routine sigmoidoscopy should be employed after ruptured AAA repair but certainly any diarrhea or unexplained leukocytosis post-op should prompt flex sig.

- Mycotic aortic aneurysm — high morbidity and mortality. Consider temporizing EVAR if ruptured or having high volume GI bleeding from aorto-duodenal fistula. Curative therapy requires resection/debridement of infected aorta with reconstruction.
  - — If reasonable surgical candidate and anatomy, in-line reconstruction with either cryopreserved aorta or rifampin-soaked DACRON® Material. No strong data to support one over the other but consider biologics if gram negative rods (GNR) are the causative agents.
  - — If poor surgical candidate, extra-anatomic reconstruction with ax-bifemoral bypass and aortic exclusion. Should cover aortic stump with tongue of omentum.

Predictors of mortality following ruptured AAA repair

1. ***Bleeding:*** 90% — May experience significant coagulopathy from massive blood loss, watch out for iatrogenic venous injuries during surgery. Balanced transfusion or goal-directed resuscitation is essential.
2. ***Renal failure:*** > 70%.
3. ***Ischemic colitis:*** > 60%.
4. Respiratory failure

ILIAC ARTERY ANEURYSMS

Background

- Up to 30% of AAA will have concomitant involvement of iliac arteries. 1–2% have isolated iliac artery aneurysms.
- 75% involve the common iliac artery, and 10–20% involve the internal iliac artery.
- Average growth is 1–2 mm/year.

Physical Examination

- Rarely palpable; if involving the hypogastric artery may palpate on rectal examination.
- ***Most series report > 50% of patients with symptoms:*** Compression related are most common with lower abdominal and flank pain frequent.

Diagnosis/Imaging

- ***Ultrasound:*** To assess for size and for surveillance.
- ***Computed tomography:*** For treatment planning of either open or endovascular repair.

Treatment

Repair when > 3.5 cm or > 2 cm at the time of open repair of AAA.

Interventional Considerations

Endovascular exclusion: Requires 15 mm of healthy artery at both proximal and distal landing zones. It is rarely feasible to do single covered stent placement with iliac limb of endograft; consider GORE® EXCLUDER® Iliac Branch Endoprosthesis, embolization of hypogastric with coverage, or IIA to EIA bypass with coverage of hypogastric origin.

GORE® EXCLUDER® Iliac Branch Endoprosthesis — for common iliac and/or aortoiliac aneurysms with intention to preserve hypogastric flow.

Open: If isolated CIA aneurysm, can do retroperitoneal or transabdominal repair with prosthetic graft interposition.

Most recommend preservation of at least one hypogastric artery to avoid pelvic ischemia.

THORACIC AND THORACOABDOMINAL AORTIC ANEURYSMS (TAA AND TAAA)

Background

- 10% national operative mortality for elective repair of TAAA aneurysms.
- Approximately 2:1 male to female ratio (unlike AAA which has a 7:1 ratio).
- 15–20% are secondary to previous dissection. 60% involve ascending aorta.
- 40% involve descending aorta (10% in arch).

Natural History

- 10 mm/year growth average.
- Growth greater in descending and dissecting aneurysms and in those with Marfan syndrome.

Annual rupture risk[1]:

- < 5 cm: 2%
- 5–5.9 cm: 3%
- 6 cm: 10%, up to 43% at 7 cm

Classification of Thoracoabdominal Aneurysms

Crawford

Type 1: Subclavian to renal arteries

Type 2: Subclavian to aortic bifurcation

Type 3: Midthoracic aorta to aortic bifurcation

Type 4: Thoracic aorta at diaphragm to aortic bifurcation

Type 5: Midthoracic aorta to renal arteries

Diagnosis/Imaging

Occasionally detected on chest X-ray, generally now identified by CT while evaluating other pathology in the chest.

Intervention

Repair if symptomatic or at least 5.5–6 cm in diameter (recommendations vary, consider repair near 5.5 cm in women and at 6 cm if the repair itself is very complex/high risk for complications). Repair at 5 cm for patients with genetic aortopathy or saccular with total aortic diameter 5 cm.

Treatment

- Endovascular or open surgical reconstruction.
- Open is much less common due to high morbidity and mortality in comparison to TEVAR. Open should be performed in setting of genetic aortopathy, infection, and maybe in young/healthy patients. Cardiopulmonary bypass may be utilized to reduce ischemic complications depending on the level and complexity of repair needed.
- The GORE® EXCLUDER® Thoracoabdominal Branch Endoprosthesis is indicated for endovascular repair in patients with thoracoabdominal aortic aneurysms and high-surgical risk patients with pararenal aortic aneurysms who have appropriate anatomy.

Basics of Endovascular Exclusion

Approved devices for thoracic aneurysm repair

GORE® TAG® Conformable Thoracic Stent Graft with ACTIVE CONTROL System helps graft deploy on angled arches.

COOK® ZENITH® TX2® Dissection Endovascular Graft and COOK® ZENITH® ALPHA® Thoracic Endovascular Graft.

MEDTRONIC VALIANT® Thoracic Stent Graft.

TERUMO® RELAY® Thoracic Stent Graft/TERUMO® RELAY®PRO Thoracic Stent Graft.

- GORE® TAG® Thoracic Branch Endoprosthesis is approved for Zone 2 TEVAR with branch extending into the subclavian artery.
  - — Requires distance from distal edge of L subclavian artery to midpoint of L carotid artery to be 2–2.5 cm for an 8 mm side branch portal and 4 cm for a 12 mm side branch portal.
  - — Requires distance from distal edge of L subclavian artery to distal edge of L common carotid artery of at least 15–36 mm, depending on Aortic Component selection.
  - — L subclavian diameters 6–18 mm and length at least 2.5–3 cm from origin to vertebral artery.
  - — Built on older GORE® SIM-PULL Delivery System so no GORE® ACTIVE CONTROL System and may be limited by large sheath requirement if access vessels are small.
- Access vessels are often the limiting factor.
- Up to one-third of patients in randomized trials required.
- Conduits. Preop imaging required from aortic valve through femoral bifurcation.
- IFU generally recommends 2.0 cm of normal aorta proximally and distally. (Cook thoracic devices, recommend 2.5 cm).
- Must deploy smaller diameter devices first to prevent Type 3 leaks (or use tapered stents).

Zones of thoracic aorta

Zone 0: Ascending aorta including the innominate artery.

Zone 1: Distal to innominate and including the left common carotid artery.

Zone 2: Distal to left common carotid artery and including left subclavian artery.

Zone 3: First 2–3 cm distal to left subclavian artery.

Zone 4: To midthoracic aorta.

Zone 5: To the celiac artery.

- Consensus statement from SVS now recommends preservation of subclavian artery flow in cases of planned subclavian artery coverage secondary to the increased risk of neurologic complications. Carotid-subclavian bypass most commonly performed with prosthetic; transposition possible but technically more challenging.
- Controversy exists over coverage of celiac artery. Only small retrospective series presently in literature on safety with this approach.

Spinal drains

Consider placing spinal drains prior to TEVAR in the following circumstances:

- Previous AAA repair, concurrent AAA repair, planned large coverage area of thoracic aorta, and in patients with branch disease—hypogastric/profunda femoris arteries.

Post-Procedure Management

- The use of adjunct distal aortic perfusion and cerebrospinal fluid (CSF) drainage has reduced neurologic deficits from spinal cord ischemia but risk increases as longer segments of aorta are covered (3–15%).
- Variety of spinal drainage protocols exist with no clear consensus: options include goals for mean perfusion pressure > 60 mmHg (mean arterial pressure-spinal pressure) vs. spinal pressure <10 mmHg, vs. fixed volume of hourly drainage (i.e., 10cc/hr). See Spinal Drain Protocol appendix in the back of this manual.
- Drain is left in place for 24–48 hours, and is capped for 24 hours, if no neurologic deficit drain can be removed.
- Delayed deficits can occur as early as two hours and up to post-op two weeks.
- If patient develops leg weakness: increase the mean arterial pressure (MAP) to > 90 and if no drain in place, place emergent spinal drain. Keep SpO_2 > 95%, Hgb > 10, euglycemic. No definitive evidence to support steroids but some centers do use them.

PERIPHERAL ARTERY ANEURYSMS

Popliteal Artery Aneurysms

Background

- Normal size of popliteal artery 6–8 mm.
- 5% of patients with AAA have popliteal aneurysms.
- **25:1 male to female.**
- 50% bilateral, > 50% have history of repair of other aneurysm, i.e., iliac, femoral, thoracic, abdominal so diagnosis of pop aneurysm should prompt CT of aorta through femoral arteries.

History and Physical Examination

- Prominent pulse on examination.
- Other previous aneurysm surgery.
- Presentation:
  - — ***Asymptomatic:*** If followed, approximately 50% will become symptomatic.
  - — ***Symptomatic:*** Most commonly due to ischemic sequela.
- ***Claudication***
- ***Thromboembolic:*** Up to 25% present with ALI.
- ***Venous compression:*** Present with leg swelling.
- ***Rupture rare***

Diagnosis

Ultrasound: Most cost effective, and very accurate in determining size and presence of mural thrombus.

- If normal ankle-brachial index (ABI), can perform CT or MRI for OR planning.
- If abnormal ABI, also want traditional digital subtraction angiography to look at the outflow.

Intervention

- ***Asymptomatic:*** > 2 cm — some recommend treating any size if mural thrombus is present due to risk of embolism.
- ***Symptomatic:*** If thrombus in outflow vessels and acute limb ischemia stage 1 or 2a then consider thrombolysis first, if 2b or good target then surgery preferred.

Specific Pre-op Checklist/Informed Consent

- Chlorhexidine gluconate solution 4.0% w/v scrub the night before, vein mapping for bypass conduit.
- Mark and sign patient on both sides of extremity if doing procedure prone.
- Discuss risks of limb loss with observation or intervention.
- Risks associated with infrainguinal surgery: i.e., infection, leg swelling, nerve injury-peroneal nerve with posterior repair, graft failure.
- Expected patency of reconstructions listed below.

Surgical Reconstruction

Technical pearls

- ***Bypass and exclusion:*** Gold standard. Ideally vein bypass, can use vascular staple or suture ligature proximal and distal to aneurysm. Five-year primary patency > 80%.
- ***Interposition — posterior approach:*** 90% patency with ringed ePTFE prosthetic interposition at two years.

Technique

- ***Posterior approach:***
  - — "S" shape incision to avoid contractures. Must identify and protect peroneal nerve. Nerve injury may result in "foot drop."
  - — May use prosthetic conduit with great long-term patency, either ringed ePTFE or DACRON® Material.
  - — Ideal treatment in patients with large aneurysms with compression symptoms and absent ipsilateral saphenous vein. Limited access far proximal or distal if aneurysmal segment is very long.
  - — Eliminates chance of late aneurysm expansion.
  - — Patency rivals bypass and exclusion and does not burn bridge of bypass and exclusion in future.

Endovascular Exclusion

- Typically, endovascular exclusion has been offered in patients at high risk for surgery or without autologous conduit.
- CT angiography (CTA) is ideal to determine anatomic candidacy in a similar fashion to EVAR cases.
- ***Ideal stent-graft patients include:*** Stent does not cross knee joint/at least two vessel runoff, and single non-overlapping stent, no significant superficial femoral artery disease that needs treated.

Technical pearls

- ***Antegrade or retrograde access:*** The availability of lower profile stent-grafts has limited the need for femoral artery cutdown. Self-expanding stent grafts are generally utilized off-label in this specific anatomy.
- ***IVUS:*** Identify mural thrombus and accurately measure diameter of sealing zones — consider in patients with renal insufficiency and those without preoperative CT scan.
- ***Must deploy smaller graft first if multiple stents are needed to treat the aneurysm:*** To prevent junctional leak.

FEMORAL ANEURYSMS

Background

- True aneurysms are uncommon.
- Anastomotic aneurysms secondary to suture fatigue but most commonly due to infection.
- Iatrogenic femoral pseudoaneurysm (PSA) are the most common.

Anatomic Location

- Most involve CFA, +/- superficial/profunda < 1% involves just SFA or deep femoral.
- ½ of true aneurysms have contralateral femoral aneurysm or AAA.

Presentation

- Can be asymptomatic but also can present with thromboembolic or compressive symptoms.
- Deep femoral aneurysm — propensity to rupture.

Diagnosis

- ***Ultrasound:*** Surveillance and initial imaging.
  — **Classic to-and-fro flow in pseudoaneurysms**
- ***Computed tomography:*** Can be used to plan operative repair.

Informed Consent

Usual risks associated with general anesthesia/infrainguinal reconstructions, plus:

- ***Graft failure:*** Expected long term patency > 90% at five years.
- ***Ultrasound guided thrombin injection (UGTI) for iatrogenic pseudoaneurysms:*** Arterial embolization, allergic reaction, rupture risks with observation.

Treatment Depends on Etiology

True aneurysms:

- ***Symptomatic or infected:*** Any size: surgical with interposition.
- ***Asymptomatic:*** > 3 cm: Surgical repair with interposition.
- ***False aneurysm:*** **Latrogenic PSA: > 3 cm, growing. 2 cm or if growth during surveillence or failure to close in six weeks of observation.**
- ***UGTI:*** Typically treat with 0.1 ml aliquots of thrombin, with tip of needle away from the neck within the aneurysm sac. Image tip location with B-mode of ultrasound.
- ***If < 3 cm, then surveillance at 1–2 week intervals:*** 90% resolve by six weeks.

"I'm going to put a balloon on a catheter. Once I get the balloon on the catheter, I'll thread it down the artery, or up the artery, I'll inflate the balloon and draw it back."

— Thomas Fogarty, M.D.

PERIPHERAL ARTERY OCCLUSIVE DISEASE

Leigh Ann O'Banion, M.D.
Clara Gomez-Sanchez, M.D.

Background

- Affects > 200 million people worldwide (> 20% in > 80 y/o individuals).[1]
- 7% prevalence in the U.S.[1]
- 30% experience intermittent claudication.[1]
- 10% will develop chronic limb threatening ischemia.[1]
- 3–4% risk of amputation for any patient diagnosed with PAD.[1]
- ***Risk factors:***
  - — Age > 70
  - — Smoking, diabetes mellitus, hyperlipidemia, chronic kidney disease, African American, hypertension, elevated homocysteine.

Anatomy

Renal arteries originate from the abdominal aorta at the L 1-2 vertebral bodies and the aorta bifurcates at L 4-5 (superficial landmark-umbilicus). The next division is the internal and external iliac arteries with the latter transitioning to the common femoral artery at the inguinal ligament. (Superficial landmark is 2–3 cm above inguinal crease.)

The common femoral artery divides into the deep femoral artery (typically laterally) and the superficial femoral artery (SFA). The SFA has been renamed the femoral artery recently to avoid confusion since it is not by definition a superficial artery. The SFA becomes the popliteal at the adductor canal in the distal thigh. The popliteal artery is divided into three portions: Adductor to top of patella — P1, top of patella to knee joint — P2 and from knee joint to takeoff of anterior tibial artery — P3.

Once crossing the knee joint, the below-knee popliteal gives rise to the anterior tibial artery which courses anteriorly and laterally through the interosseous membrane and becomes the dorsalis pedis artery after crossing the ankle joint. After the takeoff of the anterior tibial artery, the below-knee popliteal artery continues as the tibioperoneal trunk (TPT). This bifurcates into the posterior tibial and peroneal arteries. The peroneal artery is the more lateral of the two, which courses lateral just beneath the fibula at the ankle. The posterior tibial crosses the ankle joint and branches into the medial and lateral plantar arteries. The peroneal magnus is a congenital variant where a large dominant peroneal artery supplies the leg and foot and is present in 5% of the population.[2]

Clinical Severity

History

Asymptomatic

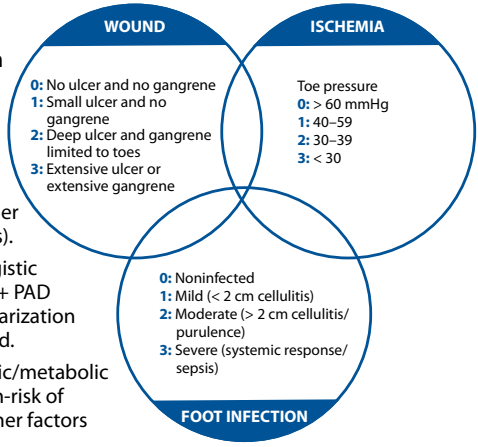
Despite having significant peripheral arterial disease, > 70% of patients exhibit no symptoms (IC or CLTI).[1] However, ankle brachial indices < 0.9 is still associated with increased risk of mortality so risk factor modification is essential.[1]

Symptomatic

- ***Claudication (Latin — to limp):*** Described by patients as calf discomfort and less often thigh and/or buttock pain with activity that is alleviated with rest. Claudication should occur in consistent muscle group at reproducible distance.
  - — Must be distinguished from other causes of leg discomfort:
    - ***Venous:*** Often progressive throughout the day, worse at night.
    - ***Neurogenic:*** Improves when patient sits or lies down (positional) and also occurs after long periods in the standing or sitting position.
      - — Burning and tingling sensation can be more consistent with neuropathic source.
- ***Ischemic rest pain:*** Typically occurs in the foot and is often worsened at night with leg elevation which impedes the gravitational effects of blood flow in patients with severe ischemia. Typically, patients with rest pain will have dependent rubor/elevation pallor and often will hang the leg over the bed for relief.
  - — Generally the ankle brachial index (ABI) is < 0.4.
  - — In severe cases can be associated with a purple hue due to tissue necrosis and impending gangrene.
- ***Tissue loss:*** Non-healing ulcerations, gangrenous changes.

WIfI classification for chronic limb threatening ischemia[3,4]

WIfI classification is The Society of Vascular Surgery recommended classification system for CLTI.[3]



Premises:

1. Increase in wound class increases risk of amputation (based on PEDIS, UT, and other wound classification systems).
2. PAD and infection are synergistic (Eurodiale); infected wound + PAD increases likelihood revascularization will be needed to heal wound.
3. Infection 3 category (systemic/metabolic instability); moderate to high-risk of amputation regardless of other factors (validated IDSA guidelines).

Estimate risk of amputation at one year for each combination

	Ischemia — 0				Ischemia — 1				Ischemia — 2				Ischemia — 3			
W-0	VL	VL	L	M	VL	L	M	H	L	L	M	H	L	M	M	H
W-1	VL	VL	L	M	VL	L	M	H	L	M	H	H	M	M	H	H
W-2	L	L	M	H	M	M	H	H	M	H	H	H	H	H	H	H
W-3	M	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	fI-0	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**

Estimate likelihood of benefit of/requirement for revascularization (assuming infection can be controlled first).

	Ischemia — 0				Ischemia — 1				Ischemia — 2				Ischemia — 3			
W-0	VL	VL	VL	VL	VL	L	L	M	L	L	M	M	M	H	H	H
W-1	VL	VL	VL	VL	L	M	M	M	M	H	H	H	H	H	H	H
W-2	VL	VL	VL	VL	M	M	H	H	H	H	H	H	H	H	H	H
W-3	VL	VL	VL	VL	M	M	M	H	H	H	H	H	H	H	H	H
	fI-0	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**	**fI-0**	**fI-1**	**fI-2**	**fI-3**

For each box, group combination into one of these FOUR classes:

VL Very low = Clinical stage 1
L Low = Clinical stage 2
M Moderate = Clinical stage 3
H High = Clinical stage 4

Clinical stage 5 would signify an unsalvageable foot.

fI: foot infection, I: Ischemia, W: Wound

Physical Examination

- ***Inspection:*** Should encompass from the abdomen to toes, evaluating the abdominal girth and cleanliness of the groins for potential intervention as well as scars from previous procedures. The toes should all be separated and inspected for cracks and ulcerations. Patients with severe ischemia often have dependent rubor with elevation pallor.
- ***Palpation:*** All pulses for quality and characteristics are important. Pulses are graded as non-palpable, 1+ faint, and 2+ as normal.

Severely calcified vessels can be assessed as well as the presence of aneurysmal degeneration. The popliteal artery is the most common peripheral artery which becomes aneurysmal. It is not easily palpable behind the knee in most patients and when a prominent pulse is present should raise one's suspicion for aneurysm. Pedal pulses, both dorsalis pedis and posterior tibial, should be charted on the same grading system. Hand-held continuous wave Doppler should be used to examine all patients when evaluating for PAD. Multiphasic and monophasic auditory waveforms should be recorded depending on the characteristic.

Non-Invasive Testing: Cornerstone of Diagnosis of PAD, and Following Interventions

Ankle brachial index (ABI): Ankle brachial index should be performed in all patients who are assessed for PAD. Toe brachial index (TBI) is often helpful in the diabetic and/or CKD patients with calcified ankle vessels, patients > 80 years of age, and in those with CLTI to assess distal perfusion.

Calculating the ABI: The highest pressure measured in tested extremity (dorsalis pedis or posterior tibial) divided by the highest of the two pressures measured in the upper extremity.

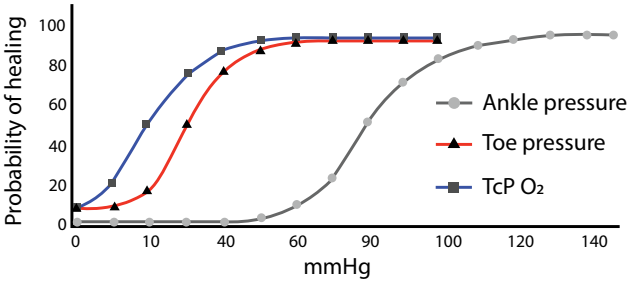
ABI

Within normal limits: > 1.3 Noncompressible
Normal: 1.0–1.3, may be falsely elevated in DM and in patients > 80 years age.
Borderline: 0.9–1.0
Mild: 0.7 – < 0.9
Moderate: 0.4 – < 0.7
Critical: < 0.4

Mortality at five years dramatically lower for declining ABI.

Toe pressure: < 30 mmHg not compatible with healing a digital amputation or significant tissue loss; digital vessels are less calcified than the ankle vessels in patients with DM/CKD, NL TBI > 0.7.

Hemodynamics and probability of healing of a diabetic foot ulcer[5]



Healing unlikely if toe pressure < 55 mmHg

Segmental pressures

- ***High thigh, above knee, below knee and ankle:*** > 20 mmHg drop between segment is a significant drop.
- ***Profunda Popliteal Collateral Index (PPCI):*** If < 0.5 should improve symptoms with profundaplasty or inflow procedure alone.
- ***AK pop — BK pop pressure/AK pop pressure:*** The higher the gradient across the knee, the more likely an infrainguinal reconstruction will be needed.

Exercise treadmill testing: To assess patients with either normal ABI and classic symptoms or combined pathology (i.e., neurogenic and arterial to assess significance). Also used to classify functional capacity and categorize severity of claudication.

- — 1.5 mph at 12% grade for five minutes or until symptoms cause patient to stop.
- — Post-exercise ABI <0.9 confirms diagnosis of PAD.
- — A 30 mmHg drop in ankle pressure is diagnostic pressure drop.
- — The lower the ABI with exercise generally correlates with worse claudication symptoms.

Duplex criteria for occlusive disease/Graft surveillance

% Stenosis	Peak systolic velocity (PSV)	Velocity ratio (VR)	Waveform
Normal	<150 cm/sec	<1.5	Multiphasic
30–49%	150–200 cm/sec	1.5–2.0	Multiphasic
50–75%	200–300 cm/sec	2.0–3.9	Multi/Monophasic
> 75%	>300 cm/sec	> 4.0	Dampened

VR: V1 is PSV at stenosis and V2 within two diameter lengths proximal or distal V1/V2.

For surveillance: Angiogram and repair if PSV > 300 cm/sec, < 25 cm / sec or decrease in ABI > 0.15.

Follow-up protocol: Within one month of procedure. If normal, 6 months, 12 months, then annually; if abnormal, recheck in 3-month intervals.

Management

All patients need risk factor modification — the leading cause of death in this population is related to cardiac causes. Patients should be counseled on smoking cessation at every visit.

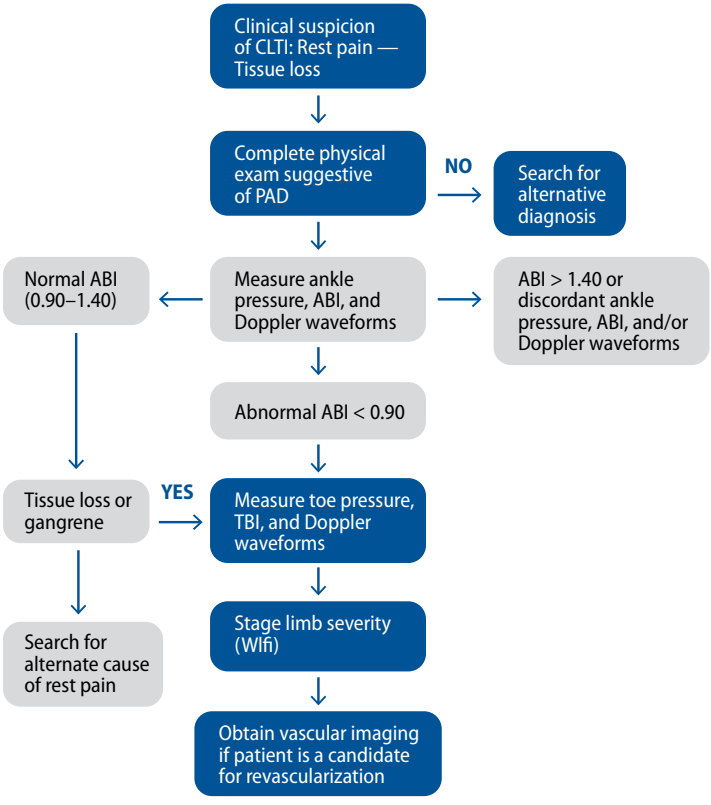
Medical treatment for the atherosclerotic disease process should include:

- Antiplatelet medications : Aspirin (acetylsalicylic acid) 81 mg or clopidogrel 75 mg daily.[3,6,7]
- Consider low dose rivaroxaban 2.5 mg BID to reduce adverse limb AND cardiac events in CLTI patients.[3,6,7]
- Moderate/High intensity statin therapy.[3,6,7]
- Control hypertension with goal systolic blood pressure < 140 and diabetes mellitus with HbA1C < 7%.[3]
- Supervised vs. unsupervised exercise therapy for intermittent claudication.
- A trial of cilostazol for 3–6 months in patients with IC has been shown to improve/increase walking distances in nearly 50% of patients. Cilostazol is contraindicated in patients with congestive heart failure.
- Patients who fail exercise programs and cilostazol therapy may be appropriate for endovascular/surgical treatment if symptoms are significantly lifestyle limiting.[8]

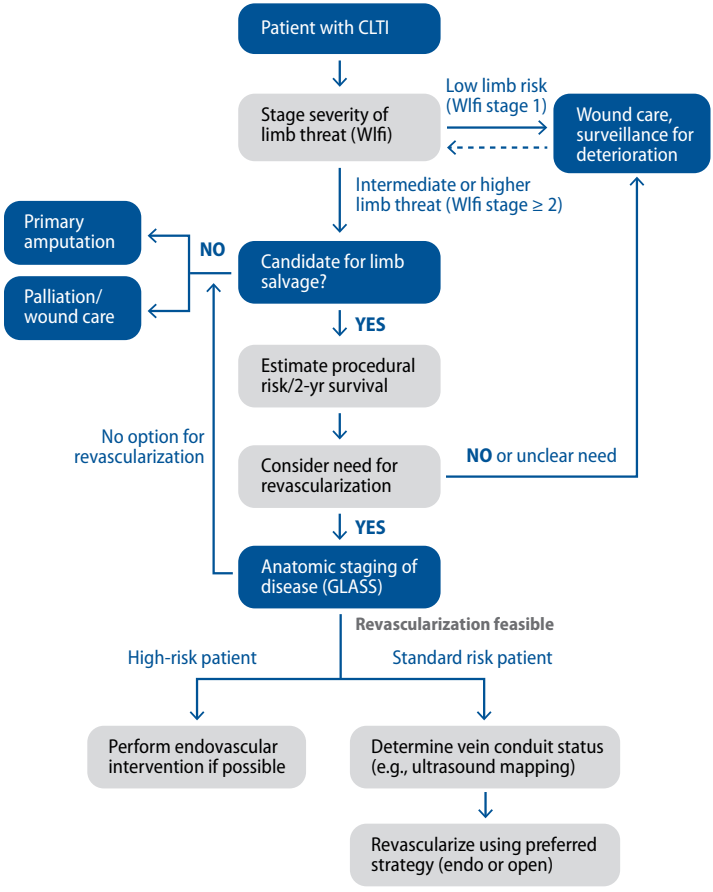
Interventions

The Global Limb Anatomic Staging System (GLASS) is a new anatomic scheme to replace the TASC II classification allowing improved understanding of the target arterial pathway (TAP) and estimated limb-based patency (LBP) rather than a purely lesion based scheme.[3]

Global vascular guidelines[3]



! *This manual does not include all the information needed to use the drugs listed herein safely and effectively. See full prescribing information and any boxed warnings for these drugs.*


Patient with CLTI
Stage severity of limb threat (WIfi)
Low limb risk (WIfi stage 1)
Wound care, surveillance for deterioration
Intermediate or higher limb threat (WIfi stage ≥ 2)
Primary amputation
Palliation/ wound care
NO
Candidate for limb salvage?
YES
Estimate procedural risk/2-yr survival
No option for revascularization
Consider need for revascularization
NO or unclear need
YES
Anatomic staging of disease (GLASS)
Revascularization feasible
High-risk patient
Standard risk patient
Perform endovascular intervention if possible
Determine vein conduit status (e.g., ultrasound mapping)
Revascularize using preferred strategy (endo or open)

CHRONIC AORTOILIAC OCCLUSIVE DISEASE

Background

- Many can be treated safely with durable results via an endovascular approach but some may require a hybrid technique due to bulky common femoral plaque. Assessment of patient risk is key to revascularization choice.
- Reportedly half of occlusions of the aorta will progress to the level of the renal arteries, and the other half will occlude below the inferior mesenteric artery and/or large lumbar arteries.
- Leriche Syndrome Triad: buttock claudication, decreased femoral pulses, and impotence.
- Expected primary patency for interventions (stenting) in the aortoiliac segment has been reported to be > 80% at five years with similar patency in both stenosis and occlusions. Covered endovascular reconstruction of the aortic bifurcation (CERAB) demonstrates similar results.[9]
- Aorta and common iliac disease is treated with balloon expandable stents; the external iliac system often treated with self-expanding stents especially in areas of hip flexion.

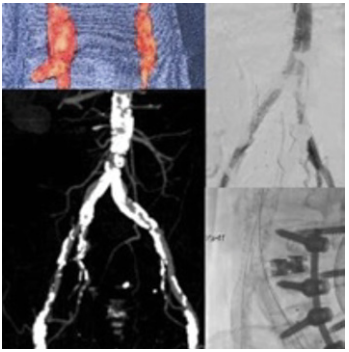
Preferred Treatment Algorithm for Endovascular Management of Aortoiliac Occlusive Disease

- The retrograde approach is most common — via femoral access, except in distal external iliac occlusive lesions which often require a contralateral approach or hybrid approach via open ipsilateral femoral access in combination with femoral endarterectomy. Arm access can also be useful.
- Cross occlusions with hydrophilic wire (.035", .018", .014" options) and angled catheter for directional changes.
  - — Wires from bilateral femoral access should cross in the aorta and have a typical appearance that must be recognized (see previous chapter for image).
- Always confirm catheter is within the true lumen.
- Reentry catheters +/- IVUS guidance — after failure with simple techniques.

- Long sheaths should be advanced across the lesion before a balloon-expandable stent (BES) is advanced. Once the stent is in place, the sheath is withdrawn, and the stent can be deployed. This prevents the stent being dislodged during advancement across the lesion.

Aortic stent placement (CERAB)

- If there is significant distal aortic stenosis or severe AIOD, CERAB may overcome disadvantages of kissing iliac stent such as flow disturbances and raised aortic bifurcation limiting future interventional options.[10]
- A balloon-expandable stent graft (BESG), typically 11 mm, is expanded in the distal aorta and post-dilated to the corresponding aortic diameter
- Subsequently two 8 mm balloon-expandable stent grafts are placed in the distal 1/3 of the aortic stent and simultaneously deployed distally into the common iliac arteries creating a new aortic bifurcation.



Courtesy of Leigh Ann O'Banion, M.D.
Used with permission.

Open Surgical Interventions

Pre-op — considerations

Gold standard is aortobifemoral bypass: Best operation for fit patients.

Extra-anatomic bypass reserved for high-risk patients or those with hostile abdomen.

1. Aortobifemoral bypass: Patency rate exceeds 80% at five years.

- No difference in patency based on conduit used (PTFE vs. DACRON® Material).
- Predictors of poor long-term outcomes of ABF:
- Aorta < 1.8 cm, < 50 years old
- Technique
  - — Midline incision.
  - — Eviscerate to right.
  - — Open retroperitoneum in midline preserving tissue adjacent to duodenum.
- Dissection: Renal vein to aortic bifurcation.
- Proximal anastomosis for aortic reconstruction in patients treated for occlusive disease:
  - — ***End to end:*** Better hemodynamics, potential less risk of duodenal erosion.
  - — ***End to side:*** Consider in cases where the inferior mesenteric artery is patent or there is severe external iliac disease/occlusions with patent common iliac artery and internal iliac arteries— in order to preserve pelvic blood flow.[11]
- The distal anastomosis should be placed over patent vessel: i.e., the profunda or SFA.
- Tunnel below ureters: Must identify
  - — Must ligate the circumflex iliac vein "vein of sorrow" under inguinal ligament prior to tunneling.

2. Axillo-bifemoral bypass: Five-year primary patency of 50–80%.[12]

- For patients who are at high risk for surgical reconstruction, extra-anatomic reconstructions have been used with variable success. Also, the classic reconstruction in patients with infected aortic grafts prior to explants.
- Check bilateral brachial blood pressure, if difference > 20 mmHg, use extremity with best pressure for proximal anastomosis.[13] Left is most common lowest.

- Equivalent patency in patients with SFA occlusion if deep femoral artery is patent.
- Technical aspects of axillary incision:
  — Transverse incision two fingerbreadths below clavicle near midclavicular line. Open clavi-pectoral fascia. Open along fibers of pectoralis major. Either divide pectoralis minor or use first portion of axillary artery. The axillary artery is anatomically divided by the pectoralis minor: first portion medial/posterior to muscle, second portion and third portion lateral. Tunnel subcutaneous to femoral region, may need counter incision at anterior axillary line. Can either use:
- Pre-made GORE-TEX® PROPATEN® Vascular Graft Removable Ring Axillobifemoral.
- Single 8 mm ringed graft to ipsilateral femoral artery with fem-fem bypass. Additional anastomosis required.
  — **Caution:** Sewing to third portion of the axillary artery (lateral to pectoralis minor) — reported axillary disruption.[14]

3. Femoral-femoral bypass: Five-year primary patency of 60% with up to 80% secondary patency.[15]

- Performed most frequently in patients with unilateral iliac occlusion (with failed endovascular attempt) and minimal disease in the ipsilateral iliac. Also, in patients with AUI, or in patients with single limb of aortobifemoral graft occluded. Steal of the donor extremity is rare unless inflow lesion present.
- Most common mode of failure is inflow progressive stenosis.

4. Ileo-femoral bypass: Retroperitoneal incision to ipsilateral iliac artery.

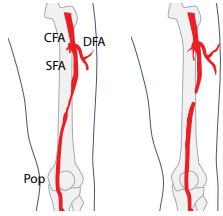
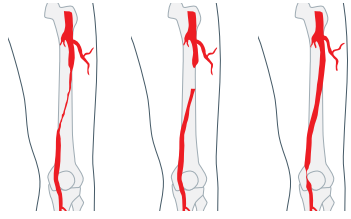
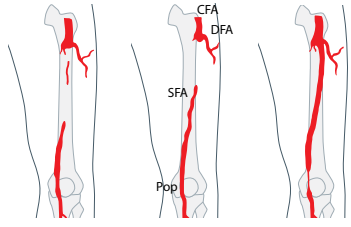
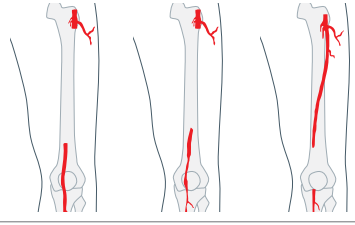
- Benefits of single groin incision, limited data suggest improved patency compared to fem-fem bypass.

INFRAINGUINAL DISEASE

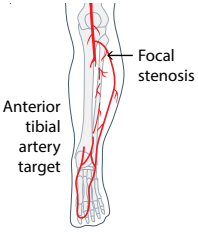
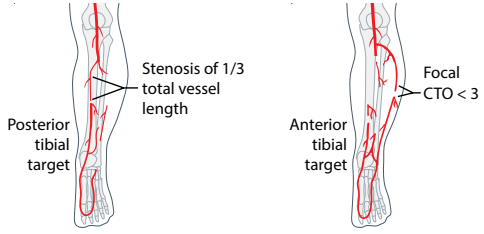
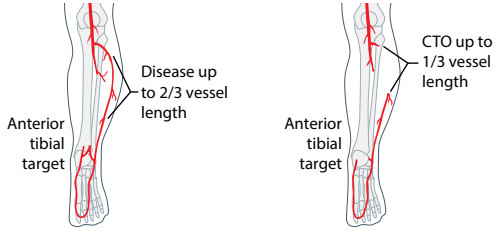
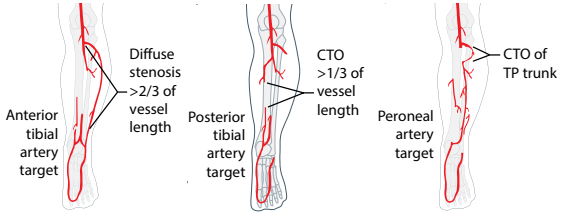
GLASS Staging of Femoral-Popliteal Disease

Stages anatomic complexity with a defined target artery pathway[3]:

GLASS staging of infrapopliteal disease[3]

0	Mild or no significant (< 50%) disease	
1	• Total length SFA disease < 1/3 (< 10 cm) • May include single focal CTO (< 5 cm) as long as not flush occlusion • Popliteal artery with mild or no significant disease	
2	• Total length SFA disease 1/3–2/3 (10–20 cm) • May include CTO totaling < 1/3 (10 cm) but not flush occlusion • Focal popliteal artery stenosis < 2 cm, not involving trifurcation	
3	• Total length SFA disease > 2/3 (> 20 cm) length • May include any flush occlusion < 20 cm or non-flush CTO 10–20 cm long • Short popliteal stenosis 2–5 cm, not involving trifurcation	
4	• Total length SFA occlusion > 20 cm • Popliteal disease > 5 cm or extending into trifurcation • Any popliteal CTO	

GLASS staging of femoral-popliteal disease[3]

0	Mild or no significant disease in the primary target artery path	
1	• Focal stenosis of tibial artery < 3 cm	
2	• Stenosis involving 1/3 total vessel length • May include focal CTO (< 3 cm) • Not including TP trunk or tibial vessel origin	
3	• Disease up to 2/3 vessel length • CTO up to 1/3 length (may include tibial vessel origin but not tibioperoneal trunk)	
4	• Diffuse stenosis > 2/3 total vessel length • CTO > 1/3 vessel length (may include vessel origin) • Any CTO of tibioperoneal trunk if AT is not the target artery	

Site Specific Management

Evidence Based Revascularization: Patient risk, Limb staging, Anatomic Pattern of disease (Have a PLAN!)

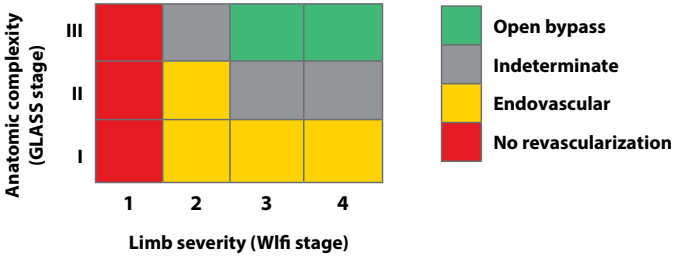
Infrainguinal Disease: BEST CLI trial results indicate that patients with acceptable risk and suitable single segment saphenous conduit are best served with open revascularization.[16] Reduced major adverse limb events for higher complexity anatomy. In the absence of adequate conduit, endovascular and open revascularization results are equivocal. However, in high-risk patients (> 5% perioperative mortality or < 50% two-year survival), an endovascular first approach is preferable.[16]

- ***CFA/Profunda:*** Common femoral endarterectomy is procedure of choice[3] but rarely as a sole procedure, except in specific cases in which the improvement is expected with this inflow intervention only — such as rest pain, or in patients with isolated common femoral disease. Endovascular intervention is discouraged.
- ***OPEN:***
  - — Acceptable targets for bypass should provide in-line flow to the ankle and foot.
  - — Small saphenous and/or arm vein may be used as acceptable bypass conduits with higher re-intervention rates and lower durability.
  - — Prosthetic conduits (heparin-bonded ePTFE grafts may be useful in select situations, with vein cuffs improving patency to distal tibial targets in limited data.
  - — Cryopreserved saphenous graft should be utilized only in CLTI and reserved as a final recourse after other open and endovascular revascularization strategies are exhausted. Extremely poor five-year patency.[17]
- ***ENDO:***
  - — Plain angioplasty, drug-coated balloon angioplasty, stent placement, intravascular lithotripsy and atherectomy may be utilized as endovascular techniques depending on the specific anatomy and lesion characteristics.
  - — Intravascular ultrasound is complementary to endovascular revascularization and can aid in sizing, identifying post-intervention dissection, etc.

Inframalleolar disease: Major challenge in CLTI.

- Open pedal bypass requires preserved pedal artery.[18, 19]
- Pedal arch revascularization and pedal loop angioplasty is reported with success in limited data sets.[18, 19]
- Deep venous arterialization (open and endovascular) is also reported with limited results — PROMISE study[20]— no options patients. Ideally need several centimeters of patent posterior tibial artery for inflow source.

Preferred initial revascularization strategies for infrainguinal disease in average risk patients with available conduit[3]



Follow-up surveillance: All patients should have ankle brachial indices/toe brachial indices performed with duplex surveillance to provide hemodynamic and anatomic evaluation or revascularization.[21]

- ***For bypass grafts:*** Same follow-up guidelines and duplex criteria as autologous bypass grafting with follow-up at 30 days, three months, six months, and annually.[21]
- ***Femoral-femoral:*** A midgraft velocity < 60 cm/sec and inflow or anastomotic velocity > 300 cm/sec predicts a high risk for failure and should prompt additional evaluation. CTA vs. angiogram.
- ***Axillofemoral bypass:*** Midgraft velocity < 85 cm/sec is predictive of failure.
- ***Infrainguinal bypass:*** < 45 cm/sec or PSV > 300 cm/sec, VR > 3.5 is at high risk for sudden graft failure and should have additional imaging, correlate with an ABI change of > 0.15.[21]

- ***Endovascular revascularization:*** Same follow-up guidelines as bypass grafts (30 days, three and six months, then annually) PSV > 275 and/or VR > 3.5 is highly specific and predictive of significant in-stent stenosis.[22]

Benefits of Procedures

Improvement in leg pain, limb salvage, and quality of life.

Complications and Post-Operative Complications

- ***Death:*** #1 cause is cardiac related.
- ***Infection:*** Up to 10% of groin incisions become infected.
- Redo operations and prosthetic implant, increase risk.
- ***Lymphocele:*** Can become infected, treated with drainage and ligation of lymphatic leak point +/- vacuum dressing/muscle flap.
- ***Leg swelling:*** Present in nearly ½ of patients.
- ***Graft failure:*** Early graft failure has high association with limb loss. Most commonly due to technical related issues during the first three months post-operative.
- ***Limb loss:*** Usually secondary to graft failure or progressive atherosclerotic disease.
- ***Nerve injury:*** Common to have paresthesia of leg (saphenous nerve injury).
- ***Post-Revascularization Ischemic Neuritis:*** Can be debilitating; education and medication may aid in improvement

Post-Operative Care

1. ***Cardiovascular medications:*** Antiplatelet, statin, rivaroxaban
2. ***Anticoagulation:*** For high-risk bypasses consider heparin drip as bridge to oral anticoagulation. Long-term plan based individually. All patients need to be dc'd with antiplatelet agent(s), consider dual antiplatelet therapy (clopidogrel and Aspirin) or Aspirin + rivaroxaban for high-risk reconstructions. Dual antiplatelet therapy (clopidogrel and Aspirin) for three months after endovascular PAD procedures.[3]

! *This manual does not include all the information needed to use the drugs listed herein safely and effectively. See full prescribing information and any boxed warnings for these drugs.*

3. ***Assess for bleeding***, compartment syndrome (reperfusion injury), and intervention success (i.e., pulse exam).
4. ***Infectious complications:***
   — Incisional: No more than 24 hours of post-op prophylactic abx unless treating a pre-existing infection (i.e., foot infection).
   — Non-incisional UTI: D/C foley, pneumonia: incentive spirometry.
5. ***Access complications:*** After percutaneous procedures
   — Bleeding (retroperitoneal bleeding may present with back pain with normal appearing groin) highest risk with puncture above the inguinal ligament.
   — Pseudoaneurysm: < 2–3 cm may undergo spontaneous thrombosis, ultrasound guided thrombin injection is typically favored treatment if > 2 cm, enlarging, or associated with significant pain. Open repair may be favored in larger aneurysms, suspicion of infection, or overlying skin changes.[23]

Pearls of CLTI

- The highest predictor of need for combined inflow and outflow procedure is tissue loss. Always address inflow first.
- Autogenous conduit is recommended for infrainguinal reconstructions, even for fem–above-knee pop in patients with expected survival more than two years.
- ***Early graft failure < three months:*** Technical issues.
- ***Late graft failure > three months to one year:*** Most commonly secondary to intimal hyperplasia.
- ***Absolute claudication distance:*** Distance patient can no longer walk on treadmill — best measure to compare pharmaceutical and intervention procedures.
- ***ABI:*** Best predictor of survival in population-based studies.

ACUTE LIMB ISCHEMIA

Background

- Embolectomy was first successfully performed in 1911. The most notable change occurred in 1963 when Fogarty, *et al*., performed an embolectomy with a balloon catheter.
- Unlike the presentation of those with chronic limb threatening ischemia, patients presenting with acute ischemia require emergent attention.
- 30-day limb loss is up to 30%.

History

- Present typically with abrupt onset of pain in the involved extremity.
- ***Symptoms:*** How long have symptoms been present?
  - — **Time course may guide decisions about post-revascularization fasciotomy**
- ***Cardiac:*** Atrial fibrillation (AFib), history of MI
- ***Vascular:*** Risk factors for Peripheral Arterial Disease (PAD)? Chronic PAD history? History of aneurysms?
- ***Etiologies:***
  - — Thrombosis/embolization
  - — Dissections, phlegmasia, trauma, compartment syndrome

Physical Examination

Exam: The five P's:

- ***Pain:*** Discomfort of the extremity.
- ***Pallor:*** Pale discoloration of the involved extremity.
- ***Pulselessness:*** May have Doppler signal.
- ***Paresthesia:*** Decreased sensation.
- ***Poikilothermic:*** Cool to touch.

Etiology source: Embolic events most commonly originate from the heart, 80% of which are secondary to atrial fibrillation or recent MI causing mural thrombosis. Other less frequent causes include arterial to arterial embolus or paradoxical embolus. Popliteal aneurysms frequently present with embolism to the tibial vessels.[24]

- Thrombosis most frequently occurs in patients with previous interventions or known PAD; sometimes occurs secondary to a hypercoagulable state such as heparin-induced thrombocytopenia or other inherent causes.

Embolic events originating from the heart most typically embolize to:

- Common femoral artery — 30–35%
  - — Can present with palpable femoral pulse — water-hammer characteristic.
- Aortoiliac — 20–25%, saddle embolus: bilateral ischemia
- Popliteal — 15%
- Brachial — 10%, usually left upper extremity

Operative Technique

Brachial:

- Left Brachial >>>>Right Brachial.
- Transverse incision below the antecubital fossa with takedown of the tendon from aponeurosis. Find the bifurcation of the radial and ulnar arteries with individual embolectomy after transverse arteriotomy proximal to the bifurcation.
- Perform completion arteriography if palpable pulses are not appreciated after embolectomy.

Femoral:

- ***Vertical vs. transverse skin incision and isolation of CFA, DFA, SFA.***
  - — ***Suspected thrombosis:*** Longitudinal arteriotomy — may need to patch.
  - — ***Suspected embolism:*** Transverse arteriotomy.

Tibial:

- Below-knee popliteal incision, two fingerbreadths inferior to tibial tuberosity. Dissection down to popliteal fossa, then extend the incision inferiorly with takedown of the soleus muscle off the tibia. The anterior tibial vein crosses over the proximal anterior tibial artery prior to its entry into the interosseus membrane. Isolate the tibioperoneal trunk and anterior tibial artery with an arteriotomy just above the anterior tibial artery.

EDWARDS FOGARTY® Occlusion Catheter: Will inflate in mm to approximately 2x the number of the catheter (i.e., #3 dilates to a diameter of approximately 6 mm).

- Color and location typically used for embolectomy.
  - — ***White 5:*** Iliacs
  - — ***Red 4:*** Femoropopliteal/brachial
  - — ***Green 3:*** Tibials/radial ulnar

SVS: Categories for acute limb ischemia

Category	Description	
I	Doppler arterial and venous signal present but acute symptoms with pain, normal sensory and motor.	**Viable**
IIa	No Doppler arterial signal present, positive venous signal and reduced sensation, intact motor function.	**Marginally threatened**
IIb	No Doppler arterial signal, venous doppler signal present. Reduced sensory and motor function.	**Immediately threatened**
III	No Doppler signal in artery or vein — no sensory or motor, non-viable — Tx. Amputation: revascularization can result in cardiac arrest secondary to release of toxins from ischemic tissue.	**Irreversible**

ATHEROEMBOLI (BLUE TOE SYNDROME)

Background

Microscopic, cholesterol-laden debris from a proximal source. Typically found in patients with palpable pulses. Source is typically from aneurysm, cardiac embolism, or severe atherosclerosis of the aorta or inflow arteries. If the embolic debris is larger, can cause more of an acute ischemia pattern than a blue toe picture.

History and Physical Examination

- Can be spontaneous or after catheter manipulation.
- Evaluate for aneurysm or asymmetry in pulse examination.
- Typically, it is very painful.

Medical treatment includes: Antiplatelet agents (often dual therapy) and statins. Warfarin has been reported to cause intraplaque hemorrhage and is contraindicated. It is recommended in cases of ≥ 4 mm mobile aortic arch plaque that is symptomatic. Direct oral anticoagulants may also be used.

Intervention

Intra-arterial stent placement has been used to stabilize a plaque causing embolic events, however traditional treatment has been either endarterectomy or ligation and bypass.

THE DIABETIC FOOT ULCER

Background[25]

- 18.6 million people affected worldwide each year (1.6 million U.S. patients)
  - — Neurogenic
  - — Vascular
  - — Biomechanical
- 50% of patients with DFU will have concomitant PAD.
- > 50% infection rate, 20% progress to major amputation.
- 30% five-year mortality.

History and Physical Examination

- History of previous diabetic foot complications.
- Annual physical screening by primary care or podiatrist.
  - — Evaluate for neuropathy.
    - Semmes-Weinstein 5.07 monofilament.
    - 128-Hz tuning fork.
    - Ipswich Touch Test.
  - — PAD screening (ABI/TBI).
  - — Monitor for skin breakdown, callus, thickened nails, digital deformities (hammer/claw toes), Charcot arthropathy.

Management

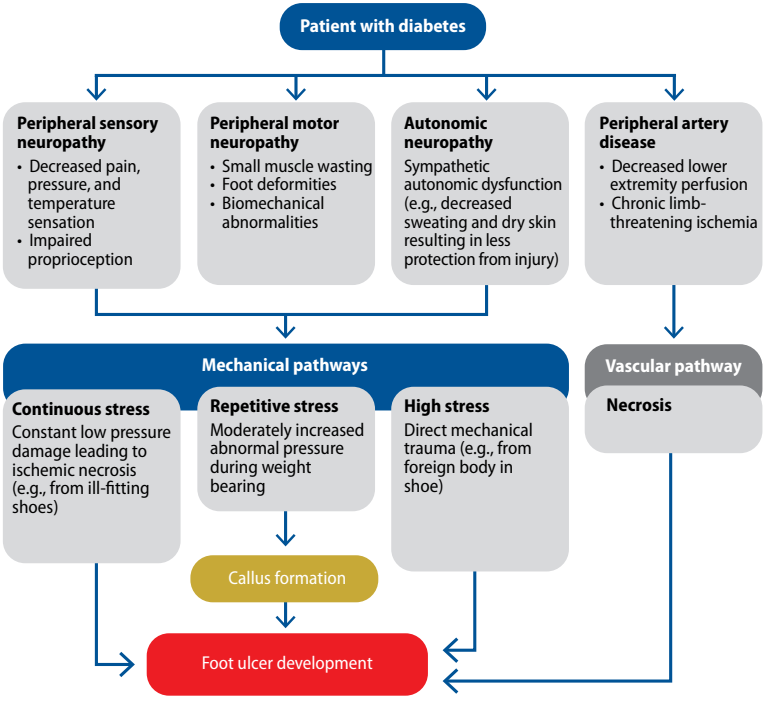
Preventative

- Education of proper foot care and footwear.
- Referral to vascular specialist if presence of PAD.
- Routine screening and reassessment for at risk patients.

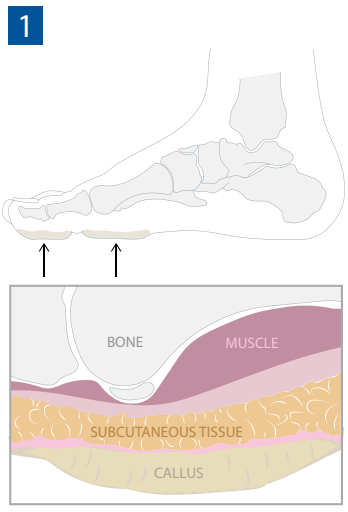
Wound Management

- Debridement.
- X-ray to evaluate for osteomyelitis.
- Off-loading.
- Dressing: Keep wound moist promoting tissue growth/ epithelialization while minimizing maceration.
- Early detection and treatment of infection.

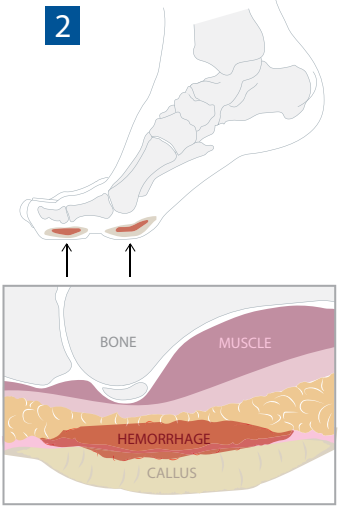
Pathways to diabetic foot ulcer development



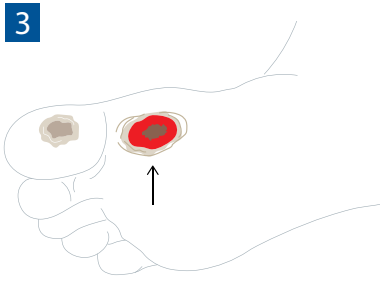
Development of typical diabetic foot ulcer from mechanical stress

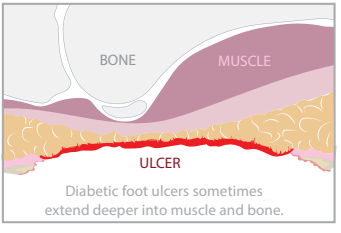


Abnormal pressures on the foot that are not felt during weight bearing due to lack of sensation can lead to superficial callus formation.



Inflammation and/or minor trauma from impact can induce hemorrhage beneath the callus.





Callus removal reveals ulcer extending through the epidermis and dermis into the subcutaneous tissue.

“Vascular access was the Achilles’ heel of chronic hemodialysis.”

— James Cimino, M.D.

HEMODIALYSIS ACCESS

Leigh-Ann O'Banion, M.D.

1966: Brescia and associates described first arteriovenous access — radiocephalic arteriovenous fistula at the wrist.

General Principles in Selection of Hemodialysis Access

- Referral for dialysis access creation should be made when chronic kidney disease reaches stage IV (estimated glomerular filtration rate 15–29) and surgery scheduled when dialysis expected within 6 months.
- Fistula first (when appropriate)
  - — Younger patients, CKD-IV, those with good caliber veins, clearly warrant fistula first
  - — Elderly patients or others with short life expectancy who are already on hemodialysis may be more appropriate for a graft
- Non-dominant arm all things equal.
- Use the most distal site with adequate vein available:
  - — Radiocephalic arteriovenous fistula (AVF) first choice
  - — Brachiocephalic AVF second choice
  - — Transposition brachiobasilic AVF third choice
  - — Forearm loop arteriovenous grafts (AVG) next
  - — Upper arm brachioaxillary AVG last choice
- Once non-dominant arm exhausted, use dominant arm.
- **Tunneled catheters are a temporary access measure only,** and should be preferentially placed in the jugular vein, reserving the subclavian vein for tunneled catheter access when you have exhausted use of the peripheral veins in that extremity.

Key History

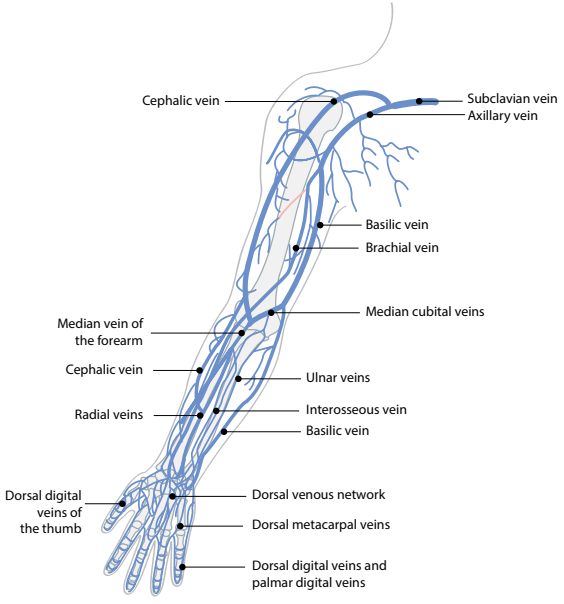
- Previous access procedures, automatic implantable cardioverter defibrillator (AICD) or pacemaker, previous central vein catheters, congestive heart failure (CHF), previous arm or neck surgery.

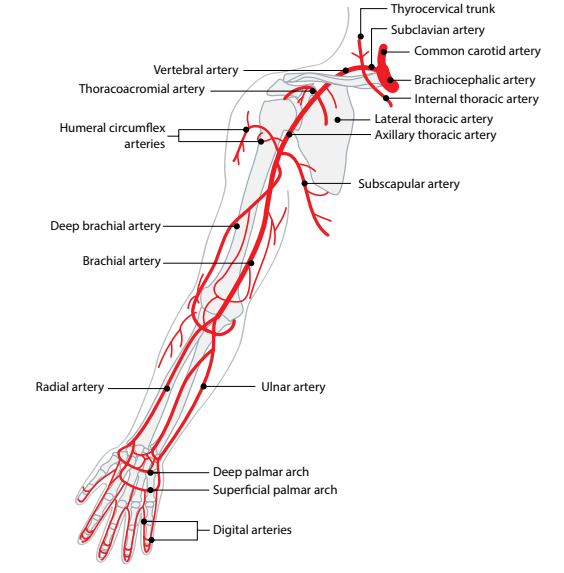
Physical Examination

- Scars from previous access, central vein catheters, ports, chest wall collaterals, examination of veins with tourniquet.
- Blood pressures should be checked bilaterally; if > 20 mmHg difference, concern for inflow disease.
- Palpation of brachial and radial/ulnar arteries; if non-palpable, then check with continuous wave Doppler.
- Allen test[1] — Evaluates for possible radial artery dominance; concern for wrist fistula if + exam.
- Barbeau test[2] — Utilizes pulse oximetry and plethysmography to assess the palmar arches; may be more sensitive than the Allen's test.

Non-Invasive Evaluation

- Vein mapping used to assess the size and patency of veins and may suggest central vein stenosis/occlusion.
- Evaluate arteries for size, plaque, and potential arterial inflow disease with blood pressure measurements, arterial waveforms, and velocities.
- Surgeon should routinely repeat non-invasive venous evaluation at time of creation in the OR, as regional blocks or anesthesia could markedly dilate veins.
- Preferred anatomic and physiologic measurements:
  - — > 2 mm transverse arterial diameter with minimal calcification
    - > 2.5 mm vein with at least 15 cm in continuity[3]
  - — Patent palmar arch
- Venogram necessary prior to creation of AV access when:
  - — Extremity edema
  - — Chest wall or arm collateral veins
  - — History of catheter on side of planned access
  - — Any previous failed access procedures
  - — History or present AICD/pacemaker


Cephalic vein
Subclavian vein
Axillary vein
Basilic vein
Brachial vein
Median cubital veins
Median vein of the forearm
Cephalic vein
Ulnar veins
Radial veins
Interosseous vein
Basilic vein
Dorsal digital veins of the thumb
Dorsal venous network
Dorsal metacarpal veins
Dorsal digital veins and palmar digital veins


Thyrocervical trunk
Subclavian artery
Common carotid artery
Vertebral artery
Brachiocephalic artery
Thoracoacromial artery
Internal thoracic artery
Lateral thoracic artery
Humeral circumflex arteries
Axillary thoracic artery
Subscapular artery
Deep brachial artery
Brachial artery
Radial artery
Ulnar artery
Deep palmar arch
Superficial palmar arch
Digital arteries

Anatomy of Upper Extremity Veins

Cephalic vein:

- Lateral to the radial artery and courses up the radial forearm on the volar side.
- At the elbow, it joins the basilic vein (which takes a similar course with ulnar artery) to form the median cubital vein.
- Cephalic vein courses up the anterolateral portion of the upper arm on the lateral side of the bicep region.

Basilic vein:

- Courses posteromedial up the arm below the fascia to join the brachial veins near the axilla typically running on the medial arm between bicep and triceps.

Central veins:

- Once the cephalic vein joins the axillary vein, it becomes the subclavian vein.
- The axillary vein originates at the lower border of the teres major muscle and becomes the subclavian vein at the lateral margin of the first rib.
- Subclavian vein joins the internal jugular vein to become the innominate vein.

Techniques

Radiocephalic fistula

- 20–50% fail to mature[4]; despite this, **patency, long-term function, and reintervention rate is greatest of all fistulas.**
- Longitudinal incision made between radial artery and cephalic vein, vein transposed to artery for end-to-side anastomosis.

Brachiocephalic fistula

- Transverse incision at antecubital fossa.
- Cephalic vein transposed medially to create end-to-side anastomosis with brachial artery.

Brachiobasilic fistula

- Can be done as a one or two-stage procedure.
- ***One stage:*** Entire basilic vein dissected and transposed anterior to the bicep muscle, either by flap creation or by subcutaneous tunneling, and anastomosis to brachial artery created at the same time.
- ***Two stage:*** First stage arteriovenous fistula creation at the antecubital fossa, followed by the second stage once ultrasound demonstrates maturation with transposition anterior to the bicep muscle.
- Possible improved long-term patency with two-stage strategy but proponents also argue if there is failure of maturation or significant steal develops, the patient has not undergone the more complex/invasive operation.[5,6]

Percutaneous AVF creation

- Two devices available (BD® WAVELINQ® EndoAVF System 4F and MEDTRONIC ELLIPSYS® Vascular Access System) but role in the algorithm still evolving — requires fluoroscopy.
- MEDTRONIC ELLIPSYS® Vascular Access System uses ultrasound guidance to puncture from the median cubital vein through a perforator into proximal radial artery and then uses heat sealing to create fistula — no fluoroscopy needed.

Forearm loop AV graft

- Arterial anastomosis at brachial artery just distal to antecubital fossa.
- Venous anastomosis can be cephalic vein, basilic vein, or an antecubital vein.
- Small incision made at apex in lower forearm as counter incision for loop tunneling.

Important to dictate anatomy and direction of flow of each limb (venous limb, arterial limb) in operative report to aid with thrombectomy at a later time.

Brachioaxillary AV graft

- Two incisions along medial aspect of arm — one for brachial artery anastomosis and one for axillary vein anastomosis. Tunneled over biceps muscle.

Post-operative Evaluation

- Arteriovenous fistula or graft should have palpable thrill or audible bruit prior to leaving OR.
- If access pulsatile, consider possibility of outflow obstruction (unidentified central venous or distal vein stenosis, twisting, or kinking of access in subcutaneous tunnel).
- Radial/ulnar arteries ideally with palpable pulses at completion of procedure but must have multiphasic Doppler signals otherwise. Diminished pulses warrant close postoperative clinical evaluation and to assess for potential steal syndrome.
- Autogenous arteriovenous fistulas typically require 6–16 weeks for maturation.[7]
- Autogenous fistula maturation typically evaluated by the "Rule of 6's":
  - — Flow of 600 cc/minute
  - — Diameter over 6 mm
  - — Depth from skin < 6 mm
  - — Cannulation length of 6 inches
- If rapid maturation or aneurysmal dilation develops, suspect central stenosis.
- Grafts that use standard wall ePTFE are accessible in 2–3 weeks.
- Some conduits are approved and designed for early access to potentially preclude catheter use, 24–48 hours after implantation.
- Less common options for patients who require grafts but may be at higher risk of infection include bovine carotid artery conduits as well as femoral or saphenous vein.
- Follow-up in two weeks for incision check and access evaluation.
- Fistulas need follow-up every 6–8 weeks for access evaluation. Any abnormalities (pulsatility, diminished thrill, or bruit, etc.) warrant further investigation with non-invasive methods or venography.

Results[7,8]

Access type	Functional patency, 1 year	Functional patency, 3 year	Maintenance procedure/year
Radiocephalic AVF	91%	83%	1.3
Including nonmaturation	*67%*	*62%*	
Upper arm AVF	92%	83%	1.8
Including nonmaturation	*83%*	*74%*	
AV graft	89%	72%	3.3
Including nonmaturation	*85%*	*69%*	

Complications

Thrombosis

- Most common complication.
- Technical if occurs early (< 30 days).
- Over 90% of late thrombotic episodes are related to venous outflow issues.

Infection

Less than 5% of grafts become infected; an infected graft typically requires graft removal, which can be partial, or total, depending upon organism involved, amount of graft, location of graft involvement (i.e., anastomosis versus isolated midportion of access), and overall condition of patient (i.e., sepsis versus local wound infection).

Edema

- Secondary to poor venous outflow.
- If persists longer than two weeks, plan venogram — treatment of outflow stenosis or ligation of access is the treatment is rarely needed.

Failure to mature (autogenous arteriovenous fistula)

- Up to 30% of wrist fistulas, < 15% of basilic transpositions.
- Etiology: poor inflow, poor vein quality, or excessive outflow due to large vein tributaries.
- Balloon-assisted maturation (BAM) may be useful to aid in slowly maturing fisutlas.

- Multiple venous branches — branch ligation vs. coil embolization.
- Arterial/venous stenosis — perform percutaneous transluminal angioplasty/stenting or open patch angioplasty.
- Mid-vein abnormality — likely secondary to valve or chronic venous disease; perform percutaneous transluminal angioplasty/stenting or open repair with patch angioplasty or interposition repair.

Steal syndrome

- Clinically significant arterial steal occurs in 2–8% of patients but physiologic steal in a higher proportion.
- Higher frequency in diabetics and more **proximal** access.
- Assessment with finger pressures and clinical examination.
- Typically, digital pressures of < 50 mmHg will have rest pain.
- Compare with contralateral extremity and assess finger pressures with and without AV access compression.
- If no significant change with access compression, then likely distal disease; if significant change with AV access compression, then likely steal.

Grade 1: Mild (cool extremity with few symptoms)

2: Moderate (symptoms with dialysis only)

3: Severe (ischemic rest pain or tissue loss)

Ischemic monomelic neuropathy[9]

- 3-4% incidence secondary to impaired blood supply.
- Highest rate in diabetics.
- Symptoms immediately post-op.
- Immediate access closure is mandatory.

Access pseudoaneurysms

- Secondary to repeated punctures at same site.
- Interposition repair is standard treatment but covered stents also an option.
- Percutaneous thrombectomy can cause significant potassium elevation secondary to lysis or RBC.

Management of Complications

Low flows during dialysis

- Etiology includes arterial stenosis, intra-vein, or intra-graft stenosis.

Persistent bleeding after dialysis or high-pressure outflow measurements during dialysis

- Usually an outflow problem — graft to vein anastomosis, central stenosis, intra-vein, or intra-graft stenosis.
- Typically, the access feels pulsatile on exam.

Treatment is either endovascular or open repair

- Endovascular: Percutaneous balloon angioplasty or stent placement.
- Open repair: Jump graft interposition repair or patch angioplasty or bypass more distally.

Thrombosed AV access

- Thrombosed fistula are often not salvageable, potentially more success with open thrombectomy.
- For thrombosed AV grafts, equivalent salvage rates for endovascular vs. open thrombectomy.
- Goal is to achieve intra-graft pressure < 40% of compressed graft pressure (systemic pressure).

Endovascular management of thrombosed AV graft

- ***Forearm graft:***
  - — Access via mid forearm limb section with sheaths placed toward apex of graft.
  - — Venous outflow treated with percutaneous thrombectomy of venous outflow followed by PTA of venous anastomosis if needed.
  - — Arterial inflow treated with thrombectomy of arterial limb with over-the-wire EDWARDS LIFESCIENCE® FOGARTY® Balloon Catheter to remove arterial plug.
  - — Identify etiology of failure and treat with PTA and/or stenting.
  - — Most common cause is stenosis at venous anastomosis.
    - Strongly consider placement of endovascular stent graft for treatment of the venous anastomosis if not across the elbow joint since patency superior to PTA.

- ***Brachioaxillary graft:***
  — Access antegrade above antecubital fossa.
  — Treatment of venous outflow similar to forearm graft.
  — Access retrograde the graft close to venous anastomosis.
  — Treatment of arterial inflow similar to forearm graft.

Surgical management of thrombosed AV graft

- Cutdown at apex of graft or at venous anastomosis.
- Open thrombectomy of graft; intraoperative fistulogram with treatment either endovascular or open of culprit issue.
- Patients with exhausted upper extremity options and functioning tunneled catheter — consider MERIT® HERO® Graft.
- Must address etiology of failure with endovascular or open technique (patch angioplasty, graft revision).
- High flow: Fistula > 600 ml/min, graft > 800 ml/min.

Steal syndrome corrective actions (typically for grade 2 or 3)

- Banding or tapering of graft or vein — plication
  — High flow steal
- Distal Revascularization Interval Ligation (DRIL) procedure
  — Procedure of choice for low flow steal
- Revision Using Distal Inflow (RUDI) procedure
  — High flow steal
- Proximalization of fistula
  — For low or high flow steal
- Ligation and abandonment of AV access

Dialysis Catheters

- Used as a **temporary access measure**. Used preferably when dialysis necessary before autogenous AV fistula has matured.
- Significantly increased morbidity and mortality with central venous catheters compared to arteriovenous fistula especially from risk of bacteremia/line infections.
- Internal jugular vein preferred. **Subclavian vein to be used only when all access options have been exhausted in the upper extremity.**

- Pre-curved catheters typically use 23 cm cuff to tip for RIJ and 27 cm for LIJ. They allow tunneling along anterior chest into internal jugular vein with less kinking or twisting of the catheter along the subcutaneous path.
- Malfunctioning catheters can be replaced by endovascular means over a stiff wire if the catheter has been in place long enough to have a well-defined subcutaneous tract.
- Many times, however, the catheter will develop a "pseudosheath" around the portion in the venous lumen — simply replacing the catheter over a wire will reintroduce the new catheter into the "pseudosheath" — therefore, balloon angioplasty is required to disrupt the pseudosheath prior to reinserting a new catheter.

“A severe attack of common sense.”

— Sven Ivar Seldinger

CENTRAL VENOUS ACCESS

Leigh Ann O'Banion, M.D.
Clara Gomez-Sanchez, M.D.

The most common procedure performed by trainees and medical students.

After 50 successful access placements, complications steadily decrease, i.e., learning curve.

Indications

Hemodialysis, chemotherapy, total parenteral nutrition, exhausted peripheral access, long-term access for antibiotics, large-bore access for patients requiring rapid infusions (shock, trauma, etc.), catheter access for hemodynamic monitoring.

Pertinent medical/surgical history

Previous catheters, automatic implantable cardioverter defibrillator (AICD) pacemakers, lung resection (access side of previous lung resection), COPD/emphysema, chronic renal insufficiency or impending dialysis needs (important to avoid subclavian access). Knowledge of medication list (antiplatelet and anticoagulants).

Labs

- ***CBC, PT, PT, INR:*** INR > 3.0 or platelets < 20x100^9/L are at significant increased risk of bleeding.[1]

Sites

- ***Internal jugular vein:*** Reliable anatomy, low complication rate, ultrasound guided, right side preferable (direct path), COPD patients (lower pneumothorax rates), and previous AICD placement (avoid competition with wires/leads).

- ***Subclavian vein:*** May be easier to access in obese patients with distorted neck anatomy, contraindicated with coagulopathy (non-compressibility).
- ***Femoral vein:*** Compressible site and likely fastest to access. Associated with higher risk of catheter-associated infection.

Hemodialysis Tunneled Catheter

- Direct ultrasound imaging during cannulation is a standard of care for jugular vein. High-frequency linear transducer allows for best imaging of vascular structures.
- Trendelenburg position for internal jugular and subclavian access.
- A lateral approach to the jugular vein with access at the base of the neck with the ultrasound probe in transverse orientation superior to the clavicle is preferred. **Right internal jugular vein is the preferred initial site.**
- Assess vein for compressibility first.
- Can use micropuncture technique for 4–5 Fr access.
- 0.035" wire introduced through access needle into central venous system — passage into IVC preferred for stability and to avoid cardiac arrhythmias due to wire coiling within atrium/ventricle.[2, 3]
- Predilation of skin and subcutaneous tissues with rigid dilators **must be** done under direct fluoroscopic guidance to avoid kinking of wire and aberrant passage of dilator tip through the wall of the central veins.
- Counter incision made medial to nipple line and 5–7.5 cm inferior to clavicle or measure for precise placement.
- Catheter tunneled in subcutaneous tissue (over the clavicle for internal jugular approach), exiting at the point of the guidewire insertion.
- Peel-away sheath is placed over-the-wire and the catheter is advanced through it into the central veins. The sheath is then removed by peeling the sheath apart, it is important to not let the catheter slip backward out of the sheath when the sheath is removed.
- The catheter tip should be placed at the level of the SVC/right atrial junction or into the right atrium to ensure there is optimal blood flow. If the catheter is placed in the right atrium, it must be made of a soft compliant material (i.e., silicone).

- Tunneled catheter lengths are measured from cuff to tip.[3]
  - — Right internal jugular/subclavian vein — 19–23 cm length usually adequate
  - — Left internal jugular/subclavian vein — 23–28 cm length usually adequate
- Although the femoral vein is an alternative access to the subclavian vein, iliofemoral vein thrombosis and femoral vein catheter infection can be prohibitively high. Femoral vein lines should not be left in place any longer than necessary.

Landmarks

Internal jugular vein access

- ***Posterolateral approach:*** Entrance just above clavicle and posterolateral to sternocleidomastoid muscle.
- ***Anterior approach:*** Identify two heads of sternocleidomastoid and puncture at apex of two heads with needle pointed at ipsilateral nipple.

Subclavian vein access

- ***Landmark:*** Lateral ⅔ of clavicle, with needle passed below the clavicle and pointed toward sternal notch. The more lateral the puncture, the higher the risk of arterial puncture.

Femoral vein access

- Vein is medial to artery and about two fingerbreadths lateral and inferior to the edge of the symphysis pubis bone—ultrasound access preferred to landmark technique but can be performed via landmarks alone in a true emergency.[3]
- If possible, place tip of catheter in inferior vena cava to improve catheter patency rates and functionality.

Complications

- ***Pneumo/hemothorax (< 2%):*** **Chest X-ray for assessment in all patients post-procedure from IJ or SC access.**
- ***Arrhythmias:*** Typically related to guidewire in the right ventricle. If persists, post-operative catheter may be extending too far into heart.
- ***Bleeding:*** Can be from arterial puncture.
- Catheter thrombosis (unable to draw or flush line).

- ***Catheter-induced deep venous thrombosis:*** Pain and swelling of access site.
- ***Central venous stenosis:*** Indwelling catheters can induce scarring of central veins.
- Local and systemic infection.
- ***Air embolism:*** Sudden onset hypotension, chest pain, confusion, dyspnea, cardiac arrest.
  - Place patient in Trendelenburg, right side up, and aspirate via the central line to evacuate air from right heart.
- ***Arterial cannulation:***
  - Standard of care for lines placed under non-emergent conditions is to confirm position in vein via ultrasound, manometry, or pressure-waveform analysis measurement.
  - Isolated needle puncture can be removed and pressure held prior to repeat attempt.
  - Treatment for carotid artery cannulation (0.1–0.5% incidence):
    - For 7 Fr sheath diameter, treatment requires open surgical removal. Endovascular techniques may be employed in high-risk settings.
  - For subclavian artery cannulation (rare):
    - Endovascular management by brachial or femoral access.
    - Options include balloon tamponade arterial puncture site after sheath removal, closure devices, or deployment of a covered stent.

“I attribute my success to this —
I never gave or took an excuse.”

— Florence Nightingale

CAROTID ARTERY OCCLUSIVE DISEASE

Leigh Ann O'Banion, M.D.

Key Facts

- According to the CDC, stroke is a leading cause of death in the U.S. and is a major cause of serious disability for adults.
- Stroke is the third leading cause of death in the U.S.
- Carotid revascularization is considered superior to medically treated patients for stenosis exceeding 50% with symptoms and > 70% without symptoms.[1]
- Up to one-half of patients report having TIA symptoms prior to stroke, with the remaining having stroke as the initial symptom.
- ***Asymptomatic:*** Incidental finding or after imaging for carotid bruit (most common reason for detecting carotid stenosis).
- ***Symptomatic:*** Within six months post-neurologic event.[2] Then reclassified as asymptomatic.
  - — TIA: Transient ischemic attack (complete resolution within 24 hours).
  - — Stroke: Cerebral infarction may have permanent deficits or complete resolution of symptoms with only imaging evidence of infarction of brain tissue.
  - — Remember FAST: Facial drooping, Arm weakness, Speech difficulty, Time to Call 9-1-1.
  - — ***Amaurosis fugax:*** Transient monocular blindness: described as "shade pulling down over eye."
  - — ***Hemispheric:*** Classic distribution of symptoms; contralateral arm and/or leg symptoms (motor or sensory deficit). Left hemispheric symptoms classically can have aphasia or dysphagia in addition to extremity symptoms.
  - — ***Non-hemispheric:*** Non-lateralizing symptoms or posterior circulation symptoms (vertigo, dizziness). Other symptoms include: Numbness or weakness of face, arm or leg, confusion, trouble seeing, trouble walking, or severe headache.

Physical Examination

Palpation of carotid artery to appreciate pulsation and auscultate for bruit. Bruit rule — one-third transmitted bruit (e.g., heart), one-third mild carotid stenosis, and one-third significant carotid stenosis.

Diastolic component of bruit typically found with severe stenosis > 70–80%.[3] Bruits have poor sensitivity and specificity for carotid stenosis.

Diagnosis/Imaging

Ultrasound: Initial assessment in most institutions that use Intersocietal Accreditation Commission-accredited laboratories. Registered vascular technologist skill dependent.

Duplex criteria: Refer to non-invasive imaging.

Recommended Modification of the SRU Consensus Conference Criteria for Internal Carotid Artery Stenosis for Implementation in IAC-Accredited Vascular Laboratories[4]

	Primary parameters		Additional parameters	
Degree of stenosis (%)	**ICA PSV, cm/sec**	**Plaque estimate (%)**	**ICA/CCA PSV Ratio**	**ICA EDV, cm/sec**
Normal	< 180	None	< 2.0	< 40
< 50	< 180	< 50	< 2.0	< 40
50–69%	180–230	> 50	2.0–4.0	40–100
> 70 but less than near occlusion	> 230	> 50	> 4.0	> 100
Total occlusion	High, low, or undetectable	Visible	Variable	Variable
	Undetectable	Visible, no detectable lumen	Not applicable	Not applicable

*Plaque estimate (diameter reduction) with grayscale and color Doppler U.S.
*Also 50–69% if plaque estimate over 50% and PSV over 125 cm/sec and ration > 2.0.

For surveillance of carotid artery stenosis ≥ 50% to < 80% stenosis should undergo duplex imaging every 12 months.

MRA: Meta-analysis of contrast-enhanced MRA has a higher sensitivity and specificity than duplex ultrasound—limitations in renal insufficiency patients, costly, also may overestimate degree of stenosis.

CT Angiography: Very accurate, eliminates risk of conventional angiography, can be lowered accuracy in calcified arteries, limitations in renal insufficiency.

Angiography: Low risk of neurologic event with diagnostic arteriography.[5]

Technique for Diagnostic Carotid and Cerebral Angiography

Femoral access:

- Insertion of 5 Fr sheath, then pigtail catheter placed just above the aortic valve.

Typical injection rates for the aortic arch are:

- 15 cc/sec for 30 cc (total volume) or 20 cc/sec for 40 cc. The intensifier should be positioned in LAO projection to profile the aortic arch. Document arch type: 1, 2, and 3. Then perform selective angiography with catheter selection based on arch type. RAO projection used to profile the right common carotid artery best. Passive and intermediate catheters can usually be used to successfully cannulate vessels in a Type 1 and Type 2 arch.

Type 3 arch often requires the use of Simmons Catheter:

- The Simmons Catheter is an aggressive catheter and may increase the risk of atheroembolic complications. The catheter is categorized as an active catheter, and it must be "'formed". This is best accomplished by inserting it into the subclavian artery over the wire until the secondary curve is approaching the subclavian origin. The wire is then withdrawn to the secondary curve and the catheter is advanced and rotated allowing it to form.

Selective injections can be performed with hand injection or with power injection:

- Typically anterior-posterior lateral, and ipsilateral oblique to best profile stenosis or spin.

- NASCET (North American Symptomatic Carotid Endarterectomy Trial) method is used to determine degree of stenosis.
- Measure stenosis diameter of internal carotid artery and subtract this distance by the normal distal internal carotid artery diameter and then divide by normal distal ICA diameter.
  — Residual luminal diameter of stenotic lesion (mm) divided by the normal luminal ICA diameter distal to the lesion.

Intervention Recommended

- > 50% symptomatic
- > 70% asymptomatic[1]
- Surgery has been a first-line treatment, but a shared decision-making strategy for either transcarotid or transfemoral options.

Surgery for Carotid Artery Occlusive Disease

Technique

Carotid endarterectomy (CEA):

- ***Skin incision:*** Transverse along skin lines or oblique incision along anterior border of the sternocleidomastoid muscle (SCM). Carotid bifurcation generally at thyroid cartilage. Ultrasound in the operating room helps identify and mark bifurcation.

Dissection:

- Retract sternocleidomastoid muscle laterally to prevent dissection into central neck.
- Vagus nerve is located between jugular vein and carotid artery.
- Facial vein typically crosses over carotid bifurcation.
- Hypoglossal nerve perpendicular to the carotid 1–2 cm above carotid bifurcation.
- Right angle test: Palpate artery over right angle to make sure there is no plaque at location of distal clamp.
- Endarterectomy between inner and outer media, start proximal then move distally.
- Tack any loose intima with U stitches.

Management of arteriotomy:

- Patch angioplasty.

— Prospective randomized trials have shown decreased perioperative strokes, carotid thrombosis, and recurrent stenosis with patching when compared to primary closure. Selected patients may be considered for primary closure.

- Multiple prospective randomized trials comparing patch types (bovine pericardial, DACRON® Material) demonstrated no significant differences in perioperative stroke/death.
- Re-establish flow to the external carotid, common carotid, internal carotid (in that sequence).

Techniques to identify which patients need intra-arterial shunt:
Shunting requires more exposure distally and has some risk of dissection when inserting; overall < 10% of patients need shunting and < 50% of those with contralateral occlusion. Methods to determine selective shunting include:

1. ***Awake:*** If neurologic symptoms develop on clamping — shunt.
2. ***EEG:*** Presence of delta waves on clamping — shunt.
3. ***Stump pressure:*** Variable thresholds reported. Generally, systolic > 40 mmHg should consider shunting.
4. ***TCD and cerebral oximetry:*** Cerebral oximetry drop by 20% should consider shunting.

Intraoperative imaging:
Not universally performed, some data suggest duplex to detect intraoperative defects, gold standard has been angiography.

Postoperative Complications

1. ***Most common is hypertension/hypotension:*** Medical management. Hypertension increases hematoma frequency and risk of cerebral hyperperfusion syndrome.
2. ***Expanding hematoma:*** 1.2–12% incidence[6] requires emergent re-exploration, symptoms may include dysphagia, difficulty breathing, and stridor.
3. ***Neurologic deficit:*** In operating room reexplore to rule out carotid thrombosis. Recovery room, consider stat CT or duplex, and if abnormal the patient should be explored urgently. CT can be performed as operating room is set up for reexploration in some settings to rule out bleed, or nonoperative causes of neurological changes.

4. Cranial nerve injury occurs in < 3% with most resolving within six months.[7]
   - Dysphagia (vagal nerve), paresthesia in the marginal mandibular branch of the facial nerve distribution, hoarseness (recurrent laryngeal nerve).
5. Myocardial infarction (MI) < 1% of patients.[8]
6. Death (< 1%).
7. Combined stroke/MI/death should be less than 3% in asymptomatic patients and < 5% in symptomatic patients.

Carotid Artery Angiography and Stenting

- ***Carotid angiography:*** This is usually done with a 5 Fr system. When possible, aortic arch flush angiography should be performed first to assess the type of aortic arch (Type 1, 2, and 3) and amount of atherosclerosis present (i.e., "hostile arch"). When possible, a passive catheter should be used and typically angiograms can be performed with an angle TERUMO® GLIDECATH® Catheter and TERUMO® GLIDEWIRE® Catheter alone for cannulation. Never let the tip of the wire extend out of the field of view, and when attempting to advance the catheter into the carotid artery, all attempts should be made to keep the wire in the common carotid artery. Even when performing cerebral angiography and the preferred placement of the catheter is in the internal carotid artery, the wire is not advanced until adequate imaging of the internal carotid artery is performed to rule out disease. Only use active catheters (i.e., Simmons Catheter) when absolutely necessary.
- ***Carotid stenting:*** Although a carotid stent may at times not be as hard technically as a renal or mesenteric stent, the complications are highly debilitating (i.e., stroke) for the patient. As already stressed above, always know the arch dynamics before attempting a carotid artery stenting procedure. Both an anchoring technique and telescoping technique can be used. The anchoring technique involves advancing a support wire into the external carotid artery and then advancing a guiding sheath into the common carotid artery. The telescoping technique is usually reserved for lesions that involve the common carotid artery (preventing safe passage of the wire into the external carotid artery) or if the external carotid artery is occluded. After the sheath is placed, then the lesion is carefully crossed (road mapping can be useful) and an embolic protection

device (EPD) can be deployed in the distal internal carotid artery (when using a flow preservation EPD). Proximal protection devices can also be used, and the lesion is not crossed until protection is in place. At this point the operator can proceed.

Considerations for Stenting vs. CEA

Anatomic:

- Stenosis at C2 or higher.
- Contralateral recurrent laryngeal nerve injury, previous neck irradiation.
- Recurrent carotid artery stenosis.
- If patient has common carotid disease or a tracheostomy, consider TRANSFEMORAL carotid stenting instead.

Physiologic:

- CHF coronary disease without revascularization options
- MI within six weeks (do not need to stop dual antiplatelet therapy [DAPT] for TCAR)
- Severe COPD
- > 75 years

Technical Issues with TCAR

- Must be on antiplatelet regimen, i.e., DAPT (Clopidogrel + Aspirin) prior to procedure.
- Symptomatic patients are at highest risk for neurologic events. SVS recommends CEA over stenting within 14 days after neurologic event.
- For TCAR, must have 5 cm between clavicle and bifurcation, CCA diameter at least 6 mm, and distal ICA diameter at least 4 mm. Severe tortuosity may be prohibitive. May not be appropriate in patients with severe calcification.
- Glycopyrrolate administered at procedure start to decrease risk of bradycardia with manipulation of the bulb.

- Small transverse incision in base of neck between sternal and clavicular heads of SCM for direct access to common carotid artery. Contralateral femoral vein access for flow-reversal device.
- Lesion is crossed with wire AFTER initiation of flow reversal (common carotid must be clamped) to prevent embolism. Pre-dilation with balloon, then self-expanding stent deployed. Post-dilation performed selectively based on degree of residual stenosis. Wait 2–3 minutes after stenting before completion angiogram to clear debris using flow reversal.
- In transfemoral stenting, a distal embolic protection device is advanced past the lesion prior to ballooning/stenting.

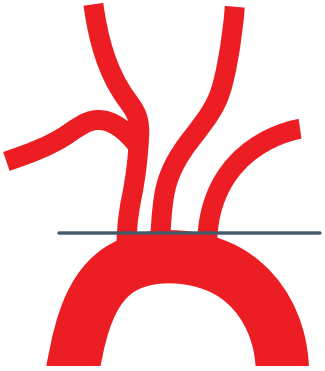
Controversial Areas

Coronary artery bypass grafting (CABG) and carotid endarterectomy (CEA): If both symptomatic, then simultaneous procedures.

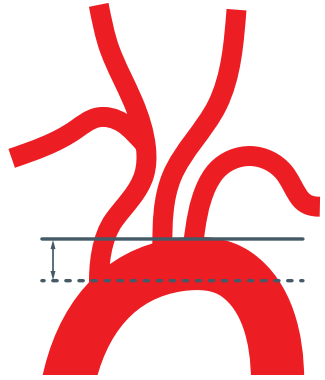
If CABG indicated, recommend either staged or concurrent procedure if: Asymptomatic bilateral severe carotid stenosis, asymptomatic unilateral severe with contralateral occlusion, or symptomatic > 50% carotid stenosis present. Choice of CEA vs. stenting depends on urgency of CABG as stenting requires at least 30 days of DAPT.

Protamine and CEA: Recommendation to administer protamine to reduce risk of hematoma. No evidence of increased thrombosis or stroke.

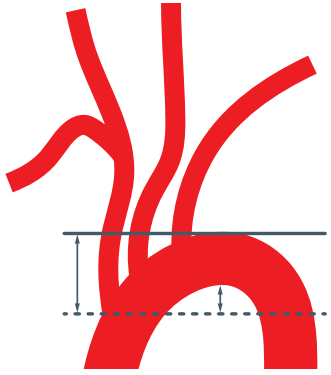
Aortic Arch Types



Type I
All arise within the arc
of the aortic arch



Type II
1–2 cm distance from
top of the aortic arch



Type III
> 2 cm distance from
top of the aortic arch

“I find I’m luckier when I work harder.”

— Denton Cooley, M.D.

BRACHIOCEPHALIC DISEASE

Leigh Ann O'Banion, M.D.

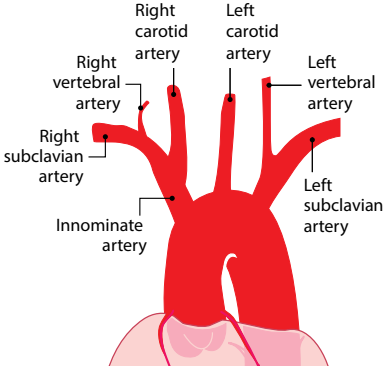
Overview

Brachiocephalic disease

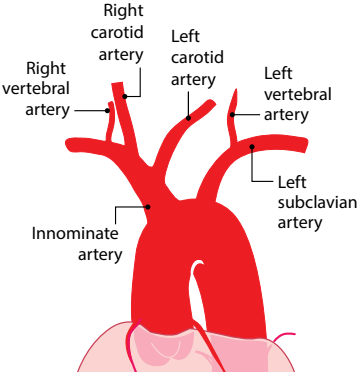
- The origins of the aortic arch great vessels rarely require intervention when compared to extracranial carotid arteries.
- < 20% of patients have more than 30% stenosis of the innominate or subclavian arteries with concomitant severe ICA disease.

Anatomy

- Most commonly, the great vessels (innominate, left common carotid, and left subclavian arteries) arise from the aortic arch separately.
- 5% — "bovine" arch: Common origin of left common carotid/ innominate artery, or left common carotid artery arises from the innominate artery.



Common aortic arch



Bovine aortic arch

Pathology

- ***Atherosclerotic:*** The most frequent indication for intervention (80%).
- ***Non-atherosclerotic:*** Takayasu, dissection, traumatic injury, aneurysmal degeneration, prior radiation.

Presentation

- ***Asymptomatic:***
  - — Asymmetric blood pressure (> 20 mmHg difference)[1] during examination or incidental finding on imaging looking for other pathology.
  - — < 10% require re-vascularization.
- ***Symptomatic:***
  - — Atheroembolic complications: TIA, stroke, limb ischemia, digital ulcerations.
  - — Claudication or vertebrobasilar insufficiency.

Work-Up

History

- TIA, stroke, amaurosis fugax.
- History of sternotomy, coronary artery disease (CAD).
- History of vasculitis (Takayasu or Giant cell arteritis).

Review of systems

- ***Vertebrobasilar insufficiency:*** Vertigo, ataxia, binocular visual symptoms, and drop attacks.
- ***Vertebral-subclavian steal:*** Vertebrobasilar insufficiency symptoms with upper extremity activity.
- ***Coronary-subclavian steal:*** Cardiac symptoms during upper extremity activity in patients with CABG with left internal mammary artery (LIMA) conduit.
- ***Upper extremity ischemia/exertional ischemia:*** Diminished or asymmetric pulses, limb fatigue, and pain with use.

Physical examination

- ***Neurologic exam:*** Neurological deficits, previous stroke.
- ***Complete pulse exam:*** Carotid, brachial, and radial/ulnar.
- ***Hand exam:*** For signs of embolic lesions.
- ***Brachial pressure:*** Difference between the two upper extremities > 20 mmHg is significant.

Imaging

- ***Duplex:***
  - ***Innominate/common carotid artery lesions:*** Dampened common carotid waveform with low velocities < 50 cm/sec.
  - ***Innominate or subclavian lesions:*** Flow reversal in the vertebral arteries, dampened or monophasic waveforms in distal subclavian artery, or increased velocities in the region of suspected stenosis are characteristic.
- ***CTA/MRA:*** Both require contrast, MRI may overestimate lesion, CTA more accurately demonstrates calcified plaque.
- ***Angiography:*** Provides ability to offer intervention simultaneously, < 1% stroke risk, requires arch manipulation.

Indications for Treatment

- No prospective randomized trials comparing medical, endovascular, and surgical treatment modalities.
- ***Asymptomatic:*** No clear guidelines for intervention. Consider intervention for high grade left subclavian artery stenosis if coronary artery bypass is planned to allow for use of the LIMA.
- ***Symptomatic:*** ≥ 50% stenosis.

Treatment

- ***Endovascular:***
  - ***PTA and stenting:*** > 70% 5-year patency.
- ***Open:***
  - ***Direct reconstruction:*** i.e., innominate endarterectomy, aorta-carotid bypass: > 80% 10-year patency.
  - ***Indirect reconstruction:*** Carotid-carotid, carotid subclavian bypass: > 80% 5-year patency.

Endovascular Tips

- Usually preferred for older patients with higher operative risk, however and also emerging as first line intervention by many due to decreased morbidity and near equivocal patency.
- Femoral or retrograde brachial/radial for subclavian interventions.
- ***Proximal common carotid artery:*** Use embolic protection when using femoral approach. Consider retrograde intervention with either flow reversal or cutdown to flush artery after intervention. Also can consider flow reversal for embolic protection.
- Intervention in patients with asymptomatic subclavian steal diagnosed by duplex is discouraged.[2]
- Endovascular interventions discouraged if subclavian disease extends to vertebral artery.
- Intravascular lithotripsy may improve endovascular outcomes in heavily calcified lesions.

Open Pearls

- ***Clamping of the brachiocephalic arteries generally does not require shunting.***
  - — Direct transthoracic approach via a median sternotomy or cervical approach:
    - Consider pre-op cardiac catheterization if median sternotomy planned for combined coronary reconstruction.
- Bypass options include subclavian-carotid (preferably ipsilateral) or carotid-carotid bypass.
  - — Transposition of carotid to subclavian or vice versa have the advantage of one anastomosis and no prosthetic material.
- Must identify phrenic nerve for subclavian reconstructions (running from lateral to medial over anterior scalene muscle).
- Transpositions are typically more technically demanding.
- For thromboembolic lesions, ligate arteries proximally to eliminate embolic sources.
- Carotid-carotid: Retropharyngeal — shorter distance vs. subcutaneous Q tunnel.

- If previous LIMA revascularization — carotid subclavian bypass preferred to transposition to reduce coronary ischemia.
- Improved patency of carotid subclavian (C-S) bypass compared to axillary-axillary (ax-ax) bypass.

Postoperative Considerations

- ***Endovascular:*** Access complications, neurologic events, limb ischemia, hematoma.
- ***Open:*** Neurologic events, stroke, cranial nerve injury, hematomas, cardiopulmonary (MI, resp distress), thoracic duct injury (ligate if leak identified), phrenic nerve injury — raised hemidiaphragm on CXR.

“But when it has been shown by the researches of Pasteur that the septic property of the atmosphere depended not on the oxygen, or any gaseous constituent, but on minute organisms suspended in it, which owed their energy to their vitality, it occurred to me that decomposition in the injured part might be avoided without excluding the air, by applying as a dressing some material capable of destroying the life of the floating particles. Upon this principle I have based a practice.”

– Joseph Lister

VASCULAR SURGICAL SITE INFECTION

Leigh Ann O'Banion, M.D.
Clara Gomez-Sanchez, M.D.

Background

Incidence depends on surgical site: < 1% with neck incisions, < 3% of aortic surgery, up to 10% of groin incisions. Host is most common source of contamination.

Prevention: Optimal OR conditions:

- Warm patient, pre-operative antibiotics within 30 min of incision, clipping, supplemental oxygen, blood sugar control, perfect wound closure.
- Consider incisional negative pressure wound therapy device (e.g., 3M PREVENA Incision Management System, SMITH+NEPHEW PICO Wound Therapy System) for groin incisions in high-risk patients.

Risk factors: Reoperative surgery, ongoing infection in affected limb, groin incision, pre-procedural hospital stay, emergency surgery

Classification

Temporal relationship:

- Early < 4 months
- Late > 4 months

Location:

- Intracavitary: Abdomen/chest
- Extra cavitary (i.e., groin)

Classification of Early Vascular Site Infection

Szilagyi:

1. Cellulitis only
2. Subcutaneous tissue infection
3. Infection involving the graft

Bacteriology

- Most common infection isolated is gram positive organism — up to 50% of cases.
- Most common bacteria isolated in early infections — **MRSA**.
- Most common bacteria isolated from late infections — #1 ***Staph epidermidis***, #2 **MRSA**.
  — Classic late presentation of groin infection is draining sinus.
- 10–15% gram negative organisms.
- Classic microbe associated with anastomotic disruption — **pseudomonas**.

Presentation

- ***Wound infection:*** Erythema and drainage from surgical site. Groin incision highest risk.
- ***Bleeding:*** Must suspect infection if recent surgery.
- ***GI bleeding:*** If previous aortic reconstruction must consider aorto-enteric fistula.
- ***Aneurysm formation:*** Pseudoaneurysm = infection unless otherwise proven.
- ***Bacteremia:*** More typical of intracavitary infections — fever, leukocytosis, malaise, weight loss.
- ***Septic emboli:*** Roth spots in extremity with bypass.

Evaluation

- ***Blood cultures:*** Bacteremia requires total graft explant. Patient is not a candidate for graft preservation.
- ***Ultrasound:*** Fluid around graft with clinical signs and symptoms of infection.
  - — Also image to identify alternative conduit, i.e., lower extremity or upper extremity vein.
  - — Baseline ABI and determination of patency of conduit.
- ***CT:*** Most sensitive/reliable.
  - — Perigraft fluid, often with stranding signifying inflammation.
  - — Perigraft air (should be resolved normally by three months), focal bowel thickening, hydronephrosis.
- ***PET Scan:*** Increasing utilization to evaluate for infected grafts.

Treatment

Graft removal with in-line replacement using autologous tissue is gold standard treatment. However, explanting the graft with extra anatomic reconstruction is acceptable as first line treatment if patient's comorbidities preclude in-line reconstruction.

- ***IV antibiotics:*** Culture specific is given for six weeks.
- ***Lifetime antibiotics:*** In patients with unacceptable risks of explantation for suppressive therapy in select cases. If GNRs present, this is highly unlikely to succeed.

Other scenarios/options:

- ***Infection limited to groin:*** If gram positive and early infection, consider local treatment with I and D, antibiotic beads, and possible muscle flap.
  - — If gram negative infection, or entire graft is infected, then autologous replacement or extra-anatomic reconstruction (i.e., obturator bypass).
- ***Infected limb of ABF:*** Retroperitoneal incision with intraoperative culture, if negative then can remove limb only, if infected at midlimb then requires total graft explant. PET scan utilization has limited the frequency of this approach.

- ***Aortic infection:*** Graft removal and axillobifemoral bypass (if stable, revascularization first then graft removal in 24–48 hours), or in-situ cryo-preserved aorta, or deep venous replacement (NAIS procedure). Mortality as high as 50%. If aortic stump is left in place, strongly recommended to use omental flap over it to reduce risk of stump blow out.
- ***Carotid patch infection:*** Incidence < 1%. Treatment should be to remove patch and perform vein patch angioplasty, or may require interposition vein graft if large section of artery debrided.

Antibiotic bead algorithm

1. Operative exploration of groin infection.
   - — Culture tissue/fluid adjacent to conduit.
   - — Pulsatile irrigation and debridement of nonviable tissues.
   - — Based on culture results, PMMA bead placement, i.e., if gram + (vancomycin), gram — (gentamycin).
   - — Place wound vac but avoid placing directly on vascular graft.
2. Return to operating room in 3–5 days for second debridement and washout.
   - — Initial culture taken then irrigation and local debridement.
   - — If stat gram stain is negative, consider definitive treatment, i.e., graft preservation with muscle flap depending on soft tissue defect.
   - — If culture is positive replace with culture specific antibiotic beads and plan third procedure.
3. If vascular surgical site cannot be sterilized on third exploration, then partial graft removal is required with either extra anatomic reconstruction or in-situ autologous procedure.

RENAL ARTERY OCCLUSIVE DISEASE

William Johnson, M.D.
Chong Li, M.D.
Molly Ratner, M.D.

Take-Away Points

- Renal artery stenosis (RAS) is an important cause of secondary hypertension and deterioration of renal function (ischemic nephropathy).
- In addition to atherosclerotic disease, there are several etiologies contributing to ischemic nephropathy including: Embolic disease, fibromuscular dysplasia, graft thrombosis, renal artery dissection, and intimal hyperplasia of transplanted kidneys.
- Treatment of renal artery stenosis remains controversial as some centers report significant improvement in renal function post-intervention in select patients; while other studies such as the CORAL trial suggest no significant benefit with surgical intervention.[1]

Etiologies

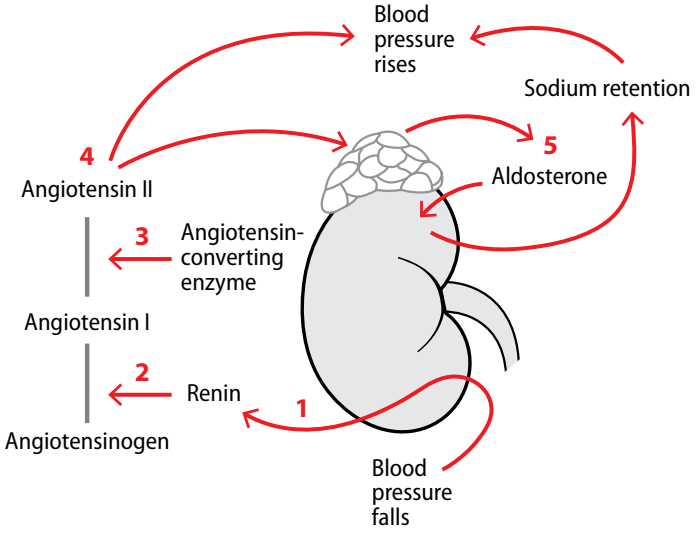
1. Atherosclerosis
   - — Usually involves ostium or proximal segment. Can be intrinsic to the renal artery or extension of aortic atherosclerotic disease. RAS > 60% typically considered hemodynamically significant.
   - — Progressive with renal dysfunction presenting in later decades of life (> 50 years).
   - — Can cause renovascular-mediated hypertension and ischemic nephropathy.

2. Fibromuscular dysplasia (FMD)
   — Usually involves the mid or distal portion of the artery.
   — Generally presents in the early decades of life (late teens to early 30s).
   — Typically not associated with ischemic nephropathy.
3. Transplant renal artery stenosis[2]
   — Most common renal transplant vascular complication.[3]
     • At least 75% of all post-transplant vascular complications.[3]
     • Affects up to 23% of recipients.[3]
   — Can present with ischemic nephropathy and graft dysfunction.
4. ***Other etiologies:*** Takayasu's, mid-aortic syndrome, renal artery dissection, radiation fibrosis, branch graft obstruction from aortic endografts.[4]

Pathophysiology

Renal occlusion or stenosis creates ischemia which then triggers increased production of renin. Renin stimulates the conversion of angiotensin I to angiotensin II, which promotes aldosterone release. Aldosterone increases sodium and water retention.

Illustration of the Renin-Angiotensin-Aldosterone System[5]



Imaging

1. ***Renal artery duplex:*** Used as first line screening and post-intervention surveillance.

Classification	Renal aortic ratio (RAR)	Peak systolic velocity (PSV)	Post-stenotic turbulence (PS)
< 60% stenosis	< 3.5	< 180 cm/s	Absent
< 60% stenosis	> 3.5	> 180 cm/s	Present
Occlusion	NA	NA Absence of flow Low amplitude parenchymal signal	NA

   — Renal resistive index = [(PSV-EDV)/PSV]
      - Normal is 0.6–0.8.
      - Renal resistive index of > 0.8 is suggestive of intrinsic parenchymal disease.
   — Normal kidney length should be > 10 cm, if < 7 cm in adults, they are atrophic and typically deemed unsalvageable.
2. ***CTA (sensitivity and specificity > 90%):*** 3D reconstruction can be used to plan and augment surgical intervention. Patients with renal artery stenosis may have CKD and contrast administration carries a risk of contrast-induced nephropathy.
3. ***MRA:*** Can be useful in patients with abnormal renal function (sensitivity and specificity ≥ 90%).
   — Newer gadolinium formulas deemed safe in patients with kidney disease.
   — MRA in patients with existing renal stents should be protocoled appropriately to mitigate signal loss.
4. ***Renal angiogram:*** Considered the "gold standard" for diagnosis but carries with it the risk of the invasive procedure. With modern imaging (CTA/MRA) rarely used for diagnosis except in patients with marked renal dysfunction (CO_2 angiography). For those patients, consider a CO_2 angiogram.

Epidemiology

- Renovascular hypertension is the most common cause of secondary hypertension.[6]
  - — Predominately secondary to atherosclerotic disease.
  - — FMD accounts for ~10% of these cases.[7]
- Patients with end-stage renal disease are at particular risk (prevalence of up to 40%).

Indications for Intervention

Consider revascularization in the following:

- ***Class I indications in presence of 70% RAS by IVUS or angio:***
  - — HTN before age 30 or severe HTN.
  - — Resistant accelerated and malignant HTN.
  - — New azotemia and worsening renal function after ACEIs/ARBs.
  - — Pulmonary edema unexplained.
  - — Atrophy and > 1.5 cm difference in kidney.
- ***Patients with hemodynamically significant ARAS and:***
  - — Flash pulmonary edema, recurrent CHF or refractory acute coronary syndrome.
  - — Medication intolerance or resistance.
  - — Progressively worsening Chronic Kidney Disease (CKD)/kidney function in setting of bilateral renal artery stenosis (RAS) or unilateral RAS to a solitary functioning kidney.
- ***Anatomic criteria:***
  - — Hemodynamically significant stenosis and resistant hypertension in patients with > 75% of overall renal mass.
    - Current guidelines for fibromuscular dysplasia (FMD)
  - — Resistant hypertension despite aggressive medical management (i.e., three-drug regimen).
  - — Short duration hypertension with anticipation of renal recovery.
  - — Preservation of kidney function in patients with severe stenosis.
  - — Renal artery aneurysm or dissection.

Revascularization Options

Renal Artery Stenting (RAS)

The main treatment modality for RAS is stenting:

- ***Risks:*** Access complications, atheroembolism, contrast induced nephropathy, and stent thrombosis.

- ***General principles:***
  - Typically use balloon-expandable stents (greater radial force) for complete coverage of the lesion with 1–2 mm of stent extending into the aorta.
  - It is important to size the stent to the "normal segment" of the renal artery and not to the post-stenotic dilatation.
  - A brachial approach can be used if the renal artery is highly tortuous or has a severe inferior angulation.
    - This can be performed with a 6 Fr system and multipurpose guide.
- Alternatively, a steerable sheath can be used from a femoral approach.
  - Two main techniques: "no touch technique"and telescoping:
    - Used to avoid atheroembolism caused by "snow plowing" the plaque with cannulation of the catheter during attempted access of the renal artery.
    - If clinically significant atheroembolism takes place, then renal function declines over a period of 3–8 weeks.

1. ***Telescoping technique:*** This technique can be used to treat de novo renal artery stenosis but it is especially useful for renal artery in-stent stenosis since it will prevent the wire from advancing through stent struts that are projecting into the aorta.
   - Typically performed with a 6 or 7 Fr system.
   - A diagnostic catheter is advanced through the proceduralists' sheath of choice and secured with a tuohy borst.
   - The renal artery is selected and the .014" wire is advanced into the renal artery.
   - The sheath is then advanced over the catheter to the ostium of the renal artery.
   - The catheter is then walked off the wire while leaving the sheath in place.
   - Proceed with PTA/stenting of the renal artery.
2. No-touch technique:
   - Usually performed with a 6 or 7 Fr system and the guide catheter of choice.
   - The guide catheter is advanced over a moderate support wire that has a good transition in the distal segment.
   - A .014" wire with both a short transition at the tip and high degree of support is advanced to the proximal segment of the catheter.

- The .035″ wire is withdrawn to let the guide catheter take shape leaving at least 3 cm of wire projecting from the guide to keep it from scraping the wall of the aorta.
- The .014″ wire is advanced into the renal artery and the .035″ wire is removed.
- By positioning the sheath close to the renal artery ostium, PTA/stenting can be performed.
- Be careful when advancing a balloon-mounted stent using this method, as the stent can be dislodged.

- For transplanted renal artery intervention, a modification of the no-touch technique is frequently used.
  - Can perform through a 5 Fr system.
  - Ipsilateral common femoral or superficial femoral artery is accessed, and a shorter sheath is used as the transplanted renal artery typically originates from the external or common iliac artery.
  - CO_2 should be predominantly used to limit contrast use and subsequent renal dysfunction.
  - A .014″ wire aided by a guide catheter is advanced through the ostium and balloon angioplasty followed by stent placement is used for treatment.
- Post-operative treatment: most patients are placed on clopidogrel for at least four weeks depending on the provider and institution preferences.

Renal Artery Bypass

Previously was the treatment of choice for many years, but it is now usually reserved for patients who have failed endovascular therapy or young patients with congenital etiologies (e.g., mid-aortic syndrome) secondary to the morbidity and mortality of the procedure.

- Perioperative mortality of ~ 10% (Medicare database), though much lower in high volume centers (< 5%).[8]
- Excellent long-term patency, up to > 90% at eight years.
- ***Technique:***
  - ***Conduits:*** Great saphenous vein, internal jugular vein, or synthetic graft (autologous tissue preferred).
- ***Pediatric population:*** hypogastric artery.[9]
- Bypass can originate from aorta, hepatic, splenic, common, or external iliac artery.

Aortic/Renal Endarterectomy

- Can be considered in patients with advanced aortic stenosis with plaque involving the renal ostium.
- Isolated renal artery endarterectomy rarely performed given advancement of endovascular techniques.

Renal Artery Stent Outcomes

There have been three main randomized trials, but there have been major criticisms of all three, particularly around the lack of inclusion of or inability to select for severe cases which would derive the greatest benefit from stenting.[10] However, a trial with only severe renal artery stenosis is unlikely to be performed as there is no clinical equipoise. Currently, the only class I recommendation for renal revascularization is in the setting of recurrent pulmonary edema.

1. **STAR trial** — 140 patients randomized to medical therapy with or without stenting. Primary endpoint of 20% or greater decrease in creatinine clearance.
   - — No difference found in the treatment groups.
   - — Flaws in study:
     - 50% stenosis was used as inclusion criteria.
     - More than half the patients had unilateral RAS.
   - — Randomization based on intention-to-treat model with severity of stenosis based on MRA, CTA, and angiography.
   - — Twelve of 64 patients in the stent group had < 50% stenosis and did not receive a stent.
   - — High complication rates (4% mortality from renal perforation, 17% hematoma rate, renal artery injury in 10% of patients).
2. **ASTRAL trial** — 806 patients randomized to medical therapy with or without stenting.
   - — Inclusion criteria:
     - Physicians had to be uncertain which treatment was appropriate—stenting with medical therapy or stenting alone.
     - > 50% stenosis of the renal artery.
   - — Demonstrated no difference in outcomes in the two groups in blood pressure response or renal function.
   - — Bottom line — If the operator is not sure if a patient should have a renal intervention, then the patient should be treated with medical therapy. Patients with questionable indications don't benefit from renal artery stenting.

3. **CORAL trial** — 931 patients assigned to renal stenting with optimal medical therapy (n = 459) or to optimal medical therapy alone (n = 472).
   - — ***Inclusion criteria:*** Renal artery stenosis (> 80% angiographic stenosis or 60–80% stenosis with 20 mmHg pressure gradient) and systolic hypertension (SBP > 155 despite 2 BP lowering medications) or CKD stage 3 or worse.
   - — Bottom line — Renal artery stenting did not confer a significant benefit with respect to the prevention of adverse cardiovascular or renal events in patients with atherosclerotic RAS and hypertension or chronic kidney disease.
   - — Likely mirrored clinical practice in that the degree of RAS was somewhat modest, and the frequency of bilateral RAS was low. The average blood pressure at baseline was 150 mmHg, at which revascularization unlikely to provide benefit.
     - Despite the aforementioned non-superior result of intervention, endovascular treatment for FMD and transplant RAS have been shown to be beneficial.
   - — For FMD, meta-analysis has shown that angioplasty or surgical revascularization yielded moderate benefits, with substantial variation across studies. Angioplasty has lower peri-procedural complications.[11]
   - — Many single center studies have shown that endovascular intervention improves graft preservation and renal function and hemodynamic parameters in transplant RAS.[12]

“Survival following amputation for PAD, correlates with stage IV cancer diagnosis.”

— Patrick Stone M.D., FACS

AMPUTATIONS

William Johnson, M.D.
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Molly Ratner, M.D.

Over 300,000 amputations are performed annually in United States. This causes significant mental and financial costs to patients, families, and the healthcare system. Most non-traumatic amputations are secondary peripheral arterial disease and diabetes mellitus.

Risk Factors for Amputations[1]

- Diabetes mellitus — 10x compared to general population.[1]
- Peripheral vascular disease.
  — Over half of amputations in the U.S. are attributed to PAD with diabetes.[2]
- Acute limb ischemia (embolus, malperfusion).
- Soft tissue infection or osteomyelitis.
- Unresectable extremity tumors.
- Trauma, frostbite.
- Paralysis, stroke, and functional disabilities in patients who develop wounds.

Pre-operative Considerations

Healing potential: Overall perfusion, presence of infection, nutritional status, immune status, extent of wound/ischemia, as well as other conditions contributing to skin healing (i.e., lymphedema and chronic venous changes).

Functional status: Patients non-ambulatory prior to amputation are at risk for contracture and wound breakdown. Consider more proximal lower extremity amputation (i.e., AKA).

Risk of anesthesia: Consider regional anesthesia in high-risk patients.

Level of Amputation

Clinical exam: Pulse exam accurately predicts healing in 80% and 90% of BKAs and AKAs.[3]

- Patients will generally heal below a palpable pulse (i.e., > 90% of patients with a palpable popliteal pulse will heal BKA). Ultimately, profunda inflow is needed to heal a BKA.
- Non-ambulatory patients and those with pre-existing knee contractures are at high risk for poor healing and wounds secondary to pressure necrosis. In these patients above the knee amputation is recommended.
- Infection and marked edema are risk factors for poor healing. Consider guillotine amputation (above infected tissue) with delayed definitive closure.

Objective testing:

- Low sensitivity studies so generally only used as an adjunct to exam:
  - Ankle pressures (> 50 mmHg permits healing of most BKAs)
  - Toe pressure (> 50 mmHg will permit healing of most foot or digit amputations)
  - Transcutaneous oxygen ($TpCO_2$ < 20–30 mmHg associated increased risk of non-healing amputation)[4]

Wound, Ischemia and Foot Infection (WIfI) Classification[5]:

- Tool to predict the risk of one-year amputation in patients with chronic limb-threatening ischemia.
- Based on three factors: wound, ischemia, and foot infection (each graded from 0–3).

Wound grade (0–3)	Ischemia grade (0–3)	foot Infection grade (0–3)			
		0	1	2	3
0	0	VL	VL	L	M
1	0	VL	VL	M	M
0	1	VL	L	M	H
1	1	VL	L	M	H
0	2	L	L	M	H
1	2	L	M	H	H
0	3	L	M	M	H
1	3	M	M	H	H
2	0	L	L	M	H
3	0	M	M	H	H
2	1	M	M	H	H
3	1	M	M	H	H
2	2	M	M	H	H
3	2	H	H	H	H
2	3	H	H	H	H
3	3	H	H	H	H

Amputations rates based on clinical stages (systematic review)[6]:

VL Very low = Clinical stage 1 = (0%)

L Low = Clinical stage 2 = (9%)

M Moderate = Clinical stage 3 = (11%)

H High = Clinical stage 4 = (38%)

Technique

Toe/ray amputation

- Circumferential incision at the base of the toe (metatarsophalangeal joint).
- Resection of cartilage and metatarsal head.

Transmetatarsal amputation (posterior flap)

- Long posterior skin flap.
- Transect metatarsals 1 cm proximal to skin edge.
- Fascial and skin closure in layers.

Above-the-knee amputation

- Fish-mouth vs. circumferential incision at femoral diaphysis (consider healing and functional level of the patient).
- Divide muscles and soft tissue.
- Ligate superficial femoral vessels.
- Transect femur at least two fingerbreadths proximal to skin and muscle for adequate soft tissue coverage.

Below-the-knee amputation (posterior flap)

- Anterolateral skin incision two-thirds the circumference of the calf ideally 10–12 cm from tibial tuberosity (at least 5 cm to preserve function of limb).
- Posterior skin incision distal (one-third the circumference of the calf) to anterolateral incision.
- Divide muscles of the anterior and lateral compartments at the level of the proximal incision.
- Ligate anterior tibial vessels.
- Transect tibia 1–2 cm proximal to anterior skin edge and bevel to prevent pressure necrosis.
- Fibula transected 1–2 cm proximal to tibia.
- Ligate posterior tibial and peroneal vessels.
- Sharply transect nerves under tension and allow to retract.
- Divide muscles of the posterior compartment accordingly.
- Fascial closure with absorbable suture and skin closed with staples/suture.

Technical Considerations

- Consider tourniquet in patients with normal blood supply to mitigate blood loss.
  - If substantial bleeding continues, then consider removing tourniquet secondary to non-compressible vessels or venous hypertension.
- Complete vs. partial removal of failed prosthetic bypass at time of amputation (decreases infection risk) with complete removal vs. transection of graft within surgical field.
- Primary closure vs. delayed closure depending on indication and presence of infection and edema.
- Negative pressure therapy (for either primary or delayed closure).
- Amputation variations (foot and BKA) based on extent of wound, infection, pattern of trauma, and blood supply.
- Myodesis, myoplasty, targeted muscle reinnervation, cryoablation, and various techniques to improve function and decrease pain in selected patients.

Post-operative Care

- DVT prophylaxis.
- ***Antibiotics:*** Length of therapy should be 24–48 hours after primary closure unless systemic infection.
- ***Early mobilization:*** Physical therapy, occupational therapy and rehabilitation consult.
- Amputation counseling and support.
- Non-weight bearing activity on operative limb until the incision is healed and evaluated.
- ***Death:*** Increases with more proximal amputation, up to 15% perioperative mortality with AKA. Some report one-year survival for major amputation as low as 50%.
- Can generally start stump shrinker after sutures or staples removed.

Perioperative Complications

- Cardiovascular events (myocardial infarction, arrhythmias, heart failure).
- VTE with most series reporting thromboembolic complications as second leading cause of death.
- Pulmonary complications (pneumonia, congestion, atelectasis).
- Wound infection and nonhealing with subsequent need for revision.
- Non-surgical site infections (PNA, UTI, line infections).
- Renal failure.

Risk of Subsequent Amputation and Functional Outcomes

- 10–20% of patients will subsequently undergo a contralateral amputation.
- Overall function is not significantly increased in toe amputations; however, great toe amputations including the first metatarsal head may have considerable changes in balance.
- Increase energy expenditure following BKA is 30% and AKA is 60%.
- Expected ambulation with a prosthesis is up to 75% with BKA and 40% after AKA.

CHRONIC MESENTERIC ISCHEMIA

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Background

- At rest, the splanchnic arteries receive around 10% of the total cardiac output. In the post-prandial state, this increases to over 25% to aid in digestion.[1,2]
- Splanchnic artery blood flow increases within an hour of eating, mostly related to increased SMA flow.
- Hepatic artery flow remains fairly constant between fed and fasting states.
- Atherosclerosis of the mesenteric arteries is relatively common and often incidentally found.
- Up to 18% of adults > 65 years old have asymptomatic stenosis of the celiac artery or SMA.[3]
- Classically, **two mesenteric arteries** need to have severe disease in order to result in clinical symptoms.
  - In patients with poor collateralization, single-vessel disease can result in symptoms.

Presentation

- ***Classic triad:*** food fear, weight loss, and abdominal discomfort beginning 30–60 minutes after eating and lasting for up to six hours.[2]
- Post-prandial abdominal pain is the most reliable clinical symptom.[2]
- Typical age at presentation is 50–70 years old; female to male ratio 3:1.[2]

- Most have had symptoms for years — It is not uncommon for patients to have undergone extensive testing or surgical intervention for other GI diagnoses (i.e., endoscopy, cholecystectomy).

Examination

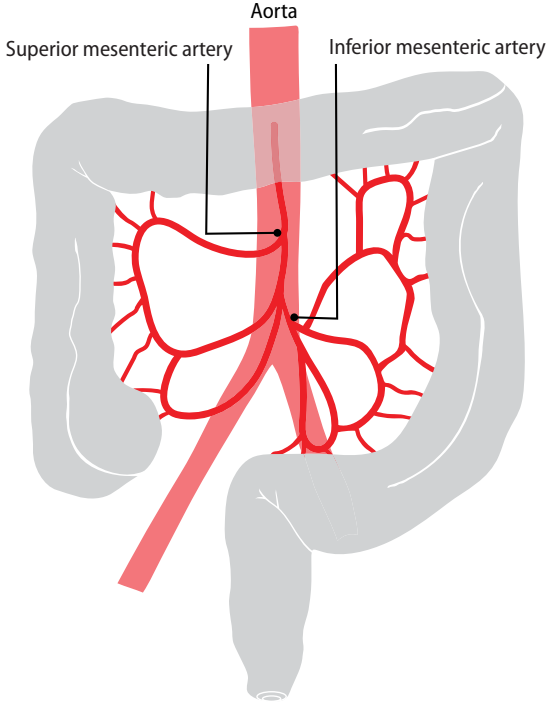
- Findings are usually nonspecific but can have scaphoid abdomen (weight loss present in ~ 80% of patients) and epigastric bruit (~ 50% of patients).[4]
- Often non-tender and non-distended unless acute mesenteric ischemia.

Diagnosis[3]

- ***Mesenteric Duplex Ultrasound:*** Preferred first line testing.[2,3]
- ***Advantages:*** Dynamic assessment of flow, high sensitivity, and negative predictive value (particularly for SMA).
- ***Limitations:*** Operator dependent, body habitus, overlying bowel gas, need to be NPO.
- ***Duplex criteria:***
  - — **Celiac:**
    - PSV > 200 cm/sec: > 70% stenosis.
    - EDV > 55 cm/sec: > 50% stenosis.
    - Retrograde hepatic artery flow is nearly 100% predictive of critical celiac stenosis or occlusion.
  - — **SMA:**
    - PSV > 275 cm/sec: > 70% stenosis.
    - EDV > 45 cm/sec: > 50% stenosis.
      - May be elevated in the setting of a replaced right hepatic artery.[5]
- ***CTA:*** Preferred **confirmative** imaging
  - — **Advantages:** Best non-invasive study to delineate the vascular anatomy, especially useful for preprocedural planning.
    - ***Determine clamp site:*** Check the degree of calcium in supra-celiac aorta, infrarenal aorta, iliac arteries, etc.
    - ***Determine treatment options:*** Degree of stenosis vs. occlusion, presence of calcification or thrombus in the diseased vessel.
  - — **Limitations:** Radiation and contrast exposure.

- ***MRA:*** Alternative to CTA
  - — **Advantages:** Can determine the severity of stenosis even in calcified lesions.
  - — **Limitations:** Lower spatial resolution, limited evaluation of the IMA and distal branches.
- ***Digital Subtraction Arteriography (DSA):*** Given the quality of CTA, DSA is now typically only used during endovascular intervention.
- ***Views:***
  - — **AP:** To identify collateral support and anatomic variations, can also assess for other pathologies (i.e., aneurysms associated with celiac occlusion or vasculitis).
  - — **Steep LAO or lateral:** Best for viewing ostium and for precise stent deployment.

Anatomy



Collateral Circulation

- ***Celiac to SMA:*** Via gastroduodenal and pancreaticoduodenal arteries, middle colic and pancreaticoduodenal arcade.
- ***SMA to IMA:*** Branches of left and middle colic arteries via the arc of Riolan.
- ***Hypogastrics to IMA:*** Via the middle and inferior rectal arteries to the superior rectal arteries from the IMA.

Informed Consent

Risks:

- Perioperative mortality (~ 3% in endovascular cases[6], ~ 10% in open), myocardial infarction, pulmonary complications.
- Recurrent ischemia secondary to intervention failure or recurrent stenosis (one study found that five-year freedom for recurrent symptoms was 89% after open revascularization vs. 51% after endovascular intervention).[7]
- ***Endovascular specific risks:*** Bowel infarction from embolization, access complications, unable to traverse occlusive lesion, dissection, in-stent restenosis (~30% of patients within two years of stenting).[3]
- ***Open specific risks:*** Development of adhesions, bowel obstruction, or hernia, enterotomy/bowel injury.
- ***Benefits:*** Eat without pain, weight gain. Untreated symptomatic chronic mesenteric ischemia has a nearly 100% five-year mortality.
- ***Alternatives:*** Catheter-based interventions, open reconstruction, or palliative care for those without suitable options.

Treatment:

Extent of revascularization dependent on approach but SMA is primary target.

- ***Endovascular:*** Decreased length of stay and peri-procedural morbidity and mortality.

Procedural Pearls/Technique

- Femoral vs. upper extremity (brachial or radial) approach.
- Upper extremity approach can be particularly useful to navigate an acute downward angle between the SMA and aorta or to cross an occlusion.[2]

— Nerve injuries are more frequently reported after brachial access due to proximity of nerves and risk of developing hematoma.[8]

- Sharp downward takeoff of the SMA can also be approached with a steerable sheath from the groin.
- ***Surgical reconstruction:*** Better long-term patency, lower long-term rates of symptom recurrence.[3]

Intraoperative Pearls/Technique

Antegrade: Supra-celiac aorta to celiac/SMA

- Takedown triangular ligament/crus of diaphragm.
- With nasogastric tube in place, identify esophagus and move to patient's left.
- Isolate supra-celiac aorta for proximal anastomosis.
- Consider bifurcated graft (short main body to prevent kinking of graft).
- SMA limb tunneled behind pancreas or through transverse colon mesentery to the SMA.

Retrograde: Aorta or iliac artery as inflow artery

- Consider in patients with previous upper abdominal surgery, calcified aorta, or for debranching procedures during complex EVAR.
- If both iliac arteries are disease free, generally a bypass from the right iliac artery lays better. Can use femoral vein or GSV, via direct open retrograde revascularization (DORR).
- Use ringed ePTFE; to reduce redundancies, can cut to size while the SMA is in near anatomic position by relaxing the retractors.[2]
- Place in a lazy C loop to reduce risk of graft kinking.
  — Higher incidence than antegrade reconstruction.

ACUTE MESENTERIC ISCHEMIA

Etiology

1. ***Embolic:*** Primary etiology (~ 30–50% of patients), typically cardiac in origin, up to 20% have synchronous emboli. SMA most susceptible secondary to its ostial angle, usually lodge just distal to the takeoff of the middle colic artery (ischemia spares the proximal jejunum).

2. ***Thrombotic:*** Critical stenosis progressing to occlusion (ischemia does not spare the proximal jejunum).
3. ***Venous thrombosis:*** 70% involve SMV, most commonly secondary to hypercoagulable state or recent GI surgery.
4. ***Non-occlusive mesenteric ischemia (NOMI):*** In critically ill patients, often on pressors, secondary to low flow state. Mortality exceedingly high secondary to underlying condition.

History and Presentation

- ***PMH:*** Cardiac arrhythmia, valvular heart disease, coronary artery disease, recent angina/MI, cerebrovascular disease, previous embolic events, hypercoagulable condition (including COVID-19).
- ***Meds:*** Digitalis or vasopressors.
- ***Presentation:*** Acute onset, often presenting symptoms are non-specific (abdominal pain, nausea, vomiting, melena).[9]

Examination

- Pain out of proportion to examination.
- Peritonitis occurs with development of transmural ischemia (grave prognosis).
- Can have heme-positive stool.

Labs

- ***CBC:*** Leukocytosis and left shift
- ***BMP:*** Fluid shifts with AKI
- ***ABG:*** Metabolic acidoseis with associated lactic acid elevation

Imaging

- ***STAT CTA:*** Quick, usually confirms presumptive diagnosis.
  - — Thrombosis vs. embolism.
  - — Pneumatosis or portal venous gas is a late finding.
  - — Bowel thickening.
- ***Ultrasound:*** Usually not helpful secondary to overlying bowel gas; MRA time-consuming.

Treatment

Initiate therapeutic anticoagulation and broad-spectrum antibiotics.

Endovascular:

- Consider in patients with early or subacute symptoms and low suspicion for bowel ischemia (lack of clinical or imaging findings).
  — **Contraindicated in patients with peritonitis.**
- Pharmacochemical thrombectomy.
- Consider covered stent to exclude residual thrombus.
- General surgery evaluation with either laparoscopy or laparotomy.

Open surgical intervention[10]:

- Abdominal exploration with examination of the entire bowel.
  — Mesentery evaluation with handheld Doppler, fluorescein, or indocyanine green dye (ICG).
- Necrotic bowel should be resected.
- If hemodynamically unstable, leave in and resuscitate in ICU.
- Thrombectomy of the SMA via small transverse arteriotomy unless bypass intended, then longitudinal arteriotomy.
- ***Hybrid approach:*** Can perform retrograde SMA stent if there's orifical stenosis after thrombectomy.
- ***If bypass necessary:*** Prosthetic graft or autologous vein (depending on stability of patient, surgeon preference, and degree of intraperitoneal soilage).
- ***Exception:*** Patients with NOMI should be aggressively medically managed unless there is evidence of gangrenous bowel that requires resection.

THORACIC OUTLET SYNDROME

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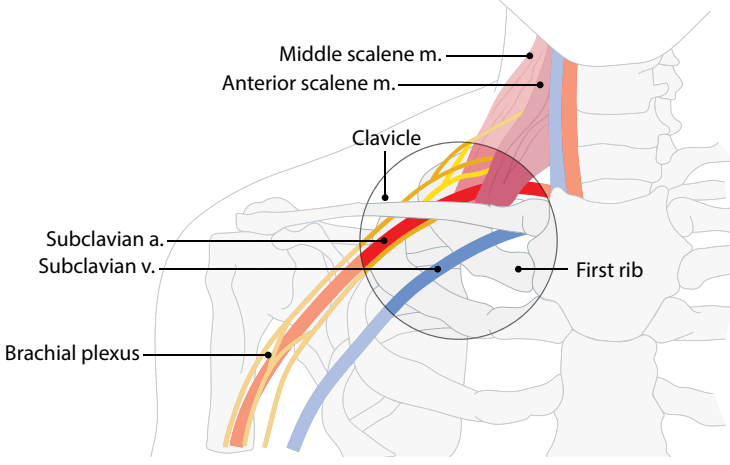
Background

- Symptoms are due to compression of neurovascular bundle at the thoracic outlet.
- Incidence: Up to 2%, 25–40 years old, female to male: 4:1.
  - — Neurogenic (94–97%)
  - — Venous (2–3%)
  - — Arterial (1–2%)

Thoracic Outlet Anatomy



Thoracic outlet: Bounded by spinal column, first ribs, and sternum; three triangles where neurovascular compression can occur:

1. ***Scalene Triangle:*** Formed by first rib, middle scalene, and anterior scalene.
   - — Subclavian artery (SCA) and brachial plexus lie between the anterior and middle scalene; subclavian vein (SCV) courses anteromedial to the triangle (inferior and lateral to the subclavius tendon); phrenic nerve runs lateral to medial on top of the anterior scalene.
   - — Most common site of brachial plexus compression.
   - — Anomalous ribs and cervical ribs compress the plexus at this site.
2. ***Costoclavicular Space:*** Area between the clavicle and first rib.
   - — SCA, SCV, and brachial plexus pass through this site.
   - — Most common site of SCV compromise.
3. ***Pectoralis Minor Space:*** Bounded by chest wall posteriorly and pectoralis minor (PM) muscle anteriorly.
   - — Not technically part of the thoracic outlet but SCA, SCV, and brachial plexus pass through this space in course to the upper arm; compression can occur between the PM and chest wall.

Nerves:

- ***Brachial plexus:*** Arises from nerve roots of C5–T1.
- ***Phrenic nerve:*** Arises from nerve roots of C3–5.
  - — Anterior to anterior scalene muscle.
  - — Only peripheral nerve that passes lateral to medial.
  - — 10–15% have a double phrenic nerve.
- ***Long thoracic nerve:*** Arises from nerve roots of C5–7.
- Traverses the middle scalene, descends over the first rib.

Other pertinent anatomy

- ***Thoracic duct (left side):*** Terminates at the junction of left subclavian and jugular veins.

Etiology

- ***Neurogenic (nTOS):*** Brachial plexus compression, commonly at the scalene triangle or pectoralis minor space.[1]
  - — Neck trauma (hypertension neck injury) is the most common cause of nTOS.[2]

— Osseous changes:
  - Cervical rib (incidence ~ 1%, F > M, most are asymptomatic)
  - Cervical fibro-cartilaginous band extending from tip of the cervical rib to the first thoracic rib.

- ***Arterial:*** Obstruction of SCA usually as it passes over the first rib leading to occlusions or aneurysmal degeneration.
  — Associated with bony abnormalities such as cervical rib or rudimentary first rib.
  — Leads to occlusions or aneurysms.
- ***Venous:*** Repetitive trauma of SCV at the costoclavicular or pec minor space.
  — Developmental anomalies of the costoclavicular space.
  — Repetitive arm movements (athletes, housekeepers).
    - Paget-Schroetter Syndrome = effort-induced thrombosis.

Presentation

Neurogenic TOS

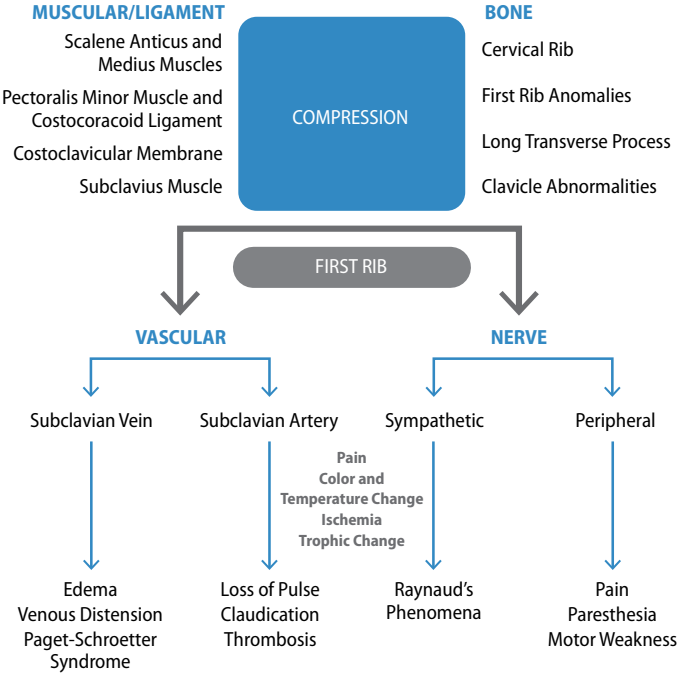
- Onset is insidious.
  — Pain in arm, hand, or shoulder girdle; occipital headache.
  — Numbness, tingling, or weakness of arm or fingers (variable pattern).
  — Symptoms exacerbated and reproducible with increased arm activity or elevation.
  — Paresthesia, often nocturnal.

Arterial TOS

- Neck, shoulder, or arm pain with activity can be early symptoms.
- Arterial embolization presents acutely as hand or arm ischemia (pain, pallor, paresthesia, coldness).

Venous TOS

- Pain and swelling of the affected arm with evident subcutaneous collateral veins on the chest wall, shoulder, or arm.
- Bluish discoloration of fingers or hand.
- May have some sensory changes associated with acute DVT of axilla-subclavian vein, rare to see phlegmasia.



Thoracic Outlet Syndrome

Examination

nTOS

- Tenderness over scalene or pec minor.
- Provocative testing.
  - — ***Adson's sign:***
    - Provider palpates the radial pulse and then passively abducts and externally rotates arm while patient extends head towards the ipsilateral side and holds deep inspiration.
    - Positive result: Weakened or absent radial pulse.
    - Widely used, although reliability in question.

— ***Elevated Arm Stress Test (EAST):***
  - Patient seated with arms abducted and elbows flexed to 90 degrees, opens and closes hands for three min.
  - Positive result: Reproduction of pain/paresthesia.
  - High NPV for nTOS if patient able to perform for three min.

— ***Modified Upper Limb Tension Test (ULTT):***
  - Arms abducted to 90 degrees with elbows extended, patient dorsiflexes both wrists.
  - Positive result: Reproduction of pain or neurologic symptoms on ipsilateral side.

— Can additionally have patient tilt head to each side (positive result if symptoms elicited on contralateral side).

aTOS

- Blood pressure differential > 20 mmHg between arms.
- Decreased pulses, coolness or pallor, digital ulceration (if have arterial occlusion or embolism).

vTOS

- Arm swelling, cyanosis, dilated subcutaneous veins over chest/shoulder/arm.

Laboratory Testing and Imaging

- ***Electromyography and nerve conduction studies (NCV):*** Usually normal or non-specific
  — Negative test doesn't rule out TOS.
- ***CXR:*** Helpful to identify cervical or supernumerary rib.
- ***Ultrasound:*** Initial imaging for aTOS or vTOS.
- ***CTA or CTV:*** High-quality images of vasculature, 3D reconstruction can aid in identifying point of compression.
  — MRA or MRV also provides excellent imaging of vasculature and surrounding soft tissue/bone.

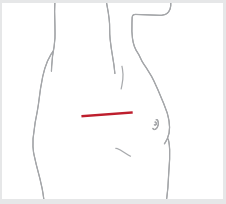
Angiogram or venogram

- Perform arm in stressed and neutral position if concerned for aTOS or vTOS, respectively.
- ***Anterior Scalene Muscle Block:*** Useful adjunct for diagnosis of nTOS, positive test if > 50% improvement in the elevated arm stress pain score.
  — Predicts symptom relief after surgery for nTOS.

Treatment

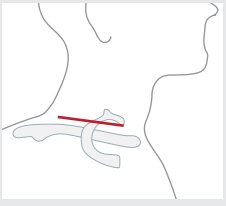
- ***Conservative:*** Education, modify activities (no forward flexed positions), physical therapy, and exercises, NSAIDS.
- Intervention for failure of conservative management, significant work disability, or vascular type.

Surgical Approaches[3]



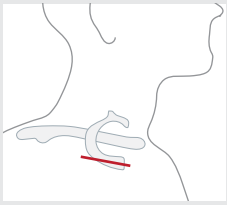
Transaxillary approach: Incision between the pec major and latissimus dorsi.

- Concomitant first rib resection.
- ***Advantages:*** Rapid and easy exposure of the first rib, cosmetic incision.
- ***Disadvantages:*** Dissection in a deep hole, requires assistants to hold arm in order to open up the space (excessive traction can lead to nerve injuries), difficult to perform vessel reconstruction.



Supra-clavicular approach: Transverse incision 1–2 cm above the clavicle.

- Concomitant scalenectomy and neurolysis; cervical rib resection as needed.
- ***Advantages:*** Excellent visualization, allows for complete scalenectomy and neurolysis with visualization of all 5 nerve roots; vascular reconstruction can be performed as needed.
- ***Disadvantages:*** Risk of nerve injury (particularly supraclavicular, phrenic, long thoracic, and brachial plexus).



Infraclavicular approach: Transverse incision 1–2 cm below the clavicle.

- Particularly useful for vTOS.
- ***Advantages:*** Excellent exposure of the SCV, can perform venous reconstruction if needed, lower risk of brachial plexus injury (do not need to retract the plexus).
- ***Disadvantages:*** Difficult to perform neurolysis.

Combined

- Transaxillary (lateral decubitus) and supraclavicular (supine) allows for first rib resection and scalenectomy.
- Paraclavicular (infra- and supra-clavicular) approach allows for first rib resection, scalenectomy, and vascular reconstruction as needed.

Posterior

- Longitudinal incision between spinous processes and medial border of scapula.
- Rarely performed, generally only considered for patients with history of XRT.

Robotic assisted first rib resection

- VATS; three thoracic ports.
- ***Advantages:*** Excellent visualization of the thoracic outlet, including the entire first rib; possible reduced post-operative pain and a shorter hospital stay.
- ***Limitations:*** Pleura opened (need drain), unexpected bleeding is challenging to control.

Adjunctive Procedures for Vascular TOS

vTOS

- Heparinization followed by thrombolysis/percutaneous thrombectomy.
- If longstanding, stenosis may require venoplasty or patchplasty.
  — Generally, DO NOT stent unless rib is resected.
- First rib resection can be performed concurrently or in a staged manner.[4]

aTOS

- Heparinization and management of ischemia if patient presents acutely.
  — Thromboembolectomy or thrombolysis.
  — Repair arterial defect (patch angioplasty for stenosis or bypass and exclusion for aneurysm).
- For post-stenotic aneurysm > 2 cm — resect and reconstruct (consider paraclavicular approach).
- Ultimately need to decompress the thoracic outlet (timing depends on degree of ischemia).

Post-operative Complications

- Pneumothorax (PTX) — Most common complication (< 10%).
  — Check CXR post-op.
  — Leave a drain intra-op if pleura violated.
- Nerve injury (temporary or permanent; usually traction injury).
  — More common in lower trunk distribution than upper trunk (lower usually permanent).

— Long thoracic nerve can be injured with middle scalenectomy — winged scapula.
— Intercostobrachial nerve (lateral cutaneous branch of the second intercostal nerve) — numbness over axilla or upper inner arm.

- Lymphatic leak — Injury to thoracic duct.
  — Occurs in supra-clavicular approach on left side.
  — Consider leaving a drain.

Surgical Outcomes

nTOS

- Very high initial success rate (~ 90%), wanes over time.[5]
- This trend is seen with ALL approaches.[5]

aTOS

- Complete symptom relief in > 90% of patients.
- Bypass patency 90–100%.

vTOS

- High technical success, excellent secondary patency in most patients (> 90%).
- In over 90% of cases, patients resume pre-operative activity.

SUPERFICIAL AND DEEP VENOUS DISEASE

William Johnson, M.D.
Chong Li, M.D.
Molly Ratner, M.D.

Background

- Venous disease is the most common diagnosis seen by vascular specialists.
- Cost of care for chronic venous diseases > $3 billion per year in the U.S.[1]
- Up to 20% of adult males and two-thirds of adult females have varicose veins.
- Nearly half of individuals over 50 years of age will have superficial venous pathology.
- The CEAP Classification which has been the most common means of classifying vein pathology has been replaced with the revised venous clinical severity score.

Classification: Revised Venous Clinical Severity Score[2]

Attribute	Absent = 0	Mild = 1	Moderate = 2	Severe = 3
Pain	None	Occasional, not restricting daily activity	Daily, interfering but not preventing daily activity	Daily, limits most daily activity
Varicose veins	None	Few, isolated branch varices, or clusters, includes ankle flare	Confined to calf or thigh	Involves calf and thigh
Venous edema	None	Limited to foot and ankle	Extends above the ankle but below knee	Extends to knee and above
Skin pigmentation	None or focal	Limited to perimalleolar	Diffuse, over lower third of calf	Wider distribution above lower third of calf
Inflammation	None	Mild cellulitis, ulcer margin limited to perimalleolar	Diffuse, over lower third of calf	Wider distribution above lower third of calf
Induration	None	Limited to perimalleolar	Diffuse, over lower third of calf	Wider distribution above lower third of calf
Ulcer number	0	1	2	≥ 3
Ulcer duration	NA	< 3 mon	< 3 mon but < 1 yr	Not healed > 1 yr
Ulcer size	NA	Diameter < 2 cm	Diameter 2–6 cm	Diameter > 6 cm
Compressive therapy	Not used	Intermittent	Most days	Full compliance

An aggregate score for the limb is calculated by adding the individual component scores. The range of total score is 0 to 30. NA: not applicable.

History and Physical Examination

Common complaints:

Pain, aching, burning, itching, and heaviness. Swelling of the leg or foot with or without skin changes, including hyperpigmentation, ulceration, bleeding, or unsightly appearance.

Physical examination (from umbilicus to feet):

- Abdominal wall and groin varicosities suggest a proximal stenosis (i.e., iliac vein or IVC).
- Swelling may be absent or present in entire leg or just below the knee.
- Distribution of varicosities should be noted as well as images taken.

- The lower leg is the most impacted by venous hypertension and skin changes are common (e.g., hyperpigmentation, lipodermatosclerosis, atrophic blanche).
- Inspect for active or healed ulcerations.
- Insurance carriers require documentation of CEAP classification for insurance approval. Please see the appendix for CEAP classification information.

Diagnostic evaluation:

- ***Duplex examination:***
  — Identifies sites of reflux and length of time of reflux.
  — ≥ 0.5 sec = significant superficial vein reflux.
  — ≥ 1 sec = significant deep vein reflux.
  — ≥ 0.5 sec = significant perforator vein reflux.
  — Diameter of perforator > 3.5 mm sign of significant reflux.[3]

Conservative Management

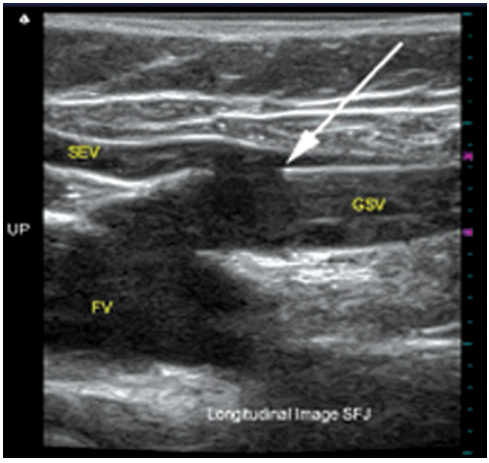
- ***Compression therapy (compression stockings, paste gauze boots, elastic wraps/dressings):*** Indicated for all patients with diagnosis of venous insufficiency.
  — ***Compression stockings:*** Minimum 20–30 mmHg, 30–40 mmHg recommended for more severe disease or lymphedema.
- Wound care for patients with ulcerations.
- Graded exercise programs.

Intervention

- ***Ligation and stripping:*** Surgical removal of greater saphenous vein (GSV) from groin to knee/ankle (rarely performed, but of historic interest).
- ***Endovenous thermal ablation procedures:***
  — Radiofrequency ablation (RFA)
  — Endovenous laser ablation (EVLA)
- ***Micro/Stab Phlebectomy:*** For residual large/symptomatic varicosities after stripping or ablation.
- ***Sclerotherapy:*** Primary or adjunct treatment of telangiectasia, reticular veins and varicose veins with ultrasound guidance.

Technique for Endovenous Ablation

- Ultrasound-guided access of GSV/SSV
  - — Access typically at knee level.
  - — Below-the-knee access increases risk of saphenous nerve paresthesia.[4]
- Ensure that catheter is at least > 2.5 cm inferior to the saphenofemoral junction (SFJ) or saphenopopliteal junction (SPJ)
  - — Confirm on longitudinal view.
- ***Tumescence injected in saphenous sheath[5]:***
  - — Standard composition: 450 ml crystalloid, 50 ml 1% lidocaine with epi, 5–10 ml of 8.4% sodium bicarb
    - Limit: 35 mg/kg
- Position patient in Trendelenburg to drain the vein, allowing better contact between catheter and vein.[6]
- Follow IFU for pullback speed for laser ablation.
- Completion ultrasound: ensure treated vein is closed; check common femoral (popliteal) vein compressibility.



- The image demonstrates the tip of catheter (white arrow) at junction of saphenous and superficial epigastric vein. The catheter should be retracted until at least 2.5 cm from the sapheno-femoral junction.

Post-operative Care

Compression, ambulation.[7]

Complications

- ***Endothermal Heat-Induced Thrombus (EHIT):*** Propagation of thrombus from the ablated superficial vein into the contiguous deep venous system.[8]
  - — Potential complication of procedure (< 3%), due to ablating too close to the junction of the superficial and deep systems (i.e., SFJ, SPJ).[8]

Classification and Treatment[8]

EHIT Class	Definition	Treatment
I	No propagation to the deep vein (up to the junction)	None
II	Propagation into the adjacent deep vein, thrombus < 50% of deep vein diameter	Weekly surveillance until resolution (consider AC/AP If high risk)
III	Propagation into the adjacent deep vein, thrombus > 50% of deep vein diameter	Weekly surveillance + therapeutic AC until resolution
IV	Occlusive DVT	Individualized (refer to CHEST guidelines for treatment of DVT)

AC: anticoagulation. AP: antiplatelet.

- ***Paresthesia:*** Usually transient, can be related to saphenous nerve irritation or for short saphenous therapy related to the sural nerve.[9]
- ***Thermal injury:*** Preventable; can be from either inadequate tumescence or very superficial veins.
- ***Clinically relevant recurrence:*** ~5% at 3-year follow-up.

DEEP VENOUS DISEASE

Venous Thromboembolism

- More than one million cases diagnosed annually in the U.S.
- Significant clinical implications, including risk of fatal pulmonary embolism (200,000 deaths/year in the U.S.) and long-term complications of post-thrombotic syndrome.

Risk Factors

- Virchow in 1856 wrote a paper identifying risk factors for DVT (Virchow's triad):
  - — ***Stasis:*** Post-operative/immobilized patients.
  - — ***Hypercoagulability:*** Factor V Leiden — most common inherited form of thrombophilia, 5% of population.[10] Also malignancy and chemotherapy, inflammation, and hormone use.
  - — ***Vein wall (endothelial injury):*** Results from physical or chemical trauma to the vessel such as surgery, trauma, or infection/inflammation.
- Other risk factors include previous DVTs and pregnancy.

Clinical Examination

- Unilateral leg swelling, warmth, erythema.
- ***Homan's sign:*** Calf pain with dorsiflexion.
- ***Limb-threatening findings:***
  - — ***Phlegmasia alba dolens:*** Significant swelling without cyanosis.
  - — ***Phlegmasia cerulea dolens:*** Significant swelling with cyanosis. Often associated with comprised arterial flow secondary to swelling.
  - — ***Venous gangrene (VG):*** Partial thickness necrosis (blisters, blebs) in early phase; full-thickness skin necrosis in advanced cases.

Laboratory Tests

- ***CBC:*** Check platelet count prior to starting anticoagulation.
- ***BMP:*** Renal failure.
- ***Arterial blood gas:*** If hypoxemia, suspect PE.
- ***D-Dimer:*** Very high negative predictive value in patients with low risk of DVT.
- ***CPK:*** High value indicates muscle damage.
- Consider hypercoagulable workup.

Imaging

- Venous duplex
- ***Acute:*** Dilated, noncompressible, low echogenic with absence of phasicity and augmentation.
- ***Chronic:*** Non-dilated, echogenic, partially compressible, and collaterals often present.
- ***CTV or MRV:*** More sensitive for proximal thrombosis (useful if DVT extends beyond the limit of the duplex); additionally consider if concerned for PE or if a candidate for endovascular thrombectomy.
- ***Venogram with intravascular ultrasound:*** Diagnostic study which can performed to directly prior therapeutic intervention.

Treatment/Intervention of DVT

- Anticoagulation is the mainstay of therapy*[,11]
  — Initial therapies include but are not limited to:
    - ***Unfractionated heparin:*** Bolus 80 mg/kg → initial infusion rate 18 U/kg/hr (q6h PTT or anti-Xa for adjustments).[12]
- Preferred in patients with severe renal failure, hemodynamic instability or requiring intervention (easily reversible).[11]
  — ***Low molecular weight heparin (e.g. enoxaparin):*** 1 mg/kg BID or 1.5mg/kg daily.[11]
- Can be used in pregnant patients.
  — ***Factor Xa inhibitors or direct thrombin inhibitors (oral)[11]:***
    - Rivaroxaban and apixaban only DOACs approved as monotherapy for tx of VTE (i.e., no need for pretreatment with heparin).
    - Consider oral Xa inhibitors for patients with active malignancy.
- If anticoagulation is contraindicated, consider placement of retrievable IVC filter for acute lower extremity DVT.
- Alternatively, can perform serial ultrasounds to check for propagation, particularly in patients with below-knee DVT.

Decision to intervene is based on patient comorbidities, function status and location of DVT:

- ***Iliofemoral:*** Percutaneous thrombectomy or thrombolysis.

Techniques:

1. Supine vs. prone position. Ultrasound-guided puncture of popliteal or femoral vein is performed (ideal to access below the profunda vein as this serves as inflow after thrombectomy).

2. Consider temporary embolic protection, particularly if passing devices through thrombus.
3. Sheath placed and percutaneous thrombectomy is performed.
4. If significant residual thrombus, can consider placing a lytic catheter.
5. Treat underlying etiology — (e.g., stenting for underlying May Thurner).

- ***Femoropopliteal:*** Intravenous or subcutaneous anticoagulation agents used initially with transition to oral agents for long-term use; can consider pharmacochemical thrombectomy in select patients.
- ***Infrapopliteal:*** If unable to receive anticoagulation, reasonable to repeat duplex in 48–72 hours days to assess for propagation vs. IVC filter placement.

*Refer to CHEST guidelines for full treatment recommendations.

Outcomes

- Around 1/3–1/2 of patients will develop long-term complications (i.e., post-thrombotic syndrome [PTS]) including pain, swelling and discoloration.[13]
- ***Villata Score:*** to define and stratify severity of PTS.
  — Some evidence that prevention of severe PTS is possible by performing catheter-based thrombectomy/thrombolysis in iliofemoral DVT.

Villata Scoring Chart[14]

Symptoms/ Clinical signs	None	Mild	Moderate	Severe
Symptoms				
Pain	0 points	1 point	2 points	3 points
Cramps	0 points	1 point	2 points	3 points
Heaviness	0 points	1 point	2 points	3 points
Paresthesia	0 points	1 point	2 points	3 points
Pruritus	0 points	1 point	2 points	3 points

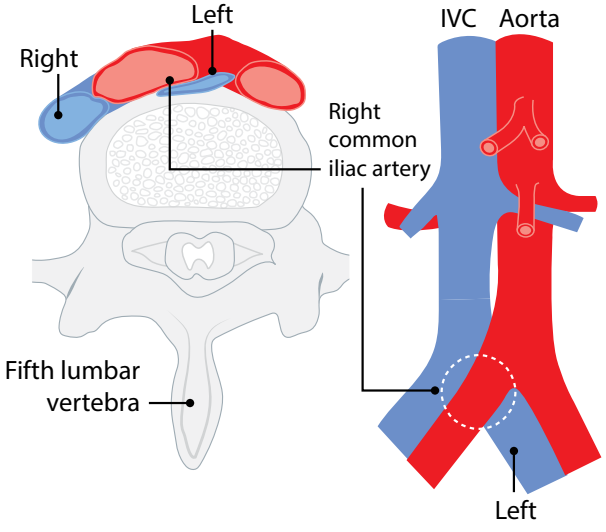
Clinical signs				
Pretibial edema	0 points	1 point	2 points	3 points
Skin induration	0 points	1 point	2 points	3 points
Hyperpigmentation	0 points	1 point	2 points	3 points
Redness	0 points	1 point	2 points	3 points
Venous ectasia	0 points	1 point	2 points	3 points
Pain on calf compression	0 points	1 point	2 points	3 points
Venous ulcer	**Absent**			**Present**

PTS: Post-thrombotic syndrome.

- Up to 1/3 of patients with Hx of DVT/PE will have a recurrence within 10 years.

May Thurner Syndrome[15]

- Most common is left iliac vein compression typically between right iliac artery and lumbar spine, compression can also occur in the external iliac vein and the right iliac vein as well.



- Most patients asymptomatic but compression can cause venous hypertension and DVT.
- Symptoms include left lower extremity pain, swelling, skin discoloration/ulceration.
- CT or MR venogram (high sensitivity and specificity).
- ***Catheter-based venography with IVUS (preferred imaging modality):*** Able to assess severity and extent of disease; useful to measure venous diameters to appropriately determine self-expanding stent length and diameter.
- ***Treatment:***
  - — Anticoagulation and pharmacochemical thrombectomy for DVT.
  - — Consider venoplasty and stenting.

Pelvic Congestion Syndrome[16]

- Chronic pelvic pain in women with periovarian varicosities (associated with the three Ds: dyspareunia, dysuria, and dysmenorrhea).
- Women of reproductive age, higher incidence with multiparity.
- Transabdominal/transvaginal ultrasound (initial study):
  - — ***Findings:*** Dilated ovarian veins (> 6 mm), blood flow < 3 cm/min, reversed caudal flow in L ovarian vein, tortuous/dilated venous plexuses in pelvis, dilated arcuate veins across myometrium.
  - — Should rule out other potential pathologies (eg. malignancy, endometriosis).
  - — Often seen secondary to iliac vein compression, and treatment of iliac vein stenosis can dramatically improve symptoms.
- ***Treatment:*** Ovarian vein coil embolization with or without pelvic vein sclerotherapy.

UPPER EXTREMITY DVT[17]

- 5–10% of all DVT cases.
- Most cases are related to central venous catheters (CVL, PICC) or malignancy.
  - — In young patient, consider Paget Schroetter syndrome.
- Around 5–8% develop clinically apparent PE.
- Primary treatment: Anticoagulation (minimum three months).
  - — Central venous catheters/lines can be left in place while on anticoagulation.

PULMONARY EMBOLISM

Background

50,000 annual deaths from PE.[18]

History and Physical Examination

Tachypnea and tachycardia most common; other symptoms/signs include pleuritic chest pain, hemoptysis, hypotension, hypoxemia, and hypocarbia.

Diagnosis

EKG: Sinus tachycardia most common finding; S1Q3T3 pattern rarely seen.

1. ***CXR:*** Westermark sign (segmental or lobar perfusion loss); helps rule out other causes.
2. ***V/Q scan:*** Ventilation perfusion defects (very sensitive but time-consuming obtained).
3. ***Computed tomography of pulmonary arteries:*** First line imaging, especially in stable patients.
4. ***Pulmonary angiography:*** Seldom necessary for diagnostic purposes (reserved for intervention).

Classification[19]

- ***Low risk/non-massive:*** Normotensive, normal biomarkers.
- ***Intermediate risk/sub-massive:*** Hemodynamically stable but evidence of RV dysfunction or infarction.
  - — ***Per the AHA, submassive is defined as PE without hypotension (> 90 mm Hg) but with signs of:***
    - ***RV dysfunction:*** A right ventricular to left ventricular (RV/LV) ratio > 0.9 by echocardiography or CT pulmonary angiography (CTPA)
    - An elevated B-type natriuretic peptide level greater than (90 ng/L)
    - An elevated troponin T level [>.01 µg/L])

- ***High risk/massive:*** Hemodynamically unstable with signs/symptoms of shock.
  - — ***Defined by hypotension:***
    - These patients present with cardiac arrest or obstructive shock (systolic blood pressure, < 90 mm Hg or the need for vasopressor support) not caused by arrhythmia.
    - Although these patients account for a relatively small percentage of hospitalizations, they carry a high mortality risk of > 50% at 3 months per the International Cooperative Pulmonary Embolism Registry (ICOPER).

Treatment[19]

- ***Low risk:*** Anticoagulation
- ***Submassive or massive PE:***
  - — Systemic thrombolysis.
  - — Catheter-directed thrombectomy/thrombolysis.
  - — Surgical thromboembolectomy (generally reserved for hemodynamically unstable patients in whom thrombolytic therapy is contraindicated or has failed).
  - — Mechanical support (i.e., VA ECMO) in patients with cardiogenic shock and massive PE.

VENA CAVA FILTERS

Indications[20]

1. Patients with acute proximal VTE with absolute contraindication to or complications from AC.
2. AC Failure (i.e., new or progressive proximal VTE or PE despite anticoagulation).
3. The use of prophylactic filters in high-risk patients (i.e., trauma) is controversial.

Filter Types

- ***Permanent/Non-retrievable:*** Designed to never be explanted.
- ***Retrievable/Optional:*** Potential to be removed, however can remain permanently in place, 10–20% removed in most series.

Technique

- ***Access:*** Femoral vs. jugular.
- ***Imaging for placement:***
  - — Fluoroscopy +/- IVUS.
  - — ***Need to identify renal veins:*** Filter to be placed inferior to renal veins (typically found at L1–L2).
- ***Techniques to identify renal veins:***
  - — Venography from distal IVC or proximal ipsilateral iliac vein.
  - — Selective catheterization.
  - — IVUS.
- Most filters can only be placed in IVC with diameter < 28 mm.*

**Check IFU of device.*

- ***Supra-renal placement is off-label but can be considered in the following:*** [21,22]
  - — Lack of landing zone in infrarenal IVC due to thrombus.
  - — Renal vein thrombosis.
  - — Thrombus extending beyond already inserted IVC filter.
  - — Pregnant women (thought to be advantageous because of the potential for the gravid uterus to compress the infrarenal IVC and perforation).

Complications of Filters

Migration, thrombosis, fracture, and/or penetration into surrounding structures (bowel, spine, artery, etc.).

“If the thought of a fasciotomy crosses your mind, perform the fasciotomy.”

— Patrick Stone M.D., FACS

COMPARTMENT SYNDROME

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Pathogenesis

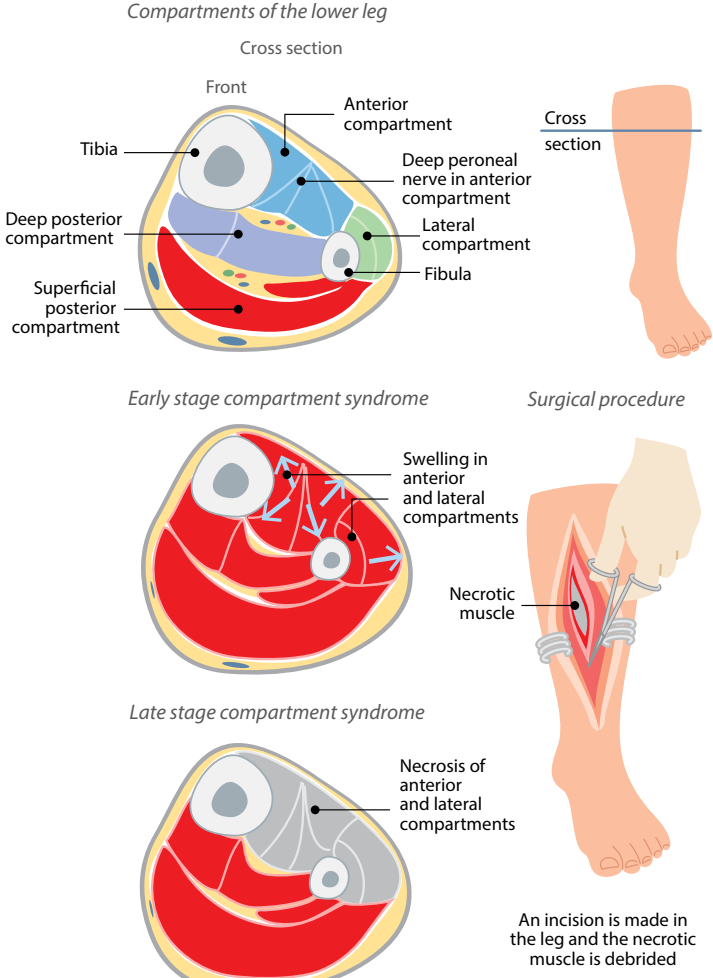
- Increase in pressure that leads to decreased tissue perfusion in a closed osteofascial compartment.
- As compartmental pressure rises, it is transmitted to postcapillary venules and:
  - — Venous pressure rises FIRST.
  - — Eventually, capillaries collapse and resistance increases.
  - — Tissue susceptibility to ischemia:
    - ***Nerve tissue:*** Permanent damage at two hours or less.
    - ***Muscle:*** Maximal contracture at 12 hours, death begins at four hours.
    - ***Skin and subcutaneous tissue:*** Much more tolerant of ischemia.

Intracompartmental Pressure (ICP) Thresholds[1]:

- **Several methods to measure. Easiest is handheld device but if not available can use angiocath connected to an arterial line setup.**
- ***Absolute pressure:***
  - — Normal compartment pressure is generally < 8 mmHg.
  - — Absolute compartment pressure > 30 mmHg is concerning for compartment syndrome.
- Pressure differential:
  - — Diastolic pressure (dBP) — compartment pressure = delta pressure.
  - — Compartment syndrome suspected if delta < 30 mmHg.

Need for fasciotomy is still most dependent on the clinical stage of ischemia, not duration.

Compartment Syndrome of Lower Leg with Muscle Necrosis



Etiologies

Ischemia-reperfusion (high risk):

- Ischemia > 6 hours, poor collateralization, poor intra-op back bleeding.

Trauma:

- Long bone fracture (~ 75% of acute compartment syndrome cases develop in setting of a fracture).[2]
- Can be caused by arterial or venous injury (highest when combined).
- Popliteal injury associated with higher fasciotomy rates compared with other lower extremity vascular injuries.
- Crush injury.
- Insects or snake bites.
- Burns — escharotomy.

Iatrogenic:

- Extravasations of fluid/medication.
- Prolonged immobilization (gluteal susceptible).
- Constricting bandages.

Chronic (exertional):

- Different entity and not an emergency;
- Pain or cramping during exercise. Treatment starts with activity modification.
- Hypotension with high vasopressors.

Clinical Evaluation

Important anatomy: Four compartments of the lower extremity (below the knee)

Anterior:

- Deep peroneal nerve, anterior tibial artery and vein.

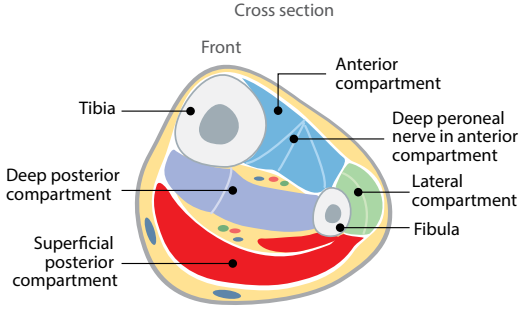
Lateral:

- Superficial peroneal nerve.

Deep posterior:

- Tibial nerve, posterior tibial artery and vein, peroneal artery and vein.

Compartments of the lower leg



Superficial posterior:

- Sural nerve.

Compartments most commonly affected:

- Anterior > lateral > deep posterior > superficial posterior.

Exam: Must do a thorough motor and sensory exam

- Pain is usually out of proportion to the extent of the injury.
- Pain on passive motion is usually seen first.
- ***Anterior compartment:*** Paresthesia in dorsum of first web space (deep peroneal nerve).
- ***Lateral compartment:*** Peroneal longus and peroneal brevis motor function, and sensory to the dorsum of the foot except first web space (superficial peroneal nerve).
- Reduced or absent pulse is a late finding and unreliable.

Perform prophylactically if:

- Patient is at high risk at the time of revascularization.

Fasciotomy

Technique:

Lower leg — most common fasciotomy by vascular surgery

- ***Two incisions:*** Classic
  - — Lateral incision allows for access to the anterior and lateral compartments and medial incision allows for access to the deep and superficial posterior compartments.

- ***Single incision:***
  — One lateral incision, retract peroneus muscle anteriorly to reach the gastrocnemius and the superficial posterior compartment; retract tibialis anterior muscle laterally to reach the interosseous membrane and deep posterior compartment.

Thigh

- ***Double incision:***
  — Three compartments; lateral incision for anterior and posterior; medial incision for adductor.

Gluteus

- ***Kocher-Langenbach or Modified Gibson incision[3]:***
  — Three compartments; tensor fasciae latae, gluteus medius/minimus, and gluteus maximus.

Upper Extremity[4]

- ***Forearm:***
  — ***Two compartments:*** Volar (superficial and deep), and dorsal.
  — Volar compartment most frequently affected.
    - Incision begins medial to the biceps tendon above the antecubital fossa.
    - Extends in a curvilinear fashion distally across flexor retinaculum.
  — For dorsal compartment, single incision from lateral condyle to the wrist.
- ***Upper arm:***
  — ***Three compartments:*** Flexor, extensor, and deltoid.
    - One skin incision over the medial intermuscular septum.

Muscle Viability Assessment (4Cs)[5]

1. Color: Red or dusky.
2. Contractility.
3. Consistency (intact or friable).
4. Capacity to bleed.

Wound Management

- Delayed primary closure.
- Allows for full demarcation of nonviable tissue prior to definitive closure.

- Secondary intention.
  — Negative pressure dressing, Roman shoelace, +/- matrix/synthetic graft.
- Split thickness skin grafting (needed in approximately one-half of cases).

Complications

Local:

- Neurologic deficit
  — Proximal extent of fasciotomy should be around 4–5 cm distal to the fibular head to avoid injury to the common peroneal nerve or its branches.[3]
- ***Wound complications:*** Significant proportion will need a split thickness skin graft.

Systemic:

- Myonecrosis (increased creatinine phosphokinase CPK), hyperkalemia, hypocalcemia, renal failure, DIC, death.

VASCULAR TRAUMA

William Johnson, M.D.
Molly Ratner, M.D.

General Principles

- ***Classic injuries:***
  - — Aorta — deceleration at ligamentum arteriosum.
  - — Carotid/vertebral — flexion/extension of neck.
  - — Brachial artery — proximal humerus fracture.
  - — Popliteal artery — posterior knee dislocation.

Initial Assessment and Resuscitation

- ***Pertinent history:***
  - — Mechanism of injury.
  - — Blunt/crush vs. penetrating type of weapon.
  - — Time since injury.
  - — Blood loss at scene.
  - — Tourniquet time.
  - — Disabilities/injuries.
  - — Body position, entrance/exit wounds.
  - — Height of fall, speed of vehicle.
- Initial assessment follows ATLS protocol.
- Significant bleeding is best controlled with direct pressure at bleeding site or at proximal artery supply.
- Consider "permissive hypotension".
  - — Used for patients in hemorrhagic shock to prevent further blood loss from disruption of formed clot.[1]

- Secondary survey:
  - — Pulses should be assessed centrally and peripherally.
  - — Bony deformities, fractures, or dislocations.
  - — Skin changes.
- Hard signs of vascular injury[2]:
  - — Pulstile bleeding, expanding hematoma.
  - — Bruit/thrill.
  - — Pulse deficit or signs of limb ischemia.
- Soft signs if[2]:
  - — Nonpulsatile and nonexpanding hematoma.
  - — Decreased distal pulses or pressure index.
  - — Unexplained hypotension.
  - — Proximity of injury to vasculature.
  - — Peripheral neurologic deficit.

Diagnostic Considerations

- ***Routine radiographs:*** CXR, pelvic X-ray, extremity X-rays.
  - — Can document fractures, foreign bodies, bullets, or shrapnel.
- CT angiography (depending on patient stability).

Operative Principles

If fracture or dislocation — reduce and reassess pulse exam with abi in lower extremity.

- ***Obtain hemostasis:*** Secure proximal and distal control.
  - — Direct pressure/proximal arterial compression.
  - — Consider proximal balloon occlusion — REBOA consideration.
- Exploration and debridement.
  - — Expose adjacent normal vessel.
  - — Preserve collateral vessels when possible.

Operative techniques: Unstable patient

- Ligation
  - — Venous ligation
    - Usually well tolerated in the extremities.
    - Can be employed for large central veins (e.g., portal vein or IVC) in extreme situations.

— ***Arterial vessels that can be safely ligated if necessary:***
  - Subclavian artery.
  - Radial or ulnar arteries (if palmar arch intact).
  - Isolated solitary tibial artery injury.
  - Internal iliac artery.

- Shunting
  — Alternative to ligation in unstable patient or bridge to repair.
  — Consideration for unstable patients and those with other major injuries delaying arterial repair.
  — Debride vascular defect to fresh edges, assure antegrade and retrograde bleeding, consider passing thrombectomy catheter.

Operative techniques: Stable patient

- ***Simple repair or patch angioplasty:***
  — Consider when minimal damage present.
  — Monofilament, permanent suture generally used, autologous patch preferred.
- ***End-to-end repair:***
  — Tension-free anastomosis.
  — Generally can resect 1–2 cm of vessel.
- ***Interposition grafting:***
  — Used when a tension-free anastomosis is not possible.
  — Autogenous vein preferred (especially for small vessels < 5 mm) from unaffected limb to prevent any further
  — Venous drainage reduction if injures limb has vein injury.

Assessment of revascularization:

- Return of normal distal pulses.
- Angiography at conclusion of procedure.

Cerebrovascular Injuries

Blunt Cerebrovascular Injuries: BCVI[3,4]

- Majority of patients do not present with obvious neurologic symptoms (latent period between injury and onset of symptoms common).
- Can lead to stroke, disability, or death.

Injury

- ***Etiologies:*** MVC, seat belt, assault, strangulation, near-hanging, intraoral trauma, basilar skull fracture.
- Denver criteria[5]
  - — ***Signs/Symptoms of BCVI — need evaluation with emergent CTA:***
    - Arterial hemorrhage from mouth/nose/neck.
    - Bruit in patient < 50 years old.
    - Expanding hematoma (cervical).
    - Focal neuro deficit.
    - Neuro deficit incongruent with CT head findings.
    - Stroke on axial imaging.
  - — ***Risk Factors for BCVI — urgent CTA:***
    - High energy mechanism.
    - Lefort II or III fractures (displaced midface fx), mandibular fracture.
    - Complex skull or basilar fracture; scalp degloving.
    - TBI with GCS < 6.
    - TBI + thoracic injury.
    - Thoracic vascular injury.
    - Cervical spine injury (fracture, subluxation, ligamentous injury).
    - Near hanging with anoxia.
    - Seat belt abrasion with swelling, pain, or AMS.
    - Upper rib fracture.
    - Blunt cardiac rupture.
- BCVI Grading Scale[6]
  - — **I:** Luminal irregularity or dissection with < 25% luminal narrowing.
  - — **II:** Dissection or intramural hematoma with ≥ 25% luminal narrowing.
  - — **III:** Pseudoaneurysm.
  - — **IV:** Complete occlusion.
  - — **V:** Transection.
- Treatment[7]
  - — **Grade I:** Anticoagulation or antiplatelet therapy.
  - — **Grade II-IV:** Consider intervention for accessible lesions; otherwise antithrombotic therapy.
  - — **Grade V:** Intervention (endo or open).

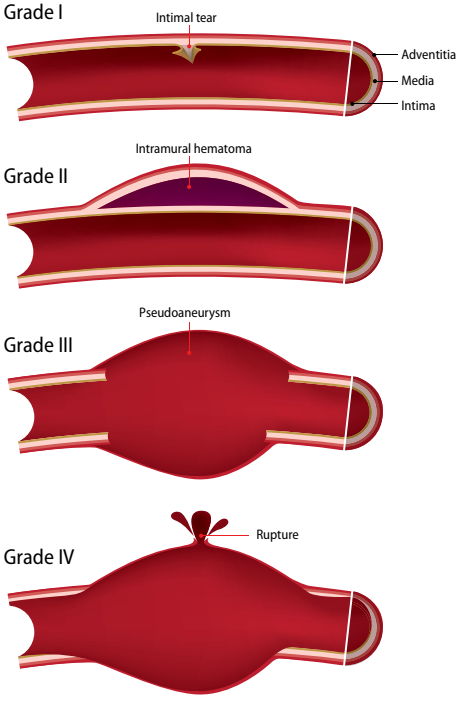
Penetrating Neck Injuries

- Hard signs of vascular injury (mandates exploration)[8]:
  - — Uncontrolled hemorrhage, expanding hematoma, nonresponsive hypotension.
  - — Expanding or pulsatile hematoma.
  - — Hypotension unresponsive to appropriate fluid resuscitation.
- Image prior to exploration if possible:
  - — Bruit/thrill.
  - — Absent or weak radial pulse.
  - — Neurologic deficits consistent with stroke.
- Soft signs (require further investigation)[8]:
  - — Proximity wounds (1–2 cm from vasculature).
  - — Minor hemorrhage.
  - — Non-expanding hematoma.
  - — Mild hypotension (fluid responsive).
- Carotid injury (majority to common carotid or bifurcation):
  - — Early revascularization is key.
  - — ***Surgically accessible regions:*** Exploration with repair or interposition graft.
    - Greater saphenous vein is usually a good size match for the internal carotid (PTFE usually better matched for the CCA).[9]
  - — Can consider endovascular approach.
- Vertebral Artery Injury (rare):
  - — Active bleeding from V1— can be ligated surgically or embolized.
    - Unilateral artery ligation or embolization is generally well tolerated.
- Zones of the neck:
  - — ***Zone 1:*** Region from the clavicle to the cricoid cartilage
  - — ***Zone 2:*** Region from the cricoid cartilage to the angle of the mandible
  - — ***Zone 3:*** Region from the angle of the mandible to the base of the skull
- Zone-based management vs. "no zone" approach is a topic of current debate.[8]

Blunt Thoracic Aortic Injury[10,11]

- Rapid deceleration— descending thoracic aorta at ligamentum arteriosum is particularly prone to injury.
- Most patients with significant injury die at scene (up to 85%).
- 1/3 — present in hemorrhagic shock with a mortality approaching 100%.

- 2/3 remain stable with a mortality of 25%; mostly due to associated injuries.
- Imaging
  - **CXR:** Widened mediastinum, hemothorax, obscured aortic knob.
  - **CTA:** Study of choice for hemodynamically stable patients.
  - **TEE:** Alternative for unstable patients.
    - Can be performed intraoperatively.
    - Can assess cardiac injury and function.
- Grading
  - **I:** Intimal tear.
  - **II:** Intramural hematoma.
  - **III:** Pseudoaneurysm.
  - **IV:** Rupture.



- Treatment
  - — ALL patients: strict blood pressure control.
    - Goal SBP < 100, HR < 100.
    - Often use short-acting beta blockers.
  - — **Grade I:** Medical management, surveillance imaging — repeat CTA 24–48 HRs.
  - — **Grade II–IV:** Surgical management (open repair via thoracotomy or endovascular repair).
- ***Intervention:*** Stent-graft repair preferred, open reserved for rare instances.
- Timing
  - — Delayed repair in patients who are hemodynamically stable without concern for impending rupture.
  - — Timing also depends on concomitant injuries.

Surgical Options

- TEVAR
  - — Ideally land in healthy aorta (i.e., without significant calcifications, tortuosity, or thrombus).
  - — In emergent setting, can cover the L subclavian artery (L SCA) vs. use of a branched device (i.e., GORE® TAG® Thoracic Branch Endoprosthesis).[12]
- Open repair
  - — Posterolateral thoracotomy vs. sternotomy depending on level of injury.
  - — Mechanical circulatory support to reduce risk of paralysis and end organ ischemia:
    - Left atrial-femoral bypass.
    - Femoral venous to femoral arterial bypass.

Abdominal Vascular Trauma

Background

- Most abdominal vasculature is located in the retroperitoneum.
- Retroperitoneal hematomas are classified as follows:
  - — **Zone 1:** Central (divided into supramesocolic and inframesocolic).
    - Vasculature: Aorta, IVC, celiac and mesenteric vessels, proximal renal vessels.
  - — **Zone 2:** Lateral
    - Vasculature: Renal vessels.
  - — **Zone 3:** Pelvis
    - Vasculature: Iliac vessels.
  - — **Zone 4:** Hepatoportal
    - Vasculature: Portal vein, retrohepatic IVC.
- ***Physical exam:*** Abdominal pain/distention, back/flank pain, ecchymosis over abdominal wall, flank or scrotum.
- Patients that require immediate OR exploration.
  - — Penetrating injury — hemodynamically unstable or fascial penetration.
  - — Peritonitis/pneumoperitoneum.
  - — Blunt trauma with positive FAST exam.

Anatomic Region	Penetrating	Blunt
Zone 1	Open	Open
Zone 2	Open	Do not open unless ruptured, pulsatile, or rapidly expanding
Zone 3	Open	Do not open unless ruptured, pulsatile, rapidly expanding, or absent iliac pulse
Portal Triad	Open	Open
Retrohepatic	Do not open unless ruptured, pulsatile, or rapidly expanding	Do not open unless ruptured, pulsatile, or rapidly expanding

- Operative techniques
- Consider balloon occlusion in unstable patients (e.g., resuscitative endovascular balloon occlusion [REBOA]).[13]

— **Zone 1:** L SCA to celiac trunk
  - Occlusion mitigates intra-abdominal hemorrhage.
  - Only use if you can obtain definitive control within 15 minutes.
  - Do not use if concerned for thoracic hemorrhage.
— **Zone 2:** Celiac trunk to lowest renal
  - Zone of "no-occlusion".
— **Zone 3:** Infrarenal aorta
  - Occlusion mitigates pelvic and lower extremity bleeding.

- Exposures
  — ***Left medial visceral rotation:*** Exposes aorta from hiatus to bifurcation; visceral vessels.
  — ***Right medial visceral rotation:*** Exposes IVC from inferior border of the liver to its bifurcation.

Peripheral Vascular Trauma

Diagnostic evaluation[14]

- "Hard signs" require surgical exploration.
- Soft signs → Noninvasive imaging:
  — ABIs (≤ 0.9 warrant further imaging).
  — Color-flow duplex imaging useful but highly operator dependent.
  — CTA has high sensitivity and specificity; may be best screening modality.
    - Can also consider intraoperative angiography.

Mangled Extremity Severity Score (MESS)[15]

Variables	Points
Mechanism	
Low energy (stab; simple fracture; pistol gunshot wound)	1
Medium energy (open or multiple fractures, dislocation)	2
High energy (high speed MVA or rifle GSW)	3
Very high energy (high speed trauma + gross contamination)	4
Limb Ischemia*	
Pulse reduced but perfusion normal	1
Pulseless, paresthesias, diminished capillary refill	2
Cool, paralyzed, insensate, numb	3

Shock	
Systolic BP > 90 mmHg (consistently)	0
Transiently hypotensive	1
Persistent hypotension	2
Age	
< 30	0
30–50	1
≥ 50:	2

*Score doubled for ischemia > 6 hours.

MESS ≥ 7 is predictive of need for amputation ultimately.[16]

Treatment

Initial closed reduction of severely displaced fractures/dislocations can restore pulses.[17]

- Endovascular management
  - — Transcatheter embolization.
- Low-flow arteriovenous fistulae, pseudoaneurysms, and active bleeding from noncritical arteries.
  - — Stents to exclude the injured area or to treat focal intimal injury.
- Surgical management
  - — Draping of entire injured extremity and contralateral extremity.
  - — Obtain proximal and distal control; consider endoluminal balloon occlusion (can provide temporary control).
  - — Debride to macroscopically healthy arterial wall.
  - — Fogarty catheters passed proximally and distally.
  - — Systemic heparinization used unless contraindicated.
  - — Consider intraluminal shunting:
    - Particularly in cases of severe limb injury and need to delay revascularization secondary to fracture fixation, complex soft tissue injury, or associated life-threatening injuries.
  - — Type of repair dictated by extent of arterial damage.
    - ***Extra-anatomic bypass:*** Contaminated fields (i.e., extensive soft tissue loss, associated bowel injury/spillage).
    - ***Conduit of choice:*** Contralateral saphenous vein.
  - — Completion arteriography as needed.

Management of Specific Injuries

Subclavian–axillary arteries

- ***Most commonly penetrating trauma:*** Up to 50% mortality.
  - — Associated with major musculoskeletal and brachial plexus injury.
    - E.g., Fracture dislocation of the posterior portion of the first rib.
- Critical ischemia of the upper extremity uncommon due to rich collateral circulation around shoulder.
- ***Surgical approach:*** Penetrating injuries of the right subclavian-axillary arteries require median sternotomy for proximal control.
- Left anterolateral or "trap door" thoracotomy may be necessary for proximal left subclavian injuries.
- Supraclavicular incision for more distal subclavian artery.
- Axillary artery approached through infraclavicular incision.
- ***Consider endovascular approach:*** Balloon occlusion to either assist in open repair or covered stent-graft for management.

Brachial, radial, and ulnar arteries

- Penetrating trauma and supracondylar fractures of the humerus.
- Injuries distal to deep brachial artery may not manifest signs of ischemia (secondary to collateral supply).
- Single vessel injury (forearm) — consider ligation if palmar arch intact.
- Ulnar artery usually dominant vessel — generally requires repair.

External iliac-femoral arteries

- Iliac artery injury associated with high mortality.[18]
- Proximal control of external iliac artery can be obtained via retroperitoneal exposure or transperitoneal approach.[18]
- Proximal profunda femoral — repair (important lower extremity collateral supply).

Popliteal artery

- Outcome depends predominantly on mechanism of injury.
  - — Traumatic popliteal injury carries the highest rate of amputation for any extremity vascular trauma.[19]
  - — Sometimes need above and below-knee exposure through separate incisions.
  - — Injuries directly behind the knee can be approached posteriorly.
  - — Interposition or bypass; autogenous vein preferred (contralateral vein).

Tibial arteries

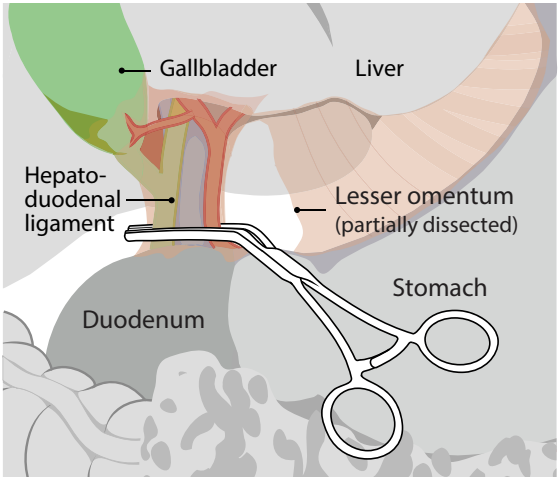
- Single actively bleeding/pseudoaneurysm — ligation/embolization.
- Tibioperoneal trunk or two infrapopliteal vessels — repair.

Extremity Venous Injuries

- ***Most commonly injured:*** Superficial femoral vein (40%), popliteal vein (25%) and the common femoral vein (15%).
- Localized injury — end-to-end/lateral venorrhaphy — unless unstable (can ligate).

Retrohepatic Vena Cava/Hepatic Vein Injury

- Life threatening bleeding occurs if supporting structures are disrupted (ligaments, diaphragm, liver parenchyma).
- Exposure may release tamponade resulting in exsanguination.
- ***Pringle Maneuver (clamping hepatoduodenal ligament):*** If clamping does not stop bleeding, consider possibility of a hepatic vein or retrohepatic IVC injury.[20]
  - — ***If bleeding slows withheld respiration:*** Supports presumed diagnosis of hepatic vein/retrohepatic IVC injury.



Management

- Hepatic vascular exclusion (HVE)
  - — ***Clamp order:*** Hepatoduodenal ligament, infrahepatic IVC, suprahepatic IVC.[21]
  - — Most patients will not tolerate HVE without aortic clamping because of sudden drop in preload.[22]
- Primary vs. patch repair; ligation if patient in extremis.
- Atriocaval shunt (rarely performed).
- ***Stenting:*** Anatomically challenging but has been described.[23]

ACUTE AORTIC SYNDROMES

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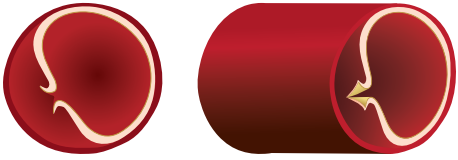
Acute aortic syndromes: Term encompassing the following disorders of the thoracic and abdominal aorta:

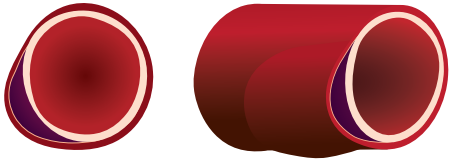
- Aortic dissection[1]
- Intramural hematoma[1]
- Penetrating aortic ulcer[1]

Acute aortic syndrome disease states

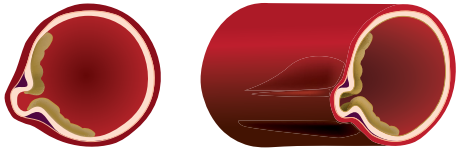
Aortic dissection



Intramural hematoma



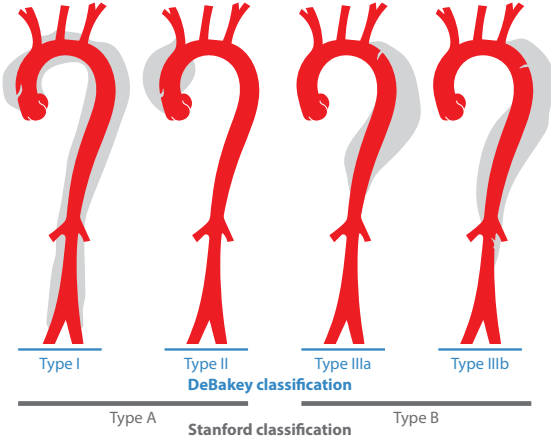
Penetrating aortic ulcer



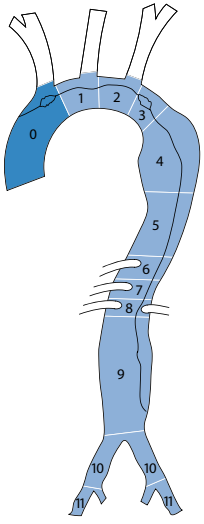
Acute aortic dissection (AAD): Tear in intima — blood accumulates between the intima and media +/- adventitia creating a false lumen.

Background

- Rare, but most common catastrophic event involving the aorta.[2]
  — 2–3x more common than aneurysm rupture.[2]
- Associated with high morbidity and mortality.[2] Higher with Type A than Type B. Type B approximately 25% mortality at three years. Higher mortality in women, renal dysfunction during admission, shock, history of prior AAA, and pleural effusion on admission.[3]
- Approximately 15% of those diagnosed have a 30-day mortality. Approximately 10-15% mortality rate in hospital.
- Historically, two main anatomic classification systems:[4]
  — ***DeBakey:***
    - **Type I:** Originates in ascending aorta extending into arch and descending aorta.
    - **Type II:** Confined to ascending aorta.
    - **Type IIIa/b:** Originating in the descending thoracic aorta, extension proximal/distal to the celiac artery.
  — ***Stanford (more commonly used):***
    - **Type A AD (TAAD):** Originates in the ascending aorta (around 2/3 of cases).
    - **Type B AD (TBAD):** Originates distal to the left subclavian artery (around 1/3 of cases).



- New Society for Vascular Surgery (SVS) guidelines:[5]
  - — ***Anatomic:***
    - **Type A:** Entry tear in Zone 0.
    - **Type B:** Entry tear in Zone 1 or beyond.
  - — ***Chronicity (based on sx onset):***
    - **Hyper-acute:** < 24 hours
    - **Acute:** 1–14 days
    - **Subacute:** 15–90 days
    - **Chronic:** > 90 days
  - — ***Acuity:***
    - ***Uncomplicated:*** No evidence of rupture or malperfusion.
    - High risk = significant risk of subsequent complications.
      - — ***High-risk clinical criteria:***
        - Refractory HTN > three different medication classes.
        - Pain > 12 hrs.
        - Readmission.
        - Radiologic findings:
          - — Aortic diameter > 40 mm
          - — False lumen diameter > 22 m
          - — Entry tear on lesser curve or > 10 mm
          - — Malperfusion
          - — Bloody pleural effusion
          - — > 5 mm change in serial imaging
    - ***Complicated:*** Rupture or clinical malperfusion.[6]



Type	Proximal Extent	Distal Extent
A_D Entry tear: **Zone 0**	0	0
	1	1
	2	2
	3	3
B_{PD} Entry tear: **≥ Zone 1**	4	4
	5	5
	6	6
	7	7
	8	8
I_D Unidentified entry tear involving: **Zone 0**	9	9
	10	10
	11	11
	12	12

Etiology/Risk Factors

- Most common risk factor: Hypertension (HTN).[4]
- Atherosclerosis, thoracic aortic aneurysm, prior cardiac surgery, aortic valve disease.[4]
- In patients < 40 years old, consider connective tissue disorder (e.g., Marfan syndrome, Ehlers-Danlos syndrome).[4]
- M > F, fifth or sixth decades.

Presentation[4,7,8]

- Hemodynamic instability (TAAD: hypotension; TBAD: hypertension).
- Chest pain (TAAD), back pain (TBAD):
  - Describe acute tearing or ripping pain.
  - Abrupt onset with severe intensity.
- Presentation often dependent on extent of dissection:
  - Syncope (may indicate impending tamponade or involvement of brachiocephalic vessels).
  - Stroke: Carotid or vertebral involvement.
  - Acute MI (involvement of coronaries).
  - Limb ischemia (extension of dissection into iliac/femoral arteries).
  - Spinal cord ischemia or focal neuro deficits (involvement of arteries supplying brain/spinal cord or general hypotension).
  - Acute kidney injury: Oliguria.

Physical Exam[4,7,8]

- Pulse variation or deficit (absence of pulse or > 20 mmHg between R and L arms). If malperfusion of left subclavian.
- Diastolic murmur (aortic regurgitation).
- Muffled heart sounds (tamponade).
- Horner's syndrome — Drooping eyelid, decreased sweating, decreased pupil size. (Type A extension into carotids.)
- Peritoneal signs (visceral ischemia).
- Loss of peripheral pulses (acute limb ischemia).

Diagnosis[4,7,8]

- Standard w/u of chest pain
  - **EKG:** Nonspecific ST or T wave changes, ischemic changes, MI.
  - **CXR:** Nonspecific findings (widened mediastinum, pleural effusion, hemothorax).

- Double density appearance within aorta.
- Calcium separation of intima from aortic wall.

- Laboratory: Troponin, BNP, Lactic acid, BMP, CBC.
- CTA chest/abdomen/pelvis with lower extremity runoff
  - — Delineates anatomy including entry tears, true and false lumen.
    - ***True lumen:*** Often smaller, wall calcifications, contiguous with aortic root.
      - — Origins of celiac/SMA/R renal artery usually arise from true lumen.
        - Right renal artery: 70% of true lumen, 20% of both true and false, 10% of false only.
        - Left renal artery: 40% of true lumen, 40% of both true and false, 20% of false only.
    - ***False lumen:*** Often larger (higher luminal pressure, beak sign).
      - — Renal artery typically arises from false lumen.

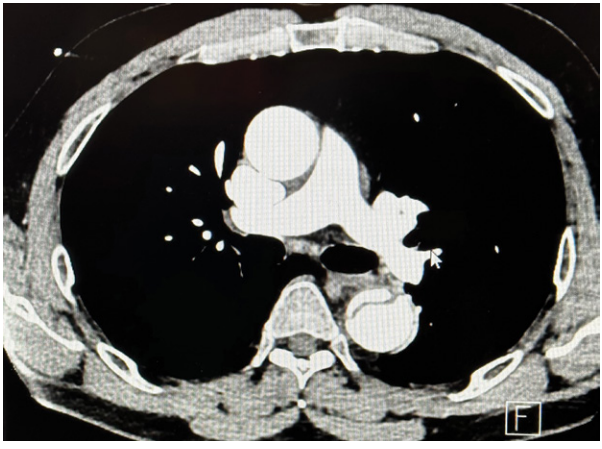


Image courtesy of Patrick A. Stone, M.D., FACS. Used with permission.

  - — Able to evaluate for distal complications including visceral malperfusion.
  - — Useful for surgical planning.
- Echo (TEE):
  - — Useful for identifying pathology in ascending aorta.
  - — Can be performed in OR in patients who are unstable.
  - — Repairing Type B and want to check if there is a Type A component.

Management[4,7,8]

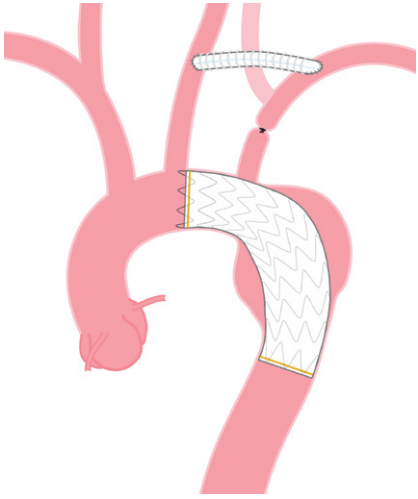
TAAD (CT surgery): Either total ascending and arch replacement (with or without AVR) or Zone 2 surgical arch replacement plus a staged branched endovascular graft.

- Current branched TEVAR devices may be used for patients with prior replacement of the ascending aorta and/or aortic arch by a surgical graft, when there is at least 2 cm of landing zone proximal to the most distal anastomosis site.

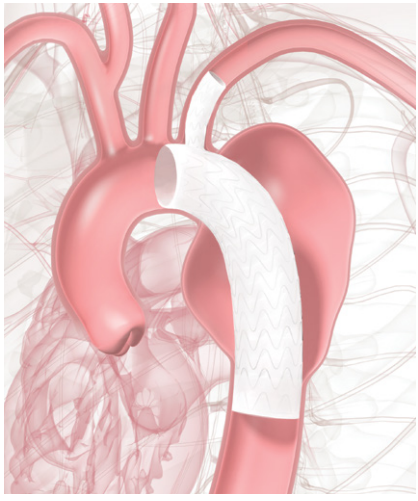
TBAD: ICU admission with invasive blood pressure monitoring prompt initiation of anti-impulse therapy to maintain HR (60-80), SBP < 120. blood pressure that does not compromise end-organ function is ultimately the goal.

- ***Uncomplicated:*** Optimal medical treatment (OMT).
  - — Beta-blockade is generally first line.
    - IV non-dihydropyridine ca channel blocker — If intolerance or contraindications of beta blocker.
  - — Vasodilators: If not controlled with beta blockage.
  - — Pain control.
  - — Long-term medical management: Beta blockade and ACE inhibitors as well as angiotensin receptor blockade to control blood pressure.
  - — Early TEVAR for uncomplicated TBAD is controversial and currently being studied.[9]
    - High-risk factors may impact decision to treat.
    - Up to 60% of patients treated with OMT develop aneurysmal degeneration of aorta.
    - TEVAR promotes favorable aortic remodeling.
- ***Complicated features:*** Requires urgent intervention.
  - — ***TEVAR:*** Lower early morbidity and mortality compared to open surgery.
    - **Technical tips:**
      - — Sizing should be based on diameter of non-dissected thoracic aorta (minimal oversizing).
      - — True lumen access via femoral or brachial.
        - Confirm true lumen position with IVUS, also angiogram to confirm branch anatomy as per pre-op.
        - TEE can also confirm wire in true lumen.
      - — Proximal landing: > or = 2 cm proximal to entry tear.
        - May need to intentionally cover left SCA (consider revascularization with extra-anatomic bypass, fenestrated.
      - — Consider use of a branched TEVAR device to avoid the potential risks and complexity of revascularizarion.

Revascularization with extra anatomic bypass



Branched graft device



— Consider placement of uncovered dissection stent to increase luminal gain distal to the stent-graft (PETTICOAT Technique).
— ***Open aortic reconstruction:*** Rarely necessary unless anatomic constraints or connective tissue disorder.

Outcomes

- TBAD medically managed: Approximately 75% three-year survival.[3]
- Majority of recurrent dissections are TB 50%.[10]
- 20% of recurrences are reported in patients with Marfan syndrome or CTD.[10]
- False lumen status is an important predictor of outcomes.[11]
  — Patent or partial thrombosis of false lumen is associated with worse outcomes.[11]
  — 1/3 of TBAD partial false lumen thrombosis.[11]

INTRAMURAL HEMATOMA (COMPROMISE 10–30% OF AAS)[12]

- IMH = hematoma contained within the aorta media.
  — With or without intimal disruption.
  — Variant of dissection but no identifiable entry tear or false lumen flow.
- Classified according to Stanford System:
  — Type A (ascending aorta).
  — Type B (descending aorta).
    - Majority are Type B.
- Variable progression/natural history.
  — Reabsorption without intervention.
  — Progression to dissection (up to 15%).

Presentation

- Patients tend to be older with significant hypertension (HTN).
- Similar symptoms, such as chest/back pain.
  — More frequently c/b pericardial effusion and periaortic hematoma.
  — Less frequently c/b aortic regurgitation or malperfusion syndromes.

High-Risk Imaging Features

- Aortic diameter > 5 cm.
- Thickness > 13 mm.
- Focal intimal disruption with ulcer in acute phase.

Imaging (PIC)

- ***CT scan (with and without contrast):***
  - — Focal, crescentic
  - — Circumferential thickening of aortic wall.
  - — No detectable intimal tear (microtears can be present).
- ***MRI:***
  - — Excellent visualization of aortic wall.
  - — No radiation exposure so useful for patients requiring follow-up imaging.
- ***Echo (can be used to obtain rapid dx in unstable patients):***
  - — Wall thickness > 5–7 mm, echolucency within the aortic wall causing compression of the lumen.

Treatment

- ***Type A IMH:***
  - — Early surgical intervention.
- ***Type B IMH:***
  - — Conservative management with anti-Impulse therapy (SBP < 120, HR < 60).
    - 50–80% resolve without intervention.
      - — Aortic diameter > 45 mm and hematoma thickness > 1 cm associated with progression to dissection or aneurysmal degeneration.
  - — Intervention for complications, including:
    - Rupture or impending aortic rupture.
    - Enlargement on serial imaging.
    - Evidence of visceral malperfusion.

PENETRATING AORTIC ULCER[2,13-15]

- PAU = atherosclerotic lesion penetrating elastic lamina leading to hematoma formation within media.
  - — 2–7% of patients that present with symptomatic aortic pathology.
  - — Can remain stable or progress to IMH/dissection.

Presentation

- Older patients (> 70) with atherosclerotic risk factors.
- Similar presentation as AD/IMH.
- Rupture rate as high as 38%.

Imaging

- CTA (preferred modality).
  - — Localized ulceration penetrating the aortic intima.
  - — Contrast filled outpouching with jagged edges ("crater-like"), often associated with extensive aortic atheroma and calcifications.
- Adjunct use of MRI and TTE (similar to IMH and dissection).

Treatment (no clear-cut guidelines)

- Indications for intervention (TEVAR):
  - — Symptomatic (higher risk for development of aneurysm, pseudoaneurysm, or rupture).
  - — Asymptomatic with high-risk features, such as:
    - Concomitant pathology (e.g., IMH) or multiple ulcers.
    - PAU diameter > 20 mm.
    - PAU depth > 10 mm.
    - Aortic enlargement (> 10 mm/year).
    - Pseudoaneurysm development.

VASCULAR SURGERY PATIENT PRE-PROCEDURE CHECKLIST

Institutions each have their own pre-operative protocol preferences. However, this checklist is intended to capture some of the commonly forgotten pre-operative tasks that can delay a patient's procedure.

1. Ensure procedure and blood consents are obtained.
   - — Procedure consents should include planned procedure and any pertinent alternative (i.e., backup such as graft if vein conduit inadequate) procedures. Do not use abbreviations.
   - — Consents should also include laterality.
2. Mark the patient's laterality.
3. Obtain appropriate pre-operative lab work including BMP, CBC, Coags, type and screen, and pregnancy test.
4. Remember to pre-medicate any patient with a contrast allergy for 24 hours prior to endovascular intervention.
5. NPO after midnight, initiate intravenous fluids.
6. Chlorhexidine gluconate (CHG) application X 3 in the 24 hours prior to surgery.
7. Ensure all oral anti-coagulants have been discontinued for the appropriate length of time, typically 2–3 days.
   - — Not routinely held for venous interventions, know the specific type of surgery scheduled
   - — Warfarin X 5 days (or until INR normalized).
   - — DOAC/NOAC X 72 hours.
   - — Aspirin therapy can typically be continued through any procedure.

! *This manual does not include all the information needed to use the drugs listed herein safely and effectively. See full prescribing information and any boxed warnings for these drugs.*

- Clopidogrel therapy can typically be continued through any procedure apart from open aortic or abdominal operations, or procedures requiring significant tunneling (such as axillary bifemoral bypass), though this is up to the discretion of the primary surgeon.
- Dual antiplatelet therapy MUST be continued through TCAR procedures. If the patient has missed any dose of Clopidogrel in the two weeks prior to TCAR, a loading dose should be administered in pre-op.

8. Hold heparin GTT 6 hours prior to surgery. Hold SQH day of surgery for patients requiring epidural or spinal placement.
9. All ESRD patients should have dialysis coordinated around their operation ensuring patients are appropriately dialyzed prior to proceeding to OR.
10. If performing a major amputation, be sure to confirm no prior orthopedic hardware is present in the operative limb.

CONTRAST ALLERGY PRE-PROCEDURE PROTOCOL

Pre-medication of patients with known or suspected contrast allergy:

Prednisone: 50 mg po at 13 hours, seven hours, and one hour before contrast media injection, and Diphenhydramine: 50 mg IV/IM/po one hour before contrast medium.

Urgent medication if can't do above:

Methylprednisolone sodium succinate 40 mg or Hydrocortisone sodium succinate 200 mg IV (q4h) until contrast study required and diphenhydramine 50 mg IV one hour prior to contrast.

Data suggest steroids of limited effect if not given more than four hours pre-contrast load.

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CATHETER-DIRECTED THROMBOLYSIS

Patients with acute symptoms < 14 days have improved outcomes when catheter-directed thrombolysis is used, however, if symptoms persist > 14 days, then open surgery is preferred. No difference in safety or efficacy between recombinant tissue plasminogen activator (r-TPA) and urokinase (UK).

Indications for catheter-directed thrombolysis:

1. Arterial occlusion
2. Venous occlusion and pulmonary embolism

Contraindication checklist[1]:

Absolute

1. Established cerebrovascular event (including transient ischemic attacks within last two months).
2. Active bleeding diathesis.
3. Recent gastrointestinal bleeding (< 10 d).
4. Neurosurgery (intracranial, spinal) within last three months.
5. Intracranial trauma within last three months.

Relative contraindications

1. Cardiopulmonary resuscitation within last 10 days.
2. Major nonvascular surgery or trauma within last 10 days.
3. Uncontrolled hypertension: > 180 mmHg systolic or > 110 mmHg diastolic.
4. Puncture of noncompressible vessel.
5. Intracranial tumor.
6. Recent eye surgery.

7. Hepatic failure, particularly those with coagulopathy.
8. Bacterial endocarditis.
9. Pregnancy.
10. Diabetic hemorrhagic retinopathy.

Post-procedural checklist:

- Infuse low dose heparin through access sheath to prevent sheath thrombosis and propagation of clot (400–500 units/hr).
- Postoperatively check PTT and fibrinogen levels every six hours and daily BMP.
- May have dark urine (blood-tinged) often secondary to lysis of RBCs if after rheolytic thrombectomy. Assure adequate hydration status.
- Fibrinogen < 150 mg/dl then TPA should be held or dosage decreased.
  - — < 100 mg/dl infusion stopped.
  - — Some advocate for cryoprecipitate transfusion if there is evidence of hemorrhage or fibrinogen < 100mg/dl.

Complications[2]:

- Intracranial hemorrhage (< 1%)
- Major bleeding requiring transfusion or surgery (10%)
- Compartment syndrome
- Distal embolization

Key references

Trials addressing arterial thrombolysis:

- STILE trial[3]
- TOPAS trial[4]

SPINAL DRAIN FOR AORTIC SURGERY

Spinal cord perfusion pressure through CSF drainage and augmentation of mean arterial pressure are important influences in the prevention of SCI. Risk estimated to occur approximately 5–10%. Some practitioners closely observe and place emergent drains if neurologic deficits occur post-operative in lieu of risk of spinal drain prophylactically.

Consider prophylactic CSF drain placement:

- > 20 cm aortic coverage.
- Coverage of the lower 1/3 of the thoracic aorta.
- Pararenal / type IV thoracoabdominal aortic aneurysm with planned coverage of > 5 cm above the celiac artery, previous abdominal aortic aneurysm repair.
- Occlusion of the left subclavian artery or internal iliac arteries.

Placed by anesthesia pre op:

- Other adjuncts to consider intraoperative.
- Systemic hypothermia (34 degrees Celsius).
- Hemoglobin > 10 g/dL.
- Mannitol (12.5 g).
- Methylprednisolone (30 mg/kg).
- Naloxone (1 mg/kg/h).

Arterial pressure goals:

- Mean > 90 mmHg.
- CSF should be drained in 10 mL increments to maintain a CSF pressure.
- < 10 mmHg, drain maintained for 24–48 hrs. Consider capping at 24 hours and then if no neurologic deficits at 48 hours, remove.

Post-op:

- Neuro checks of lower extremities hourly including leg lifts as well.
- Consider neurology consult for any deficits.

CEAP CLASSIFICATION FOR SEVERITY OF VENOUS DISORDERS

Most, if not all, insurance providers require a CEAP classification for venous disease in order to cover treatment.

The CEAP classification consensus document was written by the American Venous Forum and provides a comprehensive objective classification. Before the CEAP classification, the diagnosis of chronic venous disorder lacked precision in diagnosis. Today, it is universally accepted and endorsed, with most published papers now using all or portions of the CEAP system.

The CEAP classification system is comprised of two parts: classification and severity scoring.

Classification

C – clinical manifestation

E – etiologic factors

A – anatomic distribution

P – pathophysiologic dysfunction

Severity Scoring

- Number of anatomic segments affected
- Grading of signs and symptoms
- Disability
- Revision

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In 2020, a revised CEAP document was published by the American Venous Forum. These changes include adding corona phlebectatica as the C4c clinical subclass, introducing the modifier "r" for recurrent varicose veins and recurrent venous ulcers, and replacing numeric descriptions of the venous segments by their common abbreviations.

CEAP TABLES

Clinical

C Class	Description
C0	No visible or palpable signs of venous disease
C1	Telangiectasias or reticular veins
C2	Varicose veins
C2r	Recurrent varicose veins
C3	Edema
C4	Changes in skin and subcutaneous tissue secondary to CVD
C4a	Pigmentation or eczema
C4b	Lipodermatosclerosis or atrophie blanche
C4c	Corona phlebectatica
C5	Healed venous ulcer
C6	Active venous ulcer
C6r	Recurrent active venous ulcer
CVD: Chronic Venous Disease Each clinical class subcharacterized by a subscript indicating the presence (symptomatic, s) or absence (asymptomatic, a) of symptoms attributable to venous disease.	

Etiological

E Class	Description
Ep	Primary
Es	Secondary
Esi	Secondary — Intravenous
Ese	Secondary — Extravenous
Ec	Congenital
En	No cause identified

Anatomical

A Class	Description		
As	Superficial		
	Old	**New**	**Description**
	1.	Tel.	Telangiectasia
	1.	Ret.	Reticular veins
	1.	GSVa	Great saphenous vein above knee
	2.	GSVb	Great saphenous vein below knee
	3.	SSV	Small saphenous vein
		AASV	Anterior accessory saphenous vein
	4.	NSV	Nonsaphenous vein
Ad	Deep		
	Old	**New**	**Description**
	6.	IVC	Inferior vena cava
	7.	CIV	Common iliac vein
	8.	IIV	Internal iliac vein
	9.	EIV	External iliac vein
	10.	PELV	Pelvic veins
	11.	CFV	Common femoral vein
	12.	DFV	Deep femoral vein
	13.	FV	Femoral vein
	14.	POPV	Popliteal vein
	15.	TIBV	Crural (tibial) vein
	16.	MUSV	Muscular veins
	16.	GAV	Gastrocnemius vein
	16.	SOV	Soleal vein
Ap	Perforator		
	Old	**New**	**Description**
	17.	TPV	Thigh perforator vein
	18.	CPV	Calf perforator vein
An	No venous anatomic location identified.		

* New specific anatomic location(s) to be reported under each **P** (pathophysiologic) class to identify anatomic location(s) corresponding to **P** class.

Pathophysiological

P Class	Description
Pr	Reflux
Po	Obstruction
Pr,o	Reflux and obstruction
Pn	No pathophysiology identified

** Advanced new abbreviations for specific **A** anatomic location(s) to be reported under each **P** Pathophysiologic class to identify anatomic location(s) corresponding to **P** class.

CEAP FORMAT NOTATION GUIDE

Basic

R or L:	**C** [highest subscript] (s or a), **E** [all subscripts], **A** [all subscripts], **P** [all subscripts without anatomic notation]
C	0, 1, 2, 2r, 3, 4, 5, 6, 6r
E	p, s, se, si, c, n
A	s, d, p, n
P	r, o, r,o, n

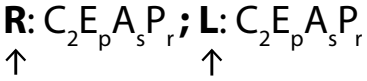
Advanced

R or L:	**C** [all subscripts] (s or a), **E** [all subscripts], **A** [all subscripts], **P** [all subscripts with anatomic notation]
C	0, 1, 2, 2r, 3, 4, 4a, 4b, 4c, 5, 6, 6r
E	p, s, se, si, c, n
A	s, d, p, n
P	r (---, ---, ---); o (---, ---, ---); r,o (---, ---, ---); n

Please use --- to indicate appropriate anatomic subscripts

HOW TO USE THE CEAP CLASSIFICATION

1. **Designations**: All CEAP designations should be subscripted if possible
2. **Laterality**
   Designate each limb being classified.
   - Use **R:** for right extremity and **L:** for left extremity (black arrow) followed by a colon (:), in front of the CEAP description.
   - If both extremities are being classified, designate right extremity first followed by left extremity separated by a semicolon.
   - **Example:**



3. **C (Clinical)**

   Basic
   - For **basic CEAP**, use the highest **numeric** clinical classification
     Example: Patient with varicose veins, advanced lipodermatosclerosis and an ulcer: C_6
   - For C_2 and C_6 patients who have a recurrent disease use "r" designation with respective numeric designation (C_{2r} or C_{6r})
   - For C_4 patients use only number 4 subscript value (don't use $4_{a, b, c}$ designation)

   Advanced
   - For **advanced CEAP**, use all clinical classifications, separated by commas. For patients with multiple C_4 designations, report them in alphabetical order separated by commas (black arrow)
   - **Example:** Patient with varicose veins, advanced lipodermatosclerosis and corona phlebectatica should be reported as:

Symptoms

— The designation of asymptomatic ('a') or symptomatic ('s') **should be used in basic and advanced CEAP** (black arrow) and should be in lower case, in parenthesis at the end of the C designation.

— **Example:** Symptomatic varicose veins with swelling reported as:

Recurrent disease

— Recurrent (r) disease **should be indicated in basic and advanced CEAP** (black arrow) and should be in lower case after clinical index (varicose veins or ulcer).

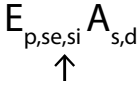
— **Example:** Recurrent venous ulcer:

4. **Etiology and Anatomy (E and A) — no distinction between basic and advanced CEAP**

— With more than one designation for E and A, report all applicable designations separated by commas.

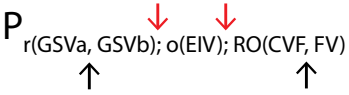
— If secondary Etiology is not known, use Es instead of Ese or Esi. In patients with extrinsic and intrinsic secondary etiologies report them in alphabetical order separated by commas.

— **Example:** Patient with primary varicose veins, iliac vein compression and post-thrombotic femoral DVT would be designated as:



5. **Pathophysiology (P)**
   - **Basic 'P'**, designation should be ordered: reflux (r), obstruction (o), or reflux and obstruction (ro). Each separated by commas.
   - **Example:** Patient with post-thrombotic DVT with deep reflux and obstruction should be reported as:

   - **Advanced 'P'**, pathologic segments are reported in the following order:
     - Anatomic segments with reflux only (semicolon) **followed by**
     - Anatomic segments with obstruction only (semicolon) **followed by**
     - Anatomic segments with reflux and obstruction
     - Anatomic segments are separated by commas (black arrow), multiple disease states separated by semicolons (red arrow)
   - **Example:**



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Appendix 3

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